BACHELOR THESIS & COLLOQUIUM – ME141502

INSPECTION PLANNING IN CONDENSATE STORAGE TANK USING RISK BASED INSPECTION (RBI) METHOD BASED ON API 581: 2016

NIKITA AYU DINI MAULIDYA
NRP. 04211441000001

SUPERVISOR :
Dr. Eng. M. Badrus Zaman., ST., MT.
Nurhadi Siswantoro, ST.,MT.

DOUBLE DEGREE PROGRAM
DEPARTMENT OF MARINE ENGINEERING
FACULTY OF MARINE TECHNOLOGY
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SKRIPSI – ME 141502

PERENCANAAN PENJADWALAN INSPEKSI PADA TANGKI PENYIMPANAN KONDENSAT MENGGUNAKAN METODE *"RISK BASED INSPECTION"* BERDASARKAN API 581:2016

Nikita Ayu Dini Maulidya

NRP. 04211441000001

DOSEN PEMBIMBING :

Dr. Eng. M. Badrus Zaman., ST., MT.

Nurhadi Siswantoro, ST.,MT

PROGRAM DOUBLE DEGREE

DEPARTEMEN TEKNIK SISTEM PERKAPALAN

FAKULTAS TEKNOLOGI KELAUTAN

INSTITUT TEKNOLOGI SEPULUH NOPEMBER

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APPROVAL FORM

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BACHELOR THESIS

Submitted to Comply One of The Requirement to Obtain a Bachelor Engineering Degree
on
Marine Operation and Maintenance (MOM)
Bachelor Program Department of Marine Engineering
Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember

Prepare by :
NIKITA AYU DINI MAULIDYA
NRP. 04211441000001

Approved by Supervisor :

Dr. Eng. M. Badrus Zaman., ST., MT. ( )

Nurhadi Siswantoro, ST.,MT ( )

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Prepare by :
NIKITA AYU DINI MAULIDYA
NRP. 04211441000001

Approved by
Head of Department of Marine Engineering

Dr. Eng. M. Badrus Zaman., ST., MT.

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Prepare by :
NIKITA AYU DINI MAULIDYA
NRP. 04211441000001

Approved by
Representative of Hochschule Wismar in Indonesia

Dr.-Ing. Wolfgang Busse

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DECLARATION OF HONOR

I hereby who signed below declare that :

This bachelor thesis has written and developed independently without any plagiarism act, and confirm consciously that all data, concepts, design, references, and material in this report own by Marine Operation and Maintenance (MOM) in Department of Marine Engineering ITS which are the product of research study and reserve the right to use for further research study and its development.

Name	: Nikita Ayu Dini Maulidya
NRP	: 04211441000001
Bachelor Thesis Title	: Inspection Planning in Condensate Storage Tank Using Risk Based Inspection (RBI) Method Based on API 581: 2016
Department	: Marine Engineering

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Surabaya, Juli 2018

Nikita Ayu Dini Maulidya

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Name	: Nikita Ayu Dini Maulidya
NRP	: 04211441000001
Department	: Marine Engineering
Supervisor I	: Dr. Eng. M. Badrus Zaman., ST., MT.
Supervisor II	: Nurhadi Siswantoro, ST.,MT

ABSTRACT

With the rapid advancement of technology, it is necessary to supply the energy for these technologies. Most of the energy supply in Indonesia comes from the oil and gas industry. The oil and gas industry has much equipment needed to support the business process. Such as pipeline, tank, heat exchanger, heater, etc. The tank is the most widely used equipment in the industry. The tank is used for temporary storage of production.

American Petroleum Institute (API) is one of the most commonly used standard in the oil and gas industry worldwide besides the DNV-GL standard. PT. XXX which is a national company engaged in oil and gas also apply the API standard during the installation process of the tank.

Because the tank is one of static equipment, the maintenance strategy that can be applied is Risk Based Inspection (RBI). By using RBI, the company will get information based on risk analysis to make inspection plan for equipment. The basis for implementing RBI is Probability of Failure and Consequence of Failure. However, the random scenario of damage must also be considered and calculated.

In this final project used Risk Based Inspection method in risk analysis as well as determining the proper maintenance type of each damage factor which become the object of analysis. In this final project, damage factor in this case already being screened is thinning damage factor and external corrosion damage factor possibly happened to Condensate Storage Tank BANG-T-05 that own by PT.X. The following results are obtained the risk value of the Condensate Storage Tank BANG-T-05 is 0.51 ft^2/year. Inspection planning for Condensate Storage Tank BANG-T-05 planned at 1,3 years after RBI Date. Which is 29th June 2019. Schedule and inspection method for operation for 10 years, there are: Inspection method for thinning damage factor is at least 5% UT scanning, automated or manual and also Inspection method for external corrosion damage factor at least 60% visual inspection of the exposed area with follow-up by UT, RT or pit gauge as required. The inspection schedule based on RBI analysis is on 29th June, 2019. The results are shorter than the provisions of SKPP Migas, which is every 3 years. The different schedule of inspections can be caused by incomplete data. Damage Factor value after inspection in target date can be lowered by 4,12 factor. So, the new damage factor at plan date after inspection is 7,01.

Keyword: Tank, Risk, Damage Factor, Consequence Area, RBI, API 581, Maintenance Planning

PERENCANAAN PENJADWALAN INSPEKSI PADA TANGKI PENYIMPANAN KONDENSAT MENGGUNAKAN METODE "RISK BASED INSPECTION" BERDASARKAN API 581:2016

Nama	: Nikita Ayu Dini Maulidya
NRP	: 04211441000001
Departemen	: Marine Engineering
Dosen Pembimbing I	: Dr. Eng. M. Badrus Zaman., ST., MT.
Dosen Pembimbing II	: Nurhadi Siswantoro, ST.,MT

ABSTRAK

Dengan kemajuan teknologi yang pesat, perlu untuk memasok energi untuk teknologi ini. Sebagian besar pasokan energi di Indonesia berasal dari industri minyak dan gas. Industri minyak dan gas memiliki banyak peralatan yang dibutuhkan untuk mendukung proses bisnis. Seperti pipa, tangki, penukar panas, pemanas, dll. Tangki adalah peralatan yang paling banyak digunakan di industri. Tangki digunakan untuk penyimpanan sementara produksi.

American Petroleum Institute (API) adalah salah satu standar yang paling umum digunakan dalam industri minyak dan gas di seluruh dunia selain standar DNV-GL. PT. X yang merupakan perusahaan nasional yang bergerak di bidang minyak dan gas juga menerapkan standar API selama proses pemasangan tangki.

Karena tangki merupakan salah satu peralatan statis, strategi pemeliharaan yang dapat diterapkan adalah Risk Based Inspection (RBI). Dengan menggunakan RBI, perusahaan akan mendapatkan informasi berdasarkan analisis risiko untuk membuat rencana pemeriksaan peralatan. Dasar untuk menerapkan RBI adalah Probabilitas Kegagalan dan Konsekuensi Kegagalan. Namun, skenario kerusakan acak juga harus dipertimbangkan dan dihitung.

Dalam tugas akhir ini digunakan metode Risk Based Inspection dalam analisis risiko serta penentuan jenis perawatan yang tepat dari setiap faktor kerusakan yang menjadi objek analisis. Pada tugas akhir ini, faktor kerusakan pada kasus ini yang sudah diskrining adalah faktor penipisan kerusakan dan faktor kerusakan korosi eksternal yang mungkin terjadi pada Tangki Penyimpanan Kondensat BANG-T-05 milik PT.X. Hasil berikut ini diperoleh nilai risiko dari Tangki

Penyimpanan Kondensat BANG-T-05 adalah 0,51 ft2 / tahun. Perencanaan inspeksi untuk Tangki Penyimpanan Kondensat BANG-T-05 direncanakan pada 1,3 tahun setelah Tanggal RBI. Yaitu 29 Juni 2019. Jadwal dan metode inspeksi untuk operasi selama 10 tahun, ada: Metode inspeksi untuk faktor penipisan kerusakan setidaknya 5% pemindaian UT, otomatis atau manual dan juga metode Inspeksi untuk faktor kerusakan korosi eksternal setidaknya 60% inspeksi visual dari area yang terbuka dengan tindak lanjut oleh UT, RT atau pit gauge sesuai kebutuhan. Jadwal pemeriksaan berdasarkan analisis RBI adalah pada 29 Juni 2019. Hasilnya lebih pendek dari ketentuan SKPP Migas, yang setiap 3 tahun. Jadwal pemeriksaan yang berbeda dapat disebabkan oleh data yang tidak lengkap. Nilai Kerusakan Faktor setelah pemeriksaan pada tanggal target dapat diturunkan dengan 4,12 faktor. Jadi, faktor kerusakan baru pada tanggal rencana setelah pemeriksaan adalah 7,01.

Kata Kunci : Tangki, Resiko, Damage Factor, Consequence Area, RBI, API 581, Penjadwalan Maintenance

PREFACE

Grateful to Allah SWT because of His grace, the author can finish this bachelor thesis with the title "INSPECTION PLANNING IN CONDENSATE STORAGE TANK USING RISK BASED INSPECTION (RBI) METHOD BASED ON API 581: 2016" in order to comply the requirement of obtaining a Bachelor Engineering Degree on Department of Marine Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember.

The author realizes that this writing can not be solved without the support of various parties both morally and materially. Therefore, the authors would like to express their gratitude to all those who have helped in the preparation of this bachelor thesis especially to :

1. Both parents, honorable father Moch. Asnawi and beloved mother Nurul Azizah Effendi, and dear brother Norton Rafli Ahmad Qomaruzzaman, Zidni Zidane Al-Barr Charomaini and sister Naura Aurelia Callista who always give their loves, prayers, supports, and encouragements for every single path the author chooses.
2. Mr. Dr. Eng. M. Badrus Zaman., ST., MT. as Head of Department of Marine Engineering, Faculty of Marine Technology ITS. And also as supervisor to this bachelor thesis who giving author a lot of advice.
3. Nurhadi Siswantoro, ST.,MT as Author's Thesis Co-Supervisor who has giving the motivation and every necessary information to help finish the bachelor thesis.
4. Mr. Aguk Zuhdi M. Fatahillah, M.Eng., Ph.D as a lecture advisor since first semester until 8^{th} semester who giving a lot of advice.
5. Mr. Diwandaru and all of PT. X team for giving any data required for this bachelor thesis.
6. For my lovely Aunty Hakimatussholikhah Effendy who giving me a lot of moral support to finish this Bachelor Thesis as soon as possible.
7. Muhamad Amin Sentosa who always be author's loyal supporter in every conditions.
8. Rika Citra, Dimas Darmawan, Raihan Dzaky, for the giving any idea and support along the process of writing this bachelor thesis.
9. Hanum Rida Almira, Putri Hikmatin, Nia Ardila Kabalmay, and Richa Meilinda for the support and held along the way to finish bachelor thesis.

10. All civitas academic of Department of Marine Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember whose giving a lot of knowledge to the author.
11. All of friends from Mercusuar and Double Degree Marine Engineering 2014 for all the memories and knowledges.
12. All member of MOM Laboratory for the great time and support.
13. Great amounts of friends that can't be mentioned, for their support, help and ideas for this thesis.

The author realizes that this bachelor thesis remains far away from perfect. Therefore, every constructive suggestion and idea from all parties is highly expected by author for this bachelor thesis correction and improvement in the future.

Finally, may Allah SWT bestow His grace, contentment and blessings to all of us. Hopefully, this bachelor thesis can be advantageous for all of us particularly for the readers.

Surabaya, 14 Juli 2018

Author

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CHAPTER I
INTRODUCTION

1.1. Background Overview

With the rapid advancement of technology, it is necessary to supply the energy for these technologies. Most of the energy supply in Indonesia comes from the oil and gas industry. The oil and gas industry has much equipment needed to support the business process. Such as pipeline, tank, heat exchanger, heater, etc. The tank is the most widely used equipment in the industry. The tank is used for temporary storage of production.

Although, tank is equipment that is crucial, but tank is also very vulnerable to damage. Such a leak that occurred in CPO tank of PT Wira Inno Mas (WIM) that causing spilled 50 tons of CPO to Teluk Bayur Padang on September 28, 2017. And also happened at PT. Badak LNG on September 27, 2017 occurred a leak in the tank no D24-6.

Thing like stated above likely to happen because the liquid inside the tanks is polluted with corrosive element, being in above work temperature, and many more possible cause that make corrosion happened faster. Except general corrosion there are some another problem like stress corrosion cracking, pitting, and another type of material stress. According to Marash & Mclennan Survey and from EU Country survey they categorize the equipment that gives most disadvantage if it breakdown is like in **table 1.1**.

Table 1. 1 *Marash & Mclennan Survey About Component Breakdown*

Equipment	Number of Breakdown in percentage	Avg. of Financial losses (Million U$D)
Piping System	31	41.9
Tanks	17	40.5
Process Drums	7	25.5
Marine Vessels	6	32
Pump/compressors	5	19.2

American Petroleum Institute (API) is one of the most commonly used standard in the oil and gas industry worldwide besides the DNV-GL standard. PT. XXX which is a national company engaged in oil and gas also apply the API standard during the installation process of the tank.

Because the tank is one of static equipment, the maintenance strategy that can be applied is Risk Based Inspection (RBI). By using RBI, the company will get information based on risk analysis to make inspection plan for equipment. The basis for implementing RBI is Probability of Failure and Consequence of Failure. However, the random scenario of damage must also be considered and calculated.

1.2. Research Problems

Based on the background, the problem can be summarized by several major problems for writing this bachelor thesis:

a. How to determine the risk level of the tank based on the RBI method?
b. How to determine a proper inspection plan for the tank?

1.3. Research Limitations

Limitations of this final project are:

a. The tank that becomes the object of writing this final task is the asset PT. X
b. All analysis and calculations based on API 580 and API 581: 2016 standards
c. Natural disasters are not considered

1.4. Research Objective

The purpose of this thesis is:

a. Determine the risk level of the tank
b. Determine the type and time of the inspection interval of the tank

1.5. Project Deliverable

a. Develop maintenance schedule for condensate storage tank according to API 581 2016
b. Develop a proper inspection method for condensate storage tank based on applied damage mechanism

1.6. Research Benefits

The benefits of writing this thesis are:

a. This final project can be used as the basis for determining the priority of the inspection strategy as a preventive effort to reducing the failure
b. Introduce RBI as a maintenance and inspection strategy for pressurized equipment
c. Increasing safety level in oil and gas industry

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CHAPTER II
LITERATURE STUDY

2.1. Problem Overview

In every major industry that needed tanks as their storage equipment must be aware that tanks need special treatment. Especially in oil and gas industry. Where the liquid that held in the tanks has high pressure and very flammable in their properties. If there any failure from the tank itself, it will make another problem that would harm the environment and also humans around the tanks.

According to James I. Chang studies about storage tanks accident which happened from 1960 until 2003, there is over 200 tanks accident that shown in **Table 2.1**[1]. A small accident may lead to million-dollar property loss and a few days of production interruption. A large accident results in lawsuits, stock devaluation, or company bankruptcy. Even though there are organizations and engineering societies such as American petroleum institute (API), American Institute of chemical engineers (AIChE), American society of mechanical engineers (ASME).They already published strict engineering guidelines and standards for the construction, material selection, design and safe management of storage tanks and their accessories, but tanks accident still occur.

Table 2. 1 *Storage Tanks Accidents from 1960 until 2003*

Years	Fire	Explosion	Spill	Toxic Gas release	Misc	Sub-Total
1960-1969	8	8	0	0	1	17
1970-1979	26	5	5	0	0	36
1980-1989	31	16	3	2	1	53
1990-1999	59	22	2	1	1	85
2000-2003	21	10	8	10	2	51
Total	145	61	18	13	5	242

[1] James I. Chang, A Study of Storage Tank Accidents, 2005, Taiwan

In American petroleum institute (API) Standard 653 there is two kind of failure that can be happened in tanks[2]:

1. Catastrophically
   The failure can happen very quickly, can cause damage or loss in adjacent equipment and dangerous to personnel.
   - Wall blowout
   - Explosion
   - Total roof collapse
2. Non-catastrophically
   The failure happened in slow period of time, general corrosion type failures, can often be repaired while still insignificant
   - Pinhole leaks
   - General corrosion

Nowadays engineer already determines some common problems that can be easily detected such as overfilling and over or under pressure. For example, an Accidental overfilling, impeding exiting vent flow, and not allowing in-breathing as a tank is being pumped out are cardinal sins. Moreover, for over or under pressure it crucial to maintain the integrity of tanks venting system. Tank venting systems must not be altered or tampered with without a management-of-change review.

In the past years, there are some major tanks failures accident that happened. Moreover, there are some of the examples of the accident:

A. The Ashland Oil Spill in Pittsburgh, United States[3]
   During the first week of January 1988, the big news story in Pittsburgh, Pennsylvania and around much of the nation was the failure of a giant oil storage tank owned by the Ashland Oil Company. On the evening of January 2nd, 1988, the big tank split apart vertically at the company's storage yard in Floreffe, Pennsylvania, located about 25 miles south of Pittsburgh on the Monongahela River. The tank released its entire contents of 3.85 million gallons of diesel fuel,

[2] Fluid Fertilizer Foundation, Steel Tank Maintenance. 2012
[3] Jack Doyle, "Disaster at Pittsburgh – 1988 Oil Tank Collapse", 2015, United States of America

flooding the complex grounds and sending some 750,000-to-800,000 gallons of the fuel into the Monongahela River. The Ashland tank failure would become one of the worst inland oil spills in the nation's history.

Figure 2. 1 *The aerial photo of a split tank remaining and "dented" neighboring tank at right.*

Source: articles.nytime.com

The force generated at the site by the escaping fuel volume as it burst from the tank was considerable. Some residents reported hearing a low-level explosion-like sound as the tank split apart. The escaping oil from the big tank propelled it backward off of its foundation, ripping and bending the structure. The steel shell of the tank itself was left "twisted and contorted" on the ground, as the Pennsylvania Department of Environmental Protection (DEP) would later report.

Figure 2. 2 *Artists' rendering of a failed storage tank at Ashland Oil Co.'s*

Source: EPA

Later on rendering of failed storage tank ware made as shown in **Figure 2.2**. The rendering is needed for case inspection process. That matter is required to prevent the same case ever happen again. From that rendering expert can determine the first part of tank that collapse.

B. The Gulf Oil Co. Burning oil Cases, Philadelphia[4]

On August 17th, 1975 near dawn, a fire started in the refinery when a 75,000-barrel oil storage tank ignited after being filled from a docked oil tanker on the Schuylkill River. However, this fire thought to be under control a few hours after it began, roared back to life a second time, taking the lives of several firefighters already on the scene, and causing a fire-storm inferno at the Gulf complex that almost took down the entire refinery, and more.

On that Sunday morning, just after midnight, at around 12:45 am., the oil tanker MT. Afran Neptune, berthed at a Gulf refinery dock, had begun off-loading its cargo of crude oil to the refinery. It was pumping reconstituted Venezuelan crude oil (containing an additional five percent naphtha) into storage tank No. 231.

[4] Jack Doyle, "Burning Philadelphia: Refinery Inferno, 1975,", 2015.

Figure 2. 3 *. Aug 1975: Aerial view of Gulf Oil refinery fire in Phila. PA.*

Source: EPA

The original cause of the fire was the overfilling of Tank 231. While no crude oil escaped from the tank as a result of being overfilled, large quantities of hydrocarbon vapors were trapped above the surface of the tank's crude oil. As the quantity of crude oil increased, these hydrocarbon vapors were forced out of the tank's vents and into the area of the No. 4 Boiler House where the initial flash occurred. The overfilling of the tank, in turn, resulted from a failure of the tanker's personnel to properly monitor the quantity of crude oil being pumped into the tank. At approximately 6:02 a.m. in the wake of the first explosions and fire, the tanker terminated its pumping operations, left its Schuylkill River berth and relocated to the Gulf piers at Hog Island.

2.2. Storage Tanks

Storage tanks are containers that hold liquids or gas. Storage tanks operate under no (or very little) pressure, distinguishing them from pressure vessels. Storage tanks are often cylindrical, perpendicular to the ground with flat bottoms, and a fixed flangible or floating roof. There are usually many environmental regulations applied to the design and operation of storage tanks, often depending on the nature of the fluid contained within.

In most cases, scenario storage tanks that use in oil and gas industry were made of steel material. Because of that all of metal tanks in contact with soil and containing petroleum products must be protected from corrosion to prevent escape of the product into the environment. The most effective and common corrosion control techniques for steel in contact with soil is cathodic protection.

The storage tank that is used in this research is an atmospheric tank a container for holding a liquid at atmospheric pressure. The major design code for welded atmospheric tanks are API 650 and API 620. API 653 is used for analysis of in-service storage tanks. And also the tank work as crude oil storage tank. That means the construction of the tank is must much better than storage of product oil.

2.2.1. Type of Storage Tank

There were many types of storage tanks. It was Fixed Roof Tanks. Fixed Roof Tanks is the least expensive kind of storage tanks. It consisting of a cylindrical shape frame with a fixed roof that cone or dome-shaped. This kind of storage tank has a breather valve to release excess vapor during slight variation of temperature.

The other type is External Floating Roof Tanks. This kind of tanks the roof is not attached to the tank. The roof is floating above the liquid that stored in the tanks. This is due to reducing the loss of liquid by minimizing evaporation. Besides the external floating roof tanks, there’s also Internal Floating Roof Tanks. This kind of tanks has both of fixed roof and a floating roof. The floating roof floats on the liquid inside the tanks which rise and falls depending with the level of the liquid.

2.2.2. Structure and P&ID Storage Tank

The construction of storage tanks for crude oil is a process that requires great care. There is no room for leaks in these tanks and they must be rigorously tested before they are put to use. The specifications for these tanks differ from client to client. Many companies that manufacture crude oil storage tanks use carbon steel, which is a type of steel that contains percentages of carbon. Stainless steel is also used, which is a type of steel that contains chromium, which is rust resistant. Carbon steel is cheaper than stainless steel, and so some companies may prefer it as the material that their tanks are made of.

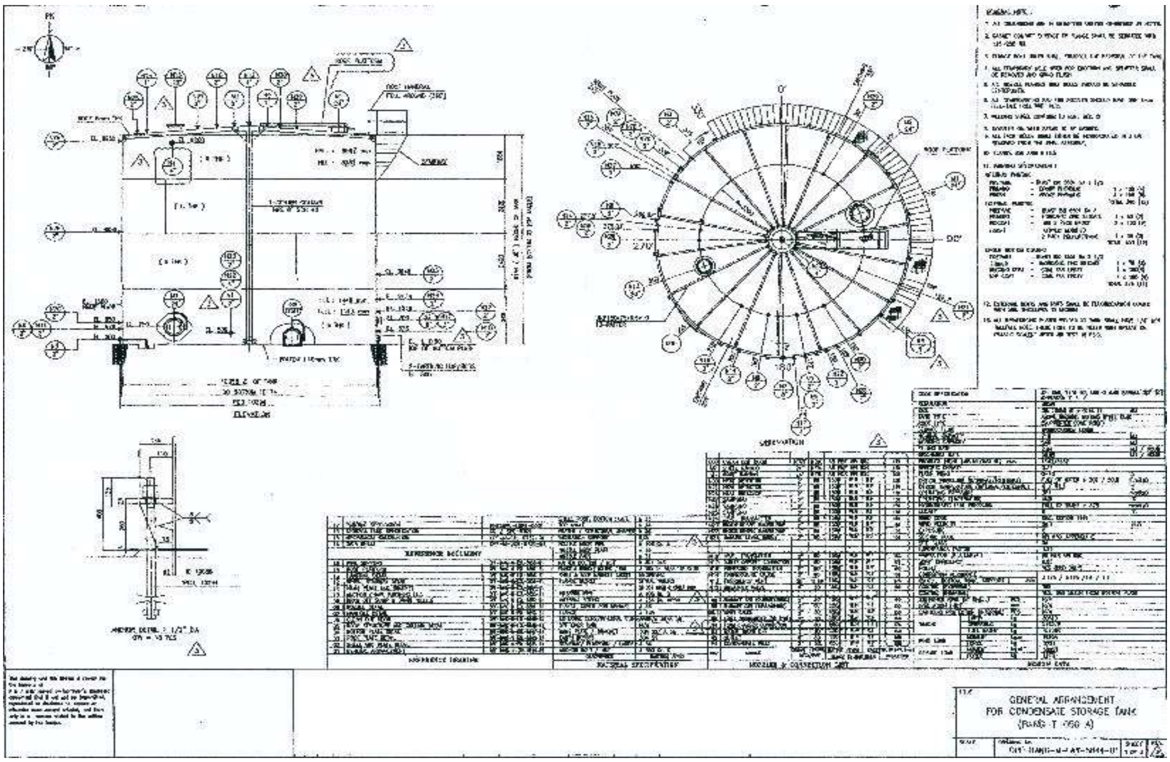

Figure 2. 4 *General Arrangement of Condensate Storage Tank*

Source: Documentation from PT. X

From the general arrangement shown in **Figure 2.4.** data of the tank that needed in RBI Calculation are already provided. The data of working fluid also can be obtained by looking the general arrangement. For another data such as piping and flow of the fluid it can be found in P&ID as shown in **Figure 2.5.**

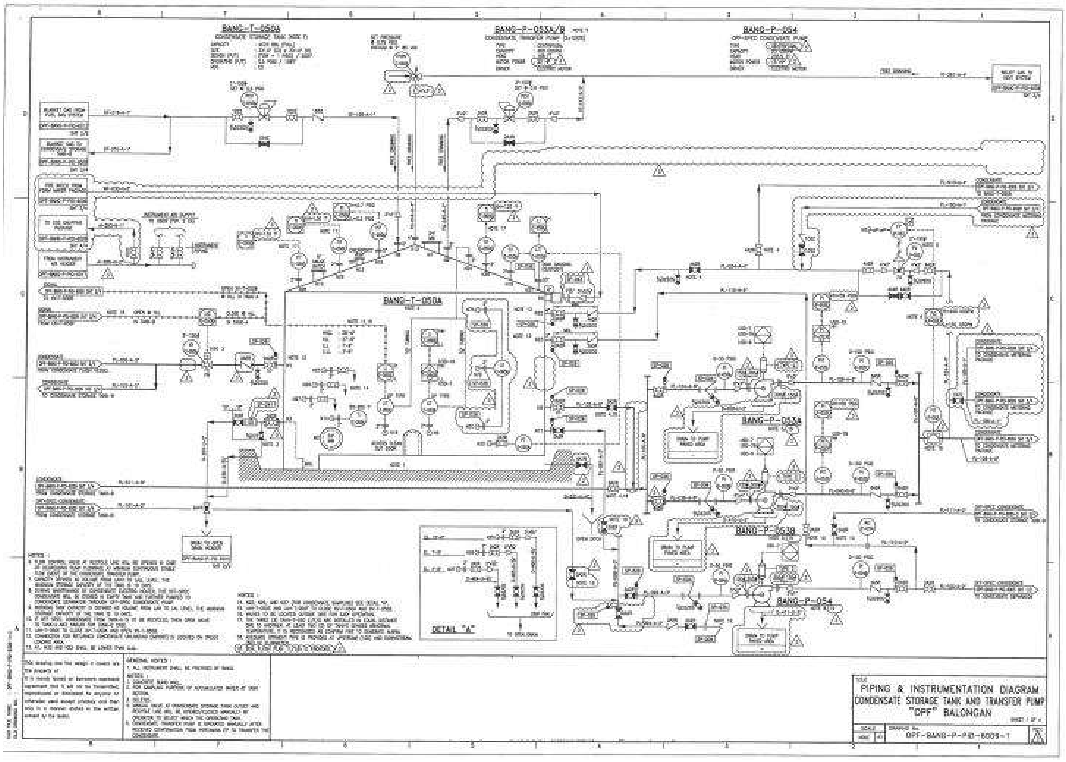

Figure 2. 5 *P&ID of Condensate Storage Tank and Transfer Pump*

Source: Documentation from PT. X

2.3. National Rules of Equipment Advisability

In every country have their own rules that are regulating the oil and gas industry. Many of the rules that regulate in the industry are concern about the safety of the workers. Especially oil and gas industry if there any failures it can be very harmful to environmental and also human. That is why it needs to be regulated for efficiency of the industrial process.

2.3.1 Law Enforcement

The Law that binding for equipment advisability are *Pasal 2* UU no.1 *tahun 1970 tentang keselamatan kerja.* And also *Pasal 42* UU *No.22 Tahun 2001 tentang Minyak dan Gas Bumi*. The institution that supervises and regulate the equipment advisability is *Ditjen (Direktorat Jendral) Minyak dan Gas.*

2.3.2 Undang-undang Nomor I Tahun 1970

This law regulated the safety of the workers in the worksite. This law consists of eleven chapter and 18 articles. In *Bab 3 pasal 3 ayat 1* stated that for safety at work it needs to be:

1. Prevent, and reduce accident
2. Prevent, reduce, and extinguish fire accident
3. prevent, and reduce Explosive risk

And in this law also regulate about equipment advisability that being stated in *pasal 2* ayat2. Moreover, in *pasal 4* stated that every equipment that possible to make some accident must fulfill some standards. And every standards must consist of engineering consideration.

2.3.3 *Peraturan Pemerintah Nomor 11 tahun 1979*

This law regulates safety at oil and gas refinery. it's consist of 31 chapters and 59 articles. In this law stated that every oil and gas industrial process must be under *Kementerian Energi dan Sumber Daya Mineral* (ESDM). However, in the process of supervising *Kementrian ESDM* gives all the rights to *Ditjen (Direktorat Jendral) Minyak dan Gas.*

2.3.4 Undang-undang Nomor 22 tahun 2001

This law is consisting of 14 chapters and 67 articles. This law regulates every aspect of Indonesian Oil and Gas Industry. In this bachelor thesis is discuss storage tank. Which equipment that uses to store oil or gas. In *Bab 5 pasal 23* stated that every companies that do storage their oil or gas must have *Izin Usaha Penyimpanan*.

2.3.5 SKPP

SKPP is (*Sertifikat Kelayakan Penggunaan peralatan)* is one of the certificates that must have to proceed the production process in oil and gas industry. The one that publishes the certificate is *Perusahaan Jasa Inspeksi Teknik* that already being approved by Ditjen Migas. SKPP only be valid for 5 years.

2.4. Risk

Risk is the possibility of something that is not wanted, or can be mathematically defined as the multiplication between the probability of failure and the consequences of failure. Commonly written as follows:

Where:

$$R(t) = P_f(t) \times C_f(t) \quad (2.1)$$

$P_f(t)$ = Probability of Failure

$C_f(t)$ = Consequence of Failure

In this case the risk is also divided into high risk, medium risk, and low risk. Risks can be said to be high risk if the probability and consequence is greater and the risk becomes low risk if the probability and consequences are lower.

2.5. Risk Assessment

The risk assessment process undertaken to identify all possible worst-case scenario. The worst possibility is caused by human activity and technology. In performing risk assessment there are three main steps:

1. Identification by using 5W1H based question
2. Consider all the consequence for any possible scenario
3. Estimating risk for possible break down that could be happened

The initial step of risk assessment is to identify hazards and their impacts. Anyone or anything impacted by the incident. The next step is to determine the frequency of occurrence or the likelihood of occurrence of the hazard Because risk is a combination of consequences and probability.

Generally, in risk assessment there are three methods. It consists of quantitative, qualitative, and semi-qualitative / semi-quantitative methods. Of each method used will have different degrees of accuracy. In the selection of this method it is important to evaluate the degradation mechanisms that will occur in each equipment to be analyzed.

2.6. Method Overview

2.6.1. RBI (Risk Based Inspection)

Risk-Based Inspection is a systematic and structured approach to the development of inspection based on an asset's risk profile. or RBI is a process used to develop inspections and other mitigation plans to maintain the mechanical integrity of pressure-based equipment based on risk.

RBI usually use for static equipment or plant. Meanwhile for rotating equipment usually use RCM (Reliability Centered Maintenance) method. For equipment that being stated in API 580 standard about RBI are:

- Pressure Vessel
- Process Piping
- Storage Tanks
- Boilers and Heaters
- Heat Exchanger
- Pressure Relief devices

The outcome of any RBI analysis is Probability of Failure and Consequence of Failure which results in failure risk. Evaluation of RBI for Safety (addressed to death of a person and injured), Environmental (aimed at environmental damage), and the most important of a business is Economic (aimed at financial losses).

2.6.2. RBI Method

In RBI there are several methods, those are quantitative methods, qualitative, and semi-quantitative / semi qualitative.

- Quantitative

  In this quantitative model is interpreted as a model-based approach based on calculations. Advantages of using this quantitative approach is to produce better accuracy. If RBI is quantitatively assessed, then:

  a) PoF has a value from 0 to 1, therefore the logarithmic scale is recommended to display the graph results
  b) The safety consequences shall be stated in Potential loss of life (PLL) terms for personnel
  c) Economic consequences should use currency units
  d) Environmental consequences expressed by units of mass or volume of spilled pollutants in the environment.

- Qualitative

  This qualitative method is defined as the approach that is determined by involving the decision of a specialist engineer (engineering judgment). The advantage of using this qualitative approach is that it is faster in calculating. And it can minimize expenses. If the RBI is qualitatively assessed, then:

a) Calculation of degradation mechanisms, CoF assessment, PoF assessment, risk and inspection scheduling are carried out separately.
b) Each assessment must have its own form sheet
c) In the assessment form for degradation mechanisms shall consist of three separate forms for each of the three groups
   - Internal degradation mechanisms
   - External degradation mechanisms
   - Mechanical damage
d) Determination of risk matrix with decision procedure must involve personnel.
e) Personnel who involved in decision-making must have at least 10 years of experience

- Semi quantitative/semi qualitative

  This method states that semi-quantitative or semi-qualitative has the following method:

  a) Assessment of PoF or CoF is performed based on a simple algorithm selected from several relevant parameters
  b) PoF and CoF assessment is determined by engineering judgement.

2.6.3. POF (Probability of Failure)

Probability of failure can be written as numerical value from 0 to 1. If the change of failure could be happened is high so the value of PoF is closer to 1 and otherwise.

Probability of Failure has mathematically equation that can be express as:

$$PoF = gff \times D_f(t) \times F_{MS} \qquad (2.2)$$

Where:

- Gff = *generic failure frequency*
- D*f*(t) = *damage factor*
- FMS = *management system factor*

The probability of failure may be determined based on one, or a combination of the following methods:

a) Structural reliability models – In this method, a limit condition of equipment is determined based on a structural model that includes all relevant damage mechanisms, and uncertainties in the independent variables of this model are defined in terms of statistical distributions. The resulting model is solved directly for the probability of failure.
b) Statistical models based on generic data – In this method, generic data is obtained for the component and damage mechanism under evaluation and a statistical model is used to evaluate the probability of failure.
c) Expert judgment – In this method, expert solicitation is used to evaluate the component and damage mechanism, a probability of failure can typically only be assigned on a relative basis using this method.

In API RBI, a combination of the above is used to evaluate the probability of failure in terms of a generic failure frequency and damage factor.

2.6.3.1. GFF (Generic Failure Frequency)

The generic failure frequency is based on industry averages of equipment failure. The generic failure frequency is intended to be the failure frequency prior to any specific damage occurring from exposure to the operating environment. API RBI uses four different damage hole sizes model the release scenarios covering a full range of events. The Hole sizes are Small, Medium, Large and Rupture.

If enough data were available for a given component, true probabilities of failure could be calculated from actual observed failures. Even if a failure has not occurred in a component, the true probability of failure is likely to be greater than zero because the component may not have operated long enough to experience a failure. As a first step in estimating this non-zero probability, it is necessary to examine a larger set of data of similar components to find enough failures such that a reasonable estimate of a true probability of failure can be made.

This generic component set of data is used to produce a generic failure frequency for the component. The generic failure frequency of a component type is estimated using records from all plants within a company or from various plants within an industry, from literature sources, and commercial reliability data bases. Therefore, these generic values typically represent an industry in general and do not reflect the true failure frequencies for a specific component subject to a specific damage mechanism.

The generic failure frequency is intended to be the failure frequency representative of failures due to degradation from relatively benign service prior to accounting for any specific operating environment, and are provided for several discrete hole sizes for various types of processing equipment (i.e. process vessels, drums, towers, piping systems, tankage, etc.).

A recommended list of generic failure frequencies is provided in **Table 2.2**. The generic failure frequencies are assumed to follow a log-normal distribution, with error rates ranging from 3% to 10%. Median values are given in Table 2.1. The data presented in the **Table 2.2** is based on the best available sources and the experience of the API.

The overall generic failure frequency for each component type was divided across the relevant hole sizes, i.e. the sum of the generic failure frequency for each hole size is equal to the total generic failure frequency for the component.

Table 2. 2 *Suggested Component Generic Failure Frequencies (gff)*

Equipment type	**Component type**	***gff* as a Function of Hole Size (failures/yr)**				***gff(total)* (failures/yr)**
		Small	**Medium**	**Large**	**Rupture**	
Tank650	TANKBOTTOM	7.20E-04	0	0	2.00E-06	7.20E-04
Tank650	COURSE-1	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	COURSE-2	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	COURSE-3	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	COURSE-4	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04

2.6.3.2. DF (Damage Factors)

The damage factor is determined based on the applicable damage mechanisms (local and general corrosion, cracking, creep, etc.) relevant to the materials of construction and the process service, the physical condition of the component, and the inspection techniques used to quantify damage. The damage factor modifies the industry generic failure frequency and makes it specific to the component under evaluation.

The basic function of the damage factor is to statistically evaluate the amount of damage that may be present as a function of time in service and the effectiveness of an inspection activity to quantify that damage.

Damage factor estimates are currently provided for the following damage mechanisms:

a) Thinning (general and local) - d_f^{thin}
b) Component Linings - d_f^{elin}
c) External Damage (corrosion and stress corrosion cracking) - d_f^{extd}
d) Stress Corrosion Cracking (internal based on process fluid, operating conditions and materials of construction) - d_f^{SCC}
e) High Temperature Hydrogen Attack - d_f^{htha}
f) Mechanical Fatigue (Piping Only) - d_f^{mfat}
g) Brittle Fracture (including low-temperature brittle fracture, temper embrittlement, 885 embrittlement, and sigma phase embrittlement.) - d_f^{brit}

Damage factors are calculated based on the techniques described in probability of failure calculation method paragraph, but are not intended to reflect the actual probability of failure for the purposes of reliability analysis. Damage factors reflect a relative level of concern about the component based on the stated assumptions in each of the applicable paragraphs of the document.

If the damage factor has combination or multiple damage mechanism, then the rules and the formulas are as follows:

a) Total damage factor, $D_{f\text{-}total}$ – If more than one damage mechanism is present, the following rules are used to combine the damage factors. The total damage factor is given by **Equation (2.3)** when the thinning is local:

$$D_{f\text{-}total} = \max[d_{f-gov}^{thin}, d_{f-gov}^{extd}] + d_{f-gov}^{SCC} + d_{f-gov}^{htha} + d_{f-gov}^{brit} + d_{f-gov}^{mfat} \quad (2.3)$$

If the thinning damage is general, then the total damage factor is given by **Equation (2.4)**:

$D_{f\text{-total}} = d_f^{thin} + d_f^{extd} + d_{f-gov}^{SCC} + d_{f-gov}^{htha} + d_{f-gov}^{brit} + d_{f-gov}^{mfat}$ (2.4)

*if a damage factor is less than or equal to one, then this damage factor shall be set to zero in the summation.
*if $D_{f\text{-total}}$ is computed as less than or equal to one, then $D_{f\text{-total}}$ shall be set equal to one.

b) Governing Thinning Damage Factor, $\mathrm{D}_{\mathrm{f-gov}}^{\mathrm{thin}}$ – governing thinning damage factor is determined based on the presence of an internal liner using **Equations (2.5)** and **(2.6)**.
d_{f-gov}^{thin} = min[d_f^{thin}, d_f^{elin}] *when an internal liner is present* (2.5)
d_{f-gov}^{thin} = d_f^{thin} *when an internal liner is not present* (2.6)

c) Governing Stress Corrosion Cracking Damage Factor, d_{f-gov}^{SCC} – The governing stress corrosion cracking damage factor is determined from **Equation (2.7)**.

$$d_{f-gov}^{SCC} = \max\left[d_f^{caustic}, d_f^{amine}, d_f^{SCC}, d_f^{\frac{HIC}{SOHIC}-H2S}, d_f^{carbonate}, d_f^{PTHA}, d_f^{CLSCC}, d_f^{HSC-HF}, d_f^{\frac{HIC}{SOHIC}-HF} \right] \quad (2.7)$$

d) Governing External Damage Factor, $\mathrm{d}_{\mathrm{f-gov}}^{\mathrm{extd}}$, governing external damage factor is determined from **Equation (2.8).**
$d_{f-gov}^{\mathrm{extd}}$ = max [d_f^{extd}, d_f^{CUIF}, $d_f^{extd-CLSCC}$, $d_f^{CUI-CLSCC}$] (2.8)

e) Governing Brittle Fracture Damage Factor, d_{f-gv}^{brit} The governing brittle fracture damage factor is determined from **Equation (2.9)**.
d_{f-gov}^{brit} = max [($d_f^{britfract}$+d_f^{tempe}), d_f^{885}, d_f^{sigma}) (2.9)
*if a damage factor is less than or equal to one (i.e. the damage is inactive), then this damage factor shall be set to zero in the summation.

***Table 2. 3** damage factor defined*

Damage Factor Variable	Damage Factor Description
d_f^{thin}	Damage factor for general and localized thinning
D_f^{liner}	Damage factor of inorganic and organis linings for all component types
$D_f^{caustic}$	Damage factor for caustic cracking
D_f^{amine}	Damage factor for amine cracking
D_f^{ssc}	Damage factor for sulfide stress corrosion cracking
$D_f^{HIC-SOHIC-H2S}$	Damage factor for HIC/SOHIC cracking in H_2S environments
$D_f^{carbonate}$	Damage factor for carbonate cracking
D_f^{PTA}	Damage factor for polythionic acid cracking in austenitic stainless steel and nonferrous alloy components
D_f^{CLSCC}	Damage factor for chloride stress corrosion cracking
D_f^{HSC-HF}	Damage factor for hydrogen stress cracking in HF environment
$D_f^{\mathrm{HIC/SOHIC-HF}}$	Damage factor for HIC/SOHIC cracking in HF environments
D_f^{extor}	Damage factor for external corrosion on ferritic components
D_f^{CUIF}	Damage factor for CUI on insulted ferritic components
$D_f^{ext-CLSCC}$	Damage factor for external chloride stress corrosion cracking on austenitic stainless steel components
$D_f^{CUI-CLSCC}$	Damage factor for external chloride stress corrosion cracking on austenitic stainless steel insulated components
D_f^{htha}	Damage factor for high temperature hydrogen attack
$D_f^{britfract}$	Damage factor for brittle fracture of carbon steel and low alloy components
D_f^{tempe}	Damage factor for temper embrittlement of Cr-Mo low alloy components
D_f^{885}	Damage factor for 885 embrittlement
D_f^{sigma}	Damage factor for sigma phase embrittlement
D_f^{mfat}	Damage factor for mechanical fatigue

All Damage Factor are defined in RBI 581: 2016 that shown **Table 2.3**. And damage factors that applied in each equipment are to be considered using damage factor screening that shown in **Table 2.4**. for full review can be seen in **Attachment B**.

Table 2. 4 *Damage Factors screening for applied in condensate storage tank*

No.	Type Damage Mechanism	Criteria based on API 581	Yes/No	Result
1	Thinning Damage factor	In an API RBI assessment, all components should be checked for thinning.	Yes	Yes
2	External Corrosion Damage Factor - Ferritic Component	Areas exposed to mist overspray from cooling towers	No	Yes
		Areas exposed to steam vents,	No	
		Areas exposed to deluge systems,	Yes	
		Area subject to process spills, ingress of moisture, or acid vapors	No	
		Carbon steel systems, operating between –12°C and 177°C (10°F and 350°F).	Yes	
		Systems that do not normally operate between -12°C and 177°C (10°F and 350°F) but cool or heat into this range intermittently or are subjected to frequent outages,	No	
		Systems with deteriorated coating and/or wrappings	No	
		Cold service equipment consistently operating below the atmospheric dew point	No	
		Un-insulated nozzles or other protrusions components of insulated equipment in cold service conditions	Yes	

2.6.3.3. Inspection Effectiveness Category

Damage factors are determined as a function of inspection effectiveness. There are five categories of inspection effectiveness, which is shown in **Table 2.5** The inspection effectiveness categories presented are meant to be examples and provide a guideline for assigning actual inspection effectiveness.

Inspections are ranked according to their expected effectiveness at detecting damage and correctly predicting the rate of damage. The actual effectiveness of a given inspection technique depends on the characteristics of the damage mechanism.

The effectiveness of each inspection performed within the designated time period is characterized for each damage mechanism. The number of highest effectiveness inspections will be used to determine the damage factor. If multiple inspections of a lower effectiveness have been conducted during the designated time period, they can be approximated to an equivalent higher effectiveness inspection in accordance with the following relationships:

a) 2 Usually Effective (B) Inspections = 1 Highly Effective (A) Inspection, or 2B = 1A
b) 2 Fairly Effective (C) Inspections = 1 Usually Effective (B) Inspection, or 2C = 1B
c) 2 Poorly Effective (D) Inspections = 1 Fairly Effective (C) Inspection, or 2D = 1C

To be noted that these equivalent higher inspection rules shall not be applied to No Inspections (E) that shown in **Table 2.5**.

Table 2. 5 *Inspection Effectiveness Categories*

Source: API 581:2016

Quantitative Inspection Effectiveness Category	Description
Highly Effective	The inspection methods will correctly identify the true damage state in nearly every case (or 80-100% confidence).
Usually Effective	The inspection methods will correctly identify the true damage state most of time (or 60-80% confidence).
Fairly Effective	The inspection methods will correctly identify the true damage state about half of time (or 40-60% confidence).
Poorly Effective	The inspection methods will provide little information to correctly identify the true damage state (or 20-40% confidence).
Ineffective	The inspection methods will provide no or almost no information that will correctly identify the true damage state and are considered ineffective for detecting the spesific damage mechanism (less than 20% confidence).

2.6.3.4. FMS (Management System Factors)

Management system factor used to measure how good the facility management system that may arise due to an accident and labor force of the plant is trained to handle the asset. This evaluation consists of a series of interviews with plant management, operations, inspection, maintenance, engineering, training, and safety personnel.

The management systems evaluation procedure developed for API RBI covers all areas of a plant's PSM system that impact directly or indirectly on the mechanical integrity of process equipment. The management systems evaluation is based in large part on the requirements contained in API Recommended Practices and Inspection Codes. It also includes other proven techniques in effective safety management. A listing of the subjects covered in the management systems evaluation and the weight given to each subject is presented in **Table 2.6**.

Table 2.6 *Management Systems Evaluation*

Source: API 581:2016

Table	Title	Questions	Points
2.A.1	Leadership and Administration	6	70
2.A.2	Process Safety Information	10	80
2.A.3	Process Hazard Analysis	9	100
2.A.4	Management of Change	6	80
2.A.5	Operating Procedures	7	80
2.A.6	Safe Work Practices	7	85
2.A.7	Training	8	100
2.A.8	Mechanical Integrity	20	120
2.A.9	Pre-Startup Safety Review	5	60
2.A.10	Emergency Response	6	65
2.A.11	Incident Investigation	9	75
2.A.12	Contractors	5	45
2.A.13	Audits	4	40
Total		**102**	**1000**
Note: For Tabels 2.A.1 through 2.A.13 are located in Annex 2.A. API RBI 581:2016			

The management systems evaluation covers a wide range of topics and, as a result, requires input from several different disciplines within the facility to answer all questions. Ideally, representatives from the following plant functions should be interviewed:

a) Plant Management
b) Operations
c) Maintenance
d) Safety
e) Inspection
f) Training
g) Engineering

The scale recommended for converting a management systems evaluation score to a management systems factor is based on the assumption that the “average” plant would score 50% (500 out of a possible score of 1000) on the management systems evaluation, and that a 100% score would equate to a one order-of magnitude reduction in total unit risk. Based on this ranking, **Equation (2.10)** may be used to compute a management systems factor, F_{MS}, for any management systems evaluation score.

*Note that the management score must first be converted to a percentage (between 0 and 100) as follows:

$$pscore = \frac{Score}{1000}\, x\, 100\ [unit\ is\ \%] \qquad (2.10)$$

$$F_{MS} = 10^{(-0.02pscore+1)}$$

The approximate formula above can be modified and improved over time as more data become available on management systems evaluation results.

It should be remembered that the management systems factor applies equally to all components and, therefore, does not change the risk ranking of components for inspection prioritization. The factor's value is in comparing one operating unit or plant site to another.

2.6.4. COF (Consequence of Failure)

The consequences of failure are the result if the asset getting failure. According to API RBI, consequences of failure assessment is performed to determining a ranking of equipment items on the basis of risk. There are four consequence categories such as; flammable, toxic consequences, non-flammable and non-toxic release and financial consequence. API RBI also provide two level consequences of failure methodology.

2.6.4.1. Consequence Categories

The major consequence categories are analyzed using different technique.

a) Flammable and explosive consequences are calculated using event trees to determine the probabilities of various outcomes (e.g., pool fires, flash fires, vapor cloud explosions), combined with computer modeling to determine the magnitude of the consequence. Consequence areas can be determined based on serious personnel injuries and component damage from thermal radiation and explosions. Financial losses are also determined based on the area affected by the release.
b) Toxic consequences are calculated using computer modeling to determine the magnitude of the consequence area as a result of overexposure of personnel to toxic concentrations within a vapor cloud. Where fluids are flammable and toxic, the toxic event probability assumes that if the release is ignited, the toxic consequence is negligible (i.e. toxics are consumed in the fire).

Financial losses are also determined based on the area affected by the release.

c) Non-flammable, non-toxic releases are also considered since they can still result in serious consequences. Consequences from chemical splashes and high temperature steam burns are determined based on serious injuries to personnel. Physical explosions and BLEVEs can also cause serious personnel injuries and component damage.

Financial Consequences includes losses due to business interruption and costs associated with environmental releases. Business interruption consequences are estimated as a function of the flammable and non-flammable consequence area results. Environmental consequences are determined directly from the mass available for release or from the release rate.

2.6.4.2. Methodology of Consequence Analysis

There are two levels of consequence Analysis assessment.

2.6.4.2.1. Level 1 Consequence

The Level 1 consequence analysis can be used for a limited number of representative fluids. This simplified method contains table lookups and graphs that can readily be used to calculate the consequence of releases without the need of specialized consequence modeling software or techniques. Fluid representative that can be calculated using level 1 consequences analysis can be seen in **Attachment E**.

The following simplifying assumptions are made in the Level 1 consequence analysis.

a) The fluid phase upon release can only be either a liquid or a gas, depending on the storage phase and the phase expected to occur upon release to the atmosphere, in general, no consideration is given to the cooling effects of flashing liquid, rainout, jet liquid entrainment or two-phase.

b) Fluid properties for representative fluids containing mixtures are based on average values i.e. molecular weight (MW), normal boiling point (NBP), density, Auto Ignition Temperature (AIT), Specific Heat (C_p).

c) Probabilities of ignition, as well as the probabilities of other release events (VCE, pool fire, jet fire, etc.) have been pre-determined for each of the representative fluids as a function of temperature, fluid AIT and release type. These probabilities are constants, totally independent of the release rate.

2.6.4.2.2. Level 2 Consequence

The Level 2 consequence analysis may be used in cases where the assumptions of the Level 1 consequence analysis are not valid. Examples of where the more rigorous calculations may be necessary are cited below.

a) The specific fluid is not represented adequately within the list of reference fluid groups provided in the Level 1 analysis, including cases where the fluid is a wide-range boiling mixture or where the fluids toxic consequences are not represented adequately by any of the reference fluid groups.
b) The stored fluid is close to its critical point, in which case, the ideal gas assumptions for the vapor release equations are invalid.
c) The effects of two-phase releases, including liquid jet entrainment as well as rainout need to be included in the assessment.
d) The effects of BLEVES are to be included in the assessment (not included in the Level 1 analysis).
e) The effects of pressurized non-flammable explosions, such as possible when non-flammable pressurized gases (e.g. air or nitrogen) are released during a vessel rupture are to be included in the assessment (not included in the Level 1 analysis.
f) Meteorology assumption can be use in dispersion calculation that became Level 1 consequence analysis that represent in data table.

In general, consequences can be divided by two. There are consequence area and finance consequence. In this bachelor thesis consequences analysis that being use is consequences area with level 1 methodology.

2.7. Inspection

Inspection is an evaluation of the quality of some characteristics related to standards or specifications. The inspection process evolves in line with the complex system in the production process. The inspection consists of several activities which include interpretation, specifications, measurements, and comparisons with standard specifications, rate of conformity, and data reporting. (Piere, 2007)

Some inspection techniques which can be used is the choice of the specific schedule will depend on the accuracy and the cost of these inspections, the balance between money spent on safety measurements with the business returned again to the system that maintained its integrity. (Piere, 2007)

In the resulting report, direct technique is one technique that measures the parameters directly and is influenced by the corrosion process. While the indirect technique is an inspection technique that provides data on the parameters that influence, or is influenced by corrosion of the environment or the product of corrosion process. (Piere, 2007)

In addition, an inspection technique can be described as intrusive if the inspection technique requires access through a pipe or vessel wall for measurement. While non-intrusive is an inspection technique that does not require such access in the measurement process. The most commonly used intrusive technique is to use some form of examination or specimen test, which includes flush mounted probe designs. Some indirect techniques can work to monitor various parameters online in real-time while others provide off-line information. After samples are collected from other flow or operational processes in further analysis by following internationally recognized methods (Piere, 2007)

NDT (Non Destructive Test) is one type of inspection that is often used in various industries. And some of the inspections included in the NDT category are:

1) Visual Inspection

   Visual inspection is the most commonly used inspection method because this inspection is performed with or without optical aids, such as microscopes, borescopes, endoscopes, or other aids that help visual inspection. In visual inspection category there are:

   a. Borescopes

      borescope works by forming an image of the display area with the objective lens. The image is transferred via a bar with an intermediate lens system. Images arrive at the ocular lens, creating virtual images that can be viewed and can be focused on viewing comfortably. Borescope often combine light near the objective lens to illuminate the displayed area. **Figure 2.6** below shows a sample inspection using a borescope.

Figure 2. 6 *inspection using Borescopes*

Source: Charles H, 2003

b. Fiberscope

Fiberscope is a fiber optic cable that transmits light from end to end. Fiberscope is similar to a borescope and the main difference is that fiberscope is more flexible and can fit into unreachable areas.

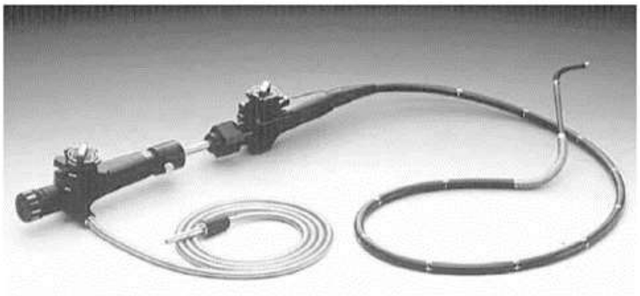

Figure 2. 7 *Fiberscope*

Source: Charles H, 2003

Fiberscope can also incorporate a light source as the subject area lighting and equipment to bend the tip in the desired direction. For fiberscope, the image is taken of the objective lens to the eyepiece with a bundle of fiber optic cables and not by a rigid lens system. Light cannot escape through the side after entering a fiber optic cable, so it always follows the wires around the bends and turns. **Figure 2.7** above shows an example of a fiberscope cable.

c. Video imaging system

   Video imaging system or "videoscope" consists of the addition of a charge-coupled device (CCD) camera at the end of a flexible probe. This system consists of an image recording camera, a processor, and a monitor that serves to display images. The **figure 2.8** below shows, an example of a videoscope tool.

Figure 2. 8 *videoscope*

Source: Charles H, 2003

2) Liquid penetrant inspection

   liquid penetrant methods included in the method of non-destructive testing (NDT). NDT is a method of examination without damaging the material being examined. This method is only able to detect the damage or defects of material on the surface. **Figure 2.9** below shows an example of a check by using a liquid penetrant.

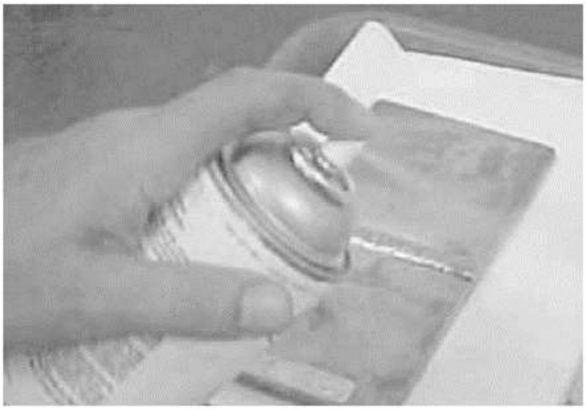

Figure 2. 9 *liquid penetrant*

Source: Charles H, 2003

3) Magnetic Particle Inspection

MPI is an inspection used to determine the presence of surface cracks or defects in ferromagnetic materials. In this inspection a magnet (yoke) is used to detect defective material. The working principle of this test is based on the nature of ferromagnetic objects that will give the magnetic poles if they are magnetized. The advantages of MPI are:

- MPI can detect very small defects
- MPI can detect defects of complex objects
- MPI can check objects that have the shape of pipes, rings, tubes, and others

This method is similar to the liquid penetrant inspection method that can only detect surface defects. **Figure 2.10** below shows the type of magnetic particle inspection.

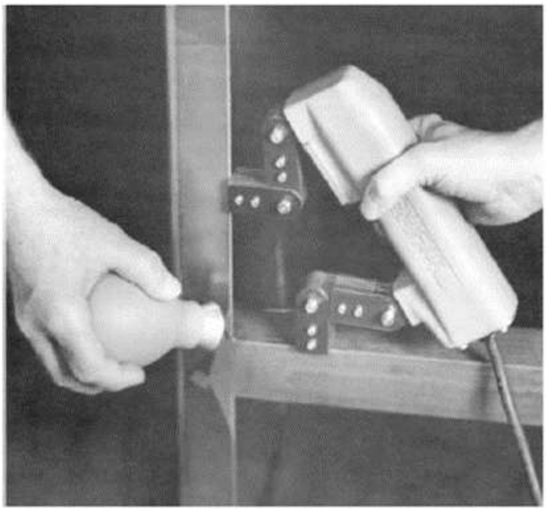

Figure 2. 10 *Magnetic particle inspection using AC yoke*
Source: Charles H, 2003

4) Ultrasonic Testing
   UT is a widely used NDT method because it can detect defects on the surface and inside of equipment made of metal or alloys. Types of ultrasonic testing inspections include;
   a. Thickness Measurement
      Measurement of thickness using ultrasonic tool. **Figure 2.11** shows an example of a thickness measurement tool.

Figure 2. 11 *Thickness gauge*

Source : Charles H, 2003

b. Defect Sizing

The combination of component and engineering capabilities makes UT the most appropriate to know the depth size of the crack and is widely used in the industrial world. **Figure 2.12** shows the type of defect sizing check.

Figure 2. 12 *Thickness gauge*

Source : Charles H, 2003

c. Time of-Flight Diffraction (TOFD)

This inspection using an interface transducer an ultrasonic signal through the inspected material. **Figure 2.13** below shows the working principle of time of-flight diffraction (TOFD).

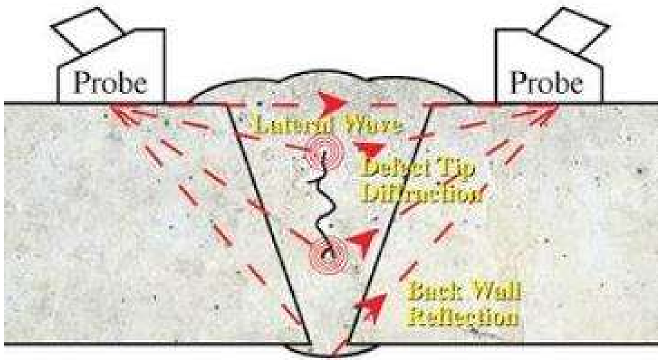

Figure 2. 13 *TOFD*

Source : Charles H, 2003

5) Radiographic Inspection

The types of inspections include:

a. Computed Tomography

The use of radiography may also be made by adding computers and complex algorithms to manipulate data. Another term is computed tomography or CT scanning. **Figure 2.14** below shows the equipment for radiographic inspection.

b. Tangential Radiography

Tangential radiography is also commonly known as a radiographic profile, which is used for detailed inspection of small pipe parts under insulation.

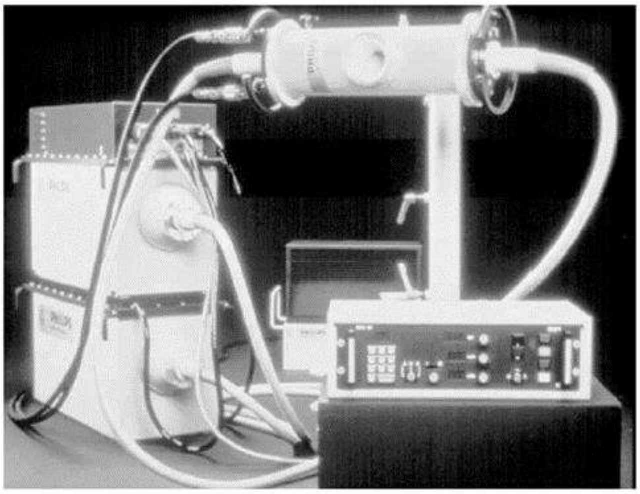

Figure 2. 14 *Sistem radiographic inspection*

Source : Charles H, 2003

6) Electromagnetic Inspection

The types of inspections by using this method includes:

a. Magnetic Flux Leakage (MFL)

Magnetic flux leakage (MFL) is the longest method and is most commonly used for in-line inspection methods in searching for metal-loss parts on pipelines that transmit gas. **Figure 2.15** below shows the working principle of electromagnetic inspection

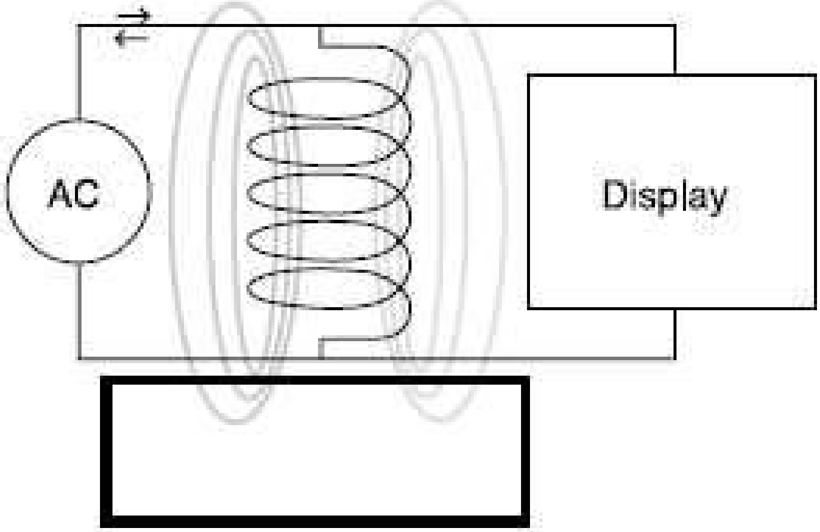

Figure 2. 15 *Electromagnetism*

Source: Charles H, 2003

b. Eddy Current Testing

Eddy Current is one of the inspection methods that utilize the current formed from the coil of wire wrapped around iron, resulting in a magnetic field. In this method the tool used is eddyscope, a component of eddyscope is a monitor that serves to display the results of the scanner. If there is a defect on the object being inspected, it will see the magnetic field changes generated by the eddy current.

steps namely cleaning, application penetrant, dye application, and inspection.

- Remote-field Eddy Current (RFEC)

  REFC was developed in the 1950s and is widely used for inspection of metallic tubing and tubing.

- Pulsed Eddy Current (PEC)

  The advantage of PEC compared with conventional EC is that it can penetrate more widely and deeply, the ability to lift-off is relatively undetectable, and the ability to determine quantitative measurements for wall thickness. Figure 2.16 below shows the working principle of eddy current system.

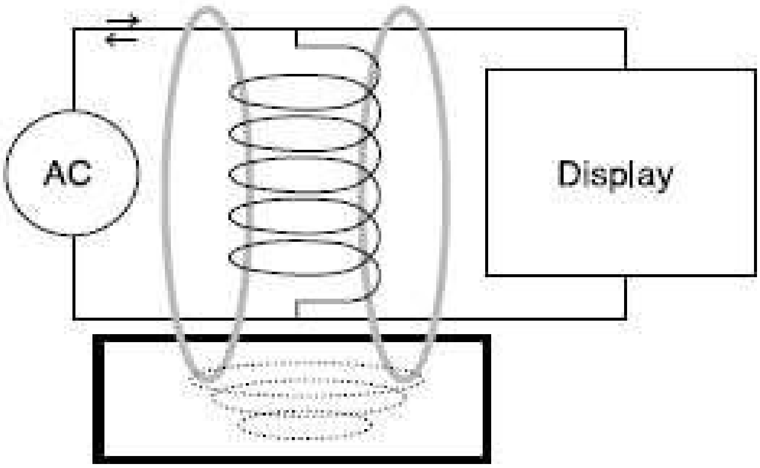

Figure 2. 16 *Eddy current system*

Source: Charles H, 2003

- *Magneto-Optic Imaging* (MOI)
  Magneto-optic Imaging / EC NDE based on Faraday's magneto-optical rotation principle
- *Thermographic Inspection*
  Thermography is a merging inspection technique in which the monitor transforms into a thermal pattern on an object that is heated, cooled, or preserved. This inspection may be used to measure variations in material characteristics and conditions.

7) Real Time Radiography

RTR is a non-destructive test inspection method that uses x-rays or gamma rays that can penetrate all metals except lead. The result of RTR is an electronic image that was taken during the inspection. The advantage of this method can detect very small defects. However, the price paid for this method is very high.

Figure 2. 17 *Real Time Radiography*
Source: nde-ed.org

CHAPTER III

METHODOLGY

The following methodology flow chart shows the process diagram of bachelor thesis.

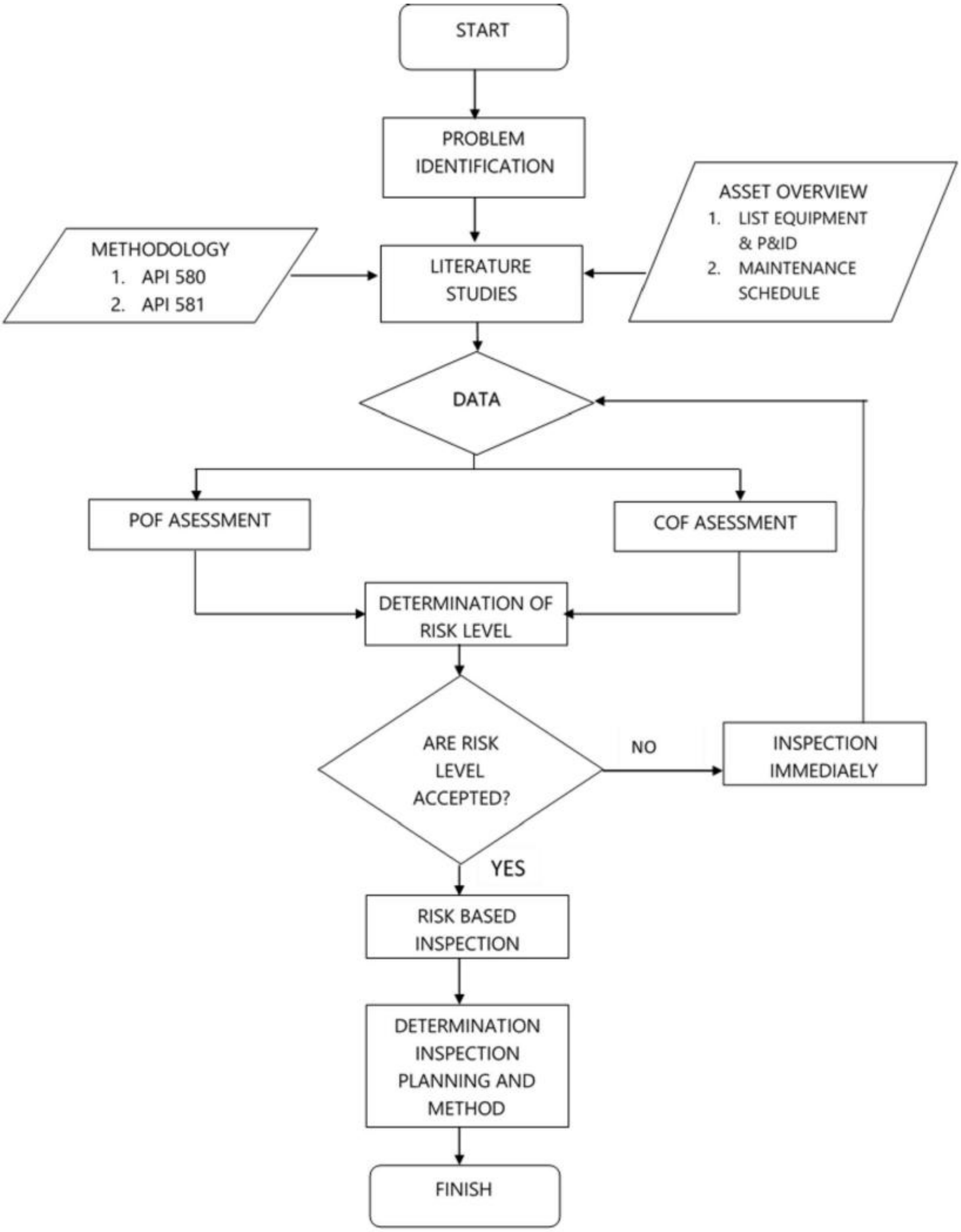

Figure 3. 1 *Methodology Flow Chart*

3.1. Problem Identification

The first step of writing bachelor thesis is started by problem identification. This process identifies and formulates the problems that occur in the tank. Problems that are taken on this final task is the damage of the tank. Because the tank used as object in this writing is a storage tank. So indirectly on the inside of the tank there is thinning on wall thickness (Thinning). If it is on leave continuously then the risk of failure rate of the tank will be greater. So need to do risk analysis with "RBI API 581" method. And doing the inspection scheduling.

3.2. Literatures Study

Next is to conduct a study literature with the aim of summarizing the basics of theory, and get various other supporting information related to this final project. Study literature is obtained from books and journals, papers, or from internet sources that support this study. In addition, by doing Questions and answers with the competent parties on this discussion. The main literature in this paper is API RP 581.

3.3. Data Collection

Basically RBI is a method that uses semi-quantitative analysis. These things are needed to answer questions that refer to API 580 and API 581. So these data are:

a) The inspection or survey data shall be used for the history of the tank and supporting equipment
b) Design drawings and tank construction (P & Id, Engineering specification, safety system, Etc.)
c) Process data is used to support calculations combined with the above data to determine the operating limits
d) Data settlement of completion of analysis by RBI method.

3.4. PoF Assessment

By using the API 581 as standard. So in the Probability of Failure assessment needs to specify Generic Failure Frequency (GFF). It starts by determining the asses analyzed and matching with the table listed in API 581. After determining the GFF then the Damage Mechanism can be determined. For step and data analyzed all set in API 581. And final calculation of some step this is determination of *PoF* which will be used in determining level of risk.

3.4.1. Analysis Thinning Damage Factors

API 581 provides the steps in calculating the thinning damage factor as follows:

1) Determining the age of the inspection since the last inspection. The inspection area can be defined as the time difference between the previous inspection and the last inspection. And also determining the furnish thickness. Which is can be found in General Arrangement of the equipment. Age of the inspection can be calculated by the following **equation 3.1**:

   age = RBI Date – Installation date (3.1)

2) Determine the Corrosion Rate of Base Material ($C_{r.bm}$) can be obtained with 1 of 3 methods below:
   a. Company Data.
   b. Measuring corrosion rate, based on inspection process.
   c. Calculating corrosion rate based on API 581 Annex 2B.

   The corrosion rate is influenced by storage temperature, storage pressure, stored fluid, and storage tank material. Annex 2B API 581 provides 13 criteria for the cause of corrosion rate. Determination of corrosion rate by performing screening on each criteria. In this bachelor thesis Corrosion Rate is determined by measuring during last inspection process.

3) Determine Age time in service since last inspection and last inspection thickness

   Determine the time in service (age_{tk}) since the last inspection known thickness, $t_{rdi.}$ The t_{rdi} is the starting thickness with respect to wall loss associated with internal corrosion If no measured thickness is available, t_{rdi} = t and age = age_{tk}. Using **equation 3.2**:

   age_{tk} = RBI Date - Last Inspection Date (3.2)

   Last inspection thickness, t_{rdi} can be obtained from last inspection report. Where:

   Age_{tk} is the component in-service time since the last inspection thickness measurement or service start date

   Tr_{di} is the furnished thickness, t, or measured thickness reading from previous inspection, only if the high level of confidence in its accuracy, with respect to wall loss associated with internal corrosion.

4) Determine age of cladding component (only for equipment with cladding material)

   For cladding/weld overlay pressure vessel components, calculate the age from the date of the starting thickness from **STEP 3** required to corrode away the cladding/weld overlay material, age_{rc} using Equation (3.3)

$$age_{rc} = max\left[\left(\frac{t_{rdi}-t_{bm}}{C_{r.cm}}\right),\ 0.0\right] \qquad (3.3)$$

No need calculates this because the equipment does not have cladding component.

5) Determine Thickness Minimum Using Original Construction Coat or Owner User Discretion.
For cylindrical, spherical or head components, determine the allowable stress, *S*, weld joint efficiency, *E*, and calculate the minimum required thickness, t_{min}, using component type in **Table 4.2**, geometry type in Table 4.3 and per the original construction code

Table 3. 1 *Component and Geometry Types Based on the Equipment Type*

Equipment Type	Component Type	Geometry Type
Tank650	COURSE-1-10	CYL

Table 3. 2 *Required Geometry Data Based on the Geometry Type*

Geometry Type	Geometry Description	Geometry Data
CYL	Cylindrical Shell	Diameter
		Length
		Volume

Thickness Minimum(t_{min})= Furnished Thickness - Corrosion Allowance (t_{min}) is the minimum allowable thickness.

6) Determine Wall Loss Fraction since Last Inspection (A_{rt})
The A_{rt} parameter using **Equation (3.4)**, as appropriate based on furnish thickness from **STEP 1,** $C_{r.bm}$ and $C_{r.cm}$ from **STEP 2**, age_{tk} and t_{rdi} from **STEP 3**, and the age required to corrode away the cladding/weld overlay, age_{rc}, if applicable from **STEP 4**.

Note that the age parameter in these equations is equal to age_{tk} from **STEP 3.** Because the component is without cladding, so age_{rc} = 0

$$A_{rt} = \frac{C_{r.bm} \,.\, age_{tk}}{t_{rdi}} \quad (3.4)$$

7) Calculate the Flow Stress *(FS^{Thin})*

$$FS^{Thin} = \frac{(YS+TS)}{2} .E.1.1 \quad (3.5)$$

8) Calculate the Strength Ratio Parameter (SR_P^{Thin})

The strength ratio parameter (SR_P^{Thin}) , using the appropriate **Equation (3.6)** or **(3.7)**. Using **Equation (3.6)** with t_{rdi} from **STEP 3**, t_{min} or t_c S, and E from **STEP 5**, and flow stress, FS^{Thin} , from **STEP 7.**

$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} . \frac{Max\,(t_{min}.t_c)}{t_{rdi}} \quad (3.6)$$

Note: The t_{min} is based on a design calculation that includes evaluation for internal pressure hoop stress, external pressure and/or structural considerations, as appropriate. The minimum required thickness calculation is the design code t_{min}, Consideration for internal pressure hoop stress alone may not be sufficient. t_c as defined in **STEP 5** should be used when appropriate.

Using and **Equation (3.7)** with t_{rdi} from **STEP 3** and FS^{Thin} from **STEP 7.**

Because the equipment is Atmospheric Storage Tank, α value for cylinder equipment is 2. So the Equation being use is:

$$SR_P^{Thin} = \frac{P \,.\, D}{\alpha .\, FS^{Thin} .\, t_{rdi}} \quad (3.7)$$

Note: This strength ratio parameter is based on internal pressure hoop stress only. It is not appropriate where external pressure and/or structural considerations dominate. When t_c dominates or if the t_{min} is calculated using another method, Equation (3.6) should be used.

9) Determine the Number of Inspection and its Effectiveness

The number of inspections for each of the corresponding inspection effectiveness, N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin} , using Section 4.5.6 for past inspections performed during the in-service time.

Table 3. 3

Number of past Inspection perform	:	**1**
Inspection Category	:	**A**
Inspection Effectiveness Category	:	**Highly Effective**

10) Determine the Inspection Effectiveness Factor Using Prior Probabilities and Conditional Probabilities

Calculate the inspection effectiveness factors, $I1^{Thin}$, $I2^{Thin}$, $I3^{Thin}$, using **Equation (3.8)**, Prior Probabilities, Pr_{p1}^{Thin}, Pr_{p2}^{Thin} and Pr_{p3}^{Thin} , from **Table 3.4**, the Conditional Probabilities (for each inspection effectiveness level), Co_{p1}^{Thin} , Co_{p2}^{Thin} and Co_{p3}^{Thin}, from **Table 3.5**, and the number of inspections, N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}, in each effectiveness level from **STEP 9.**

Table 3. 4 *Prior Probability for Thinning Corrosion Rate*

Damage State	Low Confidence Data	Medium Confidence Data	High Confidence Data
Pr_{p1}^{Thin}	0.5	0.7	0.8
Pr_{p2}^{Thin}	0.3	0.2	0.15
Pr_{p3}^{Thin}	0.2	0.1	0.05

Table 3. 5 *Conditional probability of inspection*

Conditional Probability of Inspection	E – None or Ineffective	D – Poorly Effective	C – Fairly Effective	B – Usually Effective	A – Highly Effective
Co_{p1}^{Thin}	0.33	0.4	0.5	0.7	0.9
Co_{p2}^{Thin}	0.33	0.33	0.3	0.2	0.09
Co_{p3}^{Thin}	0.33	0.27	0.2	0.1	0.01

$$I_1^{Thin} = Pr_{p1}^{Thin}(Co_{P1}^{ThinA})^{N_A^{Thin}}(Co_{P1}^{ThinB})^{N_B^{Thin}}(Co_{P1}^{ThinC})^{N_C^{Thin}}(Co_{P1}^{ThinD})^{N_D^{Thin}}$$

$$I_2^{Thin} = Pr_{p2}^{Thin}(Co_{P2}^{ThinA})^{N_A^{Thin}}(Co_{P2}^{ThinB})^{N_B^{Thin}}(Co_{P2}^{ThinC})^{N_C^{Thin}}(Co_{P2}^{ThinD})^{N_D^{Thin}}$$

$$I_3^{Thin} = Pr_{p3}^{Thin}(Co_{P3}^{ThinA})^{N_A^{Thin}}(Co_{P3}^{ThinB})^{N_B^{Thin}}(Co_{P3}^{ThinC})^{N_C^{Thin}}(Co_{P3}^{ThinD})^{N_D^{Thin}}$$

(3.8)

11) Determine Posterior Probability
Calculate the Posterior Probabilities, Po_{p1}^{Thin}, Po_{p2}^{Thin} and Po_{p3}^{Thin} using **Equation (3.9)** with $I1^{Thin}$, $I\ 2^{Thin}$ and $I3^{Thin}$ in **STEP 10.**

$$PO_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$PO_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \qquad (3.9)$$

$$PO_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

12) Calculate the parameters, $\beta_1^{extcorr}$, $\beta_2^{extcorr}$, $\beta_3^{extcorr}$ using **Equation (3.10)** and assigning $COV_{\Delta t}$=0,20 , COV_{Sf} = 0,20 , COV_P = 0.05
Where Corrosion Rate Factor for Damage State *(Ds)*. DS 1 is 1, DS 2 is 2, DS 3 is 4

$$\beta_1^{thin} = \frac{1 - D_{S_1}.A_{rt} - SR_p^{thin}}{\sqrt{D_{S_1}^2.A_{rt}^2.COV_{\Delta t}^2 + (1 - D_{S_1}.A_{rt})^2.COV_{S_f}^2 + (SR_p^{thin})^2.COV_p^2}}$$

$$\beta_2^{thin} = \frac{1 - D_{S_2}.A_{rt} - SR_p^{thin}}{\sqrt{D_{S_2}^2.A_{rt}^2.COV_{\Delta t}^2 + (1 - D_{S_2}.A_{rt})^2.COV_{S_f}^2 + (SR_p^{thin})^2.COV_p^2}}$$

$$\beta_3^{thin} = \frac{1 - D_{S_3}.A_{rt} - SR_p^{thin}}{\sqrt{D_{S_3}^2.A_{rt}^2.COV_{\Delta t}^2 + (1 - D_{S_3}.A_{rt})^2.COV_{S_f}^2 + (SR_p^{thin})^2.COV_p^2}}$$

(3.10)

13) Determine damage factor for thinning for tank bottom component

For tank bottom components, determine the base damage factor for thinning, Df_B^{thin} based on the A_{rt} parameter from **STEP 6** and Skip to **STEP 15.**

Because The Component that calculated in this calculation isn't tank bottom. So there is no need to do this step.

14) Determine Damage Factor Thinning Base Value

For all components (excluding tank bottoms covered in **STEP 13**, calculate the base damage factor, D_{fB}^{Thin}

$$D_{fB}^{Thin} = \left[\frac{\left(Po_{p1}^{Thin}\Phi(-\beta_1^{Thin})\right) + \left(Po_{p2}^{Thin}\Phi(-\beta_2^{Thin})\right) + \left(Po_{p3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-04}\right]$$

(3.11)

15) Determine maximum Damage Factor for Thinning

$$D_f^{Thin} = max\left[\left(\frac{D_{fB}^{Thin} \ . \ F_{IP} \ . \ F_{DL} \ . \ F_{WD} \ . \ F_{AM} \ . \ F_{SM}}{F_{OM}}\right), 0.1\right] \quad (3.12)$$

Where added value of damage factor is:

F_{IP} : Adjustment for Injection Point

Adjustment for injection point only used if there any Injection Point in the Tank the Value of F_{IP} is 3, otherwise is 1

F_{DL} : Adjustment for Dead Leg

Dead Leg Adjustment only applied for piping circuit. If the equipment it isn't piping circuit the value of F_{DL} is 1.

F_{WD} : Adjustment for Welded Construction

Applicable only to *ASTs*. If the component is welded then F_{WD} is 1, otherwise F_{WD} is 10.

F_{SM}: Adjustment for Settlement

Applicable only for *AST* bottoms. If the equipment it isn’t tank bottom the value of F_{SM} is 1.

F_{OM}: Adjustment for Online Monitoring

Because the equipment it isn’t online monitored. So the value of F_{OM} is 1.

3.5. *CoF* Assessment

In the assessment of *CoF* API 581 already provides parameters in determining the category of *CoF* on the asset under review. The most suitable Representative fluid for fluid that being store in this atmospheric storage tank is being chosen from **Attachment E**.

1) Choosing representative fluids
   choosing the representative fluid is determining by the type of fluid that being process inside the atmospheric storage tank.
2) Determine the stored fluid phase: liquid or vapor.
   If the stored liquid is in two-phase state it is a Level 2 Consequence analysis.
3) Determine the stored liquid properties
   Because the liquid that being stored is in liquid phase so the properties that needed for the calculation is liquid density and Auto Ignition Temperature. The properties of the stored liquid can be obtained in **Attachment E**.
4) Determine fluid phase after release to the atmosphere
   Using **table 3.6** and storage phase from Step 3.

Table 3. 6 Level 1 Guidelines for Determining the Phase of a Fluid

Phase of Fluid at Normal Operating (Storage) Conditions	Phase of Fluid at Ambient (after release) Conditions	Determination of Final Phase for Consequence Calculation
Gas	Gas	model as gas
Gas	Liquid	model as gas
Liquid	Gas	model as gas *unless* the fluid boiling point at ambient conditions is greater than 80°F, then model as a liquid
Liquid	Liquid	model as liquid

5) Based on **table 3.7** determine the release hole size are evaluated.

Table 3. 7 *Release Hole Size and Area*

Release Hole Number	Release Hole Size	Range of Hole Diameters (inch)	Release Hole Diameter, d_n (inch)
1	Small	0 – ¼	$d_1 = 0.25$
2	Medium	> ¼ – 2	$d_2 = 1$
3	Large	> 2 – 6	$d_3 = 4$
4	Rupture	> 6	$d_4 = \min[D, 16]$

6) Determine value for generic failure frequency (*gff*) for each release size. shown as **table 3.8.**

Table 3. 8 *gff for determining release hole size*

Equipment type	Component type	***gff*** **as a Function of Hole Size (failures/yr)**				***gff(total)*** **(failures/yr)**
		Small	**Medium**	**Large**	**Rupture**	
Tank650	TANKBOTTOM	7.20E-04	0	0	2.00E-06	7.20E-04
Tank650	COURSE-1	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	COURSE-2	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	COURSE-3	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	COURSE-4	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04

7) Select the appropriate release rate from Equation as described above using the stored fluid phase determined in Step 2.

8) For each release hole size, calculate the release hole size area A_n using **equation 3.13** based on d_n.

$$A_n = \frac{\pi d_n^2}{4}$$

9) For each release hole size, calculate the release rate W_n, for each release area A_n, determined in step 8 using **equation 3.14**

$$W_n = \frac{C_d}{C_2} x A_n x P_s \sqrt{\left(\frac{k\ x\ MW\ x\ gc}{R\ x\ T_s}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \qquad (3.14)$$

If the storage pressure is less than or equal to transition pressure so the calculation for release rate is using **equation 3.15**

$$W_n = \frac{C_d}{C_2}\ x\ A_n\ x\ P_s \sqrt{\left[\left(\frac{MW\ .g_c}{R\ .T_s}\right)\left(\frac{2k}{k-1}\right)\left(\frac{P_{atm}}{P_s}\right)^{\frac{2}{k}}\left(1 - \left(\frac{P_{atm}}{P_s}\right)^{\frac{k-1}{k}}\right)\right]} \qquad (3.15)$$

10) Group components and equipment items into inventory groups

11) Calculate the fluid mass, $mass_{comp}$ in the component being evaluated.

12) Calculate the fluid mass in each of the other components that are included in the inventory group $mass_{comp,I}$

13) Calculate the fluid mass in the inventory group, $mass_{inv}$ using **equation 3.16**

$$mass_{inv} = \sum_{i=1}^{N} mass_{comp,i} \qquad (3.16)$$

14) Calculate the flow rate a 203 mm (8 inch), diameter hole W_{max8}, using **equation 3.15** as applicable with A_n = A_8 = 32,450 mm^2 this is the

maximum flow rate that can be added to the equipment fluid mass from the surrounding equipment in the inventory group

15) For each release hole size, calculate the added fluid mass resulting from 3 minutes of flow from the inventory group using **equation 3.17** where W_n leakage rate for the release hole size being evaluated and W_{max8} from step 14.

$$mass_{add,n} = 180 \, x \min[W_n \, , W_{max8}] \qquad (3.17)$$

16) For each release hole size, calculate the available mass for release.
17) For each release hole size, calculate the time required to release 4.536 kgs (10000 lbs) of fluid.

$$t_n = \frac{C_3}{W_n} \qquad (3.18)$$

18) For each release hole size, determine if the release type is instantaneous or continuous using the following criteria.
    a. If the release hole size is 6.35 mm (0.25 inch) or less, then the release type is continuous.
    b. If $t_n \leq 180$ sec and the release mass is greater than 4,536 kgs (10,000 lbs), then the release is instantaneous; otherwise, the release is continuous.
19) Determine the detection and isolation systems present in the unit.
20) Using **Table 3.9**, select the appropriate classification (A, B, C) for the detection system
21) Using **Table 3.9**, select the appropriate classification (A, B, C) for the isolation system.

Table 3. 9 Leak Detection and Isolation System Rating Guide

Type of Detection System	Detection Classification
Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e., loss of pressure or flow) in the system	A
Suitably located detectors to determine when the material is present outside the pressure-containing envelope	B
Visual detection, cameras, or detectors with marginal coverage	C
Type of Isolation System	**Isolation Classification**
Isolation or shutdown systems activated directly from process instrumentation or detectors, with no operator intervention	A
Isolation or shutdown systems activated by operators in the control room or other suitable locations remote from the leak	B
Isolation dependent on manually-operated valves	C

22) Using Table 3.10 and the classifications determined in STEPs 20 and 21, determine the release reduction factor, $fact_{di}$

Table 3. 10 *Adjustments to Release Based on Detection and Isolation Systems*

System Classifications		Release Magnitude Adjustment	Reduction Factor, $fact_{di}$
Detection	Isolation		
A	A	Reduce release rate or mass by 25%	0.25
A	B	Reduce release rate or mass by 20%	0.20
A or B	C	Reduce release rate or mass by 10%	0.10
B	B	Reduce release rate or mass by 15%	0.15
C	C	No adjustment to release rate to mass	0.00

23) Using Table 3.11 and the classifications determined in STEPs 20 and 21, determine the total leak durations for each of the selected release hole sizes, Id_{maxn}

Table 3. 11 *Leak Durations Based on Detection and Isolation Systems*

Detecting System Rating	Isolation System Rating	Maximum Leak Duration, ld_{max}
A	A	20 minutes for 6.4 mm leaks 10 minutes for 25 mm leaks 5 minutes for 102 mm leaks
A	B	30 minutes for 6.4 mm leaks 20 minutes for 25 mm leaks 10 minutes for 102 mm leaks
A	C	40 minutes for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
B	A or B	40 minutes for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
B	C	1 hour for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
C	A, B or C	1 hour for 6.4 mm leaks 40 minutes for 25 mm leaks 20 minutes for 102 mm leaks

24) For each release hole size, calculate the adjusted release rate, $rate_n$, using **Equation 3.19** where the theoretical release rate, W_n, is from STEP 8. Note that the release reduction factor, $fact_{di}$, determined in

STEP 22 accounts for any detection and isolation systems that are present.

$Rate_n = W_n\ (1\text{-}fact_{di})$ (3.19)

25) For each release hole size, calculate the leak duration, ld_n , of the release using **Equation 3.20** ,based on the available mass, $mass_{availn}$ from STEP 15 and the adjusted release rate, $rate_n$, from STEP 24. Note that the leak duration cannot exceed the maximum duration, ld_{maxn} , determined in STEP 22.
26) Select the consequence area mitigation reduction factor, $fact_{mit}$, from **Table 3.12.**
27) For each release hole size, calculate the energy efficiency correction factor, $eneff_n$, using **Equation 3.21**
28) For each release hole size, calculate the component damage consequence areas for Auto-ignition Not Likely, Continuous Release (AINL-CONT)
29) For each release hole size, calculate the component damage consequence areas for Auto-ignition Likely, Continuous Release (AIL-CONT)
30) For each release hole size, calculate the component damage consequence areas for Auto-ignition Not Likely, Instantaneous Release (AINL-INST)
31) For each release hole size, calculate the component damage consequence areas for Auto-ignition Likely, Instantaneous Release (AIL-INST)
32) For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Not Likely, Continuous Release (AINL-CONT)
33) For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Likely, Continuous Release (AIL-CONT)
34) For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Not Likely, Instantaneous Release (AINL-INST)
35) For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Likely, Instantaneous Release (AIL-INST)
36) For each release hole size, calculate the instantaneous/continuous blending factor, as applicable
37) Calculate the AIT blending factor, as applicable

38) Calculate the continuous/instantaneous blended consequence areas for the component based on the consequence areas calculated in STEPs 28, 29, 30, 31, 32, 33, 34, and 35, and the continuous/instantaneous blending factor, from STEP 36.

39) Calculate the AIT blended consequence areas for the component using **Equations 3.22** and **3.23** based on the consequence areas determined in STEP 38 and the AIT blending factors, calculated in STEP 37. The resulting consequence areas are the component damage and personnel injury flammable consequence areas, for each release hole sizes selected in STEP 6.

40) Determine the final consequence areas (probability weighted on release hole size) for component damage and personnel injury using **Equations (3.24)** and **(3.25)** based on the consequence areas from STEP 39.

3.6. Determination of Risk Level

In Determining risk level according to API 581: 2016 is already provided by using risk matrix. Risk matrix in API 581 the probability is shown in the Y- Axis in the other hand the consequence is shown in X-Axis. For the probability the value can express by P_{oF} value or D_f depending on how to calculate the P_{oF}. For C_{oF} value can be express by using CA (Consequence Area) of FC (Financial Consequence) the plotting mechanism are shown in **Figure 3.2** through **Figure 3.4.**

Category	Probability Category (1,2)		Consequence Category (3)	
	Probability Range	Damage Factor Range	Category	Range (ft²)
1	$P_f(t,I_E) \le 3.06E-05$	$D_{f-total} \le 1$	A	$CA \le 100$
2	$3.06E-05 < P_f(t,I_E) \le 3.06E-04$	$1 < D_{f-total} \le 10$	B	$100 < CA \le 1{,}000$
3	$3.06E-04 < P_f(t,I_E) \le 3.06E-03$	$10 < D_{f-total} \le 100$	C	$1{,}000 < CA \le 10{,}000$
4	$3.06E-03 < P_f(t,I_E) \le 3.06E-02$	$100 < D_{f-total} \le 1{,}000$	D	$10{,}000 < CA \le 100{,}000$
5	$P_f(t,I_E) > 3.06E-02$	$D_{f-total} > 1{,}000$	E	$CA > 100{,}000$

Notes:
1. POF values are based on a GFF of 3.06E-05 and an F_{MS} of 1.0.
2. In terms of POF, see Part 1 Section 4.1.
3. In terms of the total DF, see Part 2, Section 3.4.2.
4. In terms of consequence area, see Part 3, Section 4.11.4.

Figure 3. 2 *Numerical Values Associated with POF and Area-Based COF Categories*

Category	Probability Category (1,2)		Consequence Category (3)	
	Probability Range	Damage Factor Range	Category	Range ($)
1	$P_f(t,I_E) \le 3.06E-05$	$D_{f-total} \le 1$	A	$FC \le 10,000$
2	$3.06E-05 < P_f(t,I_E) \le 3.06E-04$	$1 < D_{f-total} \le 10$	B	$10,000 < FC \le 100,000$
3	$3.06E-04 < P_f(t,I_E) \le 3.06E-03$	$10 < D_{f-total} \le 100$	C	$100,000 < FC \le 1,000,000$
4	$3.06E-03 < P_f(t,I_E) \le 3.06E-02$	$100 < D_{f-total} \le 1,000$	D	$1,000,000 < FC \le 10,000,000$
5	$P_f(t,I_E) > 3.06E-02$	$D_{f-total} > 1,000$	E	$FC > 10,000,000$

Notes:

1. POF values are based on a GFF of 3.06E-05 and an F_{MS} of 1.0.
2. In terms of POF, see Part 1 Section 4.1.
3. In terms of the total DF, see Part 2, Section 3.4.2.
4. In terms of consequence area, see Part 3, Sections 4.12.1.

Figure 3. 3 *Numerical Values Associated with POF and Financial-Based COF Categories*

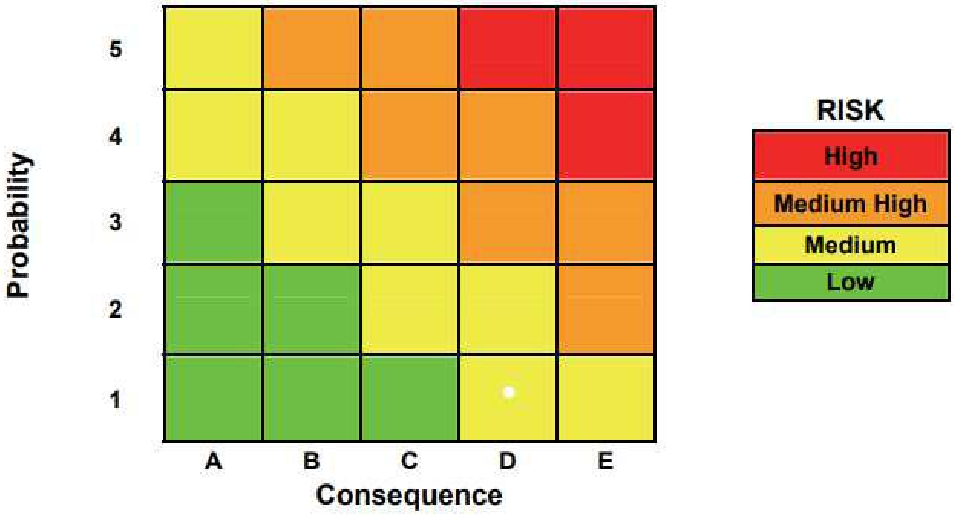

Figure 3. 4 *Risk Matrix*

3.7. RBI Planning

By using risk matrix as a reference to specify equipment condition right now, it can be base for determining equipment condition in plan date. Between RBI date and plan date, it could be having another inspection it depends on equipment condition in plan date.

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CHAPTER IV
DATA ANALYSIS

4.1. Asset Data

The first step before analyze the data is the collecting asset data. Data that needed for RBI calculation are matters concerning tank design and construction, tank operational data, data about stored fluid, past inspection data and other supporting data in this bachelor thesis. These data will be processed in accordance with the calculation formula stated in the API 581: 2016 both in the determining the probability of failure and the consequence of failure. The specification data of the condensate storage tank are shown in **Table 4.1.**

Table 4. 1 *Data Condensate Storage Tank Bang – T – 050 – A*

Equipment data	
Equipment Name	Condensate Storage Tank
Equipment Type	Atmospheric Storage Tank
Serial No.	BANG-T-050-A
Inside Diameter	10058 mm
Volume of Fluid	2209519
Year Built	2014
Design Code	API 650
Design Pressure	1 atm + Full of Water
Design Temperature	200 ^oF
Operating Pressure	0.5 Psig
Operating Temperature	108 ^oF
Yield Strength	250 Mpa
Tensile Strength	400 Mpa
Minimum Design Metal Temp.	0 ^0C
Material of Construction	Carbon Steel A36 ASTM
Furnished Thickness	8 mm
Corrosion Allowance	3.175 mm
Post Weld Heat Treatment (PWHT)	YES
Insulation	None; Not Insulated
Joint Efficiency	0.85

4.2. Generic Failure Frequency

Determine generic failure frequency is the first part to calculate probability of failure Generic failure frequency table is provided in **table 2.2**. The result of generic failure frequency in for tank course is $1.0x10^{-4}$ and for the tank bottom is $7.2x10^{-4}$ and the answer is shown by the **table 4.2**.

Table 4. 2 *Determine the generic failure frequency from table*

Equipment type	Component type	*gff* as a Function of Hole Size (failures/yr)				*gff(total)* (failures/yr)
		Small	Medium	Large	Rupture	
Tank650	TANKBOTTOM	7.20E-04	0	0	2.00E-06	7.20E-04
Tank650	COURSE-1 – 4	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04

4.3. Damage Mechanism Identification

Generating damage mechanism identification started from screening few criteria of damage mechanism; the first one is material composition of the asset, fluid data in the asset, environment around the asset, and other factors which is related to the damage mechanism. According to the asset data and identify damage mechanism with **table (4.3)** there are two type of damage factor chosen. The first is thinning damage factor and the second is external corrosion damage factor – ferritic component. As shown in **table 4.3.**

Table 4. 3 *Damage mechanism identification*

No.	*Type Damage Mechanism*	*Criteria based on API 581*	Yes/No	Result
1	*Thinning Damage factor*	Semua komponen harus di cek pada kriteria *thining damage factor*	Yes	Yes
2	*External Corrosion Damage Factor - Ferritic Component*	Berada dekat dengan percikan kabut berlebih dari pendingin	No	Yes
		Berada dekat dengan ventilasi uap	No	
		Berada pada curah hujan yang tinggi	Yes	
		Area subject to process spills, ingress of moisture, or acid	No	
		Sistem baja karbon yang beroperasi antara -23°C dan 121° C (-10°F dan 250°F)	Yes	
		Sistem baja karbon yang tidak beroperasi normal antara -23°C dan 121°C (-10°F dan 250°F) namun mendingin atau memanas pada suhu rata-rata yang tidak terus-menerus	No	
		Sistem dengan pelindung atau *wrapping* yang buruk	No	
		Sistem pendingin beroperasi dibawah titik pengembunan secara terus-menerus	No	
		Memiliki nozzle yang tidak terisolasi atau peralatan menonjol yang terisolasi pada kondisi dingin	Yes	

4.3.1 Calculation of Thinning Damage Factor

Determining the number of inspections is the first step to calculate the thinning damage factor, and the corresponding inspection effectiveness category. PT.X already did one inspection since the tank start its operation. So number of inspection is 1. There are 15 steps to calculate Thinning damage factor.

1) First step is to determine Age, *age* and furnish thickness, *t* using **Equation 4.1.** While Furnish thickness already stated in **Table 4.1.** So *t* is 8 mm.

$$age = rbi\ date - build\ date \qquad (4.1)$$

= 14 March 2018 - 24 July 2014

= 3.641 years

2) Next is determining Base Metal Corrosion Rate (C_{rbm}). For calculating must be calculated using **Equation 4.2.** And value of C_{rbm} for tank course 1 – 4 are shown in **Table 4.4.**

$$C_{r,bm} = \frac{t_{previous} - t_{actual}}{time\ between\ t_{previous}\ and\ t_{actual}} \qquad (4.2)$$

Table 4. 4 *Tank Course C_{rbm} Value*

Tank Course	C_{rbm} Value
Course 1	0.31 mmpy
Course 2	0.1733 mmpy
Course 3	0.76 mmpy
Course 4	0.76 mmpy

3) The next step for determining Thinning Damage Factor is determine the time in service, age_{tk} , since the last inspection known thickness , t_{rdi}. The value of age_{tk} for each course is same. For calculating it using **Equation 4.3.** And for t_{rdi} is shown in **Table 4.5.**

$$age = rbi\ date. - last\ inspection. \qquad (4.3)$$

= 14 March 2018 - 14 August 2017

= 0.5808 years

Table 4. 5 *Tank Course t_{rdi} Value*

Tank Course	**t_{rdi} Value**
Course 1	7.07 mm
Course 2	7.48 mm
Course 3	5.72 mm
Course 4	5.72 mm

4) Step 4 is calculating cladding age, age_{rc} Because the storage tank did not have cladding so it didn't need to calculate for age of cladding.

5) So for the next step is determine minimum thickness, t_{min} using original construction code. The minimum thickness is already stated in **table 4.1.** So, t_{min} is 4.825 mm.

6) Next is determining Component wall loss fraction, A_{rt} using **Equation 4.4.** this equation is used because the equipment is component without cladding or weld overlay. So, the value of A_{rt} for course 1-4 is shown in **table 4.6**.

$$A_{rt} = \frac{C_{rbm} \times age_{tk}}{t_{rdi}}. \qquad (4.4)$$

Table 4. 6 *Tank Course A_{rt} value*

Tank Course	**A_{rt} Value**
Course 1	0.0255
Course 2	0.0135
Course 3	0.0772
Course 4	0.0772

7) Next step is calculating the flow stress, FS^{thin} using E (weld joint efficiency) and yield strength (YS) and tensile strength (TS). Using the **equation 4.5.**

$$FS^{thin} = \frac{(YS+TS)}{2} \times E \times 1.1 \qquad (4.5)$$

$$= \frac{250+400}{2} \times 0.85 \times 1.1$$

= 303.88 Mpa

8) Determine strength ratio parameter SR_p^{thin} using **equation 4.6.** because the equipment is cylinder the **α** value is 2. Where P is design pressure and D is diameter. The SR_p^{thin} is shown in **table 4.7.**

$$SR_p^{thin} = \frac{P \times D}{\alpha \times FS^{thin} \times t_{rdi}} \qquad (4.6)$$

Table 4. 7 *Tank Course* SR_p^{thin} *value*

Tank Course	SR_p^{thin} **Value**
Course 1	1.1704
Course 2	1.1063
Course 3	1.4466
Course 4	1.4466

9) Determine The Number of Inspection and its Effectiveness

- Number of past Inspection perform: 1
- Inspection Category: A
- Inspection Effectiveness Category: Highly Effective

10) Calculate inspection effectiveness factor I_1^{thin}, I_2^{thin}, I_3^{thin} using **equation 4.7.** prior probabilities Pr_{p1}^{thin}, Pr_{p2}^{thin} , Pr_{p3}^{thin} from **table 4.8.** Inspection effectiveness level Co_{p1}^{thin}, Co_{p2}^{thin} , Co_{p3}^{thin}. Shown in **table 4.9**. and for inspection effectiveness factor for tank course 1-4 is shown in **table 4.10**.

$$\begin{aligned}
I_1^{Thin} &= Pr_{p1}^{Thin}\left(Co_{p1}^{ThinA}\right)^{N_A^{Thin}}\left(Co_{p1}^{ThinB}\right)^{N_B^{Thin}}\left(Co_{p1}^{ThinC}\right)^{N_C^{Thin}}\left(Co_{p1}^{ThinD}\right)^{N_D^{Thin}} \\
I_2^{Thin} &= Pr_{p2}^{Thin}\left(Co_{p2}^{ThinA}\right)^{N_A^{Thin}}\left(Co_{p2}^{ThinB}\right)^{N_B^{Thin}}\left(Co_{p2}^{ThinC}\right)^{N_C^{Thin}}\left(Co_{p2}^{ThinD}\right)^{N_D^{Thin}} \qquad (4.7) \\
I_3^{Thin} &= Pr_{p3}^{Thin}\left(Co_{p3}^{ThinA}\right)^{N_A^{Thin}}\left(Co_{p3}^{ThinB}\right)^{N_B^{Thin}}\left(Co_{p3}^{ThinC}\right)^{N_C^{Thin}}\left(Co_{p3}^{ThinD}\right)^{N_D^{Thin}}
\end{aligned}$$

Table 4.8 *Prior Probability for Thinning Corrosion Rate*

Damage State	Low Confidence Data	Medium Confidence Data	High Confidence Data
Pr_{p1}^{Thin}	0.5	0.7	0.8
Pr_{p2}^{Thin}	0.3	0.2	0.15
Pr_{p3}^{Thin}	0.2	0.1	0.05

Table 4. 9 *Conditional Probability for Inspection Effectiveness*

Conditional Probability of Inspection	E – None or Ineffective	D – Poorly Effective	C – Fairly Effective	B – Usually Effective	A – Highly Effective
Co_{p1}^{Thin}	0.33	0.4	0.5	0.7	0.9
Co_{p2}^{Thin}	0.33	0.33	0.3	0.2	0.09
Co_{p3}^{Thin}	0.33	0.27	0.2	0.1	0.01

Table 4.10 *Inspection Effectiveness Factor Value*

Inspection Effectiveness Number	Value
Inspection Effectiveness Factor (I_1^{thin})	0.72
Inspection Effectiveness Factor (I_2^{thin})	0.0135
Inspection Effectiveness Factor (I_3^{thin})	0.0005

11) Determine Posterior probabilities Po_{p1}^{thin}, Po_{p1}^{thin}, Po_{p1}^{thin} using inspection effectiveness factor from **table 4.10** by using **equation 4.8**. the value of posterior probabilities is shown in **table 4.11**

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$
$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \quad (4.8)$$
$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

Table 4.11 Posterior Probability Value

Posterior Probability Number	Value
Posterior Probability 1	0.9809
Posterior Probability 2	0.0184
Posterior Probability 3	0.0007

12) Calculated Z number (parameters) β_1^{thin}, β_1^{thin}, β_1^{thin} while thinning coefficient of variance ($COV_{\Delta t}$) is 0.2, flow stress coefficient of variance (COV_{sf}) is 0.2 and pressure coefficient of variance (COV_p) is 0.05. And also corrosion rate for damage state 1 (Ds_1) is 1, damage state 2 (Ds_2) is 2, and damage state 3 (Ds_{13}) is 4 using **equation 4.9.** and the value is shown in **table 4.12**.

$$\beta_1^{Thin} = \frac{1 - D_{S_1} \cdot A_{rt} - SR_p^{Thin}}{\sqrt{D_{S_1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + \left(1 - D_{S_1} \cdot A_{rt}\right)^2 \cdot COV_{S_f}^2 + (SR_p^{Thin})^2 \cdot COV_P^2}},$$
$$\beta_2^{Thin} = \frac{1 - D_{S_2} \cdot A_{rt} - SR_p^{Thin}}{\sqrt{D_{S_2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + \left(1 - D_{S_2} \cdot A_{rt}\right)^2 \cdot COV_{S_f}^2 + (SR_p^{Thin})^2 \cdot COV_P^2}} \quad (4.9)$$
$$\beta_3^{Thin} = \frac{1 - D_{S_3} \cdot A_{rt} - SR_p^{Thin}}{\sqrt{D_{S_3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + \left(1 - D_{S_3} \cdot A_{rt}\right)^2 \cdot COV_{S_f}^2 + (SR_p^{Thin})^2 \cdot COV_P^2}}.$$

Table 4.12 β *value of Course 1 - 4*

	β_1	β_2	β_3
Course 1	-0.0003	-0.0003	-0.0004
Course 2	-0.0002	-0.0002	-0.0002
Course 3	-0.0008	-0.0007	-0.0006
Course 4	-0.0008	-0.0007	-0.0006

13) Because the equipment is not tank bottom this step is to be skip.

14) Determine damage base factor for thinning using **equation 4.10** where ϕ is the standard normal cumulative distribution function (NORMSDIST in excel) the value is shown in **table 4.13**

$$D_{fb}^{Thin} = \left[\frac{\left(Po_{p1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right) + \left(Po_{p2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right) + \left(Po_{p3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E-04} \right] \quad (4.10)$$

Table 4. 13 *Value of Damage Base Factor for Course 1-4*

Tank Course	D_{fb}^{thin} **Value**
Course 1	2.6837
Course 2	2.6835
Course 3	2.6844
Course 4	2.6844

15) Last is calculating maximum damage factor for thinning using **equation 4.11** where F_{om} is adjustment for online monitoring F_{ip} is adjustment for injection. F_{dl} is adjustment for death leg. F_{wd} is adjustment for welded construction. F_{am} is adjustment for maintenance according to API STD 653. F_{sm} is adjustment for settlement. The value of maximum damage factor for thinning on course 1-4 is shown in **table 4.14**. where all the value for adjustment is 1.

$$D_f^{thin} = \frac{FIP \ x \ FDL \ x \ FWD \ x \ FSM \ x \ FAM}{FOM} \quad (4.11)$$

Table 4. 14 *Value of Maximum Damage Factor*

Tank Course	D_f^{thin} **Value**
Course 1	2.6837
Course 2	2.6835
Course 3	2.6844
Course 4	2.6844

For calculating Thinning damage factor for Plan Date is using the same equation as the Thinning Damage factor RBI Date. The difference between the two in the calculation is only the age. Using **equation (4.1)** and **(4.3)** the age and age_{tk} of plan date can be determined.

$$age = plan\ date. - build\ date. \qquad (4.1)$$

= 14 March 2028 - 24 July 2014

= 13.641 years

$$age = rbi\ date. - last\ inspection. \qquad (4.3)$$

= 14 March 2018 - 14 August 2017

= 0.5808 years

Because the difference of age between the two. There is some difference in A_{rt} value. Using **equation (4.4)** the A_{rt} value can be calculated. And the difference for each shell course are shown in **Table 4.15** below

$$A_{rt} = \frac{C_{rbm} \times age_{tk}}{t_{rdi}}. \qquad (4.4)$$

Table 4. 15 *Tank Course Art value RBI date vs Plan Date*

Tank Course	A_{rt} Value at RBI Date	A_{rt} Value at Plan Date
Course 1	0.0255	0.464
Course 2	0.0135	0.439
Course 3	0.0772	1.407
Course 4	0.0772	1.407

From the A_{rt} Value using **equation 4.9** the value of β_1^{thin}, β_1^{thin}, β_1^{thin} parameters can be determined. For the RBI date is shown in **Table 4.12** and for the Plan Date Shown in **Table 4.16**

Table 4. 16 *β value of Course 1 – 4 for plan date*

	β1	β2	β3
Course 1	-0.000351311	-0.001597049	-0.05913976
Course 2	-0.000297424	-0.001169264	-0.041409653
Course 3	-0.0153611	-0.670717546	-27.52604048
Course 4	-0.0153611	-0.670717546	-27.52604048

Last is calculating Thinning D_f for Plan Date. The calculation is using **Equation 4.10** and **4.11**. The value of D_f^{thin} for plan date are shown in **table 4.17**.

Table 4. 17 *Thinning Damage Factor for Plan Date*

Tank Course	D_f^{thin} Value
Course 1	14.5118
Course 2	14.3227
Course 3	27.28286
Course 4	27.28286

4.3.2 Calculation of External Corrosion Damage Factor

Determining the number of inspections is the first step to calculate the External Corrosion damage factor, and the corresponding inspection effectiveness category. PT.X already did one inspection since the tank start its operation. So number of inspection is 1. There are 16 steps to calculate External Corrosion damage factor.

1) First step is to determine Age, *age* and furnish thickness, *t* using **Equation 4.1.** While Furnish thickness already stated in **Table 4.1.** So *t* is 8 mm.

$$age = rbi\ date. - build\ date. \quad (4.1)$$

= 14 March 2018 - 24 July 2014

= 3.641 years

2) Next is Determine the base corrosion rate, C_{rB}, based on the driver and operating temperature using Table 4.18. and using interpolation for get the exacts answer. So the value of C_{rB} is 0.967 mmpy

Table 4. 18 *Corrosion Rates for Calculation of the Damage Factor – External Corrosion*

Operating Temperature (°F)	Corrosion Rate as a Function of Driver (1) (mpy)			
	Marine / Cooling Tower Drift Area	Temperate	Arid / Dry	Severe
10	0	0	0	0
18	1	0	0	3
43	5	3	1	10
90	5	3	1	10
160	5	2	1	10
225	1	0	0	2
250	0	0	0	0

The operating temperature of the AST is 108°F so using interpolation shown in **Table 4.19.**

Table 4. 19 *C_{rB} Value interpolation table*

Operation Temp.	C_{rB} Value
90	3
108	**2.7**
160	2

3) Next is calculate Final Corrosion rate using **equation 4.12**. where F_{EQ} and F_{IF} are adjustment for Equipment design and Adjustment Interface. The value for F_{EQ} is if the Equipment Design allows water pool and increase metal loss F_{EQ} Value is 2 otherwise the value is 1. And F_{IF} is only for piping circuit so the value in this calculation is 1.

$C_r = C_{rB}.max[F_{EQ}, F_{IF}]$ (4.12)

= 0.0697 mmpy

4) Determine the time in-service, age_{tk} , since the last known inspection thickness, t_{rde} (see Section 4.5.5. The t_{rde} is the starting thickness with respect to wall loss associated with external corrosion. If no measured thickness is available, set t_{rde} = t and age_{tk} = age

Age in Service (age_{tk}) = RBI Date - Last Inspection Date (4.13)

= 14 March 2018 - 14 August 2017

= 05808 years

Last Inspection thickness (t_{rde}) = 7.07 mm

5) Determine the in-service time, age_{coat} , since the coating has been installed using **Equation (4.14)**.

age_{coat} = RBI Date - Coating Installation Date (4.14)

= 14 March 2018 - 14 August 2014

= 3.641 years

6) Determine coating adjustment, $Coat_{adj}$ using **Equations (4.15).** Because age_{tk} is less than age_{coat} . so determining Coating adjustment using one of these equation:

$Coat_{adj}$= 0, if there are no coating or poor coating quality

Because the tank does not have coating.

Coating Adjustment ($Coat_{adj}$) = 0 , (4.15)

7) Determine the in-service time, age, over which external corrosion may have occurred using **Equation (4.16)**

In-Service time (*age*) = age_{tk} - $Coat_{adj}$ (4.16)

= 0.5808 – 0

= 0.5808

8) Determine the allowable stress, *S*, weld joint efficiency, *E*, and minimum required thickness, t_{min}, per the original construction code. In cases where components are constructed of uncommon shapes or where the component's minimum structural thickness, t_c, may govern, the user may use the t_c in leu of t_{min} where pressure does not govern the minimum required thickness criteria.

Allowable Stress (*S*) = 150 Mpa

Weld Joint efficiency (*E*) = 0.85 (4.17)

Thickness Minimum (t_{min}) = Furnished Thickness - Corrosion Allowance

= 4.825 mm

9) Determine the A_{rt} parameter using **Equation (4.18)** based on the *age* and t_{rde} from **STEP 4**, C_r from **STEP 3**

$$A_{rt} = \frac{C_r\,.age}{t_{rde}} \quad (4.18)$$

$$A_{rt} = \frac{0.0697mmpy\,.\,0.580822years}{7.07mm}$$

= 0.0057

10) Calculate the Flow Stress, $FS^{extcorr}$, using *E* from **STEP 8** and **Equation (4.19)**

$$FS^{extcorr} = \frac{(YS+TS)}{2} \times E \times 1{,}1 \quad (4.19)$$

$$FS^{extcorr} = \frac{(250\ MPa+400\ MPa)}{2} \times 0{,}85\ \times 1{,}1$$

= 303.9 Mpa

11) Calculate the strength ratio parameter, SR_P^{Thin}, using **Equation (4.20)**

$$SR_P^{extcorr} = \frac{S.E}{FS^{exrcorr}}\,.\,\frac{Max(t_{min}, t_c)}{t_{rde}}$$

$$SR_P^{extcorr} = \frac{150\ mpa.0{,}85}{303{,}88\ mpa}\,.\,\frac{Max(4{,}825{,}0)}{7{,}07} \quad (4.20)$$

= 0.2863

12) Determine the number of inspections, $N_A^{extcorr}$, $N_B^{extco}rr$, $N_C^{extcorr}$, $N_D^{extcorr}$ and the corresponding inspection effectiveness category using Section 15.6.2 for past inspections performed during the in-service time.

Table 4. 20 *inspection effectiveness category*

Number of past Inspection perform	:	**1**
Inspection Category	:	**A**
Inspection Effectiveness Category	:	**Highly Effective**

13) Determine the inspection effectiveness factors, $I1^{extcorr}$, $I2^{extcorr}$, $I3^{extcorr}$, using **Equation (4.21)**, Prior Probabilities, $Pr_{p1}^{extcorr}$, $Pr_{p2}^{extcorr}$ and $Pr_{p3}^{extcorr}$, from **Table 4.21**, the Conditional Probabilities (for each inspection effectiveness level), $Co_{p1}^{extcorr}$, $Co_{p2}^{extcorr}$ and $Co_{p3}^{extcorr}$, from **Table 4.22**, and the number of inspections, $N_A^{extcorr}$, $N_B^{extcorr}$, $N_C^{extcorr}$, $N_D^{extcorr}$, in each effectiveness level from **STEP 12.**
Where Prior Probabilities and Conditional Probabilities Value get from **table 4.21** and **4.22**

Table 4. 21 *Prior Probability for External Corrosion Rate*

Damage State	Low Confidence Data	Medium Confidence Data	High Confidence Data
$Pr_{p1}^{extcorr}$	0.5	0.7	0.8

Table 4. 22 *Conditional probability of inspection*

Conditional probability of inspection	E-None or ineffective	D - poorly effective	C - fairly effective	B - Usually effective	A - Highly effective
$Co_{p1}^{extcorr}$	0.33	0.4	0.5	0.7	0.9

Table 4. 23 *Inspection Effectiveness Value Number for external damage factor*

Inspection Effectiveness Number	Value
Inspection Effectiveness Factor ($I_1^{extcorr}$)	0.72
Inspection Effectiveness Factor ($I_2^{extcorr}$)	0.014
Inspection Effectiveness Factor ($I_3^{extcorr}$)	0.0005

14) Determine Posterior probabilities $Po_{p1}^{extcorr}$, $Po_{p1}^{extcorr}$, $Po_{p1}^{extcorr}$ using inspection effectiveness factor from **table 4.23** by using **equation 4.21**. the value of posterior probabilities is shown in **table 4.24**

$$Po_{p1}^{extcorr} = \frac{I_1^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}}$$

$$Po_{p2}^{extcorr} = \frac{I_2^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}} \quad (4.21)$$

$$Po_{p3}^{extcorr} = \frac{I_3^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}}$$

Table 4. 24 *Posterior Probability Number for external damage factor*

Posterior Probability Number	Value
Posterior Probability 1	0.9809
Posterior Probability 2	0.0184
Posterior Probability 3	0.0007

15) Calculated Z number (parameters) $\beta_1^{extcorr}$, $\beta_1^{extcorr}$, $\beta_1^{extcorr}$ while thinning coefficient of variance ($COV_{\Delta t}$) is 0.2, flow stress coefficient of variance (COV_{sf}) is 0.2 and pressure coefficient of variance (COV_p) is 0.05. And also corrosion rate for damage state 1 (D_{s1}) is 1, damage state 2 (D_{s2}) is 2, and damage state 3 (D_{s13}) is 4 using **equation 4.22.** and the value is shown in **table 4.25**

$$\beta_1^{extcorr} = \frac{1 - D_{S_1}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_1}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_1}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{extcorr}\right)^2.COV_p^2}}$$

$$\beta_2^{extcorr} = \frac{1 - D_{S_2}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_2}^2.A_{rt}^2.COV_{\Delta t}^2 + (1 - D_2.A_{rt})^2.COV_{S_f}^2 + \left(SR_p^{extcorr}\right)^2.COV_p^2}}$$

$$\beta_3^{extcorr} = \frac{1 - D_{S_3}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_3}^2.A_{rt}^2.COV_{\Delta t}^2 + (1 - D_{S_3}.A_{rt})^2.COV_{S_f}^2 + (SR_p^{extcorr})^2.COV_p^2}}$$

(4.22)

Table 4. 25 *β value of Course 1 - 4*

	β1	β2	β3
Course 1	0.0011	0.0011	0.0016
Course 2	0.0011	0.0011	0.0016
Course 3	0.001	0.001	0.001
Course 4	0.001	0.001	0.0016

16) Calculate $D_f^{extcorr}$ using (4.23)

$$D_f^{extcorr} = \left[\frac{\left(Po_{p1}^{extcorr}\Phi(-\beta_1^{extcorr})\right)+\left(Po_{p2}^{extcorr}\Phi(-\beta_2^{extcorr})\right)+\left(Po_{p3}^{extcorr}\Phi(-\beta_3^{extcorr})\right)}{1{,}56E-04}\right]$$

(4.23)

Table 4. 26 *Value of External Corrosion Damage Factor course 1-4*

Tank Course	$D_f^{extcorr}$ Value
Course 1	2.67975
Course 2	2.67974
Course 3	2.67979
Course 4	2.67979

For calculating external corrosion damage factor at plan date all the calculation done the same like in RBI Date. The difference between the two from the input data are the date of calculation. The age of equipment while plan date is older 10 years from the RBI date.

Because the difference of age between the two. There is some difference in A_{rt} value. Using **equation (4.4)** the A_{rt} value can be calculated. And the difference for each shell course are shown in **Table 4.15** below

$$A_{rt} = \frac{C_r\ .age}{t_{rde}}. \qquad (4.18)$$

Table 4. 27 *Tank Course Art value RBI date vs Plan Date*

Tank Course	A_{rt} Value at RBI Date	A_{rt} Value at Plan Date
Course 1	0.005723	0.104346
Course 2	0.005412	0.098626
Course 3	0.007074	0.128973
Course 4	0.007074	0.128973

From the A_{rt} Value using **equation 4.9** the value of β_1^{thin}, β_1^{thin}, β_1^{thin} parameters can be determined. For the RBI date is shown in **Table 4.29** and for the Plan Date Shown in **Table 4.28**

Table 4. 28 *β value of Course 1 – 4 for plan date*

	β_1	β_2	β_3
Course 1	0.0006527	0.00036795	0.00012758
Course 2	0.0006898	0.00040286	0.0001487
Course 3	0.0005074	0.00024259	5.3822E-05
Course 4	0.0005074	0.00024259	5.3822E-05

Last is calculating External Corrosion D_f for Plan Date. The calculation is using **Equation 4.10** and **4.11**. The value of $D_f^{extcorr}$ for plan date are shown in **table 4.17**.

Table 4. 29 *External Corrosion Factor course 1-4 for Plan Date*

Tank Course	D_f^{thin} **Value**
Course 1	13.87887844
Course 2	13.8786382
Course 3	13.8797232
Course 4	13.8797232

4.4. Consequence of Failure Analysis

For determining Consequence of Failure in RBI it is divided into two categories first, Consequence Area and second is Financial Consequence. And in this bachelor thesis it only considers Consequence Area. And for its analysis and calculation there are 8 steps for calculation.

4.4.1. Determine the Representative fluids and Associated Properties

The most suitable Representative fluid for fluid that being store in this atmospheric storage tank is being chosen from **Attachment E**.

a. Choosing representative fluids

choosing the representative fluid is determining by the type of fluid that being process inside the atmospheric storage tank. Fluid that being object to this research is Methane. Which has C1 group.

b. Determine the stored fluid phase; liquid or vapor.

If the stored liquid is in two-phase state it is a Level 2 Consequence analysis. But, the phase of fluid that being storage inside the atmospheric storage tank is in liquid phase.

c. Determine the stored liquid properties

Because the liquid that being stored is in liquid phase so the properties that needed for the calculation is liquid density and Auto Ignition Temperature. The properties of the stored liquid can be obtained in **Attachment E**. And for this particular liquid the fluid properties are shown below:

ρ = 15.6 lb/ft3

AIT = 1496 °Rankine

NBP = 267 °Rankine

d. Determine fluid phase after release to the atmosphere

Fluid that being analyze is storage in liquid phase and will became gas phase when being released to the atmosphere. Methane fluid has NBP value (-193°F) or less than 80°F, so from **table 4.30** ideal phase for modelling is gas phase.

Table 4. 30 *Level 1 Guidelines for Determining the Phase of a Fluid*

Phase of Fluid at Normal Operating (Storage) Conditions	Phase of Fluid at Ambient (after release) Conditions	Determination of Final Phase for Consequence Calculation
Gas	Gas	model as gas
Gas	Liquid	model as gas
Liquid	Gas	model as gas *unless* the fluid boiling point at ambient conditions is greater than 80°F, then model as a liquid
Liquid	Liquid	model as liquid

4.4.2. Release Hole Size Selection

According to section 4.2.2 part 3 API 581 for determining release hole size, typically 4 release hole size are evaluated. Based on **table 4.31** the release hole that calculated is for small is 0.25 inch in diameter, medium is 1 inch in diameter, 4 inch in diameter for large, and lastly for rupture is 16 inch in diameter.

Table 4. 31 *Release Hole Size and Area*

Release Hole Number	Release Hole Size	Range of Hole Diameters (inch)	Release Hole Diameter, d_n (inch)
1	Small	0 – ¼	$d_1 = 0.25$
2	Medium	> ¼ – 2	$d_2 = 1$
3	Large	> 2 – 6	$d_3 = 4$
4	Rupture	> 6	$d_4 = \min[D, 16]$

next step in release hole size selection is determining value for generic failure frequency (*gff*) for each release size. The value is stated in 4 different categories, as shown as **table 4.32.**

Table 4. 32 *gff for determining release hole size*

Equipment type	Component type	***gff*** **as a Function of Hole Size (failures/yr)**				***gff(total)*** **(failures/yr)**
		Small	**Medium**	**Large**	**Rupture**	
Tank650	TANKBOTTOM	7.20E-04	0	0	2.00E-06	7.20E-04
Tank650	COURSE-1	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	COURSE-2	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	COURSE-3	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	COURSE-4	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04

- Small (gff1) = 7.00E-05
- Medium (gff2) = 2.50E-05
- Large (gff3) = 5.00E-06
- Rupture (gff4) = 1.00E-07

And for the total value of gff is 1.00E-04

4.4.3. Release Rate Calculation

Release rate depend upon the physical properties of the material, the initial phase, the process operating conditions, and the assigned release hole sizes. The correct release rate equation must be chosen based on the phase of the material when is inside the equipment. Because the fluid that stored inside the tank when is release became gas so, the release rate equation is using vapor release rate. If the storage pressure is greater than the transition pressures the equation for calculating release rate is shown in **equation 4.19**

$$W_n = \frac{C_d}{C_2} x A_n x P_s \sqrt{\left(\frac{k\ x\ MW\ x\ gc}{R\ x\ T_s}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \qquad (4.19)$$

If the storage pressure is less than or equal to transition pressure so the calculation for release rate is using **equation 4.20**

$$W_n = \frac{C_d}{C_2}\ x\ A_n\ x\ P_s \sqrt{\left[\left(\frac{MW\ .g_c}{R\ .T_s}\right)\left(\frac{2k}{k-1}\right)\left(\frac{P_{atm}}{P_s}\right)^{\frac{2}{k}}\left(1-\left(\frac{P_{atm}}{P_s}\right)^{\frac{k-1}{k}}\right)\right]} \qquad (4.20)$$

In this particular equation the value of storage pressure is less than transition pressure. P_s = 15.2 psi and P_{trans} = 17.3. Where:

C_d = discharge coefficient
C_p = customary convertion factors
A_n = release hole size area ($inch^2$)
P_s = Storage Pressure (psi)
P_{atm} = atmospheric pressure (psi)
T_s = Temperature (°Rankine)
R = Constanta gas universal (lb-mol°R)
gc = Constanta gravity lb_m-ft/lb_f-s^2
k = Ideal Gas Specific Heat Capacity Ratio

for calculating the release rate calculation first it need to calculate the value of constant pressure specific heat capacity it can be calculated using **equation 4.21** as shown as below:

$$C_p = A + BT + CT^2 + DT^3 \qquad (4.21)$$

Where;

A = 12.3

B = 0.115

C = -0.0000287

D = 1.3E-09

T = 567.76°Rankine

$$C_p = 12.3 + (0.115\ x567.76) + (-0.0000287)(567.76)^2 + (1.3x10^{-9})(308)^3$$

=20597.815

From all the data above the release rate values for each hole size can be determined using **equation 4.20**. the value of each release hole size are shown below:

W_1 = 0.005082028 lb/s

W_2 = 0.081312448 lb/s

W_3 = 1.300999164 lb/s

W_4 = 20.81598662 lb/s

4.4.4. Estimate the Fluid Inventory Available for Release

The available mass for release is estimated for each release hole size as the lesser of two quantities:

a. Inventory Group Mass – The component being evaluated is part of a larger group of components that can be expected to provide fluid inventory to the release.
b. Component Mass – It is assumed that for large leaks, operator intervention will occur within three minutes, thereby limiting the amount of released material

First step for determining Fluid inventory available for release is calculating the fluid mass $mass_{comp}$, in the component that being evaluated. To calculate $mass_{comp}$ is using **(equation 4.22)**

$$Mass_{comp} = \rho \times 50\% \times V \quad (4.22)$$

Where,

ρ = 250.512 kG/m^3

V = 726.815 m^3

So value of $Mass_{comp}$ is 200738.65 lbs

So because the tank that being evaluated is only 1 tank the value of mass inventory is the same with mass of the component. $mass_{comp} = mass_{inv}$. Next is calculating flow rate from 8inch hole using equation 4.20 that shown before. While A_8 = 50.3inch. So the value of W_{max8} is 5.21 lb/s. Next is calculating $mass_{add,n}$ for each release hole size using **equation 4.23**

$$mass_{add,n} = 180\ x\ \min[W_n, W_{max8}] \quad (4.23)$$

The fluid inventory avail for release for hole 0.25inch, 1inch, 4inch, and 16inch are the same because the value of $mass_{comp}$ and $mass_{inv}$ are the same is 200738.65 lbs

4.4.5. Determine The Release Type Continuous or Instantaneous

API RBI 581 stated that the release is modeled as one of two following types:

a) Instantaneous Release – An instantaneous or puff release is one that occurs so rapidly that the fluid disperses as a single large cloud or pool.

b) Continuous Release – A continuous or plume release is one that occurs over a longer period of time, allowing the fluid to disperse in the shape of an elongated ellipse (depending on weather conditions).

Determination of Release type is applicable by using these two criteria that stated in API RBI

- If the release hole size is 6.35 mm (0.25 inch) or less, then the release type is continuous
- If $t_n \leq 180$ sec and the release mass is greater than 4,536 kgs (10,000 lbs), then the release is instantaneous; otherwise, the release is continuous

For each release hole size, calculate the time required to release 4,536 kgs (10,000 lbs) of fluid. Using **Equation 4.24.**

$$t_n = \frac{C_3}{W_n} \qquad (4.24)$$

From that equation and the value of C_3 is 10000

- Time for release in ¼ inch hole:
  t_1 = 1967718.405 seconds
- Time for release in 1-inch hole:
  t_2= 122982.4 seconds
- Time for release in 4-inch hole:
  t_3= 7686.400021 seconds
- Time for release in 16-inch hole:
  t_4= 480.40seconds

Release type for each hole can be determined as shown as below for each hole size:

- Release hole size ¼ inch = continuous release
- Release hole size 1 inch = instantaneous release
- Release hole size 4 inch = instantaneous release
- Release hole size 16 inch = instantaneous release

4.4.6. Estimate the Impact of Detection and Isolation Systems on Release Magnitude

The Calculation procedures are:

a) Determine the detection and isolation systems present in the unit.

b) Using **table (4.33)**, select the appropriate classification (A, B, C) for the detection system**.**

Table 4. 33 *Leak Detection and Isolation System Rating Guide*

Type of Detection System	Detection Classification
Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e., loss of pressure or flow) in the system	A
Suitably located detectors to determine when the material is present outside the pressure-containing envelope	B
Visual detection, cameras, or detectors with marginal coverage	C
Type of Isolation System	**Isolation Classification**
Isolation or shutdown systems activated directly from process instrumentation or detectors, with no operator intervention	A
Isolation or shutdown systems activated by operators in the control room or other suitable locations remote from the leak	B
Isolation dependent on manually-operated valves	C

c) Using **table (4.33)**, select the appropriate classification (A, B, C) for the isolation system.

d) Using **Table (4.34)** and the classifications determined in step 4.4.6.b & 4.4.6.c, determine the release reduction factor, $fact_{di}$

Table 4. 34 Adjustments to Release Based on Detection and Isolation Systems

System Classifications		Release Magnitude Adjustment	Reduction Factor, $fact_{di}$
Detection	Isolation		
A	A	Reduce release rate or mass by 25%	0.25
A	B	Reduce release rate or mass by 20%	0.20
A or B	C	Reduce release rate or mass by 10%	0.10
B	B	Reduce release rate or mass by 15%	0.15
C	C	No adjustment to release rate to mass	0.00

Table 4. 35 *Leak Durations Based on Detection and Isolation Systems*

Detecting System Rating	Isolation System Rating	Maximum Leak Duration, Id_{max}
A	A	20 minutes for 6.4 mm leaks 10 minutes for 25 mm leaks 5 minutes for 102 mm leaks
A	B	30 minutes for 6.4 mm leaks 20 minutes for 25 mm leaks 10 minutes for 102 mm leaks
A	C	40 minutes for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
B	A or B	40 minutes for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
B	C	1 hour for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
C	A, B or C	1 hour for 6.4 mm leaks 40 minutes for 25 mm leaks 20 minutes for 102 mm leaks

4.4.7. Determining the Release Rate and Mass for Consequence Analysis

The Calculation Procedure are:

For each release hole size, calculate the adjusted release rate ($rate_n$) using **Equation 4.25** where the theoretical release rate (W_n) is from step 4.4.3.b. Note that the release reduction factor ($fact_{di}$) determined in step 4.4.6.d accounts for any detection and isolation systems that are present. This equation only for continuous release, so it only in 0.25-inch hole.

$$Rate_n = W_n\,(1\text{-}fact_{di}) \qquad (4.25)$$

And **Equation 4.26** below is being used to calculating release mass for instantaneous release.

$$Mass_n = \min\left[(rate_n \text{ x } Id_n),\ mass_{avail,n}\right] \qquad (4.26)$$

Where:

$Rate_n$: Release Rate (lb/s)

Id_n : Leak Duration(second)

Determining Leak duration for 1 inch, 4 inch, and 16 inch holes size. Using **equation 4.27** below:

$$Id_n = \min\left[\left(\frac{mass_{avail,n}}{rate_n}\right), \left(60\ x\ Id_{max,n}\right)\right] \quad (4.27)$$

Leak duration, Id_n, is only applied to instantaneous release. This type of instantaneous release from the above analysis results in 1 inch, 4 inch, and 16-inch discharge holes. Leak duration at each of the discharge hole sizes is:

- Leak duration for diameter 1 inch

$$Id_2 = \min\left[\left(\frac{200738.65}{0.069115}\right), (60\ x\ 30)\right]$$

= $\min(2904390.808\,, 1800)$

= 1800 Seconds

- Leak duration for diameter 4 inch

$$Id_3 = \min\left[\left(\frac{200738.656}{1.10584}\right), (60\ x\ 20)\right]$$

= $\min(181524.42\,, 1200)$

= 1200 Seconds

- Leak Duration for diameter 16 inch

API RBI does not give the value of the duration of the leak to a diameter of 16 inches.

Next is calculates the mass of release, mass, for each size of the discharge hole using the above **Equation 4.26**.

The above formula is used to calculate the release mass if the release type is instantaneous release. The instantaneous release type from the above analysis results in the diameter of 1 inch, 4 inch, and 16-inch discharge holes

- Release Mass for diameter 1 inch:
  $Mass_2$ = 124.08 lbs
- Release Mass for diameter 4 inch:
  $Mass_3$ = 1327.019 lbs
- Release Mass for diameter 16 inch:
  The release mass for 16-inch diameter (rupture) is assumed to be equal to the available mass that can be detached, so that:
  $Mass_4$ = 200738.6569 lbs

4.4.8. Determining Flammable and Explosive Consequence

Consequence area is estimated from calculation of release rate (for continuous release) or release period (for instantaneous release).

a) Calculating Consequence area component damage

Consequence component area damage" can be divided into 4, there are:

- *Auto-ignition Not Likely, Continuous Release*

Consequence area Component Damage Auto-ignition Not Likely, Continuous Release, can be calculated using the following **Equation 4.28**:

$$CA_{cmd,n}^{AINL-CONT} = a(rate_n)^b.(1 - fact_{mit}) \quad (4.28)$$

Value (a) and (b) From **Attachment F**.

a = 43

b = 1

Value of effective release rate *Component Damage Auto-ignition Not Likely, Continuous Release,* Can be calculated using **equation 4.29** below:

$$effrate_n^{AINL-CONT} = rate_n \quad (4.29)$$

Continous release type only in ¼ inch hole, so :

$$CA_{cmd1}^{AINL-CONT} = 43(0.3)^1.(1 - 0.2)$$

$CA_{cmd1}^{AINL-CONT} = 0.165$ ft^2

$effrate_1^{AINL-CONT} = 0.004$lb/s

- *Auto-ignition Likely, Continuous Release*

Consequence area Component Damage Auto-ignition Likely, Continuous Release, can be calculated using the following **Equation 4.30** :

$$CA_{cmd,n}^{AIL-CONT} = a(rate_n)^b.(1 - fact_{mit}) \quad (4.30)$$

Value (a) and (b) From **Attachment F**.

a = 280

b = 0.95

Value of effective release rate *Component Damage Auto-ignition Likely, Continuous Release,* Can be calculated using **equation 4.31** below :

$$effrate_n^{AIL-CONT} = rate_n \quad (4.31)$$

Continous release type only in ¼ inch hole, so:

$$CA_{cmd1}^{AIL-CONT} = 280(0.3)^{0.95}.(1 - 0.2)$$

$CA_{cmd,n}^{AIL-CONT} = 1.271$ ft^2

$effrate_1^{AIL-CONT} = 0.00432$ lb/s

- *Auto-ignition Not Likely, Instantaneous Release*

Consequence area Component Damage Auto-ignition Not Likely, *Instantaneous Release*, can be calculated using the following **Equation 4.32**:

$$CA_{cmd,n}^{AINL-INST} = a(mass_n)^b . \left(\frac{1-fact_{mit}}{eneff_n}\right) \quad (4.32)$$

Value (a) and (b) From **Attachment F**.

a = 41

b = 0.67

Value of effective release rate *Component Damage Auto-ignition Not Likely, Continuous Release,* Can be calculated using **equation 4.33** below :

$$effmass_n^{AINL-INST} = mass_n \quad (4.33)$$

Instantaneous Release only occurs at diameter 1 inch, 4 inch, and 16 inch, which :

a. For 1-inch release hole

$CA_{cmd2}^{AINL-INST} = 570.9015$ ft^2

$effmass_n^{AINL-INST} = 124.208$ lbs

b. For 4-inch release hole

$CA_{cmd3}^{AINL-INST} = 613.6221$ ft^2

$effmass_n^{AINL-INST} = 1327.019$ lbs

c. For 16-inch release hole

$CA_{cmd4}^{AINL-INST} = 13602.13$ ft^2

$effmass_n^{AINL-INST} = 200738.7$lbs

- *Auto-ignition Likely, Instantaneous Release*

Consequence area Component Damage Auto-ignition Likely, *Instantaneous Release*, can be calculated using the following **Equation 4.34**:

$$CA_{cmd,n}^{AIL-INST} = a(mass_n)^b . \left(\frac{1-fact_{mit}}{eneff_n}\right) \quad (4.34)$$

Value (a) and (b) From **Attachment F**.

a = 1079

b = 0.62

Value of effective release rate *Component Damage Auto-ignition Likely, Continuous Release,* Can be calculated using **equation 4.35** below:

$$effmass_n^{AIL-INST} = mass_n \quad (4.35)$$

Instantaneous Release only occurs at diameter 1 inch, 4 inch, and 16 inch, which:

a. For 1-inch release hole:

$CA_{cmd2}^{AIL-INST} = 11804.73709$ ft^2

$effmass_2^{AIL-INST} = 124.408$ lbs

b. For 4-inch release hole :

$CA_{cmd3}^{AIL-INST} = 11271.83$ ft^2

$effmass_3^{AIL-INST} = 1327.019$ lbs

c. For 16-inch release hole

$CA_{cmd4}^{AIL-INST} = 194407.5271$ ft^2

$effmass_4^{AIL-INST} = 200738.65$ lbs

b) Calculating Consequence area for personnel Injury

Like the component damage. The consequence area for personnel injury are divided by four. The calculation of the four are shown below:

- *Auto-ignition Not Likely, Continuous Release*

Consequence Area for *Personnel Injury, Auto-ignition Not Likely, Continuous Release,* Cam be calculated using **equation 4.36**:

$$CA_{inj,n}^{AINL-CONT} = [a\ (effrate_n^{AINL-CONT})^b].(1 - fact_{mit}) \qquad (4.36)$$

Value (a) and (b) From **Attachment G**.

a = 110

b = 0.96

Value of effective release rate *Personel Injury Auto-ignition Not Likely, Continuous Release,* Can be calculated using **equation 4.37** below:

$$effrate_n^{AINL-CONT} = rate_n \qquad (4.37)$$

Continous release type only in ¼ inch hole, so:

$CA_{inj1}^{AINL-CONT} = [110.2(0.3)^{0.96}].(1 - 0.2)$

$CA_{inj1}^{AINL-CONT} = 0.4726$ ft^2

$effrate_1^{AINL-CONT} = 0.004319724$ /s

- *Auto-ignition Likely, Continuous Release*

Consequence Area for *Personel Injury, Auto-ignition Likely, Continuous Release,* Cam be calculated using **equation 4.38**:

$$CA_{inj,n}^{AIL-CONT} = [a\ (effrate_n^{AIL-CONT})^b].(1 - fact_{mit}) \qquad (4.38)$$

Value (a) and (b) From **Attachment G**.

a = 745

b = 0.92

Value of effective release rate Personnel Injury Auto-ignition Likely, Continuous Release, Can be calculated using **equation 4.39** below :

$$effrate_n^{AIL-CONT} = rate_n \tag{4.39}$$

Continous release type only in ¼ inch hole, so :

$CA_{inj1}^{AIL-CONT} = [745(0.3)^{0.92}].(1-0.2)$

$CA_{inj1}^{AIL-CONT}$ = 3.9798 ft^2

$effrate_1^{AIL-CONT} = 0.004319724$ lb/s

- *Auto-ignition Not Likely, Instantaneous Release*

  Consequence area Personnel Injury Auto-ignition Not Likely, *Instantaneous Release*, can be calculated using the following **Equation 4.40**:

$$CA_{inj,n}^{AINL-INST} = [a\,(effrate_n^{AINL-INST})^b].\left(\frac{1-fact_{mit}}{eneff_n}\right) \tag{4.40}$$

Value (a) and (b) From **Attachment G.**

a = 79

b = 0.67

Value of effective release rate *Personnel Injury Auto-ignition Not Likely, Continuous Release,* Can be calculated using **equation 4.41** below:

$$effrate_n^{AINL-INST} = mass_n \tag{4.41}$$

Instantaneous Release only occurs at diameter 1 inch, 4 inch, and 16 inch, which:

a. For 1-inch release hole

   $CA_{inj2}^{AINL-INST}$ = 56784.92 ft^2

   $effrate_2^{AINL-INST}$ = 8515.52lbs

b. For 4-inch release hole

   $CA_{inj3}^{AINL-INST}$ = 49989.992 ft^2

   $effrate_3^{AINL-INST}$ = 90832.213lbs

c. For 16-inch release hole

   $CA_{inj4}^{AINL-INST}$ = 61371.789 ft^2

   $effrate_4^{AINL-INST}$ = 148218.43lbs

- *Auto-ignition Likely, Instantaneous Release*

  Consequence area Personnel Injury Auto-ignition Likely Instantaneous Release, can be calculated using the following **Equation 4.42**:

$$CA_{inj,n}^{AIL-INST} = [a\,(effrate_n^{AIL-INST})^b].\left(\frac{1-fact_{mit}}{eneff_n}\right)$$

(4.42)

Value (a) and (b) From **Attachment G**.

a = 3100

b = 0.63

Value of effective release rate Personnel Injury Auto-ignition Likely, Continuous Release, can be calculated using **equation 4.43** below:

$effrate_n^{AIL-INST} = mass_n$ (4.43)

This calculation is only for 1 inch, 4 inch, and 16 inch, so:

a. For 1-inch release hole
   $CA_{inj2}^{AIL-INST}$ = 587501.74 ft^2
   $effrate_2^{AIL-INST}$ = 8515.52lbs
b. For 4-inch release hole
   $CA_{inj3}^{AIL-INST}$ = 389310.21 ft^2
   $effrate_3^{AIL-INST}$ = 90832.213lbs
c. For 16-inch release hole
   $CA_{inj4}^{AIL-INST}$ = 450673.51 ft^2
   $effrate_4^{AIL-INST}$ = 148218.43lbs

c) Calculating instantaneous and continuous blending factor

a. Calculates the instantaneous / continuous blending factor for each discharge hole size using the corresponding **equations 4.44, 4.45,** or **4.46**.
b. The blending factor value for the continuous release type is calculated using the following **equation 4.44**:

   $fact_n^{IC} = \min\left[\left\{\frac{rate_n}{C_5}\right\}, 1.0\right]$ (4.44)

   with C_5 = 55.6
c. The instantaneous blending factor value if the constant is not provided in table 5.8 or 5.9 then the value used **equation 4.45** below:

   $fact_n^{IC} = 0.0$ (4.45)
d. Blending factor value for instantaneous release is not provided, so the **equation 4.46** is used below:

   $fact_n^{IC} = 1.0$ (4.46)

Blending factor values are selected according to the appropriate release type for each discharge hole size, so that the respective values:

a. For ¼ inch release hole size
   Type: *Continuous release*

   $$fact_1^{IC} = \min\left[\left\{\frac{0.3}{55.6}\right\}, 1.0\right]$$

   $$fact_1^{IC} = \min[0.0054, 1.0]$$
   $$fact_1^{IC} = 0.0054$$

b. For 1-inch release hole size
   type: Instantaneous release
   $fact_2^{IC} = 1$
c. For 4-inch release hole size
   Type: *Instantaneous release*
   $fact_3^{IC} = 1$
d. For 16-inch release hole size
   Type: *Instantaneous release*
   $fact_4^{IC} = 1$

i. Calculate AIT using one of this equation

$$fact^{AIT} = 0 \quad \text{(4.47)}$$
$$if\ T_s + C_6 \leq AIT$$
$$fact^{AIT} = \frac{(T_s - AIT + C_6)}{2\ x\ C_6} \quad \text{(4.48)}$$
$$if\ \ T_s + C_6 > AIT > T_s - C_6$$
$$fact^{AIT} = 1 \quad \text{(4.49)}$$
$$if\ T_s - C_6 \geq AIT$$

Where:
T_s = 568°Rankine
C_6 = 100
AIT = 1496°Rankine
T_s + C_6 = 668°Rankine
T_s – C_6 = 468°Rankine
So , T_s + C_6< AIT and T_s – C_6< AIT
So:
$fact^{AIT} = 0$

ii. Calculate continuous/instantaneous blended consequence area using ***equation 4.50*** *to* ***equation 4.53*** that consequences area previously calculated.

$$CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST}\, x\, fact_n^{IC} + CA_{cmd,n}^{AIL-CONT}\, x\, (1 - fact_n^{IC}) \quad \text{(4.50)}$$

$$CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST}\, x\, fact_n^{IC} + CA_{cmd,n}^{AINL-CONT}\, x\, (1 - fact_n^{IC}) \quad \text{(4.51)}$$

$$CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST}\, x\, fact_n^{IC} + CA_{inj,n}^{AIL-CONT}\, x\, (1 - fact_n^{IC}) \quad \text{(4.52)}$$

$$CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST}\, x\, fact_n^{IC} + CA_{inj,n}^{AINL-CONT}\, x\, (1 - fact_n^{IC}) \quad \text{(4.53)}$$

a. The value continuous blended consequence area component damage auto-ignition likely
   - Release hole ¼ inch
     $CA_{cmd,n}^{AIL} = 1.264$ft^2
   - Release hole 1 inch
     $CA_{cmd2}^{AIL} = 11804.737$ft^2
   - Release hole 4 inch
     $CA_{cmd3}^{AIL} = 11271.8373$ft^2
   - Release hole 16 inch
     $CA_{cmd4}^{AIL} = 194407.527$ ft^2
b. The value continuous blended consequence area component damage auto-ignition not likely
   - Release hole ¼ inch
     $CA_{cmd1}^{AINL} = 0.1649$ ft^2
   - Release hole 1 inch
     $CA_{cmd2}^{AINL} = 570.9014$ ft^2
   - Release hole 4 inch
     $CA_{cmd3}^{AINL} = 613.622$ ft^2
   - Release hole 16 inch
     $CA_{cmd4}^{AINL} = 13602.133$ ft^2
c. The value instantaneous blended consequence area personnel injury auto-ignition likely
   - Release hole ¼ inch
     $CA_{inj1}^{AIL} = 4$ ft^2
   - Release hole 1 inch
     $CA_{inj2}^{AIL} = 35591.398$ ft^2
   - Release hole 4 inch
     $CA_{inj3}^{AIL} = 34798.75$ ft^2
   - Release hole 16 inch
     $CA_{inj4}^{AIL} = 631073.051$ft^2
d. The value instantaneous blended consequence area personnel injury auto-ignition not likely
   - Release hole ¼ inch
     $CA_{inj1}^{AINL} = 0.4705$ ft^2
   - Release hole 1 inch
     $CA_{inj2}^{AINL} = 1100.029$ ft^2

- Release hole 4 inch
  $CA^{AINL}_{inj3} = 1182.344$ ft^2
- Release hole 16 inch
  $CA^{AINL}_{inj4} = 26208.989$ ft^2

iii. Calculate AIT blended consequence area for component damage using **equation 4.54** and for personal injury using **equation 4.55** below.

$$CA^{flam}_{cmd,n} = CA^{AIL}_{cmd,n}\ x\ fact^{AIT} + CA^{AINL}_{cmd,n} x\ (1 - fact^{AIT}) \quad (4.54)$$

$$CA^{flam}_{inj,n} = CA^{flam-AIL}_{inj,n}\ x\ fact^{AIT} + CA^{AINL}_{inj,n} x\ (1 - fact^{AIT}) \quad (4.55)$$

a. The value AIT blended consequence area for component damage
   - Release hole ¼ inch
     $CA^{flam}_{cmd1} = 0.2$ ft^2
   - Release hole 1 inch
     $CA^{flam}_{cmd2} = 570.901$ft^2
   - Release hole 4 inch
     $CA^{flam}_{cmd3} = 613.622$ft^2
   - Release hole 16 inch
     $CA^{flam}_{cmd4} = 13602.133$ ft^2

b. The value AIT blended consequence area for personnel injury is:
   - Release hole ¼ inch
     $CA^{flam}_{inj1} = 0.5$ft^2
   - Release hole 1 inch
     $CA^{flam}_{inj2} = 1100.03$ ft^2
   - Release hole 4 inch
     $CA^{flam}_{inj3} = 1182.345$ ft^2
   - Release hole 16 inch
     $CA^{flam}_{inj4} = 26208.99$ ft^2

4.4.9. Calculating the final consequences of component damage and personnel injury

$$CA^{flam}_{cmd} = \left(\frac{\sum_{n=1}^{4} gff_n\ x\ CA^{flam}_{cmd,n}}{gff_{total}}\right) \quad (4.56)$$

$$CA^{flam}_{inj} = \left(\frac{\sum_{n=1}^{4} gff_n\ x\ CA^{flam}_{inj,n}}{gff_{total}}\right) \quad (4.57)$$

Calculation final consequences area for components damage and personnel injury on each size of release hole. The value of the generic failure frequency can be seen in **table 4.23**. This calculation will provide both of the Consequence area for determining Final Consequence Area in next step.

Consequence Area for Component Damage

Table 4. 36 *Component Damage and Gff*

Hole Category	**CA_{Cmd}**	Gff
Small	0.2	0.00007
Medium	570.901	0.00002
Large	613.622	0.000005
Rupture	13602.13	0.0000001

So from the table the value of CA_{cmd} can be determined.

$$\boldsymbol{CA_{cmd}^{FLam} = 518.232\ ft^2}$$

Consequence Area for Personnel Injury

Table 4. 37 *Personnel Injury and Gff*

Hole Category	**CA_{Cmd}**	Gff
Small	0.5	0.00007
Medium	1100.03	0.00002
Large	1182.345	0.000005
Rupture	26208.99	0.0000001

So from the table the value of CA_{inj} can be determined.

$$\boldsymbol{CA_{inj}^{FLam} = 998.894\ \ ft^2}$$

4.4.10. Determining Final Consequence Area

For determining value of Final CA is uses the highest value of CA_{cmd} and CA_{inj}. As shown in **equation 4.58**

$$CA = \max[CA_{cmd}\ , CA_{inj} \qquad (4.58)$$

= max [518.232, 998.894]

= 998.894

4.5. Risk analysis

Risk can be calculated using **equation (4.59)**

$$Risk = PoF\ x\ CoF \qquad (4.59)$$

The risk is obtained by multiplying the probability of failure by the consequences of failure. Determining the level of risk is done by comparing the risk value obtained with risk target. If the comparison results show that the risk is greater than the target risk, it will be a mitigation step. Mitigation steps can be done by performing inspections in accordance with the schedule and methods that are expected to minimize the value of these risks.

For Calculating Risk, the Value for PoF must be determine first. The value for PoF for the RBI and Plan Date are shown below:

PoF at RBI Date = 0.000510248 Failure/year

PoF at Plan Date = 0.003914561 Failure/year

Next is calculating Risk using **equation 4.60** for both RBI Date and Plan Date. Times between Plan Date and RBI Date in this case is 10 years.

- At RBI Date

$$Risk = PoF\ x\ \max[CA_{cmd}, CA_{inj}] \qquad (4.60)$$

$= 0.51\ ft^2/year$

- At Plan Date

$$Risk = PoF\ x\ \max[CA_{cmd}, CA_{inj}] \qquad (4.60)$$

$= 3.91\ ft^2/year$

By using the risk value that being calculated. It can be plotted to the risk matrix to determine the risk level. The risk level can be seen in Figure 4.

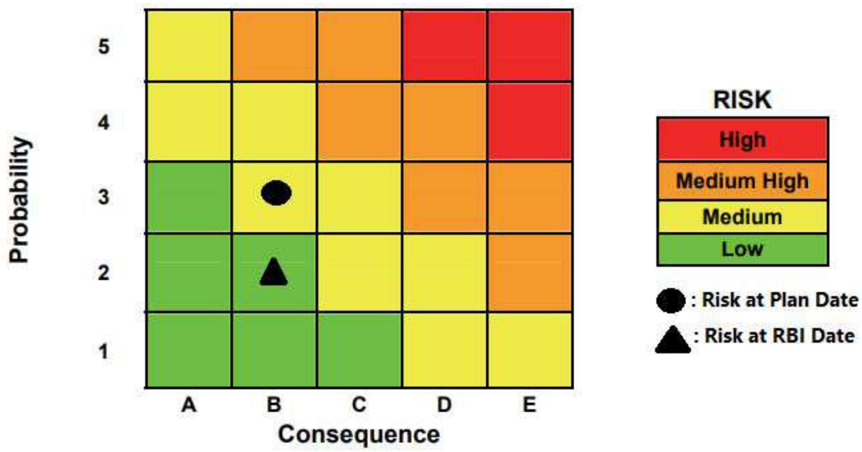

Figure 4. 1 *Plotted Risk Matrix*

4.6. Inspection Planning

If the risk value is being plotted to Risk matrix the risk at plan date is already in 3B area which is in Medium Risk Level. To make the it in Low Risk Area so it need risk Target 0.95 ft^2/year. Using Table 4.38 for tools to helping determine risk Target Date using Interpolation between RBI and Plan Date.

Table 4. 38 *Risk Target Date and RBI date interpolation*

Item	Date	Time Since Assessment	Risk Area
RBI Date	14-Mar-18	0	0.51
Risk Target	?	?	0.95
Plan Date	14-Mar-28	10	3.91

From **Table 4.38** also can help to make graphical comparison between RBI Date, Plan Date, and also the Target Date. The graphical comparison is shown in Figure

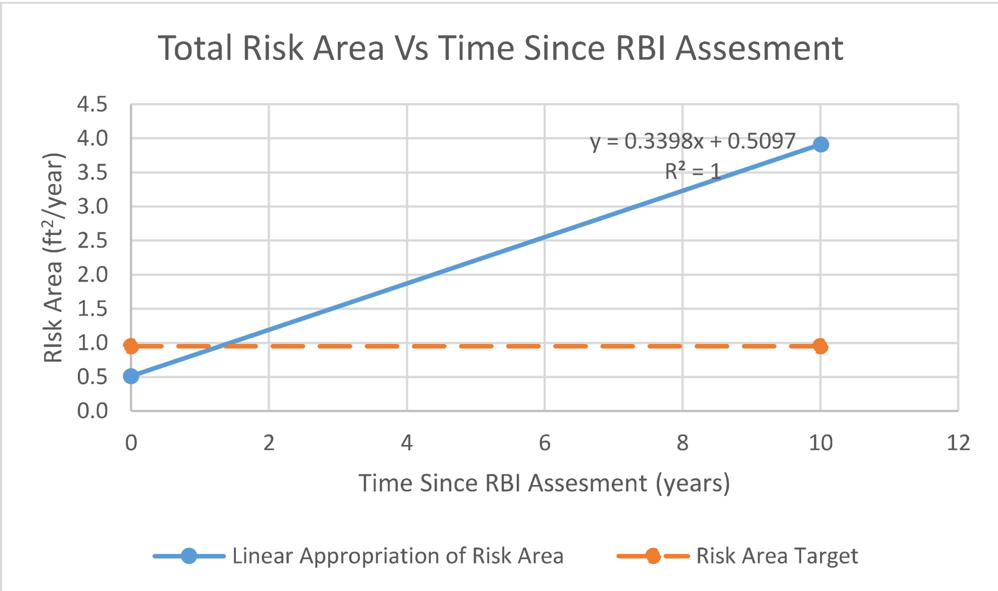

Figure 4. 2 Total Risk area vs Time since RBI Assessment.

From the table and the graph. The target date can be determined. The value of target date is below.

Target Date = 1.2959 Years Since RBI Assessment. Which is at 29th of July 2019. Using interpolation again from table 4.39 . The value of purposed

Df can be calculated. The purposed Df is 10 which is Df from Plan Date need to be lowered by 4.12 times.

Table 4. 39 *Interpolation for Target Df*

	RBI date	Target date	Plan date
D_f^{thin}	2.68	?	27.28
D_f^{extd}	2.68	?	13.88
D_f^{total}	5.37	10	41.16

Also from Table 4.39 can be determined what kind of inspection that need to held to fulfill target Df. There are two purposed Inspection that need to be done. First is Thinning Inspection (It Should be 1B thinning inspection since the Df needed to be lowered as many as possible). And next is External Damage Inspection (It Should be 1B External Damage inspection since the Df need to be lowered as many as possible).

4.7. Determine Risk at Plan Date with Inspection.

Using the same method as before to calculate both damage factor. Summary of calculation of the new damage factor for both of them are shown bellows:

- New Thinning D_f

Previous Thinning Inspection at	=	14-Aug-17	=	1A
Purposed Thinning Inspection at target date	=	29-Jun-19	=	1B

Using the Same equation as calculating CoF so the new value for new Thinning damage Factor as shown as below:

A/rt With Inspection	=	0.249	
Number of Inspection and effectiveness	=	1	1
		A	B
Inspection Effectiveness Factor (1)	=	0.315	
Inspection Effectiveness Factor (2)	=	0.0054	
Inspection Effectiveness Factor (3)	=	0.0002	
Posterior Probability (1)	=	0.98253275	
Posterior Probability (2)	=	0.01684342	
Posterior Probability (3)	=	0.00062383	

Parameters β1	=	-0.0153611
Parameters β2	=	-0.6707175
Parameters β3	=	-27.52604
D_f^{thin}	=	4.5088

- New External Corrosion Damage Factor

Prev. External Damage Inspection at	=	14-Aug-17	=	1A
Purposed External Damage Inspection at target date	=	29-Jun-19	=	1B

Using the Same equation as calculating CoF so the new value for new Thinning damage Factor as shown as below:

A/rt With Inspection	=	0.146	
Number of Inspection and effectivenes	=	1	1
		A	B
Inspection Effectivenes Factor (1)	=	0.315	
Inspection Effectivenes Factor (2)	=	0.0054	
Inspection Effectivenes Factor (3)	=	0.0002	
Posterior Probability (1)	=	0.98253275	
Posterior Probability (2)	=	0.01684342	
Posterior Probability (3)	=	0.00062383	
Parameters β1	=	0.00047193	
Parameters β2	=	0.0002102	
Parameters β3	=	3.40E-05	
$D_f^{extcorr}$	=	2.4989	

The total New Damage Factor

$$D_f^{total} = D_f^{thin} + D_f^{extd}$$

= 4.5088 + 2.4989

= 7.01

And for the Risk Area with Inspection is

Risk = PoF x CoF

= 0.67 ft^2/year

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CHAPTER V

CONCLUSION AND SUGGESTION

5.1. Conclusion

In this final project used Risk Based Inspection method in risk analysis as well as determining the proper maintenance type of each damage factor which become the object of analysis. In this final project, damage factor in this case already being screened is thinning damage factor and external corrosion damage factor possibly happened to Condensate Storage Tank BANG-T-05 that own by PT.X. The following results are obtained:

1. the risk value of the Condensate Storage Tank BANG-T-05 is 0.51 ft^2/year.
2. Inspection planning for Condensate Storage Tank BANG-T-05 planned at 1,3 years after RBI Date. Which is 29^{th} June 2019
3. Schedule and inspection method for operation for 10 years, there are:
    a. Inspection Method
    Inspection method for thinning damage factor is at least 5% UT scanning, automated or manual
    b. Inspection method
    Inspection method for external corrosion damage factor at least 60% visual inspection of the exposed area with follow-up by UT, RT or pit gauge as required.
    c. Inspection Schedule
    The inspection schedule based on RBI analysis is on 29^{th} June, 2019. The results are shorter than the provisions of SKPP Migas, which is every 3 years. The different schedule of inspections can be caused by incomplete data.
4. Damage Factor value after inspection in target date can be lowered by 4,12 factor. So, the new damage factor at plan date after inspection is 7,01.

5.2. Suggestion

1. The data used in the RBI analysis should be the data obtained during the last inspection, so the results of the analysis are expected to be more accurate. And at least the date that use for RBI calculation is more than one inspection data.

2. Measurement of thickness is done at different points. The company should have the measured thickness position data at the time of the inspection, so that the next inspection will be measured at the same point.
3. The inspection planning results are shorter than the provisions of SKPP Migas, so that for inspection schedule it is suggested to follow the provisions of this calculation. Because if the inspection is held based on SKPP Migas provisions the risk value of the tank will get higher.

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ATTACHMENT A

GENERAL DATA

1 EQIUPMENT / COMPONENT

BANG-T-050A Condensate
Storage Tank

Fabrication Date	:	7/24/2014
Design Pressure	:	1 psig
Design Temp.	:	200 F
Weld Joint Efficiency	:	0.85
Yield Strength	:	250 Mpa
Tensile Strength	:	400 Mpa
Allowable Stress	:	150 Mpa
Minimum Design Metal Temp.	:	0 ^{0}C
Material of Construction	:	Carbon Steel A36 ASTM
Furnished Thickness	:	8 mm
Corrosion Allowance	:	3.175 mm
Post Weld Heat Treatment (PWHT)	:	YES

Outside Diameter	:	10058 mm		
Inside Diameter	:	10058 mm		kg / l
Height	:	9144 mm	2209518.9	
Insulation	:	None; Not Insulated		
joint Efficiency	:	1		

2 Operating Condition

Operating Temperature	:	108 F
Operating Pressure	:	0,5 psig
Fluid	:	Hydrocarbon Liquid
Liquid Level	:	76%

Inspection History

Thinning Inspection Date	:	8/14/2017
Inspection Effectiveness	:	1A
Corrosion found	:	Localized Corrosion

Measured thickness

• course 1	:	7.07
• course 2	:	7.48
• course 3	:	5.72
• course 4	:	5.72

measured corrosion rate

• course 1	:	0.31
• course 2	:	0.17333333
• course 3	:	0.76
• course 4	:	0.76

3 Fluid Properties

Vapor Density	:	
Liquid Density	:	
NBP	:	
Auto Ignition Temp.	:	
Discharge Coeficient Liquid	:	
Invebtory Group Mass	:	

4 Fire Prevention

Detection	:	
Isolation	:	
Mitigation	:	

5 Planning

RBI date	:	3/14/2018
Plan date	:	3/14/2028
Area Risk Target	:	40ft/year
Damage Factor Target	:	100
Management Factor	:	1

ATTACHMENT B

SCREENING DAMAGE FACTOR

Screening Damage Mechanism

No.	Type Damage Mechanism	Criteria based on API 581	Yes/No	Result
1	Thinning Damage factor	In an API RBI assessment, all components should be checked for thinning.	Yes	Yes
2	Component Lining Damage Factor	The component has an inorganic or organic lining, then the component should be evaluated for lining damage	No	No
3	SCC Damage Factor - Caustic Cracking	The component's material of construction is carbon or low alloy steel	Yes	No
		Storgage Fluid Contains NaOH at high temperature	No	
		The process environment contains caustic in any concentration	No	
4	SCC Damage Factor - Amine Cracking	The component's material of construction is carbon or low alloy steel	Yes	No
		The process environment contains acid gas treating amines (MEA, DEA, DIPA, MDEA, etc.) in any concentration.	No	
5	SCC Damag Factor - Sulfide Stress Cracking	The component's material of construction is carbon or low alloy steel	Yes	No
		The process environment contains water and H_2S in any concentration	No	
6	SCC Damage Factor - HIC/SOHIC-H_2S	The component's material of construction is carbon or low alloy steel	Yes	No
		the process environment contains water and H_2S in any concentration	No	
7	SCC Damage Factor - Carbonate Cracking	The component's material of construction is carbon or low alloy steel	Yes	No
		the process environment contains carbon (CO_3)	No	
		the process environment contains sour water at pH > 7.5 in any concentration	No	
8	SCC Damage Factor - PTA Cracking	If the component's material of construction is an austenitic stainless steel or nickel based alloys	No	No
		The component is exposed to sulfur bearing compounds	Yes	

9	SCC Damage Factor - CLSCC	The component's material of construction is an austenitic stainless steel	No	No
		The component is exposed or potentially exposed to chlorides and water	No	
		The operating temperature is above 38°C	No	
10	SCC Damage Factor - HSC-HF	The component's material of construction is carbon or low alloy steel	Yes	No
		the component is exposed to hydrofluoric acid in any concentration	No	
11	SCC Damage Factor - HIC/SOHIC-HF	The component's material of construction is carbon or low alloy steel	Yes	No
		the component is exposed to hydrofluoric acid in any concentration	No	
12	External Corrosion Damage Factor - Ferritic Component	Areas exposed to mist overspray from cooling towers	No	Yes
		Areas exposed to steam vents,	No	
		Areas exposed to deluge systems,	Yes	
		Area subject to process spills, ingress of moisture, or acid vapors	No	
		Carbon steel systems, operating between –12°C and 177°C (10°F and 350°F).	Yes	
		Systems that do not normally operate between -12°C and 177°C (10°F and 350°F) but cool or heat into this range intermittently or are subjected to frequent outages,	No	
		Systems with deteriorated coating and/or wrappings	No	
		Cold service equipment consistently operating below the atmospheric dew point	No	
		Un-insulated nozzles or other protrusions components of insulated equipment in cold service conditions	Yes	

13	CUI Damage Factor - Ferritic Component	Areas exposed to mist overspray from cooling towers.	No	No
		Areas exposed to steam vents	No	
		Areas exposed to deluge systems	No	
		Area subject to process spills, ingress of moisture, or acid vapors	No	
		Insulation jacketing seams located on top of horizontal vessels or improperly lapped or sealed insulation systems	No	
		Inspection ports or plugs which are removed to permit thickness measurements on insulated systems represent a major contributor to possible leaks in insulated systems	No	
		Carbon steel systems, including those insulated for personnel protection, operating between -12°C and 175°C (10°F and 350°F).	No	
		Carbon steel systems that normally operate in services above 175°C (350°F) but are in	No	
		Dead legs and attachments that protrude from the insulation and operate at different temperature than the operating temperature of the active line	No	
		Systems in which vibration has a tendency to inflict damage to insulation jacketing providing paths for water ingress	No	
		Steam traced system experiencing tracing leaks, especially at tubing fittings beneath the insulation	No	
		Systems with deteriorated coating and/or wrappings	No	
		Cold service equipment consistently operating below the atmospheric dew point	No	

14	External CLSCC Damage Factor - Austenitic Component	The component's material of construction is an austenitic stainless stee	No	No
		The component external surface is exposed to chloride containing fluids, mists, or solids.	No	
		The operating temperature is between 50°C and 150°C (120°F and 300°F), or the system heats or cools into this range intermittently	Yes	
15	External CUI CLSCC Damage Factor - Austenitic Component	The component's material of construction is an austenitic stainless steel	No	No
		The component is insulated	No	
		The component's external surface is exposed to chloride containing fluids, mists, or solids	No	
		The operating temperature is between 50°C and 150°C (120°F and 300°F) or intermittantly operated in this range	Yes	
16	HTHA Damage Factor	The material is carbon steel, C-½ Mo, or a Cr-Mo low alloy steel	No	No
		The operating temperature is greater than 177°C (350°F) and The operating hydrogen partial pressure is greater than 0.345 MPa (50 psia)	No	
17	Brittle Facture Damage Factor	The component's material of construction is carbon or low alloy steel	Yes	No
		If Minimum Design Metal Temperature (MDMT), T_{MDMT} , or Minimum Allowable Temperature (MAT), T_{MAT} , is unknown, or the component is known to operate at or below the MDMT or MAT under normal or upset conditions.	No	
18	Temper Embrittlement Damage Factor	The material is 1Cr-0.5Mo, 1.25Cr -0.5Mo, 2.25Cr -1Mo or 3Cr-1 Mo low alloy steel	No	No
		The operating temperature is between 343 and 577°C (650 and 1,070°F)	No	
19	885 Embrittlement Damage Factor	The material is a high chromium (>12% Cr) ferritic steel	No	No
		The operating temperature is between 371°C and 566°C (700°F and 1,050 °F)	No	

<table>
<tr><td rowspan="2">20</td><td rowspan="2">Sigma Phase Embrittlement Damage Factor</td><td>The material an austenitic stainless steel</td><td>No</td><td rowspan="2">No</td></tr>
<tr><td>The operating temperature between 593°C and 927°C (1,100 and 1,700 °F)</td><td>No</td></tr>
<tr><td rowspan="2">21</td><td rowspan="2">Piping Mechanical Fatigue Damage Factor</td><td>The component is pipe</td><td>No</td><td rowspan="2">No</td></tr>
<tr><td>There have been past fatigue failures in this piping system or there is visible/audible shaking in this piping
system or there is a source of cyclic vibration within approximately 15.24 meters (50 feet) and connected to the
piping (directly or indirectly via structure).
Shaking and source of shaking can be continuous or intermittent.
Transient conditions often cause intermittent vibration.</td><td>No</td></tr>
</table>

ATTACHMENT C

LIST OF NOMENCLATURE

15.7 Nomenclature

age	is the in-service time that damage is applied
age_{coat}	is the in-service time since the coating installation
age_{tk}	is the component in-service time since the last inspection thickness measurement or service start date
A_{rt}	is the expected metal loss fraction since last inspection
α	is the component geometry shape factor
β_1^{Thin}	is the β reliability indices for damage state 1
β_2^{Thin}	is the β reliability indices for damage state 2
β_3^{Thin}	is the β reliability indices for damage state 3
$Coat_{adj}$	is the coating adjustment
C_r	is the corrosion rate
C_{rB}	is the base value of the corrosion rate
CA	is the corrosion allowance
Co_{p1}^{extcor}	is the conditional probability of inspection history inspection effectiveness for damage state 1
Co_{p2}^{extcor}	is the conditional probability of inspection history inspection effectiveness for damage state 2
Co_{p3}^{extcor}	is the conditional probability of inspection history inspection effectiveness for damage state 3
COV_P	is the Pressure variance
COV_{S_f}	is the Flow Stress variance
$COV_{\Delta t}$	is the Thinning variance
D	is the component inside diameter
D_{S_1}	is the corrosion rate factor for damage state 1
D_{S_2}	is the corrosion rate factor for damage state 2
D_{S_3}	is the corrosion rate factor for damage state 3
$D_f^{extcorr}$	is the DF for external corrosion
$Date$	is the coating installation adjusted date
$DF_P^{extcorr}$	is the DF parameter defined as the ratio of hoop stress to flow stress

E is the weld joint efficiency or quality code from the original construction code

F_{IF} is the corrosion rate adjustment factor for interface for soil and water

F_{EQ} is the adjustment factor for equipment design/fabrication detail

$FS^{extcorr}$ is the Flow Stress

$I_1^{extcorr}$ is the first order inspection effectiveness factor

$I_2^{extcorr}$ is the second order inspection effectiveness factor

$I_3^{extcorr}$ is the third order inspection effectiveness factor

$N_A^{extcorr}$ is the number of A level inspections

$N_B^{extcorr}$ is the number of B level inspections

$N_C^{extcorr}$ is the number of C level inspections

$N_D^{extcorr}$ is the number of D level inspections

Φ is the standard normal cumulative distribution function

P is the Pressure (operating, design, PRD overpressure, etc.) used to calculate the limit state function for POF

S is the allowable stress

$SR_P^{extcorr}$ is the strength ratio parameter defined as the ratio of hoop stress to flow stress

$Po_{p1}^{extcorr}$ is the posterior probability for damage state 1

$Po_{p2}^{extcorr}$ is the posterior probability for damage state 2

$Po_{p3}^{extcorr}$ is the posterior probability for damage state 3

$Pr_{p1}^{extcorr}$ is the prior probability of corrosion rate data reliability for damage state 1

$Pr_{p2}^{extcorr}$ is the prior probability of corrosion rate data reliability for damage state 2

$Pr_{p3}^{extcorr}$ is the prior probability of corrosion rate data reliability for damage state 3

t is the furnished thickness of the component calculated as the sum of the base material and cladding/weld overlay thickness, as applicable

t_c is the minimum structural thickness of the component base material

t_{min} is the minimum required thickness based on applicable construction code

t_{rde} is the measured thickness reading form prevous inspection with respect to wall loss associated with external corrosion

TS is the the Tensile Strength

ATTACHMENT D

DF THINNING

1) Determine the furnish thickness and age

Determine the furnished thickness, t , and age, age , for the component from the installation date.

- Furnish Thickness (*f*) : **8 mm**
- Age (*age*) = RBI Date - Installation Date
  = 14 March 2018 - 24 July 2014
  = **3.641 years**

a. *age* is the in-service time that the damage is applied

b. *t* is the furnished thickness of the component calculated as the sum of the base material and cladding/weld overlay thickness, as applicable

2) Determine The corrosion rate of base material

Determine the corrosion rate for the base material $C_{r.bm}$,based on the material of construction and process environment, For a component with cladding/weld overlay, the cladding/weld overlay corrosion rate $C_{r.cm}$,must be determined.

- *Corrosion Rate Base Material* ($C_{r.bm}$) : **0.3 mmpy**

  $C_{r.bm}$ is the corrosion rate for the best material

  $C_{r.cm}$ is the corrosion rate for the cladding/weld overlay

3) Determine Age time in service since last inspection and last inpection thickness

Determine the time in service, age_{tk} since the last inspection known thickness,$t_{rdi.}$ The t_{rdi} is the starting thickness with respect to wall loss associated with internal corrosion If no measured thickness is available, t_{rdi} = t and age = age_{tk}

- Age in service (age_{tk}) = RBI Date - Last Inspection Date
  Age in service (age_{tk}) = 14 March 2018 - 14 August 2017
  = **0.581 years**
- Last Inspection Thickness (t_{rdi}) = **7.07 mm**

  age_{tk} is the component in-service time since the last inspection thickness measurement or service start date

  t_{rdi} is the furnished thickness, t, or measured thickness reading from previous inspection, only if the high level of confidence in its accuracy, with respect to wall loss associated with internal corrosion

4) Determine age of cladding component (only for equipment with cladding material)

For cladding/weld overlay pressure vessel components, calculate the age from the date of the the starting thickness from STEP 3 required to corrode away the cladding/weld overlay material, age_{rc} using **Equation (2.11)**.

- $$age_{rc} = max\left[\left(\frac{t_{rdi}-t_{bm}}{C_{r.cm}}\right),\ 0.0\right]$$

No need calculate this because the equipment does not has cladding component

5) Determine Thickness Minimum Using Original Construction Coat or Owner User Discreation

For cylindrical, spherical or head components, determine the allowable stress, *S* , weld joint efficiency, *E* , and calculate the minimum required thickness, t_{min}, using component type in Table 4.2, geometry type in Table 4.3 and per the original construction code or API 579-1/ASME FFS-1 [10]

Table 4.2 – Component and Geometry Types Based on the Equipment

Equipment Type	Component Type	Geometry Type
Tank650	COURSE-1-10	CYL

Table 4.3 – Required Geometry Data Based on the Geometry Type

Geometry Type	Geometry Description	Geometry Data
CYL	Cylindrical Shell	Diameter
		Length
		Volume

- Thickness Minimum (t_{min}) = Furnished Thickness - Corrosion Allowance

  = **4.825 mm**

6) Determine Wall Loss Fraction since Last Inspection (A_{rt})

Determine the A_{rt} parameter using Equation (2.13), as appropriate, based on t from STEP 1, $C_{r.bm}$ and $C_{r.cm}$ from STEP 2, age_{tk} and t_{rdi} from STEP 3 , and the age required to corrode away the cladding/weld overlay, age_{rc}, if applicable, from STEP 4. Note that the age parameter in these equations is equal to age_{tk} from STEP 3.

Because the component is without cladding, so age rc = 0

- $$A_{rt} = \frac{C_{r.bm} \cdot age_{tk}}{t_{rdi}} \qquad 2.13$$

$$A_{rt} = \frac{0.31\ mmpy\ x\ 0.580822\ years}{7.07}$$

= **0.0255**

7) Calculate The Flow Stress (FS^{Thin})

- $$FS^{Thin} = \frac{(YS + TS)}{2} . E. 1.1$$

$$FS^{Thin} = \frac{(250\ MPa + 400\ MPa)}{2} . 0,85.1,1$$

= **303.9 Mpa**

8) Calculate the Strength Ratio Parameter (SR_P^{Thin})

Calculate the strength ratio parameter, SR_P^{Thin}, using the appropriate Equation (2.17) or (2.18). Using Equation (2.17) with t_{rdi} from STEP 3, t_{min} or t_c from STEP 5, S, and E from STEP 5, and flow stress, FS^{Thin}, from STEP 7.

- $$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} . \frac{Max\ (t_{min}. t_c)}{t_{rdi}} \qquad 2.17$$

Note: The t_{min} is based on a design calculation that includes evaluation for internal pressure hoop stress, external pressure and/or structural considerations, as appropriate. The minimum required thickness calculation is the design code t_{min}. Consideration for internal pressure hoop stress alone may not be sufficient. t_c as defined in STEP 5 should be used when appropriate.

Using and Equation (2.18) with t_{rdi} from STEP 3 and FS^{Thin} from STEP 7 Because the Equipment is Athmospheric Storage Tank, **α** value for cylinder equipment is **2**. So the Equation being use is:

- $$SR_P^{Thin} = \frac{P \cdot D}{\alpha . FS^{Thin} . t_{rdi}}$$

$$SR_P^{Thin} = \frac{0.5\, psig \,.\; 10058\, mm}{2.\;\; 303{,}875.\;\; 7{,}07\, mm}$$

= **1.1704079**

Note: This strength ratio parameter is based on internal pressure hoop stress only. It is not appropriate where external pressure and/or structural considerations dominate. When t_c dominates or if the t_{min} is calculated using another method, Equation (2.17) should be used.

9) Determine The Number of Inspection and its Effectiveness

Determine the number of inspections for each of the corresponding inspection effectiveness, N_A^{Thin} , N_B^{Thin} , N_C^{Thin} , N_D^{Thin} , using Section 4.5.6 for past inspections performed during the in-service time.

- Number of past Inspection perform : **1**
- Inspection Category : **A**
- Inspection Effectiveness Category : **Highly Effective**

10) Determine the Inspection Effectiveness Factor Using Prior Probabilities and Conditional Probabilities

Calculate the inspection effectiveness factors, I_1^{Thin} , I_2^{Thin} , I_3^{Thin} , using Equation (2.19), Prior Probabilities, $Pr_p^{Thin}{}_1$, $Pr_p^{Thin}{}_2$ and $Pr_p^{Thin}{}_3$, **from Table 4.5**, the Conditional Probabilities (for each inspection effectiveness level), Co^{Thin}_{p1} , Co^{Thin}_{p2} and Co^{Thin}_{p3} , from **Table 4.6**, and the number of inspections, N_A^{Thin} , N_B^{Thin} , N_C^{Thin} , N_D^{Thin}, in each effectiveness level from STEP 9

Table 4.5 – Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Confidence Data
Pr_{p1}^{Thin}	0.5	0.7	0.8

$p1$

Table 4.6 – Conditional probability of inspection

Conditional probability of inspection	E-None or ineffective	D - poorly effective	C - fairly effective	B - Uselly effective	A - Highly effective
$Co_{p1}^{extcorr}$	0.33	0.4	0.5	0.7	0.9

- $I_1^{Thin} = Pr_{p1}^{Thin}(Co_{P1}^{ThinA})^{N_A^{Thin}}(Co_{P1}^{ThinB})^{N_B^{Thin}}(Co_{P1}^{ThinC})^{N_C^{Thin}}(Co_{P1}^{ThinD})^{N_D^{Thin}}$
  = **0.72**
- $I_2^{Thin} = Pr_{p2}^{Thin}(Co_{P2}^{ThinA})^{N_A^{Thin}}(Co_{P2}^{ThinB})^{N_B^{Thin}}(Co_{P2}^{ThinC})^{N_C^{Thin}}(Co_{P2}^{ThinD})^{N_D^{Thin}}$
  = **0.014**
- $I_3^{Thin} = Pr_{p3}^{Thin}(Co_{P3}^{ThinA})^{N_A^{Thin}}(Co_{P3}^{ThinB})^{N_B^{Thin}}(Co_{P3}^{ThinC})^{N_C^{Thin}}(Co_{P3}^{ThinD})^{N_D^{Thin}}$
  = **0.0005**

11) Determine Posterior Probability

Calculate the Posterior Probabilities, Po^{Thin}_{p1}, Po^{Thin}_{p2} and Po^{Thin}_{p3} using Equation (2.20) with I_1^{Thin}, I_2^{Thin} and I_3^{Thin} in STEP 10

- Posterior Probability 1

$$PO_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

= **0.9809264**

- Posterior Probability 2

$$PO_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

= **0.0183924**

- Posterior Probability 3

$$PO_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

= **0.0006812**

12) Calculate the parameters, $\beta_1^{extcorr}$, $\beta_2^{extcorr}$, $\beta_3^{extcorr}$ using Equation (2.21) and assigning $COV_{\Delta t}$=0,20 , COV_{Sf} = 0,20 , COV_P = 0.05

Where Corrosion Rate Factor for Damage State (Ds). DS 1 is 1 , DS 2 is 2 , DS 3 is 4

- $\beta_1^{thin} = \dfrac{1 - D_{S_1}.A_{rt} - SR_p^{thin}}{\sqrt{D_{S_1}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_1}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{thin}\right)^2.COV_p^2}}$

  = **-0.000336357**

- $\beta_2^{thin} = \dfrac{1 - D_{S_2}.A_{rt} - SR_p^{thin}}{\sqrt{D_{S_2}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_2}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{thin}\right)^2.COV_p^2}}$

  = **-0.000346354**

- $\beta_3^{thin} = \dfrac{1 - D_{S_3}.A_{rt} - SR_p^{thin}}{\sqrt{D_{S_3}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_3}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{thin}\right)^2.COV_p^2}}$

  = **-0.000354938**

13) Determine damage factor for thinning for tank bottom component

For tank bottom components, determine the base damage factor for thinning, D_{fB}^{thin} using Table 4.8 and based on the A_{rt} parameter from STEP 6 and Skip to STEP 15

Because The Component that calculated in this calculation isn't tank bottom. So there is **no need to do this step**

14) Determine Damage Factor Thinning Base Value

For all components (excluding tank bottoms covered in STEP 13), calculate the base damage factor, D_{fB}^{Thin}

- $D_{fB}^{Thin} = \left[\dfrac{\left(Po_{p1}^{Thin}\Phi(-\beta_1^{Thin})\right) + \left(Po_{p2}^{Thin}\Phi(-\beta_2^{Thin})\right) + \left(Po_{p3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-04}\right]$

D_{fB}^{Thin} = **2.684**

15) Determine maximum Damage Factor for Thinning

- $D_f^{Thin} = max\left[\left(\dfrac{D_{fB}^{Thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}}\right), 0.1\right]$

Where added value of damage factor is

F_{IP} : Adjusment for Injection Point : **1**

Adjujustment for Injection point only used if there any Injection Point in the Tank the Value of F_{IP} is 3, otherwise is 1

F_{DL} : Adjustment for Dead Leg : **1**
Dead Leg Adjutsment only applied for piping circuit. If the equipment it isn't piping circuit the value of F_{DL} is 1

F_{WD} : Adjusment for Welded Construction : **1**
Applicable only to ASTs. If the component is welded then F_{WD} is 1, otherwise F_{WD} is 10

F_{AM} : Adjusment for Maintenance in Accordance With API 653 : **1**
Applicable only for ASTs. If the AST is maintained in accordance with API STD 653, then F_{AM} is 1, otherwise is 10

F_{SM} : Adjusment for Settlement : **1**
Applicable only for AST bottoms. If the equipment it isn't tank bottom the value of F_{SM} is 1

F_{OM} : Adjustment for Online Monitoring : **1**
Because the equipment it isn't online monitored. So the value of F_{OM} is 1

- $$D_f^{Thin} = max\left[\left(\frac{D_{fB}^{Thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}}\right), 0.1\right]$$

= **2.684**

1) Determine the furnish thickness and age

Determine the furnished thickness, t , and age, age , for the component from the installation date.

- Furnish Thickness (*f*) : **8 mm**
- Age (*age*) = RBI Date - Installation Date
  = 14 March 2018 - 24 July 2014
  = **3.641 years**

a. *age* is the in-service time that the damage is applied

b. *t* is the furnished thickness of the component calculated as the sum of the base material and cladding/weld overlay thickness, as applicable

2) Determine The corrosion rate of base material

Determine the corrosion rate for the base material $C_{r.bm}$,based on the material of construction and process environment, For a component with cladding/weld overlay, the cladding/weld overlay corrosion rate $C_{r.cm}$,must be determined.

- *Corrosion Rate Base Material ($C_{r.bm}$)* : **0.17 mmpy**

  $C_{r.bm}$ is the corrosion rate for the best material

  $C_{r.cm}$ is the corrosion rate for the cladding/weld overlay

3) Determine Age time in service since last inspection and last inpection thickness

Determine the time in service, age_{tk} since the last inspection known thickness,$t_{rdi.}$ The t_{rdi} is the starting thickness with respect to wall loss associated with internal corrosion If no measured thickness is available, t_{rdi} = t and age = age_{tk}

- Age in service (age_{tk}) = RBI Date - Last Inspection Date
  Age in service (age_{tk}) = 14 March 2018 - 14 August 2017
  = **0.581 years** 10.589
- Last Inspection Thickness (t_{rdi}) = **7.48 mm** 7.48

  age_{tk} is the component in-service time since the last inspection thickness measurement or service start date

  t_{rdi} is the furnished thickness, t, or measured thickness reading from previous inspection, only if the high level of confidence in its accuracy, with respect to wall loss associated with internal corrosion

4) Determine age of cladding component (only for equipment with cladding material)

For cladding/weld overlay pressure vessel components, calculate the age from the date of the the starting thickness from STEP 3 required to corrode away the cladding/weld overlay material, age_{rc} using **Equation (2.11)**.

- $$age_{rc} = max\left[\left(\frac{t_{rdi} - t_{bm}}{C_{r.cm}}\right),\ 0.0\right]$$

No need calculate this because the equipment does not has cladding

5) Determine Thickness Minimum Using Original Construction Coat or Owner User Discreation

For cylindrical, spherical or head components, determine the allowable stress, *S* , weld joint efficiency, *E* , and calculate the minimum required thickness, t_{min}, using component type in Table 4.2, geometry type in Table 4.3 and per the original construction code or API 579-1/ASME FFS-1 [10]

Table 4.2 – Component and Geometry Types Based on the Equipment Type

Equipment Type	Component Type	Geometry Type
Tank650	COURSE-1-10	CYL

Table 4.3 – Required Geometry Data Based on the Geometry Type

Geometry Type	Geometry Description	Geometry Data
CYL	Cylindrical Shell	Diameter
		Length
		Volume

- Thickness Minimum (t_{min}) = Furnished Thickness - Corrosion Allowance

  = **4.825 mm**

6) Determine Wall Loss Fraction since Last Inspection (A_{rt})

Determine the A_{rt} parameter using Equation (2.13), as appropriate, based on t from STEP 1, $C_{r.bm}$ and $C_{r.cm}$ from STEP 2, age_{tk} and t_{rdi} from STEP 3 , and the age required to corrode away the cladding/weld overlay, age_{rc}, if applicable, from STEP 4. Note that the age parameter in these equations is equal to age_{tk} from STEP 3.

Because the component is without cladding, so age rc = 0

-
- $$A_{rt} = \frac{C_{r.bm} \cdot age_{tk}}{t_{rdi}} \quad \textbf{2.13}$$

$$A_{rt} = \frac{0.17\ mmpy\ x\ 0.580822\ years}{7.48}$$

= **0.0135**

7) Calculate The Flow Stress (FS^{Thin})

- $$FS^{Thin} = \frac{(YS + TS)}{2}.E.1.1$$

$$FS^{Thin} = \frac{(250\ MPa + 400\ MPa)}{2}.0{,}85.1{,}1$$

= **303.9 Mpa**

8) Calculate the Strength Ratio Parameter (SR_P^{Thin})

Calculate the strength ratio parameter, SR_P^{Thin}, using the appropriate Equation (2.17) or (2.18). Using Equation (2.17) with t_{rdi} from STEP 3, t_{min} or t_c from STEP 5, S , and E from STEP 5, and flow stress, FS^{Thin}, from STEP 7.

- $$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} \cdot \frac{Max\ (t_{min}.t_c)}{t_{rdi}} \quad 2.17$$

Note: The t_{min} is based on a design calculation that includes evaluation for internal pressure hoop stress, external pressure and/or structural considerations, as appropriate. The minimum required thickness calculation is the design code t_{min} . Consideration for internal pressure hoop stress alone may not be sufficient. t_c as defined in STEP 5 should be used when appropriate.

Using and Equation (2.18) with t_{rdi} from STEP 3 and FS^{Thin} from STEP 7 Because the Equipment is Athmospheric Storage Tank, **α** value for cylinder equipment is **2**. So the Equation being use is:

- $$SR_P^{Thin} = \frac{P \,.\, D}{\alpha .\, FS^{Thin} .\, t_{rdi}}$$

$$SR_P^{Thin} = \frac{0.5\, psig \,.\; 10058\, mm}{2.\;\; 303{,}875.\;\; 7{,}07\, mm}$$

= **1.1062546**

Note: This strength ratio parameter is based on internal pressure hoop stress only. It is not appropriate where external pressure and/or structural considerations dominate. When t_c dominates or if the t_{min} is calculated using another method, Equation (2.17) should be used.

9) Determine The Number of Inspection and its Effectiveness

Determine the number of inspections for each of the corresponding inspection effectiveness, N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}, using Section 4.5.6 for past inspections performed during the in-service time.

- Number of past Inspection perform : **1**
- Inspection Category : **A**
- Inspection Effectiveness Category : **Highly Effective**

10) Determine the Inspection Effectiveness Factor Using Prior Probabilities and Conditional Probabilities

Calculate the inspection effectiveness factors, I_1^{Thin}, I_2^{Thin}, I_3^{Thin}, using Equation (2.19), Prior Probabilities, Pr_{p1}^{Thin}, Pr_{p2}^{Thin} and Pr_{p3}^{Thin}, **from Table 4.5**, the Conditional Probabilities (for each inspection effectiveness level), Co_{p1}^{Thin}, Co_{p2}^{Thin} and Co_{p3}^{Thin}, from **Table 4.6**, and the number of inspections, N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}, in each effectiveness level from STEP 9

Table 4.5 – Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Confidence Data
Pr_{p1}^{Thin}	0.5	0.7	0.8

$p1$

Table 4.6 – Conditional probability of inspection

Conditional probability of inspection	E-None or ineffective	D - poorly effective	C - fairly effective	B - Uselly effective	A - Highly effective
$Co_{p1}^{extcorr}$	0.33	0.4	0.5	0.7	0.9

- $I_1^{Thin} = Pr_{p1}^{Thin}(Co_{P1}^{ThinA})^{N_A^{Thin}}(Co_{P1}^{ThinB})^{N_B^{Thin}}(Co_{P1}^{ThinC})^{N_C^{Thin}}(Co_{P1}^{ThinD})^{N_D^{Thin}}$

  = **0.72**
- $I_2^{Thin} = Pr_{p2}^{Thin}(Co_{P2}^{ThinA})^{N_A^{Thin}}(Co_{P2}^{ThinB})^{N_B^{Thin}}(Co_{P2}^{ThinC})^{N_C^{Thin}}(Co_{P2}^{ThinD})^{N_D^{Thin}}$

  = **0.014**
- $I_3^{Thin} = Pr_{p3}^{Thin}(Co_{P3}^{ThinA})^{N_A^{Thin}}(Co_{P3}^{ThinB})^{N_B^{Thin}}(Co_{P3}^{ThinC})^{N_C^{Thin}}(Co_{P3}^{ThinD})^{N_D^{Thin}}$

  = **0.0005**

11) Determine Posterior Probability

Calculate the Posterior Probabilities, Po^{Thin}_{p1}, Po^{Thin}_{p2} and Po^{Thin}_{p3} using Equation (2.20) with I_1^{Thin}, I_2^{Thin} and I_3^{Thin} in STEP 10

- Posterior Probability 1

$$PO_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

= **0.9809264**

- Posterior Probability 2

$$PO_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

= **0.0183924**

- Posterior Probability 3

$$PO_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

= **0.0006812**

12) Calculate the parameters, $\beta_1^{extcorr}$, $\beta_2^{extcorr}$, $\beta_3^{extcorr}$ using Equation (2.21) and assigning $COV_{\Delta t}$=0,20 , COV_{Sf} = 0,20 , COV_P = 0.05

Where Corrosion Rate Factor for Damage State (Ds). DS 1 is 1 , DS 2 is 2 , DS 3 is 4

- $$\beta_1^{thin} = \frac{1 - D_{S_1}.A_{rt} - SR_p^{thin}}{\sqrt{D_{S_1}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_1}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{thin}\right)^2.COV_p^2}}$$

  = **-0.000211148**

- $$\beta_2^{thin} = \frac{1 - D_{S_2}.A_{rt} - SR_p^{thin}}{\sqrt{D_{S_2}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_2}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{thin}\right)^2.COV_p^2}}$$

  = **-0.000223471**

- $$\beta_3^{thin} = \frac{1 - D_{S_3}.A_{rt} - SR_p^{thin}}{\sqrt{D_{S_3}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_3}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{thin}\right)^2.COV_p^2}}$$

  = **-0.000243305**

13) Determine damage factor for thinning for tank bottom component

For tank bottom components, determine the base damage factor for thinning, D_{fB}^{thin} using Table 4.8 and based on the A_{rt} parameter from STEP 6 and Skip to STEP 15

Because The Component that calculated in this calculation isn't tank bottom. So there is **no need to do this step**

14) Determine Damage Factor Thinning Base Value

For all components (excluding tank bottoms covered in STEP 13), calculate the base damage factor, D_{fB}^{Thin}

- $$D_{fB}^{Thin} = \left[\frac{\left(Po_{p1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right) + \left(Po_{p2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right) + \left(Po_{p3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E-04}\right]$$

D_{fB}^{Thin} = **2.683**

15) Determine maximum Damage Factor for Thinning

- $$D_f^{Thin} = max\left[\left(\frac{D_{fB}^{Thin} \,.\, F_{IP} \,.\, F_{DL} \,.\, F_{WD} \,.\, F_{AM} \,.\, F_{SM}}{F_{OM}}\right), 0.1\right]$$

Where added value of damage factor is

F_{IP} : Adjusment for Injection Point : **1**

Adujusment for Injection point only used if there any Injection Point in the Tank the Value of F_{IP} is 3, otherwise is 1

F_{DL} : Adjusment for Dead Leg : **1**

Dead Leg Adjutsment only applied for piping circuit. If the equipment it isn't piping circuit the value of F_{DL} is 1

F_{WD} : Adjusment for Welded Construction : **1**
Applicable only to ASTs. If the component is welded then F_{WD} is 1, otherwise F_{WD} is 10

F_{AM} : Adjusment for Maintenance in Accordance With API 653 : **1**
Applicable only for ASTs. If the AST is maintained in accordance with API STD 653, then F_{AM} is 1, otherwise is 10

F_{SM} : Adjusment for Settlement : **1**
Applicable only for AST bottoms. If the equipment it isn't tank bottom the value of F_{SM} is 1

F_{OM} : Adjusment for Online Monitoring : **1**
Because the equipment it isn't online monitored. So the value of F_{OM} is 1

- $$D_f^{Thin} = max\left[\left(\frac{D_{fB}^{Thin} \,.\, F_{IP} \,.\, F_{DL} \,.\, F_{WD} \,.\, F_{AM} \,.\, F_{SM}}{F_{OM}}\right), 0.1\right]$$

= **2.683**

1) Determine the furnish thickness and age

Determine the furnished thickness, t , and age, age , for the component from the installation date.

- Furnish Thickness (*f*) : **8 mm**
- Age (*age*) = RBI Date - Installation Date
  = 14 March 2018 - 24 July 2014
  = **3.641 years**

a. *age* is the in-service time that the damage is applied

b. *t* is the furnished thickness of the component calculated as the sum of the base material and cladding/weld overlay thickness, as applicable

2) Determine The corrosion rate of base material

Determine the corrosion rate for the base material $C_{r.bm}$,based on the material of construction and process environment, For a component with cladding/weld overlay, the cladding/weld overlay corrosion rate $C_{r.cm}$,must be determined.

- *Corrosion Rate Base Material ($C_{r.bm}$)* : **0.8 mmpy**

  $C_{r.bm}$ is the corrosion rate for the best material

  $C_{r.cm}$ is the corrosion rate for the cladding/weld overlay

3) Determine Age time in service since last inspection and last inpection thickness

Determine the time in service, age_{tk} since the last inspection known thickness,$t_{rdi.}$ The t_{rdi} is the starting thickness with respect to wall loss associated with internal corrosion If no measured thickness is available, t_{rdi} = t and age = age_{tk}

- Age in service (age_{tk}) = RBI Date - Last Inspection Date
  Age in service (age_{tk}) = 14 March 2018 - 14 August 2017
  = **0.581 years**
- Last Inspection Thickness (t_{rdi}) = **5.72 mm**

  age_{tk} is the component in-service time since the last inspection thickness measurement or service start date

  t_{rdi} is the furnished thickness, t, or measured thickness reading from previous inspection, only if the high level of confidence in its accuracy, with respect to wall loss associated with internal corrosion

4) Determine age of cladding component (only for equipment with cladding material)

For cladding/weld overlay pressure vessel components, calculate the age from the date of the the starting thickness from STEP 3 required to corrode away the cladding/weld overlay material, *age* $_{rc}$ using **Equation (2.11)**.

- $$age_{rc} = max\left[\left(\frac{t_{rdi}-t_{bm}}{C_{r.cm}}\right),\ 0.0\right]$$

No need calculate this because the equipment does not has cladding

5) Determine Thickness Minimum Using Original Construction Coat or Owner User Discreation

For cylindrical, spherical or head components, determine the allowable stress, *S* , weld joint efficiency, *E* , and calculate the minimum required thickness, t_{min}, using component type in Table 4.2, geometry type in Table 4.3 and per the original construction code or API 579-1/ASME FFS-1 [10]

Table 4.2 – Component and Geometry Types Based on the Equipment Type

Equipment Type	Component Type	Geometry Type
Tank650	COURSE-1-10	CYL

Table 4.3 – Required Geometry Data Based on the Geometry Type

Geometry Type	Geometry Description	Geometry Data
CYL	Cylindrical Shell	Diameter
		Length
		Volume

- Thickness Minimum (t_{min}) = Furnished Thickness - Corrosion Allowance

= **4.825 mm**

6) Determine Wall Loss Fraction since Last Inspection (*A_{rt}*)

Determine the A_{rt} parameter using Equation (2.13), as appropriate, based on t from STEP 1, $C_{r.bm}$ and $C_{r.cm}$ from STEP 2, age_{tk} and t_{rdi} from STEP 3 , and the age required to corrode away the cladding/weld overlay, age_{rc}, if applicable, from STEP 4. Note that the age parameter in these equations is equal to age_{tk} from STEP 3.

Because the component is without cladding, so age rc = 0

-
- $$A_{rt} = \frac{C_{r.bm} .age_{tk}}{t_{rdi}}$$ **2.13**

$$A_{rt} = \frac{0.76mmpy\ x\ 0.580822\ years}{5.72}$$

= **0.0772**

7) Calculate The Flow Stress (*FS^{Thin}*)

- $$FS^{Thin} = \frac{(YS + TS)}{2}.E.1.1$$

$$FS^{Thin} = \frac{(250\ MPa + 400\ MPa)}{2}.0,85.1,1$$

= **303.9 Mpa**

8) Calculate the Strength Ratio Parameter (SR_P^{Thin})

Calculate the strength ratio parameter, SR_P^{Thin} , using the appropriate Equation (2.17) or (2.18). Using Equation (2.17) with t_{rdi} from STEP 3, t_{min} or t_c from STEP 5, S , and E from STEP 5, and flow stress, FS^{Thin} , from STEP 7.

- $$SR_P^{Thin} = \frac{S.E}{FS^{Thin}}.\frac{Max\ (t_{min}.t_c)}{t_{rdi}}$$ 2.17

Note: The t_{min} is based on a design calculation that includes evaluation for internal pressure hoop stress, external pressure and/or structural considerations, as appropriate. The minimum required thickness calculation is the design code t_{min} . Consideration for internal pressure hoop stress alone may not be sufficient. t_C as defined in STEP 5 should be used when appropriate.

Using and Equation (2.18) with t_{rdi} from STEP 3 and FS^{Thin} from STEP 7 Because the Equipment is Athmospheric Storage Tank, **α** value for cylinder equipment is **2**. So the Equation being use is:

- $$SR_P^{Thin} = \frac{P\,.\,D}{\alpha.\,FS^{Thin}.t_{rdi}}$$

$$SR_P^{Thin} = \frac{0.5\,psig\,.\;10058\,mm}{2.\;303{,}875.\;7{,}07\,mm}$$

$= $ **1.4466406**

Note: This strength ratio parameter is based on internal pressure hoop stress only. It is not appropriate where external pressure and/or structural considerations dominate. When t_c dominates or if the t_{min} is calculated using another method, Equation (2.17) should be used.

9) Determine The Number of Inspection and its Effectiveness

Determine the number of inspections for each of the corresponding inspection effectiveness, N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}, using Section 4.5.6 for past inspections performed during the in-service time.

- Number of past Inspection perform : **1**
- Inspection Category : **A**
- Inspection Effectiveness Category : **Highly Effective**

10) Determine the Inspection Effectiveness Factor Using Prior Probabilities and Conditional Probabilities

Calculate the inspection effectiveness factors, I_1^{Thin}, I_2^{Thin}, I_3^{Thin}, using Equation (2.19), Prior Probabilities, $Pr_p^{Thin}{}_1$, $Pr_p^{Thin}{}_2$ and $Pr_p^{Thin}{}_3$, **from Table 4.5**, the Conditional Probabilities (for each inspection effectiveness level), Co^{Thin}_{p1}, Co^{Thin}_{p2} and Co^{Thin}_{p3}, from **Table 4.6**, and the number of inspections, N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}, in each effectiveness level from STEP 9

Table 4.5 – Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Confidence Data
Pr_{p1}^{Thin}	0.5	0.7	0.8

$p1$

Table 4.6 – Conditional probability of inspection

Conditional probability of inspection	**E-None or ineffective**	**D - poorly effective**	**C - fairly effective**	**B - Uselly effective**	**A - Highly effective**
$Co_{p1}^{extcorr}$	0.33	0.4	0.5	0.7	0.9

- $I_1^{Thin} = Pr_{p1}^{Thin}(Co_{P1}^{ThinA})^{N_A^{Thin}}(Co_{P1}^{ThinB})^{N_B^{Thin}}(Co_{P1}^{ThinC})^{N_C^{Thin}}(Co_{P1}^{ThinD})^{N_D^{Thin}}$

  = **0.72**
- $I_2^{Thin} = Pr_{p2}^{Thin}(Co_{P2}^{ThinA})^{N_A^{Thin}}(Co_{P2}^{ThinB})^{N_B^{Thin}}(Co_{P2}^{ThinC})^{N_C^{Thin}}(Co_{P2}^{ThinD})^{N_D^{Thin}}$

  = **0.014**
- $I_3^{Thin} = Pr_{p3}^{Thin}(Co_{P3}^{ThinA})^{N_A^{Thin}}(Co_{P3}^{ThinB})^{N_B^{Thin}}(Co_{P3}^{ThinC})^{N_C^{Thin}}(Co_{P3}^{ThinD})^{N_D^{Thin}}$

  = **0.0005**

11) Determine Posterior Probability

Calculate the Posterior Probabilities, Po^{Thin}_{p1} , Po^{Thin}_{p2} and Po^{Thin}_{p3} using Equation (2.20) with I_1^{Thin} , I_2^{Thin} and I_3^{Thin} in STEP 10

- Posterior Probability 1

$$PO_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

= **0.9809264**

- Posterior Probability 2

$$PO_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

= **0.0183924**

- Posterior Probability 3

$$PO_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

= **0.0006812**

12) Calculate the parameters, $\beta_1^{extcorr}$, $\beta_2^{extcorr}$, $\beta_3^{extcorr}$ using Equation (2.21) and assigning $COV_{\Delta t}$=0,20 , COV_{Sf} = 0,20 , COV_P = 0.05

Where Corrosion Rate Factor for Damage State (Ds). DS 1 is 1 , DS 2 is 2 , DS 3 is 4

- $\beta_1^{thin} = \dfrac{1 - D_{S_1}.A_{rt} - SR_p^{thin}}{\sqrt{D_{S_1}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_1}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{thin}\right)^2.COV_p^2}}$

  = **-0.000818711**

- $\beta_2^{thin} = \dfrac{1 - D_{S_2}.A_{rt} - SR_p^{thin}}{\sqrt{D_{S_2}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_2}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{thin}\right)^2.COV_p^2}}$

  = **-0.000727405**

- $\beta_3^{thin} = \dfrac{1 - D_{S_3}.A_{rt} - SR_p^{thin}}{\sqrt{D_{S_3}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_3}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{thin}\right)^2.COV_p^2}}$

  = **-0.000598962**

13) Determine damage factor for thinning for tank bottom component

For tank bottom components, determine the base damage factor for thinning, D_{fB}^{thin} using Table 4.8 and based on the A_{rt} parameter from STEP 6 and Skip to STEP 15

Because The Component that calculated in this calculation isn't tank bottom. So there is **no need to do this step**

14) Determine Damage Factor Thinning Base Value

For all components (excluding tank bottoms covered in STEP 13), calculate the base damage factor, D_{fB}^{Thin}

- $D_{fB}^{Thin} = \left[\dfrac{\left(Po_{p1}^{Thin}\Phi(-\beta_1^{Thin})\right) + \left(Po_{p2}^{Thin}\Phi(-\beta_2^{Thin})\right) + \left(Po_{p3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-04}\right]$

  D_{fB}^{Thin} = **2.684**

15) Determine maximum Damage Factor for Thinning

- $D_f^{Thin} = max\left[\left(\dfrac{D_{fB}^{Thin}\ .\ F_{IP}\ .\ F_{DL}\ .\ F_{WD}\ .\ F_{AM}\ .\ F_{SM}}{F_{OM}}\right), 0.1\right]$

Where added value of damage factor is

F_{IP} : Adjusment for Injection Point : **1**

Adujusment for Injection point only used if there any Injection Point in the Tank the Value of F_{IP} is 3, otherwise is 1

F_{DL} : Adjusment for Dead Leg : **1**

Dead Leg Adjutsment only applied for piping circuit. If the equipment it isn't piping circuit the value of F_{DL} is 1

F_{WD} : Adjusment for Welded Construction : **1**
Applicable only to ASTs. If the component is welded then F_{WD} is 1, otherwise F_{WD} is 10

F_{AM} : Adjusment for Maintenance in Accordance With API 653 : **1**
Applicable only for ASTs. If the AST is maintained in accordance with API STD 653, then F_{AM} is 1, otherwise is 10

F_{SM} : Adjusment for Settlement : **1**
Applicable only for AST bottoms. If the equipment it isn't tank bottom the value of F_{SM} is 1

F_{OM} : Adjusment for Online Monitoring : **1**
Because the equipment it isn't online monitored. So the value of F_{OM} is 1

- $D_f^{Thin} = max\left[\left(\frac{D_{fB}^{Thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}}\right), 0.1\right]$

= **2.684358385**

1) Determine the furnish thickness and age

Determine the furnished thickness, t , and age, age , for the component from the installation date.

- Furnish Thickness (*f*) : **8 mm**
- Age (*age*) = RBI Date - Installation Date
  = 14 March 2018 - 24 July 2014
  = **3.641 years** 13.65

a. *age* is the in-service time that the damage is applied

b. *t* is the furnished thickness of the component calculated as the sum of the base material and cladding/weld overlay thickness, as applicable

2) Determine The corrosion rate of base material

Determine the corrosion rate for the base material $C_{r.bm}$,based on the material of construction and process environment, For a component with cladding/weld overlay, the cladding/weld overlay corrosion rate $C_{r.cm}$,must be determined.

- *Corrosion Rate Base Material ($C_{r.bm}$)* : **0.76 mmpy** 0.76

  $C_{r.bm}$ is the corrosion rate for the best material

  $C_{r.cm}$ is the corrosion rate for the cladding/weld overlay

3) Determine Age time in service since last inspection and last inpection thickness

Determine the time in service, age_{tk} since the last inspection known thickness,$t_{rdi.}$ The t_{rdi} is the starting thickness with respect to wall loss associated with internal corrosion If no measured thickness is available, t_{rdi} = t and age = age_{tk}

- Age in service (age_{tk}) = RBI Date - Last Inspection Date
  Age in service (age_{tk}) = 14 March 2018 - 14 August 2017
  = **0.581 years** 10.589
- Last Inspection Thickness (t_{rdi}) = **5.72 mm** 5.72

  age_{tk} is the component in-service time since the last inspection thickness measurement or service start date

  t_{rdi} is the furnished thickness, t, or measured thickness reading from previous inspection, only if the high level of confidence in its accuracy, with respect to wall loss associated with internal corrosion

4) Determine age of cladding component (only for equipment with cladding material)

For cladding/weld overlay pressure vessel components, calculate the age from the date of the the starting thickness from STEP 3 required to corrode away the cladding/weld overlay material, age_{rc} using **Equation (2.11)**.

- $$age_{rc} = max\left[\left(\frac{t_{rdi} - t_{bm}}{C_{r.cm}}\right),\ 0.0\right]$$

No need calculate this because the equipment does not has cladding

5) Determine Thickness Minimum Using Original Construction Coat or Owner User Discreation

For cylindrical, spherical or head components, determine the allowable stress, S , weld joint efficiency, E , and calculate the minimum required thickness, t_{min}, using component type in Table 4.2, geometry type in Table 4.3 and per the original construction code or API 579-1/ASME FFS-1 [10]

Table 4.2 – Component and Geometry Types Based on the Equipment Type

Equipment Type	Component Type	Geometry Type
Tank650	COURSE-1-10	CYL

Table 4.3 – Required Geometry Data Based on the Geometry Type

Geometry Type	Geometry Description	Geometry Data
CYL	Cylindrical Shell	Diameter
		Length
		Volume

- Thickness Minimum (t_{min}) = Furnished Thickness - Corrosion Allowance
  = **4.825 mm** 4.825

6) Determine Wall Loss Fraction since Last Inspection (A_{rt})

Determine the A_{rt} parameter using Equation (2.13), as appropriate, based on t from STEP 1, $C_{r.bm}$ and $C_{r.cm}$ from STEP 2, age_{tk} and t_{rdi} from STEP 3 , and the age required to corrode away the cladding/weld overlay, age_{rc}, if applicable, from STEP 4. Note that the age parameter in these equations is equal to age_{tk} from STEP 3.

Because the component is without cladding, so age rc = 0

-
- $$A_{rt} = \frac{C_{r.bm} . age_{tk}}{t_{rdi}}$$ **2.13**

$$A_{rt} = \frac{0.76mmpy\ x\ 0.580822\ years}{5.72}$$

= **0.0772** 1.4069

7) Calculate The Flow Stress (*FS* *Thin*)

-

$$FS^{Thin} = \frac{(YS + TS)}{2} . E. 1.1$$

$$FS^{Thin} = \frac{(250\ MPa + 400\ MPa)}{2} . 0{,}85.1{,}1$$

= **303.9 Mpa** 303.9

8) Calculate the Strength Ratio Parameter (SR_P^{Thin})

Calculate the strength ratio parameter, SR_P^{Thin} , using the appropriate Equation (2.17) or (2.18). Using Equation (2.17) with t_{rdi} from STEP 3, t_{min} or t_c from STEP 5, S , and E from STEP 5, and flow stress, FS^{Thin} , from STEP 7.

-

$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} . \frac{Max\ (t_{min}.t_c)}{t_{rdi}}$$ 2.17

Note: The t_{min} is based on a design calculation that includes evaluation for internal pressure hoop stress, external pressure and/or structural considerations, as appropriate. The minimum required thickness calculation is the design code t_{min} . Consideration for internal pressure hoop stress alone may not be sufficient. t_c as defined in STEP 5 should be used when appropriate.

Using and Equation (2.18) with t_{rdi} from STEP 3 and FS^{Thin} from STEP 7
Because the Equipment is Athmospheric Storage Tank, **α** value for cylinder equipment is **2**. So the Equation being use is:

- $$SR_P^{Thin} = \frac{P \, . \, D}{\alpha . \, FS^{Thin} . t_{rdi}}$$

$$SR_P^{Thin} = \frac{0.5\,psig \, . \;\; 10058\,mm}{2. \;\; 303{,}875. \;\; 7{,}07\,mm}$$

= **1.4466406** **1.44664**

Note: This strength ratio parameter is based on internal pressure hoop stress only. It is not appropriate where external pressure and/or structural considerations dominate. When t_c dominates or if the $t_{\min}$ is calculated using another method, Equation (2.17) should be used.

9) Determine The Number of Inspection and its Effectiveness

Determine the number of inspections for each of the corresponding inspection effectiveness, N_A^{Thin} , N_B^{Thin} , N_C^{Thin} , N_D^{Thin} , using Section 4.5.6 for past inspections performed during the in-service time.

- Number of past Inspection perform : **1** 1
- Inspection Category : **A** A
- Inspection Effectiveness Category : **Highly Effective** ig

10) Determine the Inspection Effectiveness Factor Using Prior Probabilities and Conditional Probabilities

Calculate the inspection effectiveness factors, I_1^{Thin} , I_2^{Thin} , I_3^{Thin} , using Equation (2.19), Prior Probabilities, $Pr_p^{Thin}{}_1$, $Pr_p^{Thin}{}_2$ and $Pr_p^{Thin}{}_3$, **from Table 4.5**, the Conditional Probabilities (for each inspection effectiveness level), Co^{Thin}_{p1} , Co^{Thin}_{p2} and Co^{Thin}_{p3} , from **Table 4.6**, and the number of inspections, N_A^{Thin} , N_B^{Thin} , N_C^{Thin} , N_D^{Thin}, in each effectiveness level from STEP 9

Table 4.5 – Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Confidence Data
Pr_{p1}^{Thin}	0.5	0.7	0.8

$p1$

Table 4.6 – Conditional probability of inspection

Conditional probability of inspection	E-None or ineffective	D - poorly effective	C - fairly effective	B - Uselly effective	A - Highly effective
$Co_{p1}^{extcorr}$	0.33	0.4	0.5	0.7	0.9

- $I_1^{Thin} = Pr_{p1}^{Thin}(Co_{P1}^{ThinA})^{N_A^{Thin}}(Co_{P1}^{ThinB})^{N_B^{Thin}}(Co_{P1}^{ThinC})^{N_C^{Thin}}(Co_{P1}^{ThinD})^{N_D^{Thin}}$

  = **0.72** **0.5**
- $I_2^{Thin} = Pr_{p2}^{Thin}(Co_{P2}^{ThinA})^{N_A^{Thin}}(Co_{P2}^{ThinB})^{N_B^{Thin}}(Co_{P2}^{ThinC})^{N_C^{Thin}}(Co_{P2}^{ThinD})^{N_D^{Thin}}$

  = **0.014** **0.027**
- $I_3^{Thin} = Pr_{p3}^{Thin}(Co_{P3}^{ThinA})^{N_A^{Thin}}(Co_{P3}^{ThinB})^{N_B^{Thin}}(Co_{P3}^{ThinC})^{N_C^{Thin}}(Co_{P3}^{ThinD})^{N_D^{Thin}}$

  = **0.0005** **0.002**

11) Determine Posterior Probability

Calculate the Posterior Probabilities, Po^{Thin}_{p1}, Po^{Thin}_{p2} and Po^{Thin}_{p3} using Equation (2.20) with I_1^{Thin}, I_2^{Thin} and I_3^{Thin} in STEP 10

- Posterior Probability 1

$$PO_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

= **0.9809264** 0.939457

- Posterior Probability 2

$$PO_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

= **0.0183924** 0.056367

- Posterior Probability 3

$$PO_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

= **0.0006812** 0.004175

12) Calculate the parameters, $\beta_1^{extcorr}$, $\beta_2^{extcorr}$, $\beta_3^{extcorr}$ using Equation (2.21) and assigning $COV_{\Delta t}$=0,20 , COV_{Sf} = 0,20 , COV_P = 0.05

Where Corrosion Rate Factor for Damage State (Ds). DS 1 is 1 , DS 2 is 2 , DS 3 is 4

- $$\beta_1^{thin} = \frac{1 - D_{S_1}.A_{rt} - SR_p^{thin}}{\sqrt{D_{S_1}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_1}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{thin}\right)^2.COV_p^2}}$$

  = **-0.000818711** -0.0153611

- $$\beta_2^{thin} = \frac{1 - D_{S_2}.A_{rt} - SR_p^{thin}}{\sqrt{D_{S_2}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_2}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{thin}\right)^2.COV_p^2}}$$

  = **-0.000727405** -0.670717546

- $$\beta_3^{thin} = \frac{1 - D_{S_3}.A_{rt} - SR_p^{thin}}{\sqrt{D_{S_3}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_3}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{thin}\right)^2.COV_p^2}}$$

  = **-0.000598962** -27.52604048

13) Determine damage factor for thinning for tank bottom component

For tank bottom components, determine the base damage factor for thinning, D_{fB}^{thin} using Table 4.8 and based on the A_{rt} parameter from STEP 6 and Skip to STEP 15

Because The Component that calculated in this calculation isn't tank bottom. So there is **no need to do this step**

14) Determine Damage Factor Thinning Base Value

For all components (excluding tank bottoms covered in STEP 13), calculate the base damage factor, D_{fB}^{Thin}

- $$D_{fB}^{Thin} = \left[\frac{\left(Po_{p1}^{Thin}\Phi(-\beta_1^{Thin})\right) + \left(Po_{p2}^{Thin}\Phi(-\beta_2^{Thin})\right) + \left(Po_{p3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-04}\right]$$

D_{fB}^{Thin} = **2.684** 27.283

15) Determine maximum Damage Factor for Thinning

- $$D_f^{Thin} = max\left[\left(\frac{D_{fB}^{Thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}}\right), 0.1\right]$$

Where added value of damage factor is

F_{IP} : Adjusment for Injection Point : **1** 1

Adujusment for Injection point only used if there any Injection Point in the Tank the Value of F_{IP} is 3, otherwise is 1

F_{DL} : Adjusment for Dead Leg : **1** 1

Dead Leg Adjutsment only applied for piping circuit. If the equipment it isn't piping circuit the value of F_{DL} is 1

F_{WD}	:	Adjusment for Welded Construction Applicable only to ASTs. If the component is welded then F_{WD} is 1, otherwise F_{WD} is 10	:	**1**	1
F_{AM}	:	Adjusment for Maintenance in Accordance With API 653 Applicable only for ASTs. If the AST is maintained in accordance with API STD 653, then F_{AM} is 1, otherwise is 10	:	**1**	1
F_{SM}	:	Adjusment for Settlement Applicable only for AST bottoms. If the equipment it isn't tank bottom the value of F_{SM} is 1	:	**1**	1
F_{OM}	:	Adjusment for Online Monitoring Because the equipment it isn't online monitored. So the value of F_{OM} is 1	:	**1**	1

- $D_f^{Thin} = max\left[\left(\frac{D_{fB}^{Thin}\ .\ F_{IP}\ .\ F_{DL}\ .\ F_{WD}\ .\ F_{AM}\ .\ F_{SM}}{F_{OM}}\right), 0.1\right]$

= **2.684** #

ATTACHMENT E

DF EXTERNAL CORROSION

1) **Determine the furnishet thickness, *t* , and age, *age* , for the component from the installation date.**

- Furnish Thickness (*f*) : **8 mm**
- Age (*age*) = RBI Date - Installation Date
  = 14 March 2018 - 24 July 2014
  = **3.641 years**

a age is the in-service time that the damage is applied

b t is the furnished thickness of the component calculated as the sum of the base material and cladding/weld overlay thickness, as applicable

2) **Determine the base corrosion rate C_{rB} , based on the driver and operating temperature using Table**

- Corrosion Rate Base Material C_{rB} using the driver and operating temperature from the table 15.2 and

- Operating temperature = **108 F**

Operating Temp.	C_{rB} mpy)
90	3
108	**2.74**
160	2

- C_{rB} in mmpy = **0.0697 mmpy**

3) **Calculate the final Corrosion Rate (C_r) using equation (2.34)**

- Final Corrosion Rate (C_r)

$$C_r = C_{rB}.max[F_{EQ}, F_{IF}]$$

Where F_{EQ} and F_{IF} are adjustment for Equipment design and Adjustment Interface

F_{EQ} : <u>Adjusment for Euipment Design or Fabrication</u> = **1**
if the Equipment Design allows water pool and increase metal loss F_{EQ} Value is 2 otherwise the value is 1

F_{IF} : Adjusment for interface = **1**
its only for piping circuit that interface with soil or water so the value is 2, otherwise the value is 1

- C_r = 0.0697 mmpy x max [1,1]
  = **0.0697**

4) Determine the time in-service, *age_{tk}* , since the last known inspection thickness, *t_{rde}* (see Section 4.5.5. The t_{rde} is the starting thickness with respect to wall loss associated with external corrosion. If no measured thickness is available, set *t_{rde}* = t and *age_{tk}* = age

- Age in Service (age_{tk}) = RBI Date - Last Inspection Date
  = 14 March 2018 - 14 August 2017
  = **0.58082 years**
- Last Inspection thickness (t_{rde}) = **7.07 mm**

5) Determine the in-service time, age_{coat} , since the coating has been installed using Equation (2.35).

- age_{coat} **=** RBI Date - Coating Installation Date
  = 14 March 2018 - 14 August 2014
  = **3.641 years**

6) Determine coating adjustment, *$Coat_{adj}$* , using Equations (2.36) through (2.41)

Because age_{tk} is less then age_{coat} so determining Coating adjustment using one of these 3 equation:

- $Coat_{adj}$ = 0 if there are no coating or poor coating quality
- $Coat_{adj}$ = $$Coat_{adj} = min[5, age_{coat}] - min[5, age_{coat} - age_{tk}]$$
- $Coat_{adj}$ = $$Coat_{adj} = min[15, age_{coat}] - min[15, age_{coat} - age_{tk}]$$

Because the tank does not have coating

- Coating Adjustment ($Coat_{adj}$) = **0**

7) Determine the in-service time, *age* ,over which external corrosion may have occurred using Equation (2.42).

- In-Service time (*age*) = age_{tk} - $Coat_{adj}$
  = 0.5808 - 0
  = **0.581**

8) Determine the allowable stress, S , weld joint efficiency, E , and minimum required thickness, t_{min} , per the original construction code. In cases where components are constructed of uncommon shapes or where the component's minimum structural thickness, t_c , may govern, the user may use the t_c in leu of t_{min} where pressure does not govern the minimum required thickness criteria

- Allowable Stress (*S*) = **150 Mpa**
- Weld Joint efficiency (*E*) = **0.85**
- Thickness Minimum (t_{min}) = Furnished Thickness - Corrosion Allowance
  = **4.825 mm**

9) Determine the A_{rt} parameter using Equation (2.43) based on the *age* and t_{rde} from STEP 4, C_r from STEP 3

- $$A_{rt} = \frac{C_r\,.age}{t_{rde}}$$

$$A_{rt} = \frac{0.0697mmpy\,.0.580822years}{7.07mm}$$

= **0.00572**

10) Calculate the Flow Stress, $FS^{extcorr}$, using *E* from STEP 8 and Equation (2.44)

- $$FS^{extcorr} = \frac{(YS + TS)}{2} \times E \times 1{,}1$$

$$FS^{extcorr} = \frac{(250\ MPa + 400\ MPa)}{2} \times 0{,}85\ \times 1{,}1$$

= **303.9 Mpa**

11) Calculate the strength ratio parameter, SR_P^{Thin} , using Equation (2.45) or (2.46).

- $$SR_P^{extcorr} = \frac{S.E}{FS^{exrcorr}} \cdot \frac{Max(t_{min}, t_c)}{t_{rde}}$$

$$SR_P^{extcorr} = \frac{150\, mpa. 0{,}85}{303{,}88\, mpa} \cdot \frac{Max(4{,}825{,}0)}{7{,}07}$$

= **0.28635**

12) Determine the number of inspections, $N_A^{extcorr}$, $N_B^{extcorr}$, $N_C^{extcorr}$, $N_D^{extcorr}$ and the corresponding inspection effectiveness category using Section 15.6.2 for past inspections performed during the in-service time.

- Number of past Inspection perform **1**
- Inspection Category **A**
- Inspection Effectiveness Category **Highly Effective**

13) Determine the Inspection Effectiveness $I_1^{extcorr}$, $I_2^{extcorr}$, $I_3^{extcorr}$, using Equation (2.47) , Prior Probabilities, $Pr_{p1}^{extcorr}$, $Pr_{p2}^{extcorr}$ and $Pr_{p3}^{extcorr}$, from Table 4.5, Conditional Probabilities (for each inspection effectiveness level), $Co_{p1}^{extcorr}$, $Co_{p2}^{extcorr}$, $Co_{p3}^{extcorr}$ from Table 4.6, and the number of inspections, $N_A^{extcorr}$, $N_B^{extcorr}$, $N_C^{extcorr}$, $N_D^{extcorr}$, in each effectiveness level obtained

Where Prior Probabilities and Conditional Probabilities Value get from table **4.5** and **4.6**

Table 4.5 – Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Confidence Data
$Pr_{p1}^{extcorr}$	0.5	0.7	0.8

Table 4.6 – Conditional probability of inspection

Conditional probability of inspection	E-None or ineffective	D - poorly effective	C - fairly effective	B - Usually effective	A - Highly effective
$Co_{p1}^{extcorr}$	0.33	0.4	0.5	0.7	0.9

- Inspection Effectiveness Factor $I_1^{extcorr}$ **0.72**
- Inspection Effectiveness Factor $I_2^{extcorr}$ **0.014**
- Inspection Effectiveness Factor $I_3^{extcorr}$ **0.0005**

14) Calculate the posterior probabilities $Po_{p1}^{extcorr}$, $Po_{p2}^{extcorr}$, $Po_{p3}^{extcorr}$ using equation (2.48) using $I_1^{extcorr}$, $I_2^{extcorr}$, $I_3^{extcorr}$ in STEP 13

- Posterior Probability 1

$$Po_{p1}^{extcorr} = \frac{I_1^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}}$$

= **0.98093**

- Posterior Probability 2

$$Po_{p2}^{extcorr} = \frac{I_2^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}}$$

= **0.01839**

- Posterior Probability 3

$$Po_{p3}^{extcorr} = \frac{I_3^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}}$$

= **0.00068**

15) Calculate the parameters, $\beta_1^{extcorr}$, $\beta_2^{extcorr}$, $\beta_3^{extcorr}$ using Equation (2.49) and assigning $COV_{\Delta t}$=0,20 , COV_{Sf} = 0,20 , COV_P = 0.05

Where Corrosion Rate Factor for Damage State (Ds). DS 1 is 1 , DS 2 is 2 , DS 3 is 4

- $$\beta_1^{extcorr} = \frac{1 - D_{S_1}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_1}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_1}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{extcorr}\right)^2.COV_p^2}}$$

  = **0.00112**

- $$\beta_2^{extcorr} = \frac{1 - D_{S_2}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_2}^2.A_{rt}^2.COV_{\Delta t}^2 + (1 - D_2.A_{rt})^2.COV_{S_f}^2 + \left(SR_p^{extcorr}\right)^2.COV_p^2}}$$

  = **0.00108**

- $$\beta_3^{extcorr} = \frac{1 - D_{S_3}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_3}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_3}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{extcorr}\right)^2.COV_p^2}}$$

  = **0.0016**

16) Calculate $D_f^{extcorr}$ using Equation (2.50)

- $$D_f^{extcorr} = \left[\frac{\left(Po_{p1}^{extcorr}\Phi(-\beta_1^{extcorr})\right) + \left(Po_{p2}^{extcorr}\Phi(-\beta_2^{extcorr})\right) + \left(Po_{p3}^{extcorr}\Phi(-\beta_3^{extcorr})\right)}{1{,}56E - 04}\right]$$

  = **2.679756283**

External Corrosion Damage Factor
Course 2

1) Determine the furnishet thickness, *t* , and age, *age* , for the component from the installation date.

- Furnish Thickness (*f*) : **8 mm**
- Age (*age*) = RBI Date - Installation Date
  = 14 March 2018 - 24 July 2014 8 mm
  = **3.641 years**

a *age* is the in-service time that the damage is applied

b *t* is the furnished thickness of the component calculated as the sum of the base material and cladding/weld overlay thickness, as applicable

2) Determine the base corrosion rate C_{rB} , based on the driver and operating temperature using Table

- Corrosion Rate Base Material C_{rB} using the driver and operating temperature from the table 15.2 and

- Operating temperature = **108 F**

Operating Temp.	C_{rB} mpy)
90	3
108	**2.74**
160	2

- C_{rB} in mmpy = **0.0697 mmpy**

3) Calculate the final Corrosion Rate (C_r) using equation (2.34)

- Final Corrosion Rate (C_r)

$$C_r = C_{rB}.max[F_{EQ}, F_{IF}]$$

Where F_{EQ} and F_{IF} are adjustment for Equipment design and Adjustment Interface

F_{EQ} : <u>Adjusment for Euipment Design or Fabrication</u> = **1**
if the Equipment Design allows water pool and increase metal loss F_{EQ} Value is 2 otherwise the value is 1

F_{IF} : Adjusment for interface = **1**
its only for piping circuit that interface with soil or water so the value is 2, otherwise the value is 1

- C_r = 0.0697 mmpy x max [1,1]
  = **0.0697**

4) Determine the time in-service, age_{tk} , since the last known inspection thickness, t_{rde} (see Section 4.5.5. The t_{rde} is the starting thickness with respect to wall loss associated with external corrosion. If no measured thickness is available, set t_{rde} = t and age_{tk} = age

- Age in Service (age_{tk}) = RBI Date - Last Inspection Date
  = 14 March 2018 - 14 August 2017
  = **0.58082 years**
- Last Inspection thickness (t_{rde}) = **7.48 mm**

5) Determine the in-service time, age_{coat} , since the coating has been installed using Equation (2.35).

- age_{coat} = RBI Date - Coating Installation Date
  = 14 March 2018 - 14 August 2014
  = **3.641 years**

6) Determine coating adjustment, $Coat_{adj}$, using Equations (2.36) through (2.41)

Because age_{tk} is less then age_{coat} so determining Coating adjustment using one of these 3 equation:

- $Coat_{adj}$ = 0 if there are no coating or poor coating quality
- $Coat_{adj}$ = $$Coat_{adj} = min[5, age_{coat}] - min[5, age_{coat} - age_{tk}]$$
- $Coat_{adj}$ = $$Coat_{adj} = min[15, age_{coat}] - min[15, age_{coat} - age_{tk}]$$

Because the tank does not have coating

- Coating Adjustment ($Coat_{adj}$) = **0**

7) Determine the in-service time, *age* ,over which external corrosion may have occurred using Equation (2.42).

- In-Service time (*age*) = age_{tk} - $Coat_{adj}$
  = 0.5808 - 0
  = **0.581**

8) Determine the allowable stress, S , weld joint efficiency, E , and minimum required thickness, t_{min} , per the original construction code. In cases where components are constructed of uncommon shapes or where the component's minimum structural thickness, t_c , may govern, the user may use the t_c in leu of t_{min} where pressure does not govern the minimum required thickness criteria

- Allowable Stress (*S*) = **150 Mpa**
- Weld Joint efficiency (*E*) = **0.85**
- Thickness Minimum (t_{min}) = Furnished Thickness - Corrosion Allowance
  = **4.825 mm**

9) Determine the A_{rt} parameter using Equation (2.43) based on the *age* and t_{rde} from STEP 4, C_r from STEP 3

- $$A_{rt} = \frac{C_r \, .age}{t_{rde}}$$

$$A_{rt} = \frac{0.0697mmpy \, .0.580822years}{7.48mm}$$

= **0.0054098**

10) Calculate the Flow Stress, $FS^{extcorr}$, using *E* from STEP 8 and Equation (2.44)

- $$FS^{extcorr} = \frac{(YS + TS)}{2} \times E \times 1{,}1$$

$$FS^{extcorr} = \frac{(250\ MPa + 400\ MPa)}{2} \times 0{,}85 \times 1{,}1$$

= **303.9 Mpa**

11) Calculate the strength ratio parameter, SR_P^{Thin} , using Equation (2.45) or (2.46).

-

$$SR_P^{extcorr} = \frac{S.E}{FS^{exrcorr}} \cdot \frac{Max(t_{min}, t_c)}{t_{rde}}$$

$$SR_P^{extcorr} = \frac{150\,mpa. 0{,}85}{303{,}88\,mpa} \cdot \frac{Max(4{,}825{,}0)}{7{,}48}$$

= **0.2706518**

12) Determine the number of inspections, $N_A^{extcorr}$, $N_B^{extcorr}$, $N_C^{extcorr}$, $N_D^{extcorr}$ and the corresponding inspection effectiveness category using Section 15.6.2 for past inspections performed during the in-service time.

- Number of past Inspection perform **1**
- Inspection Category **A**
- Inspection Effectiveness Category **Highly Effective**

13) Determine the Inspection Effectiveness $I_1^{extcorr}$, $I_2^{extcorr}$, $I_3^{extcorr}$, using Equation (2.47) , Prior Probabilities, $Pr_{p1}^{extcorr}$, $Pr_{p2}^{extcorr}$ and $Pr_{p3}^{extcorr}$, from Table 4.5, Conditional Probabilities (for each inspection effectiveness level), $Co_{p1}^{extcorr}$, $Co_{p2}^{extcorr}$, $Co_{p3}^{extcorr}$ from Table 4.6, and the number of inspections, $N_A^{extcorr}$, $N_B^{extcorr}$, $N_C^{extcorr}$, $N_D^{extcorr}$, in each effectiveness level obtained

Where Prior Probabilities and Conditional Probabilities
Value get from table **4.5** and **4.6**

Table 4.5 – Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Confidence Data
$Pr_{p1}^{extcorr}$	0.5	0.7	0.8

Table 4.6 – Conditional probability of inspection

Conditional probability of inspection	E-None or ineffective	D - poorly effective	C - fairly effective	B - Uselly effective	A - Highly effective
$Co_{p1}^{extcorr}$	0.33	0.4	0.5	0.7	0.9

- Inspection Effectiveness Factor $I_1^{extcorr}$ **0.72**
- Inspection Effectiveness Factor $I_2^{extcorr}$ **0.014**
- Inspection Effectiveness Factor $I_3^{extcorr}$ **0.0005**

14) Calculate the posterior probabilities $Po_{p1}^{extcorr}$, $Po_{p2}^{extcorr}$, $Po_{p3}^{extcorr}$ using equation (2.48) using $I_1^{extcorr}$, $I_2^{extcorr}$, $I_3^{extcorr}$ in STEP 13

- Posterior Probability 1

$$Po_{p1}^{extcorr} = \frac{I_1^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}}$$

= **0.98093**

- Posterior Probability 2

$$Po_{p2}^{extcorr} = \frac{I_2^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}}$$

= **0.01839**

- Posterior Probability 3

$$Po_{p3}^{extcorr} = \frac{I_3^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}}$$

= **0.0006812**

15) Calculate the parameters, $\beta_1^{extcorr}$, $\beta_2^{extcorr}$, $\beta_3^{extcorr}$ using Equation (2.49) and assigning $COV_{\Delta t}$=0,20 , COV_{Sf} = 0,20 , COV_P = 0.05

Where Corrosion Rate Factor for Damage State (Ds). DS 1 is 1 , DS 2 is 2 , DS 3 is 4

- $$\beta_1^{extcorr} = \frac{1 - D_{S_1}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_1}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_1}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{extcorr}\right)^2.COV_p^2}}$$

  = **0.00114**

- $$\beta_2^{extcorr} = \frac{1 - D_{S_2}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_2}^2.A_{rt}^2.COV_{\Delta t}^2 + (1 - D_2.A_{rt})^2.COV_{S_f}^2 + \left(SR_p^{extcorr}\right)^2.COV_p^2}}$$

  = **0.00111**

- $$\beta_3^{extcorr} = \frac{1 - D_{S_3}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_3}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_3}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{extcorr}\right)^2.COV_p^2}}$$

  = **0.0016**

16) Calculate $D_f^{extcorr}$ using Equation (2.50)

- $$D_f^{extcorr} = \left[\frac{\left(Po_{p1}^{extcorr}\Phi(-\beta_1^{extcorr})\right) + \left(Po_{p2}^{extcorr}\Phi(-\beta_2^{extcorr})\right) + \left(Po_{p3}^{extcorr}\Phi(-\beta_3^{extcorr})\right)}{1{,}56E-04}\right]$$

  = **2.679746122**

External Corrosion Damage Factor
Course 3

1) Determine the furnishet thickness, *t* , and age, *age* , for the component from the installation date.

- Furnish Thickness (*f*) : **8 mm**
- Age (*age*) = RBI Date - Installation Date

 = 14 March 2018 - 24 July 2014 8 mm

 = **3.641 years**

a *age* is the in-service time that the damage is applied

b *t* is the furnished thickness of the component calculated as the sum of the base material and cladding/weld overlay thickness, as applicable

2) Determine the base corrosion rate C_{rB} , based on the driver and operating temperature using Table

- Corrosion Rate Base Material C_{rB} using the driver and operating temperature from the table 15.2 and

- Operating temperature = **108 F**

Operating Temp.	C_{rB} mpy)
90	3
108	**2.74**
160	2

- C_{rB} in mmpy = **0.0697 mmpy**

3) Calculate the final Corrosion Rate (C_r) using equation (2.34)

- Final Corrosion Rate (C_r)

$$C_r = C_{rB}.max[F_{EQ}, F_{IF}]$$

Where F_{EQ} and F_{IF} are adjustment for Equipment design and Adjustment Interface

F_{EQ} : <u>Adjusment for Euipment Design or Fabrication</u> = **1**
if the Equipment Design allows water pool and increase metal loss F_{EQ} Value is 2 otherwise the value is 1

F_{IF} : <u>Adjusment for interface</u> = **1**
its only for piping circuit that interface with soil or water so the value is 2, otherwise the value is 1

- C_r = 0.0697 mmpy x max [1,1]
  = **0.0697**

4) Determine the time in-service, *age_{tk}* , since the last known inspection thickness, *t_{rde}* (see Section 4.5.5. The t_{rde} is the starting thickness with respect to wall loss associated with external corrosion. If no measured thickness is available, set *t_{rde}* = t and *age_{tk}* = age

- Age in Service (age_{tk}) = RBI Date - Last Inspection Date
  = 14 March 2018 - 14 August 2017
  = **0.58082 years**
- Last Inspection thickness (t_{rde}) = **5.72 mm**

5) Determine the in-service time, age_{coat} , since the coating has been installed using Equation (2.35).

- age_{coat} **=** RBI Date - Coating Installation Date
  = 14 March 2018 - 14 August 2014
  = **3.641 years**

6) Determine coating adjustment, *$Coat_{adj}$* , using Equations (2.36) through (2.41)

Because age_{tk} is less then age_{coat} so determining Coating adjustment using one of these 3 equation:

- $Coat_{adj}$ = 0 if there are no coating or poor coating quality
- $Coat_{adj}$ = $$Coat_{adj} = min[5, age_{coat}] - min[5, age_{coat} - age_{tk}]$$
- $Coat_{adj}$ = $$Coat_{adj} = min[15, age_{coat}] - min[15, age_{coat} - age_{tk}]$$

Because the tank does not have coating
- Coating Adjustment ($Coat_{adj}$) = **0**

7) Determine the in-service time, *age* ,over which external corrosion may have occurred using Equation (2.42).

- In-Service time (*age*) = age_{tk} - $Coat_{adj}$
  = 0.5808 - 0
  = **0.581**

8) Determine the allowable stress, S , weld joint efficiency, E , and minimum required thickness, t_{min} , per the original construction code. In cases where components are constructed of uncommon shapes or where the component's minimum structural thickness, t_c , may govern, the user may use the t_c in leu of t_{min} where pressure does not govern the minimum required thickness criteria

- Allowable Stress (*S*) = **150 Mpa**
- Weld Joint efficiency (*E*) = **0.85**
- Thickness Minimum (t_{min}) = Furnished Thickness - Corrosion Allowance
  = **4.825 mm**

9) Determine the A_{rt} parameter using Equation (2.43) based on the *age* and t_{rde} from STEP 4, C_r from STEP 3

- $$A_{rt} = \frac{C_r\ .age}{t_{rde}}$$

$$A_{rt} = \frac{0.0697mmpy\ .0.580822years}{5.72mm}$$

= **0.0070743**

10) Calculate the Flow Stress, $FS^{extcorr}$, using *E* from STEP 8 and Equation (2.44)

- $$FS^{extcorr} = \frac{(YS + TS)}{2} \times E \times 1{,}1$$

$$FS^{extcorr} = \frac{(250\ MPa + 400\ MPa)}{2} \times 0{,}85\ \times 1{,}1$$

= **303.9 Mpa**

11) Calculate the strength ratio parameter, SR_P^{Thin} , using Equation (2.45) or (2.46).

-
$$SR_P^{extcorr} = \frac{S.E}{FS^{exrcorr}} \cdot \frac{Max(t_{min}, t_c)}{t_{rde}}$$

$$SR_P^{extcorr} = \frac{150\, mpa. 0{,}85}{303{,}88\, mpa} \cdot \frac{Max(4{,}825{,}0)}{5{,}72}$$

= **0.3539293**

12) Determine the number of inspections, $N_A^{extcorr}$, $N_B^{extcorr}$, $N_C^{extcorr}$, $N_D^{extcorr}$ and the corresponding inspection effectiveness category using Section 15.6.2 for past inspections performed during the in-service time.

- Number of past Inspection perform **1**
- Inspection Category **A**
- Inspection Effectiveness Category **Highly Effective**

13) Determine the Inspection Effectiveness $I_1^{extcorr}$, $I_2^{extcorr}$, $I_3^{extcorr}$, using Equation (2.47) , Prior Probabilities, $Pr_{p1}^{extcorr}$, $Pr_{p2}^{extcorr}$ and $Pr_{p3}^{extcorr}$, from Table 4.5, Conditional Probabilities (for each inspection effectiveness level), $Co_{p1}^{extcorr}$, $Co_{p2}^{extcorr}$, $Co_{p3}^{extcorr}$ from Table 4.6, and the number of inspections, $N_A^{extcorr}$, $N_B^{extcorr}$, $N_C^{extcorr}$, $N_D^{extcorr}$, in each effectiveness level obtained

Where Prior Probabilities and Conditional Probabilities Value get from table **4.5** and **4.6**

Table 4.5 – Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Confidence Data
$Pr_{p1}^{extcorr}$	0.5	0.7	0.8

Table 4.6 – Conditional probability of inspection

Conditional probability of inspection	E-None or ineffective	D - poorly effective	C - fairly effective	B - Uselly effective	A - Highly effective
$Co_{p1}^{extcorr}$	0.33	0.4	0.5	0.7	0.9

- Inspection Effectiveness Factor $I_1^{extcorr}$ **0.72**
- Inspection Effectiveness Factor $I_2^{extcorr}$ **0.014**
- Inspection Effectiveness Factor $I_3^{extcorr}$ **0.0005**

14) Calculate the posterior probabilities $Po_{p1}^{extcorr}$, $Po_{p2}^{extcorr}$, $Po_{p3}^{extcorr}$ using equation (2.48) using $I_1^{extcorr}$, $I_2^{extcorr}$, $I_3^{extcorr}$ in STEP 13

- Posterior Probability 1

$$Po_{p1}^{extcorr} = \frac{I_1^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}}$$

= **0.98093**

- Posterior Probability 2

$$Po_{p2}^{extcorr} = \frac{I_2^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}}$$

= **0.01839**

- Posterior Probability 3

$$Po_{p3}^{extcorr} = \frac{I_3^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}}$$

= **0.0006812**

15) Calculate the parameters, $\beta_1^{extcorr}$, $\beta_2^{extcorr}$, $\beta_3^{extcorr}$ using Equation (2.49) and assigning $COV_{\Delta t}$=0,20 , COV_{Sf} = 0,20 , COV_P = 0.05

Where Corrosion Rate Factor for Damage State (Ds). DS 1 is 1 , DS 2 is 2 , DS 3 is 4

- $$\beta_1^{extcorr} = \frac{1 - D_{S_1}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_1}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_1}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{extcorr}\right)^2.COV_p^2}}$$

  = **0.00101**

- $$\beta_2^{extcorr} = \frac{1 - D_{S_2}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_2}^2.A_{rt}^2.COV_{\Delta t}^2 + (1 - D_2.A_{rt})^2.COV_{S_f}^2 + \left(SR_p^{extcorr}\right)^2.COV_p^2}}$$

  = **0.00097**

- $$\beta_3^{extcorr} = \frac{1 - D_{S_3}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_3}^2.A_{rt}^2.COV_{\Delta t}^2 + \left(1 - D_{S_3}.A_{rt}\right)^2.COV_{S_f}^2 + \left(SR_p^{extcorr}\right)^2.COV_p^2}}$$

  = **0.0016**

16) Calculate $D_f^{extcorr}$ using Equation (2.50)

- $$D_f^{extcorr} = \left[\frac{\left(Po_{p1}^{extcorr}\Phi(-\beta_1^{extcorr})\right) + \left(Po_{p2}^{extcorr}\Phi(-\beta_2^{extcorr})\right) + \left(Po_{p3}^{extcorr}\Phi(-\beta_3^{extcorr})\right)}{1,56E-04}\right]$$

  = **2.679799710**