BACHELOR THESIS & COLLOQUIUM – ME 184841

INSPECTION PLANNING PROGRAM USING RISK BASED INSPECTION API 581 FOR ABOVEGROUND STORAGE TANKS IN PT. X. GRESIK

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DOUBLE DEGREE PROGRAM
DEPARTMENT OF MARINE ENGINEERING
FACULTY OF MARINE TECHNOLOGY
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SKRIPSI – ME 184841

PROGRAM PERENCANAAN JADWAL INSPEKSI MENGGUNAKAN “*RISK-BASED INSPECTION*” API 581 UNTUK TANGKI PENYIMPANAN DI PT. X. GRESIK

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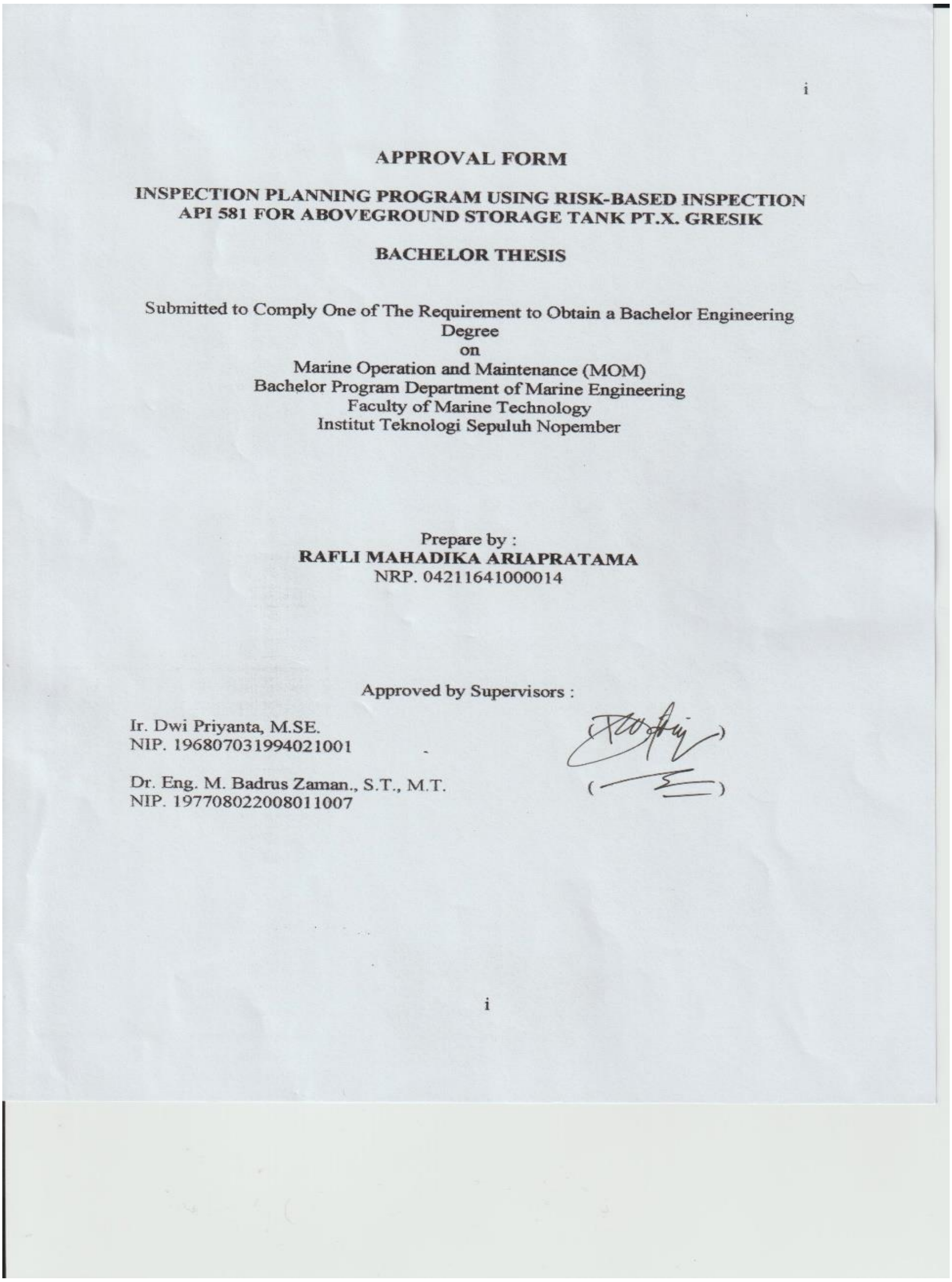

APPROVAL FORM

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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

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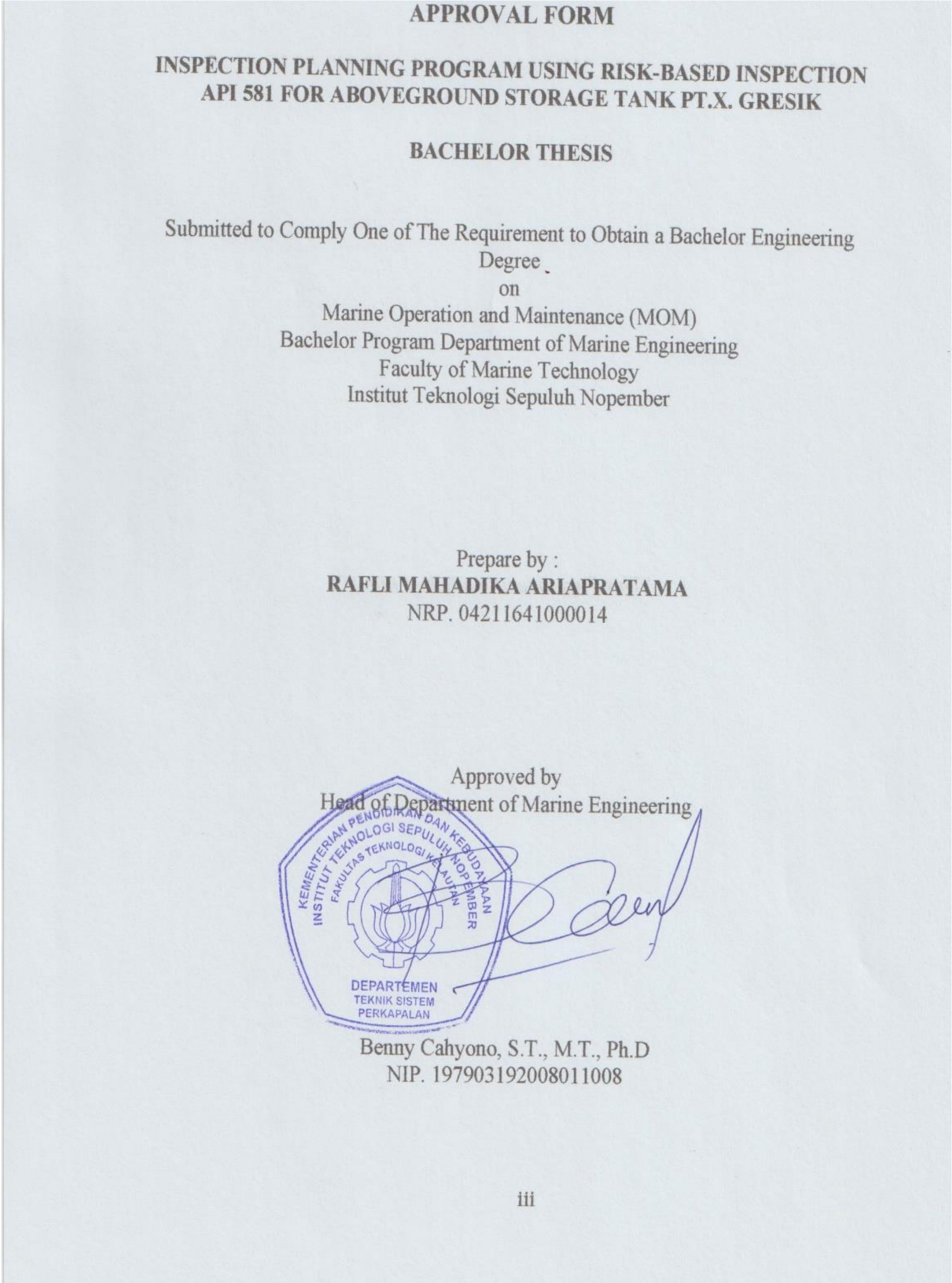

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DECLARATION OF HONOR

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, designm 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 use for further study and its development.

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Department : Marine Engineering

If there is plagiarism act in the future, i will fully responsible and receive the penalty given by ITS according to the regulation applied.

Surabaya, January 2020

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INSPECTION PLANNING PROGRAM USING RISK BASED INSPECTION API 581 FOR ABOVEGROUND STORAGE TANKS IN PT. X. GRESIK

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Abstract

Because the increase of oil demand to fulfil the human needed for daily basis makes the market to use the oil storage tank increasing too. It makes storage tank become one of the critical equipment used in the oil and gas industry. The tank condition should be monitored. It is to make sure that the storage tank always in ready to be operated condition. When the tank was not in ready to be operated condition it can ruin the oil distribution process to the customer. There should be an inspection or maintenance process to control the storage tank condition. The oil storage inspection process commonly done by focused on the tank condition. The inspection commonly done with the time-based inspection.

With RBI method that assess into Tank 21 that located in PT.X gresik it can determine the risk ranking of the tank. The risk ranking is used to determine when the inspection should be done for the next inspection. The standart that used to assess the tank with the RBI method is API 581 STD. RBI method determined the equipment based on the risk that the equipment has. There will be a risk ranking from the equipment that has a high-risk level until the equipment that has a low-risk level. The inspection can be done based on the risk that the equipment has.

From the RBI calculation to determine the probability of failure and the consequences of failure. From both of them each tank shell course risk will catagorized. The risk should be determined on the RBI date and Planned date. From both of them each tank shell course risk will catagorized. The tank has 6 shells course. So, each tank course shell has different risk, the risk of each shell course around = 0,068$\frac{m^2}{year}$. After the RBI calculation, the tank shell has Probability of Failure value = 1,43E-04 failure/year. For the consequences of failure value it can be determine as 477,65 m^2. From that calculation the risk can catagorized into 2C.

The Inspection planning can be determine based on the damage factor or the risk. From the calculation the isnpection planning date is longer than the planned date which is on 17/10/2022 and 19/10/2022.

Key words - Risk Based Inspection, Aboveground Storage Tank, API 581

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PROGRAM PERENCANAAN INSPEKSI MENGGUNAKAN *"RISK-BASED INSPECTION"* API 581 UNTUK TANGKI PENYIMPANAN DI PT.X. GRESIK

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Abstrak

Dikarenakan kenaikan kebutuhan minyak untuk memenuhi kebutuhan sehari-hari maka kebutuhan penggunaan tangki timbun mengalami kenaikan. Hal ini menyebabkan tangki timbun menjadi salah satu alat penting di industri minyak dan gas. Kondisi tangki timbun harus selalu diperiksa. Hal ini dikarenakan untuk menjaga kondisi tangki pada kondisi siap beroperasi. Ketika tangki timbun berada kondisi tidak dapat digunakan maka akan mengganggu distribusi kepada konsumen. Inspeksi yang dilakukan untuk tangki timbun berfokus pada kondisi tangki timbun tersebut. Inspeksi yang dilakukan biasanya menggunakan waktu penggunaan tangki sebagai acuan.

Dengan metode RBI yang dilakukan pada tangki nomor 21 yang terletak di PT. X. Gresik maka dapat didapatkan urutan resiko yang ada pada tangki tersebut. Urutan resiko tersebut digunakan untuk menentukan kapan dilakukan inspeksi selanjutnya. Dasar yang digunakan untuk melakukan RBI adalah API 581. Metode RBI digunakan untuk menghitung tingkat resiko yang terdapat pada suatu alat. Hasil dari perhitungan tersebut didapatkan urutan resiko mulai dari tingkatan beresiko tinggi hingga tingkatan beresiko rendah. Inspeksi dapat dilakukan berdasarkan tingkat resiko yang dimiliki.

Dari perhitungn RBI yang dilakukan maka akan didapatkan hasil untuk kemungkinan terjadi kesalah pertahun dan konsekuensi yang akan terjadi ketika kesalahan. Dari kedua aspek yang dihitung, maka akan diketahui tingkat resiko untuk tiap ruas plat pada tangki tersebut dan dapat dikategorikan berdasarkan tingkat resikonya. Tingkat resiko harus dihitung pada tanggal RBI dilakukan dan pada tanggal target inspeksi selanjutnya yang sudah ditetapkan oleh perusahaan. Tangki timbun yang dilakukan perhitungan RBI disini memiliki 6 tingkat ruas plat. Hal ini menyebabkan tiap tingkat ruas plat memiliki tingkat resiko yang berbeda, tingkat resiko untuk tiap tingkat ruas plat didapatkan hasil sekitar = 0,068$\frac{m^2}{tahun}$. Setelah perhitungan RBI dilakukan maka hasil untuk kemungkinan terjadi kesalahan = 1,43E-04 kesalahan/tahun. Untuk perhitungan konsekuensi ketika kesalahan terjadi didapatkan hasil sekitar = 477,65 m^2. Dari hasil perhitungan tersebut maka resiko pada tiap ruas tangki yang dapat dikategorikan pada tingkat 2C.

Perencanaan inspeksi dapat dilakukan denga memperhitungkan faktor kerusakan yang terjadi pada tangki tersebut. Perencanaan inspeksi selanjutnya dapat dilakukan pada tanggal 17/10/2022 dan 19/10/2022.

Kata kunci - Risk Based Inspection, Aboveground Storage Tank, API 581

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PREFACE

Praise be to God Almighty, for His blessings, the authors can finish “Final Project Proposal” of reports in accordance with a predetermined time. The authors hope this report can be useful for readers and writers so that they can understand what considerations are used as a reference in making statements about the final project research and data collecting in a particular oil and gas company. Not to forget the authors to thank the parties who have helped in completing the preparation of this report so that it can be realized include :

1. Ir. Dwi Priyanta, M.SC., as lecturer supervising the subjects of Bachelor Thesis that has taken the time to give guidance and direction in every workmanship.
2. Dr. Eng. M. Badrus Zaman, S.T., M.T., as lecturer supervising the subjects of Bachelor Thesis that has taken the time to give guidance and direction in every assistance.
3. Beloved parents, for prayers and support both morally and materially so that this report is completed properly.
4. Faizatuluzmi Mardhiana who always support my work all the time that increasing my spirit to done this bachelor thesis. She is a really biggest supporter of mine.
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8. And friends who have given an explanation when the author has not understood in the work of the assignments given.

The author hopes that by writing of the Final Project Proposal can be useful and provide information to the reader. Because of the limitations of author, constructive criticisms and suggestions are indispensable for perfection in this report.

Surabaya, January 20th 2020

Rafli Mahadika Ariapratama

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CHAPTER I

INTRODUCTION

1.1 Background

Nowadays, the fuel needed to fulfil the daily basis is increasing because of the increasing of the population. To make sure that distribution of the product oil to the consumer is in the right time and does not get into fuel supply deficiency phase, so there are many of oil storage tanks that used as a temporary stored from the ship before it will be distributed into the customer by a truck after that. Demand for the oil in 2000 was 27,74 billion bbl/year, and it is predicted increasing to 37,6 – 50,4 billion bbl/year in 2030 [1][1].

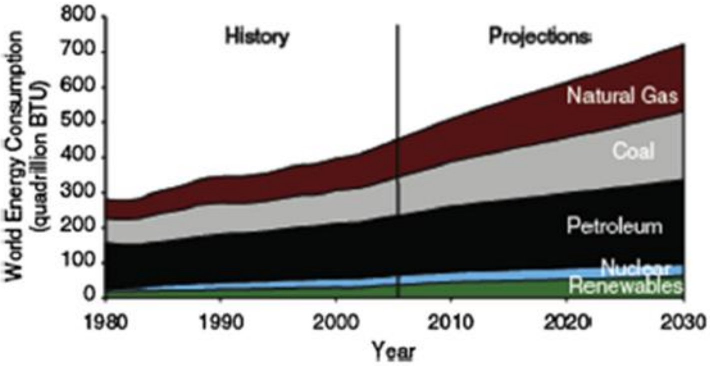

Figure 1 : Energy Consumption Prediction

Source : Papavinasam, S. (2014). The Oil and Gas Industry. Corrosion Control in the Oil and Gas Industry

Because of the demand, so there are many oil storage tanks in Indonesia. One of them that located in Gresik and owned by PT.X. The oil depot has 30 oil storage tanks, and the total volume that can be stored there were almost 30.000m^3. The tanks size were around 630kl, 750kl, 1000kl, 1250kl, 1500kl, and 2000kl[2]. The oil depot is to distribute the product oil to the consumer that has domicile at Gresik, Lamongan and its surrounding.

Oil Storage tanks in this depot are equipment that has a function to store the product oil tank that carried out by the ship before it transported to the consumer by the truck. The fluids that stored in the storage tanks are product oil that commonly used in Indonesia for daily needed basis such as; Premium, Pertamax, and Pertalite. Not only stored the product oil but some of the tanks in this depot were stored chemical product.

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[1] Papavinasam, S. (2014). The Oil and Gas Industry. Corrosion Control in the Oil and Gas Industry.

[2] https://www.dovechemmaspion.com/services-xm-what-we-do-xm/facilities.html

In the petroleum industry, corrosion is one of the leading caused. If the corrosion did not detect, and there were no mitigation and preventive process to avoid it. The most common of the corrosion type that happened for the atmospheric storage tank was the pitting corrosion. It makes 80% of the storage tank shutdown. Bottom perforation and leakage accidents were caused by tank bottom corrosion [2][3]. The corrosion can create a storage tank leakage. If the tank leakage, it can be effected to the tank operational condition. The tank operation should be shut down, and the tank should be done the reparation process. The mitigation process is not only about the maintenance process. There are some inspection should be done for the storage tank.

To make sure that the oil storage tank owned by PT. X still on the ready to be operated and to minimize the probability that equipment to broke and got into trouble, PT. X already did the inspection and the maintenance management process. However, there are still needed a risk analysis to determine the risk level of each tank. The risk can be defined as Probability Consequence of the accident that happened in the tank.

One of the methods to do the risk analysis is to use the Risk-Based Inspection. The risk-based inspection can be done for the oil storage tank because the oil storage tank is one of the equipment lists that can be applicated the RBI method[4]. The RBI method is to calculated and measured the risk from each equipment and placed it into the risk ranking from the low-risk level, medium risk level, and high-risk level. So when the tank in one depot was applicated the RBI, the owner can know the risk level for each tank.

The RBI method to calculate the risk was from Probability of Failure (POF) and Consequences of Failure (COF) from the equipment that included in the list[5]. The risk calculation result is the risk ranking for each equipment. For the equipment that has a high risk can be prioritized to be done the inspection first compared with the equipment that has a low-risk level. So the inspection process can be focused on the equipment that has a high risk.

Other methods can be used to do the inspection. The most common practice was by the time-based inspection. For the time-based inspection, the inspection interval was scheduled. However, in the operation condition, it cannot make all of the equipment is in the same situation. The time-based inspection not including the risk analysis to calculate the next interval time for the equipment inspection. In reality, the inspection cannot be scheduled in the same interval of time on the useful period of equipment. It can be that the inspection time interval was too often or the inspection time interval is too rarely. To avoid the problem above the RBI method is the method to calculate the inspection time interval by calculated the risk analysis.

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[3] Haisheng Bi, Zili Li, Jianguo Liu, Yuanpeng Cheng, Isaac Toku-Gyamerah. (2015). Study on Pitting Corrosion of Storage Tank Bottom Steel in Acidic Condition Using Acoustic Emission

[4] API RBI 580 : Risk-Based Inspection. (2009)

[5] Ibid

1.2 Problem Statements

Based on the background above, problems that are possible to discuss further are:

1. How to Calculated the Probability of Failure (PoF) and Consequences of Failure (CoF) from the oil storage owned by PT. X by the Risk-Based Inspection Method?
2. How to determine the inspection planning that suitable for the storage tank owned by PT. X. using the Risk-Based Inspection method?

1.3 Scope Problems

1. The RBI calculation applied for the Aboveground Storage Tanks (AST) that contain product oil.
2. The analysis of Storage Tank reliability based on American Petroleum Institution (API) 580 and 581.
3. In this calculation not including a particular cost calculation inside this inspection/research when applying the Risk-Based Inspection.

1.4 Objectives

Purposes aimed from this research are:

1. Determining the Probability of Failure (POF) based on Risk-Based Inspection (RBI).
2. Determining the Consequence of Failure (COF) based on Risk-Based Inspection (RBI)
3. Assessing the risk analysis or risk level of Aboveground Storage Tank That owned by PT. X. In Gresik using Risk-Based Inspection method.
4. Determining the right inspection plan and inspection method for the aboveground storage tank using RiskBased Inspection based on American Petroleum Institution (API) 581

1.5 Benefits

Benefits of this bachelor thesis are:

1. To give information about what are the risk that can affect the oil storage tank owned by PT. X. that can cause any failure in the tank operation.
2. To give information about the inspection planning, inspection time interval, and inspection method that suitable for the oil storage tank owned by the PT. X

1.6 Deliverable

The deliverable from this bachelor thesis for the Risk-based Inspection in the oil storage tank is inspection planning. The inspection planning included the next inspection date and the inspection method used when the inspection process happened.

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CHAPTER II

LITERATURE STUDY

2.1 Problem Overview

From the late 1800s, the oil industry has produced 1.063 trillion barrels (bbl). Now the production of oil can be cover all of the human needed for daily needed. Every year the demand for the energy resources is increasing because of the industrial required and the human population is growing too. It can compare that the global demand for oil in 2000 was 27,74 billion bbl/year and its estimated that will be increasing until 50-60% in 2030. The estimation of oil demand in 2030 is up to 50,4 billion bbl/ year[6].

Indonesia is one of the oil producers that the product consumes by all of the worlds. The oil wells are spread from west Indonesia until East Indonesia. Indonesia was producing oil from many years ago until now. The crude oil production was increasing year by year because of the technology advances and the daily needed. The crude oil cannot be immediately used as one of the energy resources daily. The oil should be refining first, and after that, the derivative products from the crude oil can be used daily.

Because of the large quantity of oil demand, demand for oil storage tank will be increasing too. This can happen because after the oil passed the refining process, the oil should be stored into some oil storage tanks before the oil transported to the consumer. There are around 8,5 million aboveground storage tanks and underground storage tanks for storing hazardous materials in the USA[7]. With a massive quantity of storage tanks that used to store the oil makes the oil storage tank become one of the critical equipment that always used in the oil and gas industry.

The oil storage tanks were spread to all of Indonesia, and one of them was located in Gresik. 30 storage tanks capable of stored around 30.000m^3 Of fluid. In the future depot that located in Gresik would be built and expand the capacity of storage tank become 40.000m^3. The final project of the oil depot can be stored up to 200.000m^3 Of product oil and chemical product[8]. The problem was to maintain the condition of the tank to make sure the tanks are on a good condition, ready to be operated and doesn’ get into any trouble such as corrosion and leakage. Because when the tanks were corroded, so it takes the tank into a higher risk of leakage. Many tanks leakage problem from the tank corrosion.

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[6] Papavinasam, S. (2014). The Oil and Gas Industry. Corrosion Control in the Oil and Gas Industry.

[7] Ibid

[8] https://www.dovechemmaspion.com/services-xm-what-we-do-xm/facilities.html

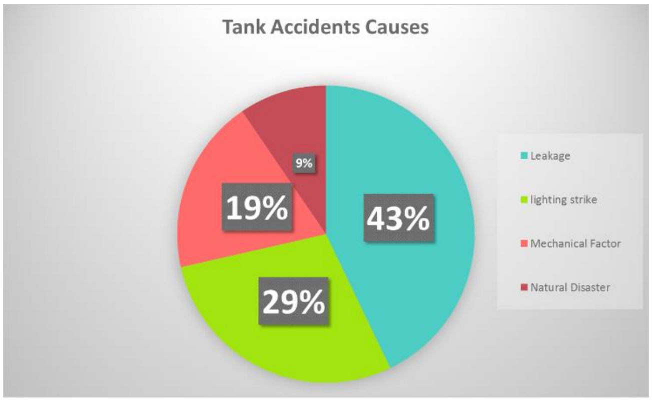

Figure 2 : Tank Problems Causes

Source : .M. Tauseef, Tasneem Abbasi, V. Pompapathi, S.A. Abbasi. (2018). Case studies of 28 major accidents of fires/explosions in storage tankfarms in the backdrop of available codes/standards/models for safely configuring such tank farms.

Because of the oil storage tanks were located in the oil depot so the risk will be higher. It is because when one of the oil storage tanks got into trouble and there are fire and explosion because of tank corrosion that makes the tank leakage so it can affect other tanks that located there. It is because the stored fluid inside contains large amounts of harmful substances and energy with a high probability of accidental release can pose risks to person [3], equipment facilities and environment[9]. With any kinds of damage mechanism that can cause the tank accident. 43% of tanks accidents were caused by leakage of the flammable liquid or gas. The corrosion damage mechanisms are the ones which could lead to the leakage of the process fluid to the environment (leakage of containment). Typical corrosion damage mechanisms are given below [4][10]:

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[9] Jian Kang, Wei Liang, Laibin Zhang, Zhong Lu, Detian Liu, Wenzhu Yin, Guizan Zhang. (2012). A new risk evaluation method for oil storage tank zones based on the theory of two types of hazards.

[10] K. Elaya Perumal. (2014). Corrosion Risk Analysis, Risk Based Inspection and a Case Study Concerning a Condensate Pipeline

Table 2. 1 : Corrosion Damage Mechanism

Damage type	**Description**
Thinning, General and Localized	Loss of metal from the surface throughout (general uniform corrosion, erosion-corrosion) or from confined places (pitting, crevice, galvanic corrosion) either from inside or from outside
Surface connected cracking	• Stress Corrosion Cracking by chloride, caustic, sulfide, amines, etc • Corrosion Fatigue • Liquid Metal Embrittlement
Sub-surface Cracking	Hydrogen Induced Cracking and its variations such as blistering, hydrogen embrittlement, etc.

The major caused of tank accident was from flammable liquid or gas leakage. Leakage problem was started from the corrosion, so the corrosion becomes one the topic that should be concerned. Many sources can cause the tank corrosion especially for the tank bottom corrosion such as several ions liked Na^{+}, Ca^{2+}, $SO4^{2-}$, Cl^{-}, and S^{2-}. Not only the ions that commonly found in the fluid that store in the storage tank but also corrosion can be found because the dissolved of $O_2,\ H_2S,\ and\ CO_2$ That from the sedimentary water on tank bottom [2][11]. The failure of the oil storage tank is the result of the combined and synergistic interaction of mechanical stress and corrosion reactions [5][12]. When the tank failure it can make some consequences such as explosive could formation, releasing toxic liquid or gas, harmful material leakage, shutdown, and environmental consequences [6][13].

In the oil depot, there is have not only one oil storage tank but also many oil storages tanks. Each tank will have a different ranking of risk level based on the operation condition. Risk-Matrix method was applied to determine the risk rank. Commonly the maintenance management or the inspection just based on the lifetime of the oil storage tank and scheduled not based the condition of tank. But in reality the condition and risk level of each oil storage tank are different. When the tank inspection and maintenance were done following the scheduled time. It is good because the process was to make sure the tank in good condition. But in other ways the resources to do that thing is not sufficient and efficient. The inspection problem can be over inspection and under inspection due to the lack of jurisdictional requirements on the inspection interval and method for the tank [7][14].

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[11] Haisheng Bi, Zili Li, Jianguo Liu, Yuanpeng Cheng, Isaac Toku-Gyamerah. (2015). Study on Pitting Corrosion of Storage Tank Bottom Steel in Acidic Condition Using Acoustic Emission

[12] Jae-Seong Kim, Dae-Hwan An, Sang-Yul Lee, Bo-Young Lee. (2009). A failure analysis of fillet joint cracking in an oil storage tank

[13] Tan Zhaoyang, Li Jianfeng, Wu Zongzhi, Zheng Jianhu, He Weifeng. (2011). An evaluation of maintenance strategy using risk based inspection

[14] Ming-Kuen Chang, Ren-Rong Chang, Chi-Min Shu, Kung-Nan Lin. (2005). Application of risk based inspection in refinery and processing piping

Most storage tank damage is attributable to age deterioration, corrosion, and seismic motions [8] [15]. The initial crack and local corrosion accelerated the propagation of break due to the stress concentration at the fillet joint areas. Some of the storage tank case is crack of a storage tank at a Floreffe, Pennsylvania terminal in 1988 released 92,400 barrels of diesel oil. In the last two decades, there have been>100 major incidents involving storage facilities in the world. In 1999 crude oil spills from storage tanks at Fawley, Hampshire, UK refinery caused by corrosion of tank bottom. In 2002 crack at the bottom of a crude oil storage tank at Kaohsiung, Taiwan refinery caused a tank leakage. The accident caused by the corrosion of tank bottom [9][16]. The worse cataclysmic event took place at the Buncefield Oils Storage Depot in Hertfordshire in 2005. That been considered as the largest explosion in Europe since the Second World War [10] [17].

There were 114 occurred in North America, 72 in Asia and 38 in Europe. USA had 105 accidents reviewed because of the easy accessibility to accident information. In China, there is 435 fire, and explosion accidents happened along 1951-2013 in oil depots [11] [18]. The oil depots here, including oil or gas terminals that stored a lot of flammable petroleum product. The accident affected the environment, caused an injured and dead, and caused the lost from the economic sector.

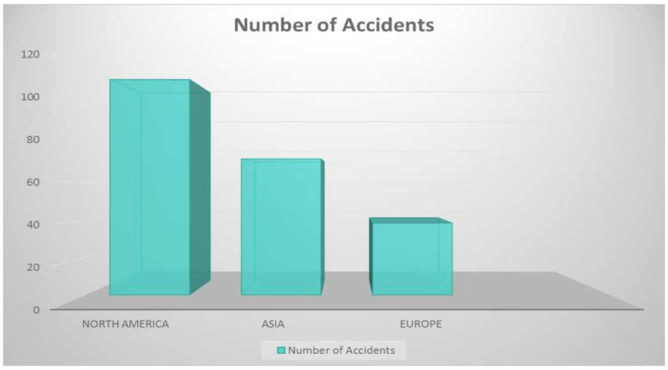

Figure 3 : Number of Tank Accidents

Source : .M. Tauseef, Tasneem Abbasi, V. Pompapathi, S.A. Abbasi. (2018). Case studies of 28 major accidents of fires/explosions in storage tankfarms in the backdrop of available codes/standards/models for safely configuring such tank farms

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[15] Jae-Seong Kim, Dae-Hwan An, Sang-Yul Lee, Bo-Young Lee. (2009). A failure analysis of fillet joint cracking in an oil storage tank

[16] James I. Chang, Cheng-Chung Lin. (2006). A study of storage tank accidents

[17] Pablo.G. Cirimelloa, Jose L. Oteguia, Damián Ramajo, Guillermo Carfi. (2019). A major leak in a crude oil tank: Predictable and unexpected root causes

[18] Yi Zhou, Xiaogang Zhao, Jianyu Zhao, Du Chen. (2016). Research on Fire and Explosion Accidents of Oil Depots

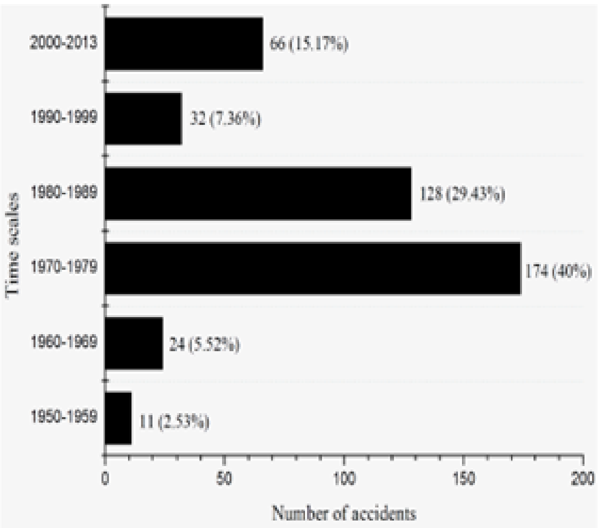

Figure 4 : Fire and Explosion Accident in China

Source : Yi Zhou, Xiaogang Zhao, Jianyu Zhao, Du Chen. (2016). Research on Fire and Explosion Accidents of Oil Depots

From the data collected along the time above the accident that caused in the oil storage tank was the highest. The accident can cause because many factors such as an electric spark, lighting, open fire, leakage, and many more. Leakage can be done because of natural disaster or corrosion. If the leakage caused by the corrosion so it must be because the inspection is done by the owner of the tank not followed the standard operational procedure. If there is any corrosion that more than the corrosion rate that the tank has the operation process of the tank should be shut down and the tank should be done the maintenance process before it can be operated again.

Figure 5 : Tank Accident

Source : https://upload.wikimedia.org/wikipedia/commons/f/ff/Oil_sullage_tank_burns_after_explosion.jpg

In 2015 an oil washing tank at a crude oil treatment plant in Argentina suffered a catastrophic failure involving its total loss of integrity. Eventually, the leaks were excluded from the inside of the tank, or there could have been a contribution by external corrosion. An approximate but statistically reliable way to answer that is to take an average by estimating the relative magnitude of the undercuts in both surfaces around each hole. Undercuts profiles define whether corrosion is internal or external. It was found that external corrosion represents almost 40% of the thickness loss.

Not only in China that the accident happened for the oil storage tank. In Indonesia, there was an accident that occurred on October 24th 1995. The accident was happened because of the lighting and made the tank exploded. The economical lost in this accident around 38 million dollars. The accident not only make lost from the economic sector but also makes the plan just can be operated 70% until March 1997.

The tank accident mostly cause by corrosion. The corrosion can make the structural tank damage. When the tank structural is damage, there will be a leakage. The leakage make the fluid that stored inside the tank come outside. The fluid containt as a flammable and toxic fluid. The fluid can affcted the environment. The fluid stored inside the tank mostly the expensive one and when the fluid lost effected the economical sector for the company that owned the tank. When the tank broken an there is leakage, the tank should be done the repairation and maintenance process. The process should be done in tank shut down condition. The tank shut down condition also affected the econcomical sectpr of the company.

All of the accident can be avoided if the inspection and the maintenance were done on the schedule and follow the standard operating procedure. Its because the inspection is to make sure that the equipment or in this topic is a storage tank in the ready and safe to be operated condition. When the inspection result determines the storage tank is not in good condition and not ready to be operated so the tank will not be operated under the high-risk condition and the accident probability can be reduced.

Each standardization for inspection process regulate the inspection based on the time, or the inspection planning followed the traditional one. In Taiwan, the pressure vessel should be done the inspection process at least once per two years. In China, the inspection time interval is 3-4 years based on the pressure vessel level. Japan also has its standardization for inspection at least once per 2 to 4 years. However, all of the standardization to regulate the inspection interval time does not look at the equipment risk. Indonesia also has the standardization to inspected the pressure vessel included storage tank at least once per four years.

The risk level of the oil storage tank can be added to one of the methods to determine the inspection planning in the future that is Risk-Based Inspection (RBI). When properly implemented, risk-based inspection is highly effective in improving plant safety, compared to conventional code-based inspection programs. RBI can reduce the risk considerably, even before any corrosion mitigation methods were put into practice. The RBI can reduce the risk level of the tank. RBI method allows the area of the plant that operating in high-risk level to reliably identified and focused there compared with the equipment that has low-risk level[19]. Because of the inspection can be focused on the tank that has a high-risk level. All of the resources that will be done the inspection can do the job there. After the inspection was done for the high-risk level equipment, the resources can inspect the low-risk level of tank in the time that calculated by the RBI method.

The RBI method was accomplished done so many equipment listed on API 580. Some of the cases that implemented the Risk-Based Inspection method to determine the risk level of each equipment, the next inspection interval time, and the inspection planning for the equipment such as RBI done for the condensate pipeline[20], RBI did for the crude oil storage tank in China [12][21].

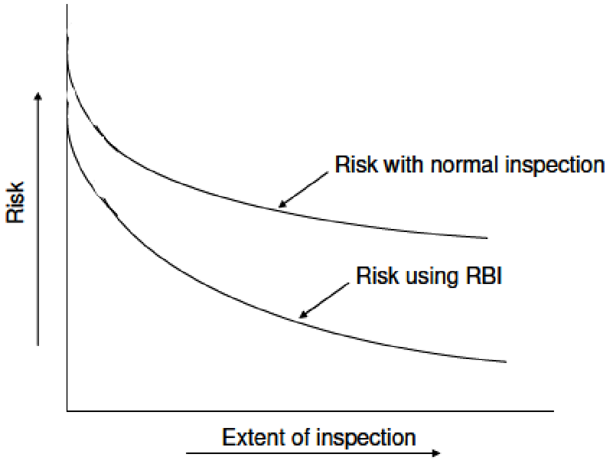

Figure 6 : Comparison of Risk arrived at through RBI that of Normal Inspection

Source : API RP 581. (2016). Risk-Based Inspection Methodolgy, 3rd Edition. Washington, D.C. : API Publishing Service

The Risk-Based Inspection was applicated for large-scale crude oil tanks in China. The method was applicated for 18 oil storage tank from 37 oil storage tank located in depot. The 18 inspected tank that applicated the RBI method has a lower risk compared with the others 19 oil storage tank that did not use RBI. The risk of tank bottom was 90% from whole tank risk. So the trouble mostly from the tank bottom. The problem can be corrosion that can make leakage from the tank. The Risk-Based Inspection was to estimate the reasonable internal inspection interval for the large crude oil tank in this depot. The RBI standard that used to calculate the inspection planning and range was API 580 and API 581.

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[19] Ibid

[20] Ibid

[21] Jian Shuai, Kejiang Han, Xuerui Xu. (2011). Risk-based inspection for large-scale crude oil tanks

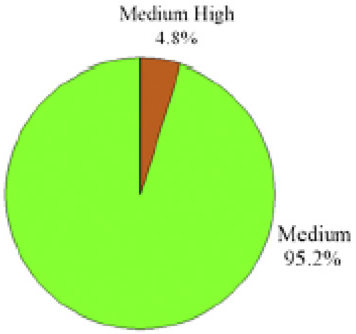

Figure 7 : Risk Categorized in China Oil Depot

Source : Jian Shuai, Kejiang Han, Xuerui Xu. (2011). Risk-based inspection for large-scale crude oil tanks

The risk product was from Probability of Failure (PoF) that can be happened for the tank and the Consequences of Failure (CoF) if the accident occurred in the tank. The POFs of tank bottom for 19 uninspected tanks are higher than that of the inspected tanks. The POF ranking of tank shell is similar to the tank bottom. Due to long in-service time and uncertainty in deterioration rate, the predicted POFs for tank shell of uninspected tanks are higher than that of inspected tanks.

Risk-Based Inspection output is inspection planning based on the equipment risk level. The inspection planning was focused on the equipment risk level, safe working, and the environmental effect. Not only three aspects that think here, but also from the economic factor. There was some expected result when the RBI method was applied for the equipment such as :

- Risk reduction for the equipment that calculated with the RBI method
- Working Safety when done the Inspection was is increasing because the inspection followed the international standard or international code
- Can estimate where does the equipment that needed inspection and where does the equipment so that the inspection process can be pended until the risk of the equipment reach the risk target

RBI output will make the inspection planning for each equipment based on the equipment risk, and practical from the economic sector RBI is a better method to calculate the next inspection time interval based on the equipment, but there some limitation that can make the RBI method is not sufficient to be applicated to the equipment such as :

- Incomplete and incorrect data needed for the CoF and PoF calculation
- Missed equipment installation
- Missed design from the manufacturer
- Not effective RBI planning
- Incompetent Team that done the RBI assessment

Risk-based Inspection does not make the equipment risk become zero. It can reduce the risk level from each equipment. With a Risk-based Inspection method, it can calculate the risk level from each equipment into the reach target that still acceptable and still prioritize the equipment that has a higher risk of doing the inspection first.

The output of an RBI assessment based on the Recommended Practice (RP) of American Petroleum Institute 580 is an inspection and maintenance plan for each equipment on a plant assessed and the actions that should be taken to provide reliable and safe operation., which should include the following:
a. Identified risk drivers or it can be called as bad actors;
b. Inspection method that can be used;
c. The extent of inspection (per cent of the total area to be examined or specific location);
d. Inspection interval or next inspection date (inspection timing);
e. Other risk mitigation activities (such as changes of repair, replacement, equipment upgrades, redesign, maintenance program, controls on operating conditions, and variations of corrosion inhibitors);
f. The residual level of risk after inspection and other mitigation actions have been implemented.

2.1.1. Storage Tank

The storage tank in the refinery industry and chemical industry is essential equipment that contains dangerous goods inside it. When there are small accidents in this equipment can cause million-dollar losses from the company that used it [13] [22]. Not only a loss in economical sector but also could affect the environmental sector too. If there are some accidents such as explosion or leakage, it can make a severe effect of many sectors above. Storage tank to store flammable and combustible liquids can have 5 meters to 150 meters in diameter and have an average height 15 meters [14][23]. The oil storage tank that used in PT. X has capacity around 630kl, 750kl, 1000kl, 1250kl, 1500kl, and 2000kl that separated into 40 oil storage tanks. The tank that assested with the Risk-Based Inspection for this bachelor thesis is the tank number 21.

2.1.2. Fixed Roof Tank

Fixed roof tanks are welded to the curb at the top of the shell and covered from top section and shell is formed in such a way that the forces are resisting downwards, such as dome roof and conical shape. The minimum thickness of the roof plating is 5 mm on the new tank. All fixed roof should be vented by open vents or pressure/vacuum valves. Fixed roof tank includes cone roof tanks, dome roof tanks, and column supported roof tanks, all of which are of either welded, riveted, or bolted construction.

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[22] Naghdali Hosseinzadeh, Hamid Kazem, Masoud Ghahremannejad, Ehsan Ahmadi, Navid Kazem. (2013). Comparison of API650-2008 provisions with FEM analyses for seismic assessment of existing steel oil storage tanks.

[23] Vaibhav Sharma, Abhishek Nandan and Nihal Anwar Siddiqui. (2018). Study and Analysis of Storage Tank Hazards and its Mitigation Measures Using Bow Tie Diagram

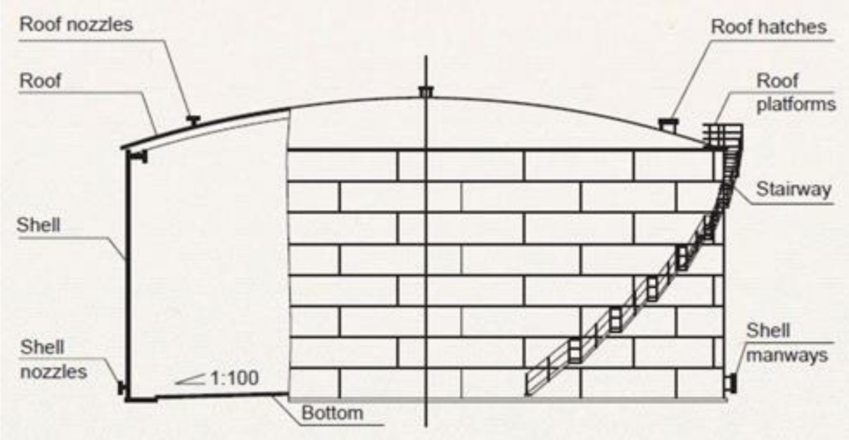

Figure 8 : Fixed Roof Tank

Source : http://saeedly.com/blog/fixed-and-floating-roof-storage-tanks/

2.1.3. Internal Floating Roof Tank

Internal floating roof tank is a permanently fixed roof with a floating roof inside the tank. The internal roof floats on pontoons or has a double deck for floatation over the liquid surface. This type of tank is used to store the liquid with high volatility or low flash point and a toxic liquid. Internal floating roof tank can reduce the vapor losses by at least 95%. This tank equipped with a pressure vacuum vent and some of them included with a gas blanketing system [15] [24]. The tank design regulated in Appendix C of the API Standart 650.

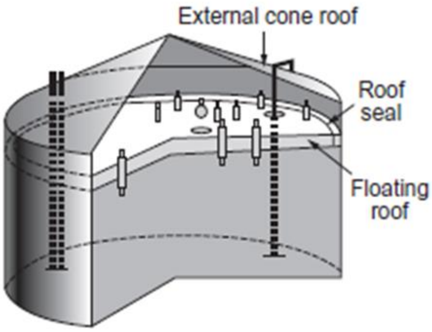

Figure 9 : Internal Floating Roof Tank

Source : https://www.quora.com/Why-do-storage-tanks-have-floating-roofs

2.1.4. External Floating Roof Tank

External floating roof tank consists of a roof which floats on the surface of the liquid, but the roof is exposed to the atmosphere[25]. The roof can be moved up and

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[24] Banker, G. (2018). Storage Tanks, The Engeineer’s Guide to Plant Layout and Piping Design for the Oil and Gas Industries, 361-380.

[25] Ibid

down based on the liquid level. When the liquid level decreased so the roof can be moved down, vice versa. The external floating roof consists of rim seal which prevents the vapours from escaping. This type of storage tank commonly used to store the crude oil because the crude oil is categorized as a liquid that stores low flashpoint.

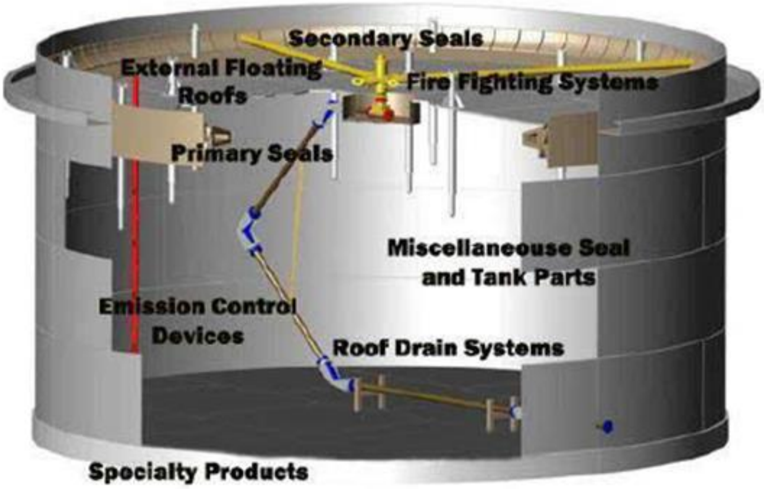

Figure 10 : External Floating Roof Tank
Source : http://www.ansonindustry.com/floating-roof-tank.html

2.1.5. Tank Assess with RBI in PT. X Gresik

There are 40 Aboveground Storage Tanks that located in PT. X Gresik. There are many fluids that stored inside the tank such as ; Butyl Acrlate (BA), Methyl Ethyl Ketone (MEK), Ethyl Acetat (EA), High Speed Diesel (HSD) and etc. There are not only the product oil fluid that stored in this company but also the chemical fluids. The fluid seperated into 40 Aboveground Storage Tanks(ASTs). The Tank that will be done the Risk-Based Inspection for this bachelor thesis is Tank number 21. Tank 21 stored High Speed Diesel with 1500 m3 of volume capacity. For the complete data for the Tank 21 it can be seen in the attachment 3 in this document.

2.2 Inspection

Inspection is an important task to do for storage tank because the equipment stored the combustible, toxic, or chemical liquid. The storage tank should be ready to be operated all the time. Inspection is done to make sure that tank condition is ready to be operated and not get in any trouble that can affect the tank operation. Two kinds of inspections can be done for the tank such as; Inspection Tank Outside and Internal Inspection [16][26].

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[26] API 653 : Tank Inspection, Repair, Alteration, and Reconstruction

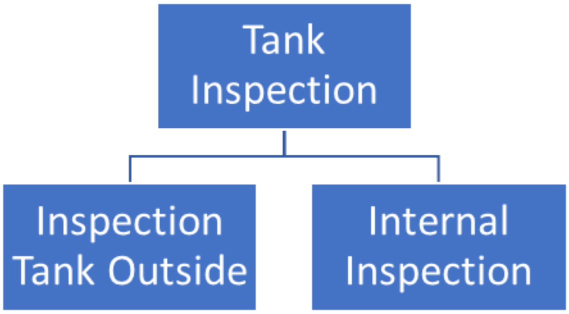

Figure 11 : Inspection Types Based on API 653

Source : Author's Documentation

2.2.1. External Inspection

External inspection is an inspection that done for any storage tank that inspected the tank from the outside. The inspection can be divided more into; Routine In-Service Inspections, External Inspection, Ultrasonic Thickness Inspection, and Cathodic Protection Surveys.

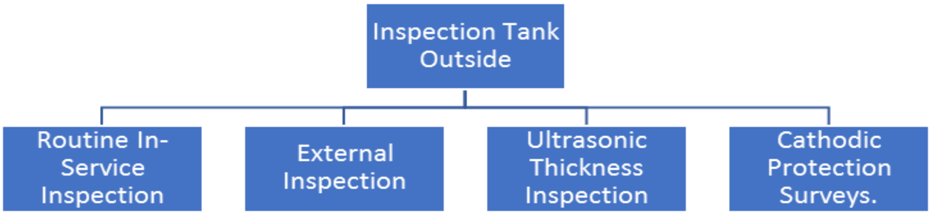

Figure 12 : Inspection Tank Outside Types

Source : Author's Documentation

2.2.1.1. Routine In-Service Inspection

This type of inspection is done by the visual inspection from outside of the tank. The inspection done by the owner or the operator and the inspection should be done routinely and shall not exceed one month[27]. This inspection to make sure there are no leakage, shell distortion, paint coating, and many else that can be inspected visually.

2.2.1.2. External Inspection

External inspection is an inspection done by the authorised inspector that proved by the owner of the tank. The inspection can be done by checking visualised from the tank outside. The tank condition in the inspection time still in the operation condition

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[27] Ibid

or it can be in shut down condition. Not only the tank condition that should be checked in the inspection time but also the tank grounding system components such as cable should be inspected too. The inspection should be done at least once per 5 years.

2.2.1.3. Ultrasonic Thickness Inspection

This inspection type is to determine the remaining thickness of the tank plate. The result from this inspection would be guidelines to determine what should the tank owner did for the tank, is that the tank should do the maintenance process or the tank still can be operated with the remaining thickness. This inspection should be done at least once per 5 years[28].

2.2.1.4 Cathodic Protection Survey

This type of inspection can be done if the cathodic protection system controls the tank bottom corrosion. When the tank not protected with a periodic cathodic system so the owner can pass this type of inspection. The essential things that can affect the inspection result were the inspector. The tank owner should choose the approved inspector to do the inspection[29].

2.2.2. Internal Inspection

The internal inspection can be done if the tank bottom not severely corroded and doesn’t have any leakage. The internal inspection was focused on the tank bottom thickness because most of the tank problems such as leakage and corrosion are in the tank bottom. When the inspection is done, the data that should be collected are tank bottom thickness, corrosion rate, and integrity. The authorised inspector should do this type of inspection. The inspection should be done at least once per 20 years if the corrosion rate is known. When the corrosion rate is not known so the interval of the internal inspection should be done at least once per 10 years[30].

2.3 Regulation for Tank Inspection in Oil and Gas Industry

Some regulations regulated to do the inspection for Oil Storage tank. The regulation made a standard to do the inspection process. The inspection itself is a process to make sure the equipment condition. The regulation that used for the tank inspection such as API 653: Tank Inspection, Repair, Alteration, and Reconstruction for the international regulation that can be applicated in Indonesia and Peraturan Menteri ESDM No. 38 Tahun 2017 for the national regulation.

2.3.1. API 653: Tank Inspection, Repair, Alteration, and Reconstruction

The API 653 was applicable for the tank that used low alloy carbon steel. This regulation just can be applicated when the tank was build following API Standart 650. The inspection part that regulated by this regulation was tank foundation, tank bottom structure, tank shell, tank bottom, tank roof, nozzle to the face of the first flange and the primary welding connection. The regulation also regulated the inspection types

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[28] API 653 : Tank Inspection, Repair, Alteration, and Reconstruction

[29] Ibid

[30] Ibid

that should be done by the owner and the inspector. The inspection time interval also controlled in this regulation.

2.3.2 Peraturan Menteri ESDM No. 38 Tahun 2017

In this national regulation, it regulated that all of the equipment used in the oil and gas industry should be done the inspection and overhaul at least once per 4 years. It was a good regulation, but also there was some lack because not all of the equipment should be done the inspection and overhaul at least once per 4 years. This regulation also regulated that inspection should be done when the equipment before installation, in installation time, after the installation, in operation and conditionally based on the equipment condition.

2.4 Risk-based Inspection

2.4.1 Risk-based Inspection Definition

RBI is a method that used to make a risk ranking for the equipment that included as a pressure vessel that certified and manufactured following the API standard. The RBI method is also to make the inspection planning scheduling and maintenance program that would be done for the equipment. The risk-based inspection is taking from the Probability of Failure (PoF) and Consequence of Failure (CoF). The risk for each equipment in the plan was not always same based on the equipment condition. The condition can be measured with the inspection data record, maintenance data record and operation data record. An effective program then uses risk to identify and prioritise when those uncertainties must be reduced, typically by improved knowledge through additional data [17][31]. The equipment's hazards, risk, financial, and inspection plan are intimately compromised when using RBI method. The risk level was systematically prioritized so that the inspection program can be focused on high-risk equipment, if it is not too high then it can be adjusted. So, it can save resources.

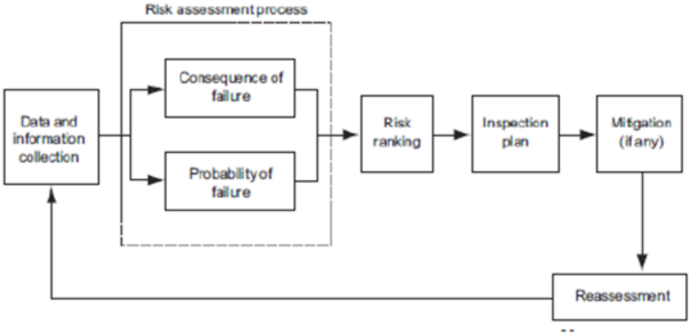

Figure 13 : Risk-based Inspection Planning Process

Source : API RP 580. (2016). Risk-Based Inspection Technology, 3rd Edition. Washington, D.C. : API Publishing Service

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[31] API RP 580. (2016). Risk-Based Inspection Technology, 3rd Edition. Washington, D.C. : API Publishing Service

Process for doing the RBI methodology can be done by following these steps: :

1. RBI is a methodology that uses risk as a first action for prioritising and managing the inspection program and inspection planning, including the recommendations for monitoring and testing.
2. The Probability of Failure (POF) and Consequence of Failure (COF) are assessed separately and then combined to determine the risk of failure level.
3. Then, the risk is compared and prioritised for inspection planning and risk mitigation.
4. Risk mitigation plan may include options in addition to or other than inspection such as changes in materials of construction, the use of corrosion inhibitors, the use of chemical inhibitors, changes in operating condition and fluids, etc.

2.4.2 Risk Defination

Risk is the combination of the probability of some event occurring during a time period of interest and the consequences (generally negative) associated with the event Risk can be determined as probability of failure that can be happened to the equipment during the operation time[32].

2.4.3 Standard & Recommended Practice (RP)

Risk-based Inspection method was described clearly in API 580 and API 581. The two things become based for the engineer to reduce the risk level, calculate the next inspection interval time, and makes the inspection planning that safely for the workers that done the process. API 580 and API 581 is recommended for the equipment that commonly working in the pressurised condition or content the flammable, dangerous and toxic fluid inside it. Usually all of the equipment described above was founded in the Petroleum and Petrochemical Industry.

2.4.3.1. American Petroleum Institute (API) 580: Risk-Based Inspection

API inspection codes and standards give a better solution to the owner/user to plan an inspection strategy and increase or decrease the code designated inspection frequencies and activities based on the results of an RBI assessment. The assessment must systematically evaluate both the POF and COF. The POF assessment should be evaluated by considering all credible damage mechanisms[33]. The use of risk-based methodologies for inspection planning is not compulsory.

RBI guideline issues covered include an introduction to the concepts and principles of RBI for risk management; and individual sections that describe the steps in applying these principles such as :

a) Understanding the design premise;
b) Planning the RBI assessment;
c) Data and information collection;

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[32] API RP 580. 2016. Risk-Based Inspection Technology, 3nd edition

[33] API RP 580. (2009). Risk-Based Inspection, 2nd Edition. Washington, D.C. : API Publishing Service

d) Identifying damage mechanism and failure modes;
e) Assessing the probability of failure (POF);
f) Assessing the consequence of failure (COF);
g) Risk determination, assessment, and management;
h) Risk management with inspection activities and process control;
i) Other risk mitigation activities;
j) Reassessment and uploading;
k) Roles, responsibilities, training, and qualifications;
l) Documentation and recordkeeping.

RBI provides equipment for continuously improving the inspection of facilities and systematically reducing the risk associated with pressure boundary failures. RBI offers the added advantage of identifying gaps or shortcomings in the effectiveness of commercially available inspection technologies and applications. RBI assessment is a team-based process. The data collected will provide the information needed to assess potential damage mechanisms, possible failure modes, and scenarios of failure. Examples of data sources include:

a) design and construction records;
b) inspection and maintenance records;
c) operating and process technology records;
d) hazards analysis and MOC records;
e) materials selection records; corrosion engineering records and library/database

2.4.3.2. American Petroleum Institute (API) 581: Risk-based Inspection Methodology

The calculation of risk in API RBI 581 involves the determination of a probability of failure (POF) combined with the consequence of failure (COF). Risk increases as damage accumulate during in-service operation as the risk tolerance, or risk target is approaching, and an inspection is recommended of sufficient effectiveness to quantify the damage state of the component better. Inspection action does not reduce the risk but minimise uncertainty. Risk is defined as the product of probability and consequence when likelihood and impact are express numerically.

2.4.3.2.1. Probability of Failure (PoF)

Likelihood of an equipment or component failure due to a single damage mechanism or multiple damage mechanisms were occurring under specific operating conditions [18][34].

$$\boldsymbol{P_f\ (t) = gff.D_f\ (t).F_{MS}}$$

Probability of Failure as a function of time $P_f\ (t)$ is determined the product of GFF gff , a damage factor (DF), $D_f\ (t)$, and management systems factor F_{MS}. The Probability of Failure that calculated will be used provide the risk ranking and inspection plan for a component subject to process and environmental condition. Mostly equipment

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[34] API RP 581. (2016). Risk-Based Inspection Methodolgy, 3rd Edition. Washington, D.C. : API Publishing Service

that done the Risk-Based Inspection for calculate the risk ranking used in the refining, exploration and production facilities and petrochemical industry.

There are some methods that can be used to determined the Probability of Failur to calculate the risk using the Risk-Based Inspection such as Structural Reability Models, Statistical Models based on generic data and expert judgement. The Probability of Failure can be determined using one of the methods above or can be combination of it. the combination of this method used to evaluate the Probabiity of Failure in terms of Generic Failure Frequency and Damage Factor. The detail explanation about each method to determine the Probability of Failure describe below.

- Structural reability models – a limit state is defined 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 POF.
- Statistical models based on generic data — generic data is obtained for the component and damage mechanism under evaluation and a statistical model is used to evaluate the POF.
- Expert judgment — expert solicitation is used to evaluate the component and damage mechanism, a POF can be assigned on a relative basis.

2.4.3.2.1.1. Generic Failure Frequency (GFF)

Generic failure Frequency is set at a value representative of the failure data at the refining and petrochemical industry. GFF was intended to be the failure frequency before any specific damage occurring from exposure to the operating environment and was provided for several discrete hole size for equipments such as ; process vessels, drums, towers tankage and etc. If enough data is available for a given component, true probabilities of failure can be calculated from actual observed failures. Even if a failure has not occurred in a component, the true POF is likely to be greater than zero because the component may not have operated long enough to experience a failure. The GFFs are assumed to follow a log-normal distribution, with error rates ranging from 3% to 10%. The overall GFF 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 : Generic Failure Frequency

Equipment Type	Component Type	gff as a function of hole size (failure/yr)				gff total (failure/yr)
		Small	Medium	Large	Rupture	
Tank650	TANK BOTTOM	7,2E-04	0,00E+00	0,00E+00	2,00E-06	7,20E-04
Tank650	COURSE 1-10	7,0E-05	2,50E-05	5,00E-06	1,00E-07	1,00E-04

2.4.3.2.1.2. Management System Factor

The management systems factor, FMS, is an adjustment factor that accounts for the influence of the facility's management system on the mechanical integrity of the plant equipment. The methods include an evaluation tool of the management system and the result will be impact the Probability of Failure of the component that assess with the Risk-Based Inspection method to knowing the risk ranking of the equipment. The evaluation consist of interview with operations, plant management, inspection, maintenance, training, engineering and safety personel. This factor accounts for the probability that accumulating damage that may result in a loss of containment will be discovered before the occurrence.

Management system factor used to measure the facility management system and the labor capability to handle the equipment of the company are in the good quality or not. That's why the the evaluation that happened to measur the management system factor is for all of the division in the company. The measurement should be done to get the exact point of the management system in the company. The American Petroleum Institue (API) and some inspection codes recommended some practices that can be used to determined the management system factor. There are some list that recommended by API that covered the management system evaluatuion. There are some classification of point that should be measured and each of them has different point. Detail of the subjects list from API to calculated the management system factor described belom in table.

Table 2. 3 : Management System Evaluation

Table	Title	Questions	Points
2.A.1	Leadership and Admisntration	6	70
2.A.2	Process Safety Information	20	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 Practice	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 Tables 2.A.1 through 2.A.13 are located in Annex 2.A. API RBI 581 : 2016			

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.

$$pscore = \frac{Score}{1000} . 100 \text{ [unit is } 100\%]$$

Note : Management score must first be converted to a percentage between 0 and 100

$$Fms = 10^{(-0.02 \, . \, pscore+1)}$$

2.4.3.2.1.3. Damage Factor (DF)

Damage Factor is determined based on the applicable damage mechanisms that relevant to the materials of construction and the process service, the physical condition of the component, and the inspection techniques used to quantify the damage. Different component with different fluid inside must has different damage mechanism. Damage is getting from the damage mechanism that applied for tank such as :

1. Thinning Damage Factor
2. Component Lining Damage Factor
3. SCC Damage Factor – Caustic Cracking
4. SCC Damage Factor – Amine Cracking
5. SCC Damage Factor – Sulfide Stress Cracking
6. SCC Damage Factor – HIC / SOHIC – H2S
7. SCC Damage Factor – Alkaline Carbonate Cracking
8. SCC Damage Factor – PTA Cracking
9. SCC Damage Factor – CLSCC
10. SCC Damage Factor – HSC-HF
11. SCC Damage Factor – HIC / SOHIC – HF
12. External Corrosion Damage Factor – Ferritic Component
13. External CLSCC Damage Factor Austenitic Component
14. CUI Damage Factor – Ferritic Component
15. External CUI CLSCC Damage Factor – Austenitic Component
16. HTHA Damage Factor
17. Brittle Damage Factor
18. Temper Embrittlement Damage Factor
19. Embrittlement Damage Factor
20. Sigma Phase Embrittlement Damage Factor
21. Piping Mechanical Fatigue Damage Factor.

Damage factor is a screening tool to determine inspection priorities and optimize inspection efforts and it can’t provide definitive Fitness-For_Service assessment of the component. The twenty-one damage factors have their criteria. Starting the calculation of the probability of failure on a particular component, by doing filtering damage factor, the damage occurs in these components will be known, the screening through component data and on-site observations.

Damage factor basic function is to statistically evaluate the amount of damage as a function of time service and the effectiveness of the inspection. Damage factor not indeed represennt the actual Probability of Failure to calculate the reability analysis. It represent relative level of concern about the component based. If the damage factor has combination or multiple damage mechanism, then the rules and the formulas are as follows:

a)Total damage factor, Df-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 (2.2)** when the thinning is local:

$$D_{f-total} = max\left[D_{f-gov}^{thin}, D_{f-gov}^{extd}\right] + D_{f-gov}^{scc} + D_{f}^{htha} + D_{f-gov}^{brit} + D_{f}^{mfat}$$

If the thinning damage is general, then the total damage factor is given by **Equation (2.3)**:

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{scc} + D_{f}^{htha} + D_{f-gov}^{brit} + D_{f}^{mfat}$$

*****if a damage factor is less than or equal to one, then this damage factor shall be set to zero in the summation.
*****if Df-total is computed as less than or equal to one, then Df-total shall be set equal to one.

b) Governing Thinning Damage Factor, Df−govthin – governing thinning damage factor is determined based on the presence of an internal liner using **Equations (2.4)** and **(2.5)**.

$$D_{f-gov}^{Thin} = \min[D_{f}^{Thin}, D_{f}^{elin}] \quad \textit{when an internal liner is present}$$
$$D_{f-gov}^{Thin} = D_{f}^{Thin} \quad \textit{when an internal liner is not present}$$

c) Governing Stress Corrosion Cracking Damage Factor, $df{-}govSCC$ – The governing stress corrosion cracking damage factor is determined from **Equation (2.6)**.

$$D_{f-gov}^{scc} = MAX\ [D_{f}^{caustic}, D_{f}^{amine}, D_{f}^{scc}, D_{f}^{\frac{HIC}{SOHIC}-H2s},$$
$$D_{f}^{ACSCC}, D_{f}^{PASCC}, D_{f}^{CLSCC}, D_{f}^{HSC-HF}, D_{f}^{\frac{HIC}{SOHIC}-HF}]$$

d) Governing External Damage Factor, df−govextd, governing external damage factor is determined from **Equation (2.7).**

$$D_{f-gov}^{extd} = MAX\ [D_{f}^{extf}, D_{f}^{CUIF}, D_{f}^{ext-CLSCC}, D_{f}^{CUI-CLSCC}]$$

e) Governing Brittle Fracture Damage Factor, $df{-}gvbrit$ The governing brittle fracture damage factor is determined from **Equation (2.8)**.

$$D_{f-gov}^{brit} = MAX\ [(D_{f}^{brit} + D_{f}^{tempe}), D_{f}^{855F}, D_{f}^{sigma}]$$

Table 2. 4 : Damage Factor for Tank 21

No	Damage Factor	Screening Criteria			Yes/No
1.	Thining	All component should be checked for thining			Yes
12.	External Corrosion Damage Factor-Ferritic component	If the component is un-insulated and subject to any of the following , then the component should be evaluated for external damage from corrosion.			YES
		a.	Areas exposed to mist overspray from cooling towers.	Y	
		b.	Areas exposed to steam vents	Y	
		c.	Areas exposed to deluge system	Y	
		d.	Areas subject to process spills, ingress of moisture, or acid vapors.	N	
		e.	Carbon steel system, operatinng between -12°C and 177°C (10°F and 350°F). External corrosion is particulartly aggressive where operating temperatures cause frequent or continuous condensation and re-evaporation of atmospheric moisture. (Operating Temperature is 185.4 °C.	Y	
		f.	Systems that do not operating in normally temperature between -12°C and 177°C (10°F and 350°F) but cool or heat into this range intermitterntly or are subjected to frequent outages.	N	
		g.	Systems with deteoriated coating and/or wrappings.	Y	
		h.	Cold service equipment consistently operating below the atmospheric dew point.	N	

		i.	Un-insulated nozzles or other prostrusions components of insulated equipment in cold service conditions.	N	

2.4.3.2.1.3.1. Thinning Damage Factor

Thinning damage factor can be calculated following some steps below, such as :

- STEP 1 — Determine the furnished thickness, t , and age, age, for the component from the installation date.
- STEP 2 — Determine the corrosion rate for the base material, Crbm , based on the material of construction and process environment, using guidance from Section 4.5.2 and examples in Annex 2.B for establishing corrosion rates. For a component with cladding/weld overlay, the cladding/weld overlay corrosion rate, Cr,cm , must be determined.
- STEP 3 — Determine the time in service, *agetk* , since the last inspection known thickness , trdi . The *trdi* is the starting thickness with respect to wall loss associated with internal corrosion (see Section 4.5.5). If no measured thickness is available, set *trdi = t* and *agetk = age*
- STEP 4 — For cladding/weld overlay pressure vessel components, calculate the age from thedate of the starting thickness from STEP 3 required to corrode away the cldding/ welld overlay material *agerc* using **Equation (2.11)**

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

- STEP 5 — Determine train using one of the following methods:
  1) For cylindrical, spherical or head components, determine the allowable stress, S , weld joint efficiency, E , and calculate the minimum required thickness, *tmin* , 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].
  2) In cases where components are constructed of uncommon shapes or where the component's minimum structural thickness, *tc* , may govern, the user may use the *tc* in lieu of *tmin.*
  3) If the component is a tank bottom, use *tmin* = 0.1 in if the AST does not have a release prevention barrier or *tmin* = 0.05 in if the AST has a release prevention barrier, in accordance with API STD 653 [11].
  4) A specific *tmin* calculated by another method and documented in the asset management program maybe used at the owner-user's discretion
- STEP 6 - Determine the *Art,* parameter using Equation (2.12), (2.13), (2.14) or (2.15), as appropriate, based on t from STEP 1, *Cr,bm* and *Cr,cm* from STEP 2, *agetk* and *trdi* from STEP 3, and the age required to corrode away the cladding/weld overlay, *agerc* , if applicable, from STEP 4. Note that the age parameter in these equations is equal to *agetk* from STEP 3.
  1) For Tank bottom components, calculate the *Art* parameter using equation (2.12) and skip to the STEP 13

$$A_{rt} = \max\left[\left(1-\frac{t_{rdi}-(\,C_{r,}bm\ x\ agetk}{tmin\ -CA}\right), 0.0\right]$$

2) For components without cladding/weld overlay or where the cladding/weld overlay is corroded away at the date of the starting thickness from STEP 2, i.e, *agerc* = 0.0 , use Equation (2.13).

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

- STEP 7 — Calculate the Flow Stress, *FSThin* , using E from STEP 5 and Equation (2.16)

$$FS^{Thin} = \frac{(YS+TS)}{2}.\ \mathrm{E.1,1}$$

- STEP 8 — Calculate the strength ratio parameter, *SRpThin* , using the appropriate Equation (2.17) or (2.18). Using Equation (2.17) with *trdi* from STEP 3, *tmin* or *tc* from STEP 5, S , and E from STEP 5, and flow stress, *FSThin* , from STEP 7

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

Note: The *tmin* 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 *tmin* . Consideration for internal pressure hoop stress alone may not be sufficient. *tc* as defined in STEP 5 should be used when appropriate.

- STEP 9 — 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.
- STEP 10 — 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},

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.

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

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

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

- STEP 11 — Calculate the Posterior Probabilities, $Po_{p1}^{Thin}, Po_{p2}^{Thin}$ and Po_{p3}^{Thin}

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

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

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

- STEP 12 — Calculate the parameters, ß1, ß2, and ß3 using Equation (2.21) and assigning COVA, = 0.20, CO V s f = 0.20 and COVE = 0.05.

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}\,.\,A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S1}}^2.\,{A_{rt}}^2.\,{COV_{\Delta t}}^2+(1-D_{S1}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}\,.\,A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S2}}^2.\,{A_{rt}}^2.\,{COV_{\Delta t}}^2+(1-D_{S2}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}\,.\,A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S3}}^2.\,{A_{rt}}^2.\,{COV_{\Delta t}}^2+(1-D_{S3}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

Where Ds =1, Ds, = 2 and Ds, = 4 . These are the corrosion rate factors for damage states 1, 2 and 3 as as discussed in Section 4.5.3 [35]. Note that the DF calculation is very sensitive to the value used for the coefficient of variance for thickness, COVA, . The COVA, is in the range 0.10 COVA, 0.20, with a recommended conservative value of COVAt = 0.20

- STEP 13 — For tank bottom components, determine the base damage factor for thinning, *Dthin* , using Table 4.8 and based on the *Art* parameter from STEP 6 and Skip to STEP 15.
- STEP 14 — For all components (exclude tank bottom) calculate the base damage factor

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right)+\left(Po_{P2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right)+\left(Po_{P3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E-0.4}$$

Where c is the standard normal cumulative distribution function (NORMSDIST in Excel)

- STEP 15 — Determine the DF for thinning, Lf using Equation (2.23).

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin}.\ F_{IP}\,.\ F_{DL}\,.F_{WD}.\,F_{AM}\,.\,F_{SM})}{F_{OM}}),0.1]$$

2.4.3.2.1.3.2. External Corrosion Damage Factor – Ferritic Component

External Corrosion damage factor – ferritic component can be calculated following some steps below, such as :

- STEP 1 — Determine the furnished thickness, t , and age, age, for the component from the installation date.
- STEP 2 — Determine the base corrosion rate, CB , based on the driver and operating temperature using Table 15.2.
- STEP 3 — Calculate the final corrosion rate, Cr , using Equation (2.34)

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

Adjustment for Equipment Design or Fabrication, FEQ, — If the equipment has a design which allows water to pool and increase metal loss rates, such as piping supported directly on beams, vessel stiffening rings or insulation supports or other such configuration that does not allow water egress and/or does not allow for proper coating maintenance, then Feq = 2 ; otherwise, Feq =1. Adjustment for Interface, Fif — If the piping has an interface where it enters either soil or water, then Fif = 2 ;otherwise, Fif =1

- STEP 4 — Determine the time in-service, *agetk* , since the last known inspection thickness, *trde* (see section 4.5.5. The *trde* is the starting thickness with respect to wall loss associated with external corrosion. If no measured thickness is available, set *trde = t* and *agetk = age*
- STEP 5 — Determine the in-service time, agecoat , since the coating has been installed using Equation (2.35)

$$age_{coat} = Calculation\ Date\ - Coating\ Installation\ Date$$

- STEP 6 — Determine coating adjustment, *Coatadj* , using Equations (2.36) through (2.41).

If *agetk* ≥ *agecoat*

$$Coat_{adj} = 0$$
$$Coat_{adj} = \min[5,\ age_{coat}]$$
$$Coat_{adj} = \min[15,\ age_{coat}]$$

If *agetk* < *agecoat*

$$Coat_{adj} = 0$$
$$Coat_{adj} = \min[5,\ age_{coat}] - \min[5,\ age_{coat} - age_{tk}]$$
$$Coat_{adj} = \min[15,\ age_{coat}] - \min[15,\ age_{coat} - age_{tk}]$$

- STEP 7 — Determine the in-service time, age , over which external corrosion may have occurred using Equation (2.42).

$$age = age_{tk} - Coat_{adj}$$

- STEP 8 — Determine the allowable stress, S , weld joint efficiency, E, and minimum required thickness, *tmin*, per the original construction code or API 579-1/ASME FFS-1 [10]. In cases where components are constructed of uncommon shapes or where the component's minimum structural thickness, *tc* , may govern, the user may use the *tc* in lieu of *tmin* where pressure does not govern the minimum required thickness criteria
- STEP 9 - Determine the A, parameter using Equation (2.43) based on the *age* and *trde* from STEP 4, *Cr* from STEP 3

$$A_{rt} = \frac{Cr.\ agetk}{t_{rde}}$$

- STEP 10 — Calculate the Flow Stress, *FSextcorr* using S from STEP 8 and Equation (2.44)

$$FS^{extcorr} = \frac{(YS+TS)}{2}.\ \mathrm{E.1,1}$$

- STEP 11 — Calculate the strength ratio parameter, SR, Thin , using Equation (2.45)

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

Note: The *tmin* 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 *tmin* . Consideration for internal pressure hoop stress alone may not be sufficient. *tc* as defined in STEP 5 may be used when appropriate.

- STEP 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 (see Section 4.5.5).
- STEP 13 — $I_1^{extcorr}$, $I_2^{extcorr}$, $I_3^{extcorr}$ using Equation (2.47), Prior Probabilities, $Pr_{p1}^{extcorr}$, $Pr_{p2}^{extcorr}$, $Pr_{p3}^{extcorr}$
  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 inspections, $N_A^{extcorr}$, $N_B^{extcorr}$, $N_C^{extcorr}$,$N_D^{extcorr}$ in each effectiveness level obtained from STEP 12.

$$I_1^{extcorr} = Pr_{P1}^{extcorr}\left(Co_{P1}^{extcorrA}\right)^{N_A^{extcorr}}\left(Co_{P1}^{extcorrB}\right)^{N_B^{extcorr}}\left(Co_{P1}^{extcorrC}\right)^{N_C^{extcorr}}\left(Co_{P1}^{extcorrD}\right)^{N_D^{extcott}}$$

$$I_2^{extcorr} = Pr_{P2}^{extcorr}\left(Co_{P2}^{extcorrA}\right)^{N_A^{extcorr}}\left(Co_{P2}^{extcorrB}\right)^{N_B^{extcorr}}\left(Co_{P2}^{extcorrC}\right)^{N_C^{extcorr}}\left(Co_{P2}^{extcorrD}\right)^{N_D^{extcott}}$$

$$I_3^{extcorr} = Pr_{P3}^{extcorr}\left(Co_{P3}^{extcorrA}\right)^{N_A^{extcorr}}\left(Co_{P3}^{extcorrB}\right)^{N_B^{extcorr}}\left(Co_{P3}^{extcorrC}\right)^{N_C^{extcorr}}\left(Co_{P3}^{extcorrD}\right)^{N_D^{extcott}}$$

- STEP 14 — Calculate the Posterior Probabilities,
  $Po_{p1}^{extcorr}$, $Po_{p2}^{extcorr}$, Po_{p3}^{extcor} using Equation (2.48)

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

$$Po_{p2}^{extcorr} = \frac{I_2^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}}$$

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

- STEP 15 — Calculate the parameters, ß1, ß2, and ß3 using Equation (2.49) and COVAt = 0.20 , CO Vsf= 0.20 and COVE = 0.05.

$$\text{ß}_1^{extcorr} = \frac{1-D_{S1}\,.\,A_{rt}-SR_P^{extcorr}}{\sqrt{{D_{S1}}^2.\,{A_{rt}}^2.\,{COV_{\Delta t}}^2+(1-D_{S1}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{extcorr})^2.(COV_P)^2}}$$

$$\text{ß}_2^{extcorr} = \frac{1-D_{S2}\,.\,A_{rt}-SR_P^{extcorr}}{\sqrt{{D_{S2}}^2.\,{A_{rt}}^2.\,{COV_{\Delta t}}^2+(1-D_{S2}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{extcorr})^2.(COV_P)^2}}$$

$$\text{ß}_3^{extcorr} = \frac{1-D_{S3}\,.\,A_{rt}-SR_P^{extcorr}}{\sqrt{{D_{S3}}^2.\,{A_{rt}}^2.\,{COV_{\Delta t}}^2+(1-D_{S3}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{extcorr})^2.(COV_P)^2}}$$

Where Ds =1, Ds, = 2 and Ds, = 4 . These are the corrosion rate factors for damage states 1, 2 and 3 as discussed in 4.5.3 [35]. Note that the DF calculation is very sensitive to the value used for the
coefficient of variance for thickness, COVAt . The COVAt is in the range 0.10 COVAt 0.20, with a recommended conservative value of COVAt = 0.20.

- STEP 16 — Calculate $D_f^{extcorr}$ using Equation (2.50).

$$D_f^{extcor} = [\frac{\left(Po_{P1}^{extcorr}\Phi\left(-\beta_1^{extcorr}\right)\right)+\left(Po_{P2}^{extcorr}\Phi\left(-\beta_2^{extcorr}\right)\right)+\left(Po_{P3}^{extcorr}\Phi\left(-\beta_3^{extcorr}\right)\right)}{1.56E-0.4}$$

Where c is the standard normal cumulative distribution function (NORMSDIST in Excel)

2.4.3.2.1.4. Inspection Effectiveness Category

Damage factors are determined as a function of inspection effectiveness. Inspection effectiveness catagories are example to provide a guideline in assigning actual inspection effectiveness. The effectiveness of the inspection designated time period is characterized of each damage mechanism that happened in the equipment that assess with Risk-Based Inspection.

Number of inspection and effectiveness in each inspection should calculated to determined the damage factor that happened in each equipment. For external corrosion and thinning damage factor the isnpection effectiveness included in the damage factor calculation. If multiple inspections have been performed, equivalent relationships are used for SCC, External Damage and HTHA Inspections of different grades (A, B, C and D) are approximated as equivalent inspection effectiveness 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

2.4.3.2.2. Consequences of Failure (CoF)

Consequences of Failure is Loss of containment of hazardous fluids from pressurised processing equipment may result in damage to surrounding equipment, severe injury to personnel, production losses, and undesirable environmental impacts. Consequences of Failure is use to determine the risk ranking and inspection plan for a component that used in the refining, petrochemical and exploration & production facilities. On the API 581 there is two levels of CoF such as level 1 that used for listed dangerous liquid and level 2 more rigorous and can be applied for the broader range of hazardous liquid. There are some special method to calculate the Consequences of Failure for the Aboveground Storage Tank that provide in API 581.

2.4.3.2.2.1. Consequences Catagories

The consequence categories are analyzed using different techniques such as :

a) **Flammable and explosive consequence**
The consequences 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 determined based on the area affected by the release.

b) **Toxic consequence**
The consequences 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 determined based on the area affected by the release.

c) **Non-flammable, non-toxic**
The consequences releases are considered since they can still result in serious consequences. Consequence from chemical splashes and high temperature steam bums are determined based on serious injuries to personnel. Physical explosions and Boiling Liquid Expanding Vapor Explosions (BLEVE) can also cause serious personnel injuries and component damage.

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

2.4.3.2.2.2. Consequences Analysis Level 1

The Level 1 consequence analysis can be performed for a defined list of representative fluids. This methodology can be used to calculate the consequence of releases without the need of specialized modeling software or techniques. There are some assuption that made for the level 1 Consequences analysis such as :

a) The fluid phase upon release can be 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 releases.

b) Fluid properties for representative fluids containing mixtures are based on average values (e.g., MW, NBP, density, specific heats, AIT).

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, that is, totally independent of the release rate.

d) The effects of BLEVEs are not included in the assessment.
e) The effects of pressurized non-flammable explosions, such as those possible when non-flammable pressurized gases (e.g., air or nitrogen) are released during a vessel rupture, are not included in the assessment.
f) Meteorological conditions were assumed and used in the dispersion calculations that form the basis for the consequence analysis table lookup (see Annex 3.A).
g) Consequence areas do not consider the release of a toxic product during a combustion reaction (e.g. burning chlorinated hydrocarbons producing phosgene; hydrochloric acid producing chlorine gas; amines producing hydrogen cyanide; sulfur producing sulfur dioxide.

2.4.3.2.2.3. Consequences Analysis Level 2

Level 2 consequence analysis is used in cases where the assumptions of the Level 1 consequence analysis are not valid. Examples of where the more rigorous calculations are desired or necessary are :
a) The specific fluid is not represented adequately within the list of reference fluid groups provided, including cases where the fluid is a wide-range boiling mixture or where the fluids toxic consequence is 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 BLEVEsS are to be included in the assessment.
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.
f) The meteorological assumptions (see Annex 3.A) used in the dispersion calculations (that form the basis for the Level 1 consequence analysis table lookups) do not represent the site data.

2.4.3.2.2.4. Consequence of Failure — Atmospheric Storage Tanks

Consequences of Failure for AST Bottom component Calculations are performed for financial COF only based on environmental consequences, component damage cost and business interruption cost. AST consequence analysis for flammable and/or explosive or toxic are not provided in the methodology. Consequences of Failure for AST Shell Calculations are performed for both area and financial-based methods. But in this bachelor thesis about Risk-Based Inspection for Atmospheric Storage Tank (AST) doesn’t calculated the consequences analysis for the financial consequences. The Consequences of Failure for the AST can be calculated following some steps such as :

- **Calculation of Fluid Seepage Velocity for AST Bottom**
  - STEP 1.1 — If a Level 1 analysis is being performed, select a representative fluid from Table 6.1 to be used in the analysis.
  - STEP 1.2 — Determine properties including density, and dynamic viscosity, of the stored fluid. If a representative fluid is being used, these properties can be obtained in Table 6.1.
  - STEP 1.3 — Calculate the hydraulic conductivity for water by averaging the upper and lower bound hydraulic conductivities provided in Table 6.2 for the soil type selected using Equation (3.207).

$$k_{h,water} = C_{31}\left(\frac{k_{h,water-lb} + k_{h,water-ub}}{2}\right)$$

  - STEP 1.4 — Calculate the fluid hydraulic conductivity, *kh,prod* , for the fluid stored in the AST using Equation (3.205) based on the density, and dynamic viscosity, from STEP 1.2 and the hydraulic conductivity for water, *kh,water* ' from STEP 1.3.

$$k_{h,prod} = k_{h,water}\left(\frac{\rho_l}{\rho_w}\right)\left(\frac{\pi_w}{\pi_l}\right)$$

  - STEP 1.5 — Calculate the product seepage velocity, vekprod , for the fluid stored in the AST using Equation (3.206) based on fluid hydraulic conductivity, kh,prod , from STEP 1.4 and the soil porosity provided in Table 6.2

$$vel_{s,prod} = \left(\frac{k_{h,prod}}{P_s}\right)$$

- **Release Hole Size Selection**
  - STEP 2.1 — Determine the release hole size, dn , from Table 6.3 for AST shell courses and from Table 6.4 for AST bottoms.
  - STEP 2.2 — Determine the generic failure frequency, gffn , for the nthrelease hole size and the total generic failure frequency from Part 2, Table 3.1 or from Equation (3.208).

- **Release Rate Calculation**
  - **For Tank Shell**
  - STEP 3.1 — For each release hole size, determine the height of the liquid, above the release hole size,
  - STEP 3.2 — For each release hole size, determine the hole area, An , using Equation (3.213).

$$An = \frac{\pi dn^2}{4}$$

  - STEP 3.3 - Determine the liquid height above the shell course where *hliq* is the maximum fill height in the tank and CHT is the height of each shell course.

$$L\,H\,T_{above,i} = [\,h_{liq} - (\,i - 1\,)\,C\,H\,T\,]$$

  - STEP 3.4 - For each release hole size, determine the flow rate, Wn , using Equation (3.209)

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

- **For Tank Bottom**
- STEP 3.1 - For each release hole size, determine the number of release holes, from Table 6.5.
- STEP 3.2 - Determine the hydraulic conductivity of the stored liquid, *khprod* , from STEP 1.4.
- STEP 3.3 - For each release hole size, determine the flow rate, Wn , using Equation (3.210) or Equation (3.211), as applicable. The liquid height, hug , to use in this calculation is determined as follows:
  1) The AST has an RPB: hug = 0.0762 m [.25 ft]
  2) The AST does not have an RPB: hug = Actual Product Height

- **Estimate the Inventory Volume and Mass Available for Release**
- **For tank shell**
- STEP 4.1 - Determine the liquid height above the shell course where is the maximum fill height in the tank and CHT is the height of each shell course.

$$L\,H\,T_{above,i} = [\,h_{liq} - (\,i - 1\,)\,C\,H\,T\,]$$

- STEP 4.2 - Determine the volume above the course in question

$$Lvol_{above,i} = \left(\frac{\pi D_{tank}^{2}}{4}\right) x\, LHT_{above,i}$$

- STEP 4.3 - For each release hole size, determine the location of the hole on the AST shell. Based on this location, determine the available volume of the release. Note that the release hole should be assumed to be at the bottom of the course.

$$Lvol_{avail,n} = Lvol_{above,i}$$

- STEP 4.4 - Calculate the AST volume in barrels using Equation (3.217)

$$BBl_{avail,n} = Lvol_{avail,n\,x}\ C_{13}$$

- STEP 4.5 - Calculate the AST mass using from Table 6.1 and using Equation (3.218).

$$Mass_{avail,n} = Lvol_{avail,n\,x}\,\rho_l$$

- **For tank bottom**
- STEP 4.1 — Calculate liquid volume in the AST in m3 (ft3) using Equation (3.219)

$$Lvol_{total} = \left(\frac{\pi D_{tank}^{2}}{4}\right) x\, h_{liq}$$

- STEP 4.2 — Calculate the total AST volume in barrels using Equation (3.220).

$$BBl_{total} = Lvol_{total\,x}\ C_{13}$$

- STEP 4.3 — Calculate the AST mass using Equation (3.221)

$$Mass_{total} = Lvol_{total\,x}\,\rho_l$$

- **Determine the Type of Release**

  The type of release for the AST shell and the AST bottom is assumed to be continuous

- **Estimate the Impact of Detection and Isolation Systems on Release Magnitude**

  Detection and isolation systems are not accounted for in the AST consequence analysis

- **Determine the Release Rate and Volume for the Consequence of Failure Analysis**
  - **For Tank Shell**
  - STEP 7.1 — For each release hole size, determine the release rate, raten , in bbls/day using Equation (3.222) where the release rate, Wn , is from STEP 3.3.

$$Rate_n = W_n$$

  - STEP 7.2 — Determine the leak detection time, as follows:

$$t_{ld} = 7\ days\ \ for\ d_n \leq 3.17mm\ [0.125\ in]$$, or

$$t_{ld} = 1\ days\ \ for\ d_n > 3.17mm\ [0.125\ in]$$

  - STEP 7.3 — For each release hole size, calculate the leak duration, Idn , of the release using Equation (3.223) based on the release rate, raten , from STEP 7.1, the leak detection time, tld , from STEP 7.2, and the AST volume, Bbl , from STEP 4.4.

$$ld_n = \min[\left(\frac{Bbl_{avail,n}}{rate_n}\right),\ 7\ days\ ]$$

  - STEP 7.4 — For each release hole size, calculate the release volume from leakage using equation (3.224) based on the release rate from STEP 7.1, the leak duration from STEP 7.3, available volume from step 4.4

$$Bbl_n^{leak} = \min[\,(rate_n\ x\ Id_n),\ Bbl_{avail,n}]$$

  - STEP 7.5 — For each release hole size, calculate the release mass from leakage, using Equation (3.235) based on the available volume, from STEP 7.4

$$mass_n^{leak} = Bbl_n^{leak}$$

  - STEP 7.6 — For each release hole size, calculate the release volume from rupture, using Equation (3.226) based on the available volume, from STEP 4.4

$$Bbl_n^{rupture} = Bbl_{avail,n}$$

  - STEP 7.7 — For each release hole size, calculate the mass from rupture using equation (3.277) based on the available mass from STEP 7.6

$$mass_n^{rupture} = Bbl_n^{rupture}$$

  - **For Tank Bottom**

  - STEP 7.1 — For each release hole size, determine the release rate, raters , using Equation (3.222) where the release rate, Wn , is from STEP 3.5

$$Rate_n = W_n$$

  - STEP 7.2 — Determine the leak detection time, tid , as follows:
    1) tld = 7 days for a AST on a concrete or asphalt foundation, or
    2) tld = 30 days for a AST with a RPB, or
    3) tid = 360 days for a AST without a RPB.
  - STEP 7.3 — For each release hole size, calculate the leak duration, ldn , of the release using Equation (3.228) based on the release rate, raters , from STEP 7.1, the leak detection time, tid , from STEP 7.2, and the total volume, from STEP 4.2

$$ld_n = \min[\left(\frac{Bbl_{total}}{rate_n}\right),\ t_{Id}]$$

- STEP 7.4 — For each release hole size, calculate the release volume from leakage, using equation (3.229) based on the release rate from STEP 7.1, the leak duration from STEP 7.3 and the total volume from STEP 4.2

$$Bbl_n^{leak} = \min[\,(rate_n \; x \; Id_n),\; Bbl_{total}]$$

- STEP 7.5 — For each release hole size, calculate the release volume from a rupture, using Equation (3.230) based on the total volume, from STEP 4.2

$$Bbl_n^{rupture} = Bbl_{total}$$

- **Determine Flammable and Explosive Consequences for AST Shell Courses**

  The Flammable and explosive consequences for AST Shell course is same as like the flammable and explosive consequences analysis level 1. The Flammable and Explosive Consequences for AST Shell can be calculated following some steps, such as :

- STEP 8.1 — Select the consequence area mitigation reduction factor, factmit , from Table 4.10
- STEP 8.2 — For each release hole size, calculate the energy efficiency correction factor, eneffn , using Equation (3.18).

$$eneff_n = 4.\,log_{10}[C_{4A}\;.\;mass_n] - 15$$

- STEP 8.3 — Determine the fluid type, either TYPE 0 or TYPE 1 from Table 4.1.

- STEP 8.4 — For each release hole size, calculate the component damage consequence areas for Auto-ignition Not Likely, Continuous Release (AINL-CONT

$$\alpha = \alpha_{cmd,n}^{AINL-CONT}$$

$$b = b_{cmd}^{AINL-CONT} \qquad CA_{cmd,n}^{AINL-CONT} = \alpha(rate_n)^b\;.\;(1 - fact_{mit})$$

- STEP 8.5 — For each release hole size, calculate the component damage consequence areas for Auto-ignition Likely, Continuous Release (AIL-CONT),

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

- STEP 8.6 — For each release hole size, calculate the component damage consequence areas for Auto-ignition Not Likely, Instantaneous Release (AINL-INST),

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

- STEP 8.7 — For each release hole size, calculate the component damage consequence areas for Auto-ignition Likely, Instantaneous Release (AIL-INST)

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

- STEP 8.8 — For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Not Likely, Continuous Release (AINL-CONT)

$$CA_{inj,n}^{AINL-CONT} = [\alpha.\,(rate_n^{AINL-CONT})^b].\,(1 - fact_{mit})$$

- STEP 8.9 — For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Likely, Continuous Release (AIL-CONT)

$$CA_{inj,n}^{AIL-CONT} = [\alpha.\,(rate_n^{AIL-CONT})^b].\,(1 - fact_{mit})$$

- STEP 8.10 — For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Not Likely, Instantaneous Release (AINL-INST)

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

- STEP 8.11 — For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Likely, Instantaneous Release (AIL-INST),

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

- STEP 8.12 — For each release hole size, calculate the instantaneous/continuous blending factor, factic using Equation (3.19), (3.20), or (3.21), as applicable

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

- STEP 8.13 — Calculate the AIT blending factor, fact , using Equations (3.24), (3.25), or (3.26), as applicable.
- STEP 8.14 — Calculate the continuous/instantaneous blended consequence areas for the component using Equations (3.53) through (3.56) based on the consequence areas calculated in STEPs 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 8.10 and 8.11, and the continuous/instantaneous blending factor, from STEP 8.12

$$CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST}.fact_n^{IC} + CA_{cmd,n}^{AIL-CONT}.(1-fact_n^{IC})$$

$$CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST}.fact_n^{IC} + CA_{inj,n}^{AIL-CONT}.(1-fact_n^{IC})$$

$$CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST}.fact_n^{IC} + CA_{cmd,n}^{AINL-CONT}.(1-fact_n^{IC})$$

$$CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST}.fact_n^{IC} + CA_{inj,n}^{AINL-CONT}.(1-fact_n^{IC})$$

- STEP 8.15 — Calculate the AIT blended consequence areas for the component using Equations (3.57) and (3.58) based on the consequence areas determined in STEP 8.14 and the AIT blending factors, fact` calculated in STEP 8.13. The resulting consequence areas are the component damage and personnel injury flammable consequence areas, for each release hole sizes selected in STEP 2.2.

$$CA_{cmd,n}^{flam} = CA_{smd,n}^{AIL}.fact^{AIT} + CA_{cmd,n}^{AINL}.(1-fact^{AIT})$$

$$CA_{inj,n}^{flam} = CA_{inj,n}^{flam-AIL}.fact^{AIT} + CA_{inj,n}^{AINL}.(1-fact^{AIT})$$

- STEP 8.16 — Determine the final consequence areas (probability weighted on release hole size) forcomponent damage and personnel injury using Equations (3.59) and (3.60) based on the consequence areas from STEP 8.15.

$$CA_{cmd}^{flam} = \left(\frac{\sum gff_n \cdot CA_{cmd,n}^{flam}}{gff_{total}}\right) \quad CA_{inj}^{flam} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{flam}}{gff_{total}}\right)$$

- **Determine Toxic Consequences for AST Shell Courses**

  Because of the fluid that stored inside the tank is not catagorized as toxic fluid so the value becomes 0

- **Determine Non-Flammable, Non-Toxic Consequences**

  Non-Flammable, Non-Toxic consequences are not determined for ASTs.

- **Determine Component Damage and Personnel Injury Consequences for AST Shell Courses**
  - STEP 11.1 - Calculation the final component damage consequences area

$$CA_{cmd} = CA_{cmd}^{flam} + \max\left[psafe.CA_{cmd}^{safe}\ ,\ CA_{cmd}^{nfnt}\right]$$

  - STEP 11.2 - Calculation the final personel injury consequences area

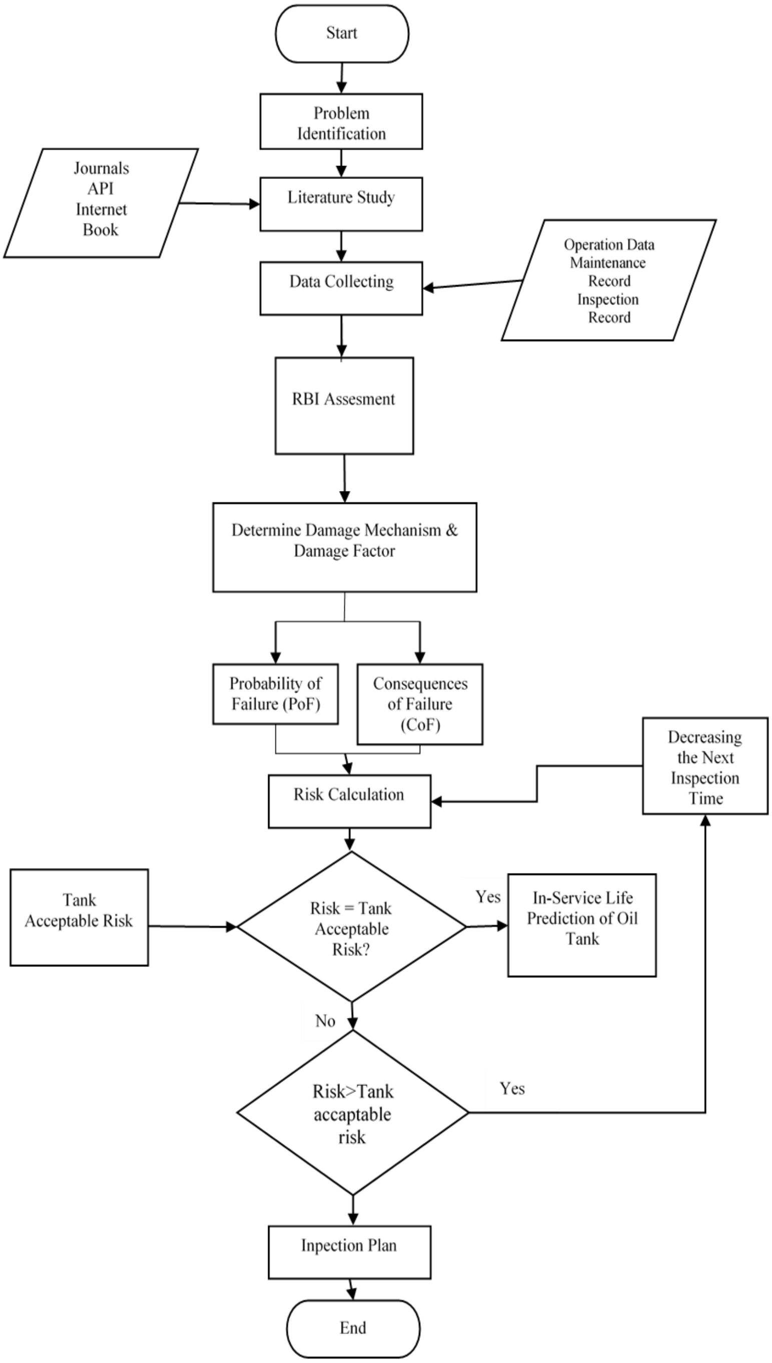
$$CA_{inj} = CA_{inj}^{flam} + \max\left[psafe\ .\ CA_{inj}^{safe},\ CA_{inj}^{tox}\ ,\ CA_{inj}^{nfnt}\right]$$

  - STEP 11.3 - Calculation the final consequences are

$$CA = \max\left[CA_{cmd}\ ,\ CA_{inj}\right]$$

CHAPTER III

Methodology



3.1. Problem Identification

Problem identification is a process that should be done before doing the assessment to the equipment with a methodology. The problem should be identified and think for the worst case when the failure happen to the equipment. After knowing the problem, it should be think about the effect when the failure happen. Next step is identified the mitigation process with one of the methodology that commonly used to prevent the accident happen. It can be completed with literature study to make a good decision to choose the methodology to applied to the problem that happened before.

3.2. Literature Study

Table 3. 1 : Literature Study Result

References	Result
Company Database about the tank, and tank inspection data record	Used as a reference to do the research for this Bachelor Thesis that help as the reference.
Textbook: International Journal of Petroleum and Petrochemical Industry	Additional reference to order the for literature study.
Guidelines : API 580 API 581 API 653 API 650	Recommended Practice (RP) which provides guidelines to order minimum program requirements to qualify for establishing inspection intervals based on Risk-Based Inspection (RBI) analysis and provides additional suggested guidelines on risk analysis to develop an effective inspection plan.
Internet Reference	Giving additional information about pressure vessel Process storage tank and Corrosion
Discussion with the company supervisor	Storage tank that owned by PT. X was a storage tank that stored tank from the ship before distributed to the customer by truck
Discussion with the bachelor thesis supervisor	The analysis of storage tank tends to be a corrosive pressure vessel because of its function.

A literature study is a process to understand the problem from the book, journal, and any reference that can increase the knowledge to solve the existing problem that chosen before. The literature review can be for the oil and gas industry, the method to solve the problem, how come the problem can exist, and how does the problem solving using the method that chosen. Not only from the book and journal but also we needed to study the data that given form the company such as like PI&D, PFD and many more that the data were a secret data for each company so we should also discuss with the supervisor that lead us in the company. All of the steps were described in table 3.1 about the literature study result

3.3. Collecting Data

Collecting data on the research component was carried out at PT X in Gresik Data required in this Bachelor Thesis research as followed below:

- PID and PFD of Process oil storage tank
- Data Sheet about Process to store the oil
- Heat material Balance (HMB) for the oil storage tank
- Safety Plan of the fuel stored in the oil depot
- Corrosion study report
- Chemical Composition Data for the fluid stored inside the tank

The collected data next will be processed as it meant to be to determine the probability of failure and consequence of failure in order the inspection program can be done correctly and the scheduling of inspection planning can be run in the right time before the plant is shut down.

3.4. Data Processing

All of data processing was based on Recommended Practice API 581 which provides a basis for managing risk by calculating the likelihood of each equipment that covered to help the making decision process on inspection frequency level of detail and types of Non-Destructive Examination (NDE). The calculation needed is consisted of POF calculation, COF calculation, and risk analysis. After that, the inspection planning program can be determined.

3.5. Calculating Probability of Failure (PoF)

The methods for calculating the Probability of Failure (POF) for pressure vessel (Aboveground Storage Tank) are covered in Recommended Practice API 581 Part 2. The POF is based on the component type and damage mechanisms present referred on:

- The process fluid characteristics
- Design conditions
- Materials of construction
- the original construction code

POF is as a function of time and inspection effectiveness is determined using a generic failure frequency, factor management system, and DFs for the applicable active damage mechanisms.

3.6. Calculating Consequences of Failure (CoF)

The method for calculating the Consequences of Failure can be determined by 2 methods such as :

- Level 1 Consequences Analysis
- Level 2 Consequences Analysis

But there are some special Consequences of Failure for the Atmospheric Storage Tank (AST). It has different calculation compare with the 2 other methods. But some of the calculation is come from level 1 consequences analysis or level 2 consequences analysis too. There are two types of consequences area that can be calculated with the Consequences of Failur method such as ; consequences area for the component damage and consequences area for the personel injury.

3.7. Data Processing

The methodology for calculating the Consequence of Failure (COF) for pressure vessel (Aboveground Storage Tank) are covered in Recommended Practice API

581 Part 3. The COF methodology is performed to aid in establishing a ranking of equipment items on the basis of risk and also intended to be used for establishing priorities for inspection programs. In this RBI case, the author has implemented the calculation consequence area procedure of pressure vessel or Aboveground Storage Tank owned by PT X. As described in the API Recommended Practice 581, there are two kinds of COF levels namely Level 1 and Level 2 which has different application of fluid characteristics one and another. In this Consequence Area calculation of Process Gas Piping is used Level 1 of COF because the major fluids contain inside the pressure vessel has been defined in a list of representative fluids provides by the API RP 581 itself.

3.8. Risk Result

Result here means that the calculation of storage tank risk was done. The calculation was done for all of the storage tanks owned by PT. X. in Gresik. The tanks included tank that stored the petroleum product and chemical product. If the risk calculation from the tank didn’t reach the risk target so the inspection for the tank can be pended. The calculation for the tank that has higher risk calculation compared with the risk target should be done the inspection immediately. After all count is done, the inspection planning program can be planned.

3.9. Inspection Plan

After calculating both of Probability of Failure (POF) and Consequence of Failure (COF), the result can be determined. If the result is accepted, the we can continue to do the inspection planning using the right methodology of maintenance. In the other hand, if the result is denied, so, we have to do some mitigation step which requires to re-calculate both POF and COF until result is entirely accepted. Type of the Damage. This type of damage can be seen in Recommended Practice API 581. The opportunity for Non-Destructive Evaluation (NDE) methods to identify the damage Maximum interval as specified in the code and standards

3.10. Result

The final stage is decision making from the result of comparative inspections that have been applied to the relevant company. In the last step, conclusion will be drawn from this final project analysis. At this stage comment and suggestion can be formulated and used as references for further decision making.

CHAPTER 4

DATA ANALYSIS AND DISCUSSION

4.1. Atmospheric Storage Tank Data

Doing the Risk-Based Inspection (RBI) calculation needs several bundles of data based on the American Petroleum Institution (API) 580 which are design and construction of the Production Atmospheric Storage Tank (AST) (PFD and P&ID), Atmospheric Storage Tank (AST) operating conditions, Heat Material Balance (HMB), Chemical Composition Data of the Atmospheric Storage Tank (AST), inspection report of the Atmospheric Storage Tank (AST), and many more. Those data will be processed and referred to the steps and formulation contained in the API 581 both for Probability of Failure (POF) and Consequence of Failure (COF). Here are the detail explanation about analyzed data:

4.1.1. General Data

General Data is the data containing basic information and general specification about the Atmospheric Storage Tank (AST) starting from its Tag Number, Quantity, Service, Serial Number, Manufacturer, Type of the pressure Vessel, Geometry Data, and the Code of the Atmospheric Storage Tank (AST) which is referred to the ASTM 283 grade C. The data for the corrosion rate little bit unvalid that used to calculate the Risk-Based Inspection because it used the corrosion rate of one tank. In the real condition there are no way for each tank shell course has same corrosion rate.

Table 4. 1 : Tank 21 General Specification

GENERAL SPECIFICATION	
Tag Number	TANK 21
Quality	1
Service	Storage Tank
Serial No.	-
Manufactured by	PT. Cahaya Hidup Primakarya
Type of Pressure Vessel	Vertical
	Aboveground Storage Tank
Building Code	API STD 650 : Welded Steel Tank for Oil Storage, Eleventh Edition June 2007
Inspection Code	API STD 653 : Tank Inspection, Repair, Alteration and Reconstruction Third Edition, September 2003
Design Pressure	101 kPa
Design Temperature	60 °C

Table 4. 2 : Tank 21 General Specification

GENERAL SPECIFICATION	
Operating Pressure	98 kPa
Operating Temperature	30 °C
Vessel Volume	1500 m^3
Joint Effeciency	0,85 mm
Corrosion Allowance	1,5 mm
Year Built	2008
Material	ASTM 283 Grade C
Last Inspection	July 123th 2018
Allowable stress	136999 kPa
Yield Strength	205000 kPa
Tensile Strenth	380000 kPa
Shell 1-3 thickness	8 mm
Shell 4-6 Thickness	6 mm
Bottom Thickness	8 mm
Tank Diameter	13,5 m
Tank Height	10,5 m
Shell 1-5 Height	1,828 m
Shell 6 Height	1,54 m

Table 4. 3 : Tank 21 General Specification

GENERAL SPECIFICATION	
Fluid Inside	High Speed Diesel (HSD)
Corrosion Rate	0,167 mm/year

The corrosion rate data for this tank is the corrosion rate for the whole tank. In the reality the corrosion of each shell course should be different. It can be happened because the tank not always in the fuel condition. It will be effected the POF calculation.

4.1.2. Operating Condition

Operating conditions are set of conditions for operating a particular system or process, in this case the will be reach when the Atmospheric Storage Tank (AST) is being operated. This set of data is containing operating pressure, operating temperature, Maximum Allowable Working Pressure (MAWP), Corrosion Allowance, Vessel Volume, and so on. In this case, the operating condition is explained deeper both in the shell and bottom of the Atmospheric Storage Tank (AST).

4.1.3. Material Data

Material is the basic component metal ingredients used to build the Atmospheric Storage Tank (AST) based on the several factors and considerations. In PT.”X” that located in Gresik, the material that used to make the Atmospheric Storage Tank (AST) is ASTM 283 grade C.

4.2. Risk Analysis

4.2.1 Probability of Failure (PoF)

Probability of Failure as a function of time is determined the product of GFF gff , a damage factor (DF), and management systems factor. The Probability of Failure that calculated will be used provide the risk ranking and inspection plan for a component subject to process and environmental condition. Mostly equipment that done the Risk-Based Inspection for calculate the risk ranking used in the refining, exploration and production facilities and petrochemical industry.

4.2.1.1. Analysis Thinning Damage Factor

Thinning damage factor can be determined as a damage factor that shoould be included into every RBI calculation for every equipment. It is because in API 581 required to calculate thinning damage factor in every calculation of RBI. Thinning damage factor can be determined following some steps that provides by API 581 such as :

1. **Determining the furnished thickness, t, and age for the component from the installation date.**

Table 4. 4 : Installation & RBI date

Installation Date	23/07/2008
RBI Date	29/10/2019

The component age can be determine from the installation date until the RBI date so the component age = 11,266 years

Table 4. 5 : Furnished Thickness

Furnished Thickness		
Component	Thickness	Unit
Bottom	8	mm
Shell 1	8	mm
Shell 2	8	mm
Shell 3	8	mm
Shell 4	6	mm
Shell 5	6	mm
Shell 6	6	mm

Based on the installation data the components thickness are determined like in the table above.
For detail explanation it can be seen on Attachment 6

2. **Determining the corrosion rate for base material, Cr,bm based on the materia**l construction and environment, and cladding/weld overlay corrosion rate, Cr,cm.

Table 4. 6 : Tank Corrosion Rate

Corrosion Rate	0,167	mm/year

The corrosion rate used for the Risk-Based Inspection calculation for Tank 21 in PT. X Gresik was obtained from inspection data that has been done before for the thickness measurement. This Corrosion rate applied for all of the components in the Tank 21 from Tank Bottom, Tank Shell 1, Tank Shell 2, Tank Shell 3, Tank Shell 4, Tank Shel 5 and Tank Shell 6.
For detail calculation it can be seen on Attachment 6

3. **Determine the time in service, *agetk*, since the last known inspection, *trdi*.**

Table 4. 7 : Last Inspection, RBI, & Planned Date

Last Inspection Date	23/07/2008
RBI Date	29/20/2019
Planned Date	28/06/2022

The *agetk* for all components in Tank 21 can be determined from the last inspection date data and RBI date data. **The *agetk* = 1,268 years.**

Not only calculated the *agetk* but also it should be calculate the *agepd* too. The *agepd* is the time that calculated from the last inspection date data and the planned date data for the next inspection from the company. **The *agepd* = 3,932 years**

Table 4. 8 : Last Inspection Thickness

trdi		
Component	**Thickness**	**Unit**
Tank Bottom	6,96	mm
Tank Shell 1	6,96	mm
Tank Shell 2	7,68	mm
Tank Shell 3	7,71	mm
Tank Shell 4	5,72	mm
Tank Shell 5	5,86	mm
Tank Shell 6	5,72	mm

The *trdi* is the thickness of each component of the Tank 21 in the last inspection date. The result of *trdi* for each component in Tank 21 is given in the table above. For detail calculation it can be seen on Attachment 6

4. **Calculate the age from the date starting thickness** from STEP 3 required to corrode away the cladding/weld overlay material, *agerc*, only for the cladding/weld overlay pressure vessel components,

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

The calculation to determine the age of cladding/weld overlay material didn’t used in this Risk-Based Inspection assessment for Tank 21 because there are no cladding/weld overlay material.

For detail calculation it can be seen on Attachment 6

5. **Determine the minimum thickness of each component *tmin***
   Actually there are 4 methods used to determine the minimum thickness of the equipment (*tmin*). Based on the condition, the method used by the author is the fourth method which is specific *tmin* calculated by another method and documented in the asset management program may be used at the owner-user's direction.

   The tank's owner used the API 653 Standart for Tank Inspection, Repair , Alteration and Reconstruction Third Edition December 2001 to determine the *tmin* of each tank shell for the Tank 21. Based on the API 653 STD, the calculation use equation below ;

$$tmin = \frac{2{,}6\ (H-1)DG}{SE}$$

   The equiation to determine *tmin* is for tank that has diameter under 200 ft. The requiered minimum thickness for each component is 2,54 mm or 0,1 inch.

   The minimum thickness tmin for the tank bottom determined in API 581 STD divided into two catagorizes : with release prevention barrier or without release prevention barrier. When the tank bottom is have release prevention barrier so the tmin = 0,05 inch or 1,27 mm. When the tank bottom doesn't have release prevention barrier so the tmin = 0,1 inch or 2,54 mm. Because of the Tank 21 bottom have a release prevention barrier so the tmin = 1,27 mm

Table 4. 9 : Minimum Thickness

tmin		
Component	**Thickness**	**Unit**
Tank Bottom	1,27	mm
Tank Shell 1	3,52	mm
Tank Shell 2	2,92	mm
Tank Shell 3	2,54	mm
Tank Shell 4	2,54	mm
Tank Shell 5	2,54	mm
Tank Shell 6	2,54	mm

For detail calculation it can be seen on Attachment 6

6. **Determine the component wall loss fraction sice the last inspection thicknesss measurement or service date**
   The component wall loss fraction for the tank bottom can be determined with the equation below ;

$$A_{rt} = \max\left[\left(1 - \frac{t_{rdi} - (C_{r,bm}\ x\ agetk}{tmin\ - CA}\right), 0.0\right]$$

The component wall loss fraction for the tank shell can be determine with the equation below because the component is without cladding/weld overlay *agerc* = 0.

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{tk}}{t_{rdi}}$$

The component wall loss fraction should be determind in the two periode of time such as at the RBI date and at planned date. The equation is same, when the calculation is at the RBI date so, the age use the *agetk.* When the calculation at the planned date so, the age use the *agepd* .

Table 4. 10 : Component Wall Loss Fraction

Art		
Component	**At RBI Date**	**At Planned Date**
Tank Bottom	0	0
Tank Shell 1	0,030415713	0,094334694
Tank Shell 2	0,02756424	0,085490817
Tank Shell 3	0,027456986	0,085158168
Tank Shell 4	0,037009329	0,114784873
Tank Shell 5	0,036125147	0,112042572
Tank Shell 6	0,037009329	0,114784873

For the tank bottom component after get the Art value, it skip to the STEP 13
For detail calculation it can be seen on Attachment 6

7. **Determine the Flow Stress**

Calculation for the flow stress for the thinning damage factor for each component in Tank 21 using the equation below :

$$FS^{Thin} = \frac{(YS+TS)}{2}. \text{E.1,1}$$

All of the flow stress result for each component in Tank 21 is same because of there are using the same data.

Table 4. 11 : Flow Stress

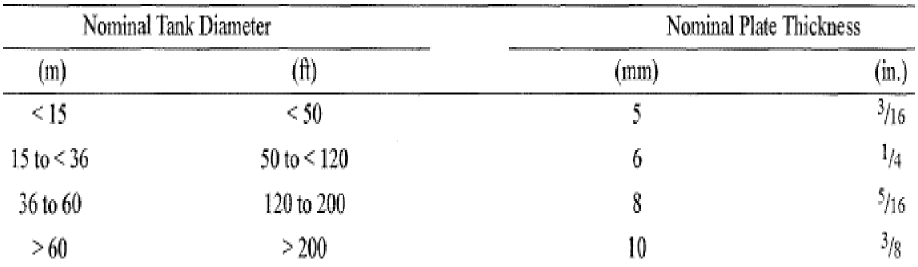
$\boldsymbol{FS^{Thin}}$	
Component	**Result**
Tank Shell 1	273487500
Tank Shell 2	273487500
Tank Shell 3	273487500
Tank Shell 4	273487500
Tank Shell 5	273487500
Tank Shell 6	273487500

For detail calculation it can be seen on Attachment 6

8. **Determine the strength ratio parameter**
The strength ratio parameter for each component can be determined with the equation below :

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

The *tc* is the minimum structural thickness of the component base material. The equation is from the API STD 650 for the minimum thickness requirement based on the tank diameter. The minimum structural thickness of the component base mateial *tc* = 5 mm



Nominal Tank Diameter		Nominal Plate Thickness	
(m)	(ft)	(mm)	(in.)
< 15	< 50	5	3/16
15 to < 36	50 to < 120	6	1/4
36 to 60	120 to 200	8	5/16
> 60	> 200	10	3/8

Table 4. 12 : Strength Ratio Parameter

SR_P^{Thin}	
Component	**Result**
Tank Shell 1	0,000305886
Tank Shell 2	0,000277209
Tank Shell 3	0,00027613
Tank Shell 4	0,000372197
Tank Shell 5	0,000363305
Tank Shell 6	0,000372197

For detail calculation it can be seen on Attachment 6

9. **Determine the number of inspections for each of the correspondesing inspection effectiveness**
Number of inspection is the total inspection that has been done before the RBI date for the corresponding inspectio effectiveness

Table 4. 13 : Number of Inspection

	N_A^{Thin}	N_B^{Thin}	N_C^{Thin}	N_D^{Thin}
Shell 1	0	0	0	2
Shell 2	0	0	0	2
Shell 3	0	0	0	2
Shell 4	0	0	0	2
Shell 5	0	0	0	2
Shell 6	0	0	0	2

For detail calculation it can be seen on Attachment 6

10. Determine the Inspection effectiveness factors

The inspection effectiveness factors for each tank shell affected by the prior probabilities, conditional probabilities and number of inspectionn in each effectiveness can be determined by the equation below :

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

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

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

Table 4. 14 ; Inpesction effectiveness

	I_1^{Thin}	I_2^{Thin}	I_3^{Thin}
Shell 1	0,08	0,03267	0,01458
Shell 2	0,08	0,03267	0,01458
Shell 3	0,08	0,03267	0,01458
Shell 4	0,08	0,03267	0,01458
Shell 5	0,08	0,03267	0,01458
Shell 6	0,08	0,03267	0,01458

For detail calculation it can be seen on Attachment 6

11. Determine the Posterior Probability

Posterior probability for each shell affected by the inspection effectiveness factor can be determined following the equation below :

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

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

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

Table 4. 15 ; Posterior Probability

	Po_{p1}^{Thin}	Po_{p2}^{Thin}	Po_{p3}^{Thin}
Shell 1	,62863694	256738703	,114577603
Shell 2	,62863694	256738703	,114577603
Shell 3	,62863694	256738703	,114577603
Shell 4	,62863694	256738703	,114577603
Shell 5	,62863694	256738703	,114577603
Shell 6	,62863694	256738703	,114577603

For detail calculation it can be seen on Attachment 6

12. Determine the parameter of reability indices for each damage state

Parameter of reability indices for each damage state for each shell can be determined by following equation below :

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}\,.\,A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S1}}^2.\,{A_{rt}}^2.\,{COV_{\Delta t}}^2+(1-D_{S1}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}\,.\,A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S2}}^2.\,{A_{rt}}^2.\,{COV_{\Delta t}}^2+(1-D_{S2}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}\,.\,A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S3}}^2.\,{A_{rt}}^2.\,{COV_{\Delta t}}^2+(1-D_{S3}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

Table 4. 16 ; Reability Indices at RBI Date

	ß_1^{Thin}	ß_2^{Thin}	ß_3^{Thin}
Shell 1	4,996	4,987	4,950
Shell 2	4,996	4,99	4,96
Shell 3	4,996	4,99	4,96
Shell 4	4,994	4,982	4,924
Shell 5	4,994	4,982	4,928
Shell 6	4,994	4,982	4,924

Table 4. 17 ; Reability Indices at Planned Date

	ß_1^{Thin}	ß_2^{Thin}	ß_3^{Thin}
Shell 1	4,971	4,868	4,273
Shell 2	4,976	4,895	4,434
Shell 3	4,977	4,896	4,44
Shell 4	4,956	4,789	3,809
Shell 5	4,958	4,801	3,878
Shell 6	4,956	4,789	3,809

For detail calculation it can be seen on Attachment 6

13. Determine the base damage factor for AST Bottom

The base damage factor for AST Bottom can be determine by looking up into Table 4.7 and Table 4.8 on API 581 STD.

Table 4. 18 : Tank Bottom Base Damage Factor

	Art	D_{fb}^{Thin}
RBI Date	0	0,1
Planned Date	0	0,1

For others component skip this step into STEP 14
For detail calculation it can be seen on Attachment 6

14. Determine the base damage factor for AST (excluding AST bottom)

The base damage factor for AST (excluding AST bottom) for each shell can be determined following the equation below :

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right)+\left(Po_{P2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right)+\left(Po_{P3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E-0.4}$$

Table 4. 19 : Tank Shell Base Damage Factor

	D_{fb}^{Thin}	D_{fb}^{Thin}
	BI Date	At Planned Date
Shell 1	0,35414	0,35414
Shell 2	0,35414	0,35414
Shell 3	0,35414	0,35414
Shell 4	0,35414	0,35414
Shell 5	0,35414	0,35414
Shell 6	0,35414	0,35414

For detail calculation it can be seen on Attachment 6

15. Determine the damage factor for thinning

The damage factor for thinning can for each component of tank 21 can be determine by following the equation below :

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin}.\ F_{IP}\ .\ F_{DL}\ .\ F_{WD}.\ F_{AM}\ .\ F_{SM})}{F_{OM}}),0.1]$$

Table 4. 20 : Thinning Damage Factor

	D_f^{Thin}	D_f^{Thin}
	RBI Date	Planned Date
Shell 1	0,35414	0,35414
Shell 2	0,35414	0,35414
Shell 3	0,35414	0,35414
Shell 4	0,35414	0,35414
Shell 5	0,35414	0,35414
Shell 6	0,35414	0,35414

$$D_{f-gov}^{Thin} = D_f^{Thin}$$

When there are no internal liner present so it can assumed that like a equation above

Table 4. 21 : Thinning Damage Factor

	D_{f-gov}^{Thin}	D_{f-gov}^{Thin}
	RBI Date	Planned Date
Shell 1	0,35414	0,35414
Shell 2	0,35414	0,35414
Shell 3	0,35414	0,35414
Shell 4	0,35414	0,35414
Shell 5	0,35414	0,35414
Shell 6	0,35414	0,35414

For detail calculation it can be seen on Attachment 6

4.2.1.2. External Corrosion Damage Factor – Feritic Component

External corrosion Damage Factor for feritic component can be determine by following some steps that published by the API 581. For detail calculation of external corrosion damage factor – feritic component can be seen on Attachment 6 in this document.

$$D_f^{extcor} = [\frac{\left(Po_{P1}^{extcorr}\Phi\left(-\beta_1^{extcorr}\right)\right)+\left(Po_{P2}^{extcorr}\Phi\left(-\beta_2^{extcorr}\right)\right)+\left(Po_{P3}^{extcorr}\Phi\left(-\beta_3^{extcorr}\right)\right)}{1.56E-0.4}$$

Table 4. 22 ; External Corrosion damage Factor

	D_f^{extcor}	D_f^{extcor}
	RBI Date	Planned Date
Shell 1	1,079542	1,079058
Shell 2	1,079707	1,079512
Shell 3	1,079711	1,079523
Shell 4	1,078573	1,074812
Shell 5	1,078779	1,075897
Shell 6	1,078573	1,074812

For detail calculation it can be seen on Attachment 6

4.2.1.3. Determining Damage Factor Total

Because there are two damage factors that work for th AST 21 in PT. X. Gresik such as Thinning and External corrosion – feritic component so the total damage factor is sum both damage factor

Table 4. 23 ; Total Damage Factor

	D_f^{total} RBI Date	D_f^{total} Planned Date
Bottom	0,1	0,1
Shell 1	1,4336898	1,4332048
Shell 2	1,4338544	1,4336595
Shell 3	1,4338589	1,4336707
Shell 4	1,4327211	1,4289598
Shell 5	1,4329263	1,4300441
Shell 6	1,4325516	1,4229957

4.2.1.4. Determing of General Failure Frequency (gff)

Determining of gff explain in API 581 STD on table 3.1 based on the equipment type and the release hole size.

Table 4. 24 : Tank Generic Failure Frequency

Equipment Type	Component Type	gff as a function of hole size (failure/yr)				gff total (failure/year)
		small	medium	large	rupture	
Tank 650	Tank Bottom	7,20E-04	0,00E+00	0,00E+00	2,00E-06	7,20E-04
Tank 650	Tank Shell	7,00E-05	2,50E-05	6,00E-06	1,00E-07	1,00E-04

4.2.1.5. Determining Management System Factor (FMS)

Management System Factor can be determine with answering some coupon that will have different value for each sector that ca affected the management system of the company.

Management system factor score according from the survey that has score 500. After that, calculate the *pscore* with equation below :

$$pscore = \frac{Score}{1000} \,.\, 100 \text{ [unit is 100\%]}$$

With the equation above the *pscore* = 50%

After that, calculate the fms with equation below :

$$Fms = 10^{(-0.02\,.\,pscore+1)}$$

With the equation above the Fms = 1

4.2.1.6. Determine the PoF

$$Pf\,(t) = gff \,.\, Fms \,.\, D\,f\,(t)$$

Table 4. 25 : Tank Probability of Failure

	Pf (t)	*Pf (t)*
	At RBI Date	Planned Date
Tank Bottom	0,1	0,1
Tank Shell 1	0,00143	0,00143
Tank Shell 2	0,00143	0,00143
Tank Shell 3	0,00143	0,00143
Tank Shell 4	0,00143	0,00143
Tank Shell 5	0,00143	0,00143
Tank Shell 6	0,00143	0,00143

For detail calculation it can be seen on Attachment 6

4.2.2 Consequences of Failure (CoF)

Consequences of Failure that happen for the AST has owned determination in chapter 6 of API 581 STD that talk about it. The calculation of the consequences of failure that applied for the AST different with COF that applied in others equipments. But in the STEP 8 later that talk determination of consequences flammable area is same like the level 1 consequences analysis that applid to others equipments.

4.2.2.1 Determine the Fluid Seepage Velocity for AST Bottom

Fluid seepage Velocity for AST bottom can be determined with the equation below :

$$vel_{s,prod} = \left(\frac{k_{h,prod}}{P_s}\right)$$

Fluid seepage Velocity for AST bottom can be affected by the hydraulic conductivity for the fluid that stored inside the tank. The items that can affected are liquid density, liquid dynamic viscosity, hydraulic conductivity for water and etc. After that the result of the fluid seepage velocity for Tank 21 bottom is = 3,31141E-10 m/day

For the detail calculation can be seen in attachment 7 in this document.

4.2.2.2 Determine the Release Hole size

There are 4 release hole size that measure for the AST by the API 581 STD such as ; small, medium, large, and rupture. The detail of each release hole size explain in attachment 7.

4.2.2.3 Determine the release rate

The release rate for the Aboveground Storage Tank determine with barrels per day. When the result want to be use to calculate the consequences area later itu should be change to kilogram per second. The release rate should be determined for each tank shell and each release hole size that happen for the tank. The release rate can be determine with the following equation below :

$$W_n \quad = \quad C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

Because there are 6 tank shells that Tank 21 have so the release rate should be determined for the 6 shells too for each release hole size that the tank have.

Table 4. 26 : Tank Shell Release Rate

	Release Rate Small (bbl/day)	Release Rate Medium (bbl/day)	Release Rate Large (bbl/day)	Release Rate Rupture (bbl/day)
Shell 1	37,62	150,48	9630,98	42509992
Shell 2	34,28	136,75	8752,57	38632784
Shell 3	30,37	121,49	7775,55	34320323
Shell 4	26	104	6656,63	29381579
Shell 5	20,72	82,91	5306,83	23423701
Shell 6	19,42	77,7	4973,42	21952065

For the tank bottom the calculation for determine the release rate using the equation below ;

$$W_n \quad = \quad C_{35}\ x\ C_{qo}\ x\ d_n^{0,2}\ \mathrm{x}\ h_{liq}^{0,9}\ x\ k_{h,prod}^{0,74}\ x\ n_{rh,n}$$

Tank bottom just have 3 release hole size such as ; small, medium, and large.

Table 4. 27 : Tank Bottom Release Rate

	Release Rate Small (bbl/day)	Release Rate Medium (bbl/day)	Release Rate Large (bbl/day)	Release Rate Rupture (bbl/day)
Bottom	3,06E-08	0	0	0

For detail calculation, it can be seen in the attachment 7 on this document.

4.2.2.4 Determine the Estimation Inventory Volume and Mass Available for Release

Estimation Inventory Volume and Mass Available for Release can be determine with the following equation below :

$$Mass_{avail,6} = Lvol_{avail,6\ x}\,\rho_l$$

The mass can be determined when the volume was determined first. When the volume was known so it just multiple it with fluid density to get the mass result. The calculation for the estimation inventory volume and mass available for release should be done for each tank shell.

Table 4. 28 : Volume & Mass Available

	Volume Available for Release (m3)	Mass Available for Release (kg)
Shell 1	1502	1102628
Shell 2	1240	910665
Shell 3	979	718703
Shell 4	717	526741
Shell 5	456	334778
Shell 6	400	294034

For detail calculation, it can be seen in the attachment 7 on this document.

4.2.2.5 Determine the Release Type

The type of release for the AST Shell and the AST bottom is assumed to be continous release.

4.2.2.6 Determine the impact of detection and isolation system on release magnitude

Detection and isolation systems are not accounted for in the AST consequences analysis.

4.2.2.7 Determine the Release Rate & Volume for the Consequences of Failure Analysis

Release rate and volume for the consequences of failure analysis should be determine for each tank shell. It should be done because each tank shell has own rate and volume for release. From that data, release rate and volume in each tank shell can be used to determine the consequences area analysis in the next step. The release rate and volume for the consequences of failure analysis can be determine with following equation below :

$$Rate_n = W_n \qquad mass_n^{leak} = Bbl_n^{leak}$$

The release rate should be determine for each release hole size that the tank has. It should be done also to determine the mass for each release hole size. The mass can be determine from the volume multiply with fluid density. The unit of mass is kilogram

Table 4. 29 ; Mass Leakage

	$mass_1^{leak}$	$mass_2^{leak}$	$mass_3^{leak}$	$mass_4^{leak}$
Shell 1	30731	1229925	1102628	1102628
Shell 2	27928	111713	910665	910665
Shell 3	24810	99243	718703	718703
Shell 4	21240	84962	526741	526741
Shell 5	16933	67733	334778	334778
Shell 6	15869	63478	194034	194034

Firstly, the release rate for the AST is determine as barrels per day. But, for determine the consequences area in the next step so it should converted to kilogram per second. The unit of release rate is kg/s

Table 4. 30 : Flow Rate

	$Rate_1$	$Rate_2$	$Rate_3$	$Rate_4$
Shell 1	0,0489	0,1956	12,52	55262,99
Shell 2	0,0444	0,1777	11,37	50222,62
Shell 3	0,0394	0,1579	10,10	44616,42
Shell 4	0,0338	0,1352	8,65	38196,05
Shell 5	0,0269	0,1077	6,898	30460,81
Shell 6	0,0252	0,1010	6,465	28537,68

For the tank bottom the release rate and mass inventory use the equation below :

$$Rate_n = W_n \qquad Bbl_n^{rupture} = Bbl_{total}$$

For the tank bottom the mass for the relase is the mass total that carried by the tank bottom from the available fluid inside the tank. For mass the unit is kilogram ad for the release rate is using kilogram per second unit.

Table 4. 31 : Bottom Mass Leak

	$mass_1^{leak}$	$mass_2^{leak}$	$mass_3^{leak}$
bottom	8001	8001	8001

Table 4. 32 ; Bottom Flow Rate

	$Rate_1$	$Rate_2$	$Rate_3$
Bottom	2,17E-10	0	0

For detail calculation, it can be seen in the attachment 7 on this document.

4.2.2.8 Determine the Flammable and Explosive Consequences

For flammable and explosive consequences it determine the consequences as an area consequences. The calculation of flammable and explosive consequences should be done for each tank shell. Tank bottom doesn't need to determine the flammable and explosive consequences because it just need to measure into the financial consequence. In this bachelor thesis has a limitation that doesn't count the financial consequence.

There are two types of the flammable and explosive consequences such as ; component damage consequences area and personel injury consequences area. Both of the consequences area can be determined using the equation below :

$$CA_{cmd}^{flam} = \left(\frac{(gff_1 . CA_{cmd,1}^{flam}) + (gff_2 . CA_{cmd,2}^{flam}) + (gff_3 . CA_{cmd,3}^{flam}) + (gff_4 . CA_{cmd,4}^{flam})}{gff_{total}} \right)$$

$$CA_{inj}^{flam} = \left(\frac{\left(gff_1 \cdot CA_{inj,1}^{flam}\right) + \left(gff_2 \cdot CA_{inj,2}^{flam}\right) + \left(gff_3 \cdot CA_{inj,3}^{flam}\right) + \left(gff_4 \cdot CA_{inj,4}^{flam}\right)}{gff_{total}} \right)$$

Because the consequences is determined as an area, so, the unit for flammable and explosive component damage and flammable and explosive personel injury area is m2. Each tank shell should be done the calculation for the flammable and explosive consequences and the results describe below :

Table 4. 33 ; Flammable & Explosive Consequences Area

	CA_{cmd}^{flam}	CA_{inj}^{flam}
	m2	m2
Shell 1	166,12	477,65
Shell 2	153,31	440,79
Shell 3	139,03	399,72
Shell 4	122,48	352,14
Shell 5	102,13	293,65
Shell 6	97,02	278,96

For detail calculation, it can be seen in the attachment 7 on this document.

4.2.2.9 Determine the Toxic Consequences for AST Shell

Because of the fluid that stored inside the tank is not catagorized as toxic fluid so the value becomes 0.

4.2.2.10 Determine the Non-Flammable, Non-Toxic Consequences for AST Shell Course

Non-Flammable, Non-Toxic consequences are not determined for ASTs.

4.2.2.11 Determine the Final Consequences for AST Shell Course

The final consequences for AST Shell can be determine with the consequences from the flammable and explosive consequences. It can be done because the others consequences such as ; toxic and Non-Toxic, Non-Flammable not determine for the this tank. So, the final consequences area can be determine following the equation below :

$$CA = \max\left[CA_{cmd}\,,\ CA_{inj}\right]$$

Because of the value of the personel injury in flammable and explosive consequences has a bigger value, so, the final consequences area are using the personel injury consequences area from flammable and explosive consequences. The final consequences area should be determined for each tank shell. The unit for the final consequences area is meter square (m2).

Table 4. 34 : Final Consequences Area

	CA
	m2
Shell 1	477,65
Shell 2	440,79
Shell 3	399,72
Shell 4	352,14
Shell 5	293,65
Shell 6	278,96

For detail calculation, it can be seen in the attachment 7 on this document.

4.2.3 Risk

Risk can be determine by multiplying the Probability of Failure and the Consequences of Failure. In this case the POF unit is failure per year. The unit of the COF is meter square (m2). When it calculated as a risk so the unit is meter square per year (m2/year). Risk should be determine in the RBI date and at the planned date.

Table 4. 35 : Probability of Failure

	Pf (t)	***Pf (t)***
	At RBI Date	Planned Date
ank Bottom	0,1	0,1
ank Shell 1	0,00143	0,00143
ank Shell 2	0,00143	0,00143
ank Shell 3	0,00143	0,00143
ank Shell 4	0,00143	0,00143
ank Shell 5	0,00143	0,00143
ank Shell 6	0,00143	0,00143

Table 4. 36 : Consequences of Failure

	CA
	m2
Shell 1	477,65
Shell 2	440,79
Shell 3	399,72
Shell 4	352,14
Shell 5	293,65
Shell 6	278,96

Table 4. 37 : Risk at RBI Date

Risk (m2/year)	
Shell 1	0,0684787
Shell 2	0,0632024
Shell 3	0,0573146
Shell 4	0,0504462
Shell 5	0,0420740
Shell 6	0,0399625

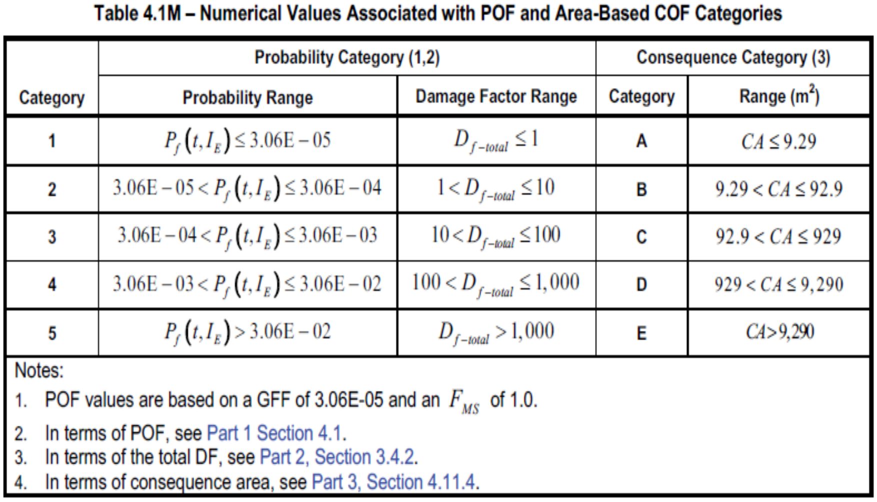


Table 4.1M – Numerical Values Associated with POF and Area-Based COF Categories

Category	Probability Category (1,2)		Consequence Category (3)	
	Probability Range	Damage Factor Range	Category	Range (m^2)
1	$P_f(t,I_E) \le 3.06E-05$	$D_{f-total} \le 1$	A	$CA \le 9.29$
2	$3.06E-05 < P_f(t,I_E) \le 3.06E-04$	$1 < D_{f-total} \le 10$	B	$9.29 < CA \le 92.9$
3	$3.06E-04 < P_f(t,I_E) \le 3.06E-03$	$10 < D_{f-total} \le 100$	C	$92.9 < CA \le 929$
4	$3.06E-03 < P_f(t,I_E) \le 3.06E-02$	$100 < D_{f-total} \le 1,000$	D	$929 < CA \le 9,290$
5	$P_f(t,I_E) > 3.06E-02$	$D_{f-total} > 1,000$	E	$CA > 9,290$

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.

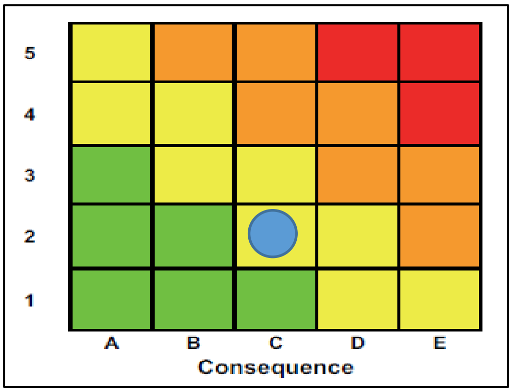


Table 4. 38 : Risk at Planned Date

	Risk (m2/year)
Shell 1	0,0684303
Shell 2	0,0631860
Shell 3	0,0573003
Shell 4	0,0501097
Shell 5	0,0418637
Shell 6	0,0396959

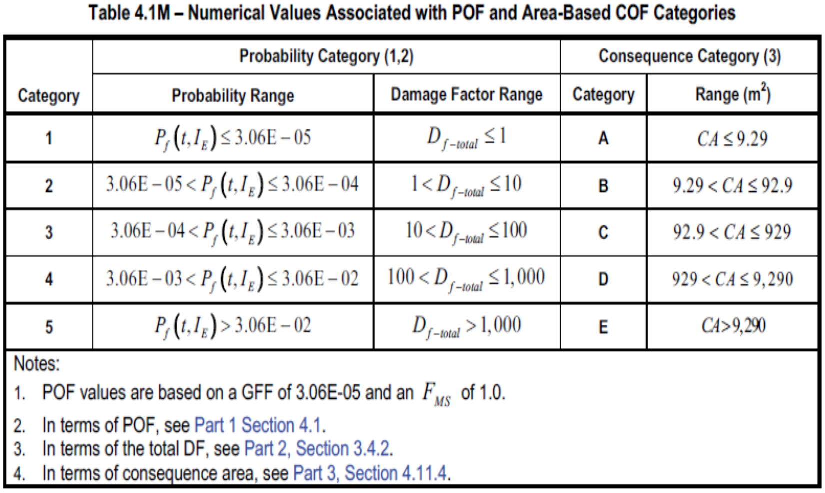
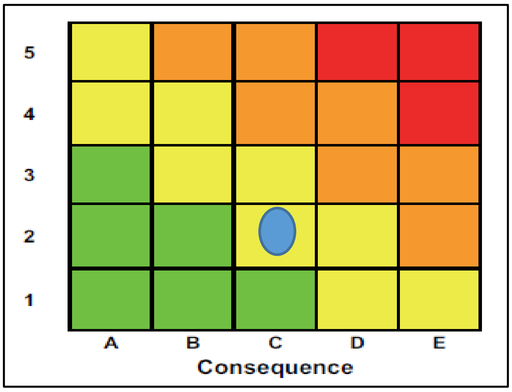


Table 4.1M – Numerical Values Associated with POF and Area-Based COF Categories

Category	Probability Category (1,2)		Consequence Category (3)	
	Probability Range	Damage Factor Range	Category	Range (m^2)
1	$P_f(t,I_E) \le 3.06E-05$	$D_{f-total} \le 1$	A	$CA \le 9.29$
2	$3.06E-05 < P_f(t,I_E) \le 3.06E-04$	$1 < D_{f-total} \le 10$	B	$9.29 < CA \le 92.9$
3	$3.06E-04 < P_f(t,I_E) \le 3.06E-03$	$10 < D_{f-total} \le 100$	C	$92.9 < CA \le 929$
4	$3.06E-03 < P_f(t,I_E) \le 3.06E-02$	$100 < D_{f-total} \le 1,000$	D	$929 < CA \le 9,290$
5	$P_f(t,I_E) > 3.06E-02$	$D_{f-total} > 1,000$	E	$CA > 9,290$

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.



For detail calculation, it can be seen in the attachment 7 on this document.

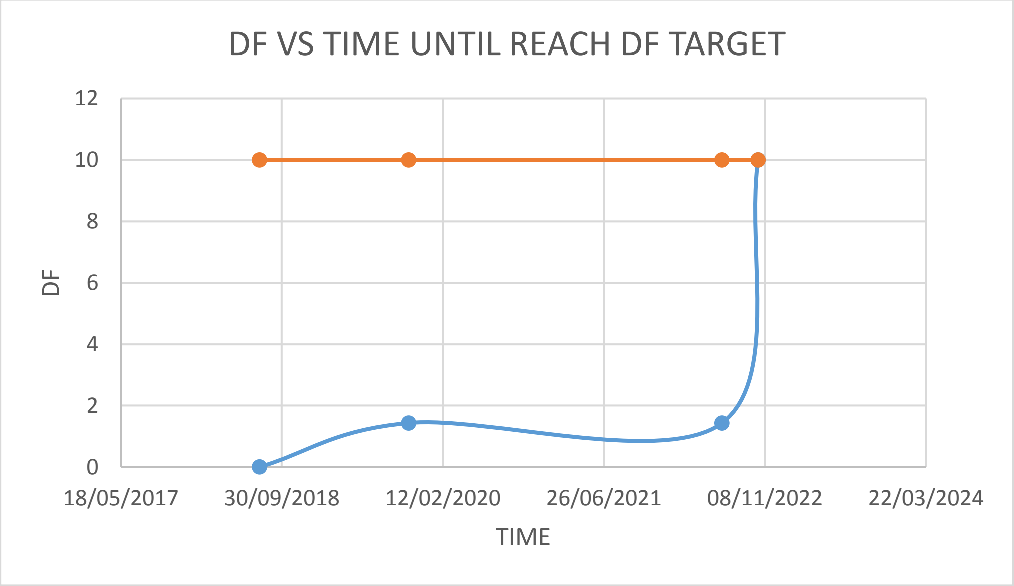
4.2.4 Inspection Planning

Inspection planning can be determine using the risk target or using the damage factor maximum that has same range as the probability of failure. The inspection planning is to determine when the inspection should be done because of the tank is reaching the damage factor Target or the risk target.

Inspection planning can be more faster than the planned date or it can be longer than the planned date. When its longer than a planned date so it can save tthe resources to done a inspection for the tank. If the inspection planning is faster than the planned date so, so the tank is reach the damage factor or risk target and should be done maintenance immediately to make sure that the Aboveground Storage Tank still below the risk target or damage factor target condition.

Table 4. 39 : Inspection Planning Date

	RBI Date	Planned Date	Inspection Planning
Shell 1	29/10/2019	28/06/2022	17/10/2022
Shell 2	29/10/2019	28/06/2022	19/10/2022
Shell 3	29/10/2019	28/06/2022	17/10/2022
Shell 4	29/10/2019	28/06/2022	17/10/2022
Shell 5	29/10/2019	28/06/2022	17/10/2022
Shell 6	29/10/2019	28/06/2022	17/10/2022



For detail calculation, it can be seen in the attachment 7 on this document.

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CHAPTER 5

CONCLUSION & SUGGESTION

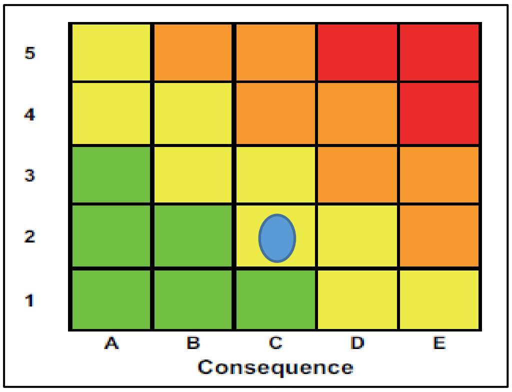
5.1. Conclusion

In this final project to determine the risk ranking of the tank components using the Risk-Based Inspection an have a conclusion :

- the tank has two damage factor such as; thinning and external corrosion – feritic component. The risk rangking is to make sure is the tank should be inspected faster or longer than the planned that that established before.
- The tank that assessed with the Risk-Based Inspection is the Tank number 21 that have 1500m3 of volume with 13,5m of diameter and 10,5m of height. Fluid that stored inside the tank is High Speed Diesel (HSD).
- After doing assessment for the Tank 21 with Risk-Based Inspection Method so the result is tank shell course and tank bottom has own probability of failure value.
- When calculation for the consequences of failure happened, the tank bottom not included because of the tank bottom doesn’t has the consequences area. The tank bottom just have consequences of financial.
- After that the risk calculation can be determined from the probability of failure and consequences of failure value. The risk result for each tank shell course can be determined into a risk catagories.

Table 5. 1: Risk at RBI Date

	Risk (m2/year)
Shell 1	0,0684787
Shell 2	0,0632024
Shell 3	0,0573146
Shell 4	0,0504462
Shell 5	0,0420740
Shell 6	0,0399625



- After the risk is known, so it should calculate the inspection planning date for each tank shell course. The calculation of inspection planning date is using the damage factor target calculation as a references.

Table 5. 2 : Inspection Planning

	RBI Date	Planned Date	Inspection Planning
Shell 1	29/10/2019	28/06/2022	17/10/2022
Shell 2	29/10/2019	28/06/2022	19/10/2022
Shell 3	29/10/2019	28/06/2022	17/10/2022
Shell 4	29/10/2019	28/06/2022	17/10/2022
Shell 5	29/10/2019	28/06/2022	17/10/2022
Shell 6	29/10/2019	28/06/2022	17/10/2022

5.2. Suggestion

- The corrosion rate data that used to done the assessment with Risk-Based Inspection should be determine for each tank shell course. In this calculation the corrosion rate is for one tank.
- 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.

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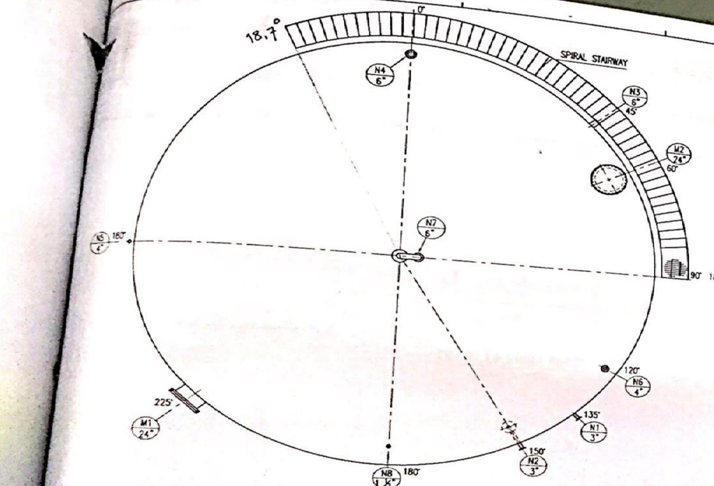
INSPECTION PLANNING PROGRAM USING RISK BASED INSPECTION API 581 FOR ABOVEGROUND STORAGE TANKS IN PT. X. GRESIK

ATTACHEMENT 1:

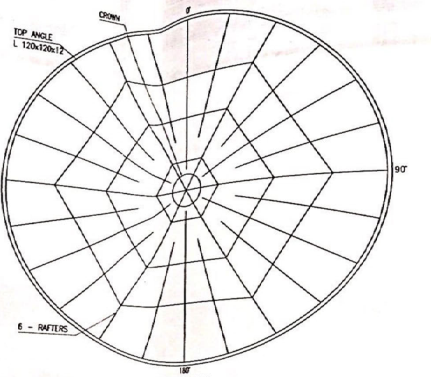
ABOVEGROUND STORAGE TANK GENERAL ARRANGEMENT

Rev.	Tanggal	Keterangan	Disusun Oleh:		Disetujui Oleh:	
			Nama	Paraf	Pembimbing	Paraf
			Rafli Mahadika Ariapratama		Ir. Dwi Priyanta, M.SE	
			No. Registration :		Dr. Eng. M. Badrus Zaman, S.T. , M.T.	
			04211641000014			

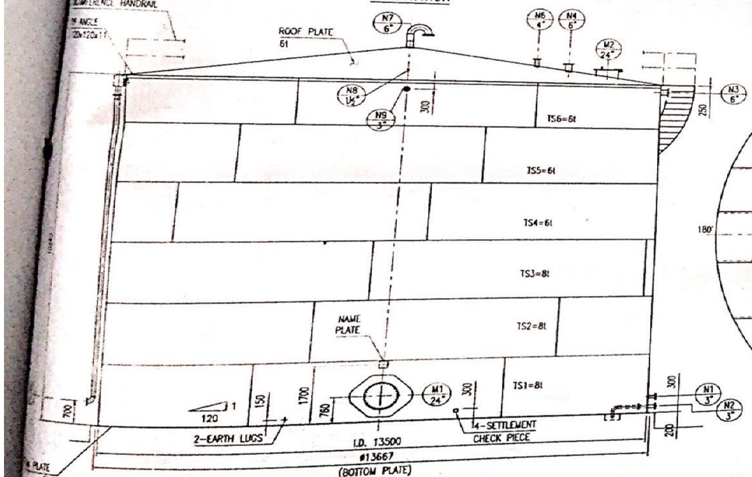
Baso kerong :



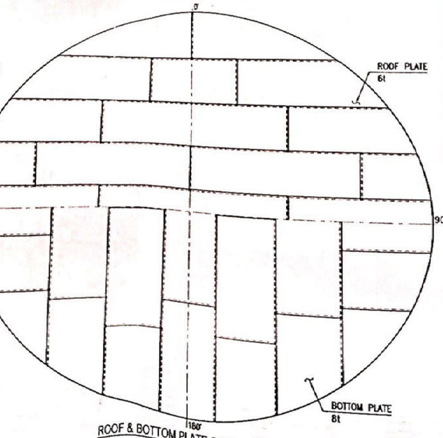
ORIENTATION



ROOF RAFTER



(BOTTOM PLATE)
ELEVATION



ROOF & BOTTOM PLATE ORIENTATION

ATMOSPHERIC STORAGE TANK DATA

TAG NUMBER	: -		SERVICE FLUID	: FUEL OIL	
TYPE OF TANK	: VERTICAL CYLINDER		DESIGN CODE	: API 650 10 TH ED.Addn 2.W/APP.E,F&H	

DESIGN CONDITIONS

NET WORKING CAP.	: -	m3	CORRS. ALLOWANCE	: SHEL :1, BOTTOM :2.5	mm
INSIDE DIAMETER (ID)	: 13500	mm	DESIGN SP GRAVITY	: 1	kg/m3
HEIGHT (H)	: 10640	mm	DESIGN PRESSURE	: ATM	MPaG
ROOF TYPE	: CONE ROOF		DESIGN TEMP	: AMB	°C
FILLING RATE	: -		TEST PRESS. HYDRO	: FULL WATER	MPaG
EMPTYING RATE	: -		WIND VELOCITY	: 31.29	M/SEC
NOMINAL CAP.	: -	m3	PROD. DESIGN (HT)	: -	mm

MATERIALS

SHEEL PLATE	: A283 Gr.C	FLANGE	: A 105
BOTTOM PLATE	: A283 Gr.C	GASKET (INT/EXT)	: COMPRESSED GRAPHITE GASKET
FIX ROOF PLATE	: A36 (SS400)	BOLT & NUT (INT/EXT)	: A 193 B7 & A 194 2.H
NOZZLE NECK	: A 106 Gr.B	ROOF STRUCTURAL	: A 36 OR SS400
INTERNAL	: A36 (SS400)		

TANK APPURTENANCES

SHELL APPURTENANCES			ROOF APPURTENANCES		
SERVICE	QTY-SIZE	REMARK	SERVICE	QTY-SIZE	REMARK
MANHOLE	1-24"	M1-API 650 (3)	MANHOLE	1-24"	M2-API 650 (4)
OUTLET	1-3"	N1-150#SOFF	SPARE	1-6"	N4-150#SOFF
DRAIN	1-3"	N2-150#SOFF	SAMPLING	1-4"	N6-150#SOFF
INLET	1-6"	N3-150#SOFF	VENT	1-6"	N7-150#SOFF
AIR FOAM CHAMBER	1-4"	N5-150#SOFF	LEVEL INDICATOR	1-1 1/2"	N8-150#SOFF
OVERFLOW	1-3"	N9-150#SOFF			
STAIRWAY	1 SET				

NOTES

1. NOZZLE ORIENTATION SHALL REFER TO ORIENTATION DRAWINGS
2. INTERNAL PAINTING : NO EXTERNAL PAINTING : YES
3. W/ BLIND FLANGE
4. W/ COVER & HINGE

NO	REVISIONS	DATE	DRAWN	CHECK	APP
△					
△					
△					
0	ISSUED FOR APPROVAL				

DRAWN : MH
CHECKED : NB
APPROVED : AMN

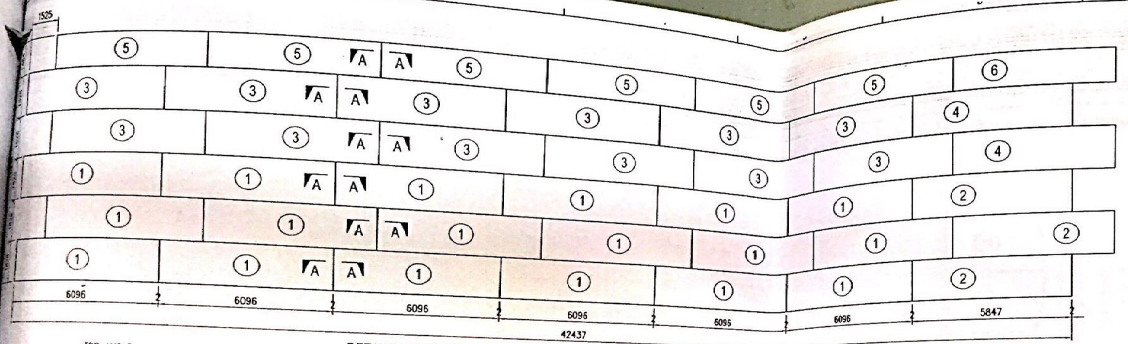
PT. CAHAYA HIDUP PRIMAKARYA

PROJECT TITLE :

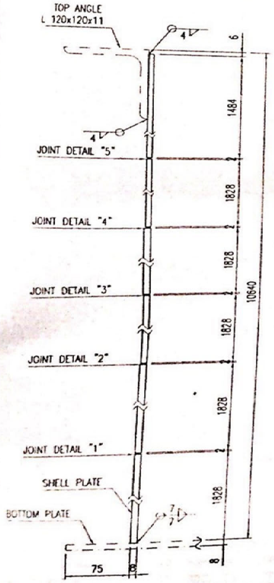
DRAWING TITLE :
FUEL OIL STORAGE TANK 1500 KL
GENERAL ARRANGEMENT

SCALE	JOB NO.	MANUFACTURER DRAWING NUMBER	REV.
1 : 110		ID. NO : - DWG. NO : 1500.T001-DW-001	0

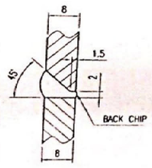
Dua karang :



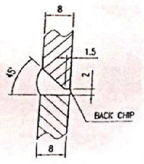
DETAIL OF SHELL PLATE
SCALE 1 : 150



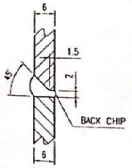
SECTIONAL DETAIL OF SHELL PLATE
SCALE 1 : 5



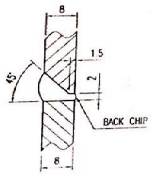
JOINT "1"
SCALE 1 : 1



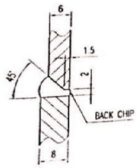
JOINT "2"
SCALE 1 : 1



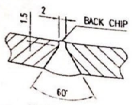
JOINT "5"
SCALE 1 : 1



JOINT "3"
SCALE 1 : 1



JOINT "4"
SCALE 1 : 1



SECTION A - A
SCALE 1 : 1

LIST OF MATERIALS

POST	Q'TY	DESCRIPTION	LENGTH	MAT	WEIGHT	REMARK
1	18	PL 8 x 1828	6096	A283Gr.C		
2	3	PL 8 x 1828	5847	A283Gr.C		
3	12	PL 6 x 1828	6096	A283Gr.C		
4	2	PL 6 x 1828	5847	A283Gr.C		
5	6	PL 6 x 1484	6096	A283Gr.C		
6	1	PL 6 x 1484	5847	A283Gr.C		

NOTES :

1. LIST OF MATERIALS ABOVE FOR 1 (ONE) SET FABRICATION

NO	REVISIONS	DATE	DRAWN	CHECK	APP
△					
△					
△					
0	ISSUED FOR APPROVAL				

DRAWN : MH
CHECKED : NB
APPROVED : AMN

PT. CAHAYA HIDUP PRIMAKARYA

PROJECT TITLE :

DRAWING TITLE :
FUEL OIL STORAGE TANK 1500 KL
DETAIL OF SHELL PLATE

SCALE	JOB NO.	MANUFACTURER DRAWING NUMBER	REV.
AS SHOWN		ID. NO : –	0

INSPECTION PLANNING PROGRAM USING RISK BASED INSPECTION API 581 FOR ABOVEGROUND STORAGE TANKS IN PT. X. GRESIK

ATTACHEMENT 2:

ABOVEGROUND STORAGE TANK LAST INSPECTION DATA

Rev.	Tanggal	Keterangan	Disusun Oleh:		Disetujui Oleh:	
			Nama	Paraf	Pembimbing	Paraf
			Rafli Mahadika Ariapratama		Ir. Dwi Priyanta, M.SE	
			No. Registration :		Dr. Eng. M. Badrus Zaman, S.T. , M.T.	
			04211641000014			

PT SERTIFIKASI RAHARJA INDONESIA
WISMA BSG 9 th FLOOR, JL. ABDUL MUIS NO.40 JAKARTA 10160, INDONESIA
PHONE : (62-21) 3483 4337 (HUNTING) FAX : (62-21) 3483 4338
EMAIL : ptsri@ptsri.com WEBSITE : www.ptsri.com

Quality Approved ISO 9001
Safety Approved OHSAS 18001

Sertifikat Inspeksi

No. : 526/ST/SRI/VII/2018

PT. SERTIFIKASI RAHARJA INDONESIA

Berdasarkan

1. Peraturan Menteri ESDM No.18 tahun 2018
2. Hasil Pemeriksaan Teknis dengan nomor laporan, 526/ST/SRI/VII/2018

Menyatakan bahwa :

TANGKI PENIMBUN

dengan informasi dan hasil sebagai berikut berikut ini :

Pemilik/Pengguna : PT Dovchem Maspion Term
Subyek / Deskripsi : HSD Storage Tank
Tag / Nomor Seri : T – 21 / -
Fluida Servis : HSD
Tinggi Cairan : 10,15 m
Lokasi : Kawasan Industri Maspion Manyar
Gresik – Jawa Timur
Tanggal Inspeksi : 28 Juni 2018
Referensi : API STD 653
Lampiran : 2 halaman

layak dan memenuhi persyaratan keamanan dan keselamatan kerja sehingga dapat digunakan, dengan ketentuan:

1. Sesuai dengan data teknis pada lampiran sertifikat ini;
2. PT Dovchem Maspion Terminal bertanggung jawab sepenuhnya atas keselamatan pengoperasian peralatan Tangki Penimbun tersebut di atas;
3. Selambat-lambatnya tiga bulan sebelum berakhir masa berlaku sertifikat, PT Dovchem Maspion Terminal wajib melakukan pemeriksaan teknis terhadap Tangki Penimbun tersebut di atas; dan
4. Apabila terjadi hal-hal yang dapat menyebabkan Tangki Penimbun tersebut tidak layak dan tidak aman untuk dioperasikan maka Sertifikat Inspeksi ini dapat ditinjau kembali oleh PT Dovchem Maspion Terminal.

Sertifikat ini berlaku sejak tanggal diterbitkan dan berakhir tanggal 28 Juni 2022

Jakarta, 20 Juli 2018

Inspektur

(Amri Royan Hidayat)

Direktur

(Handoko Tri Wibowo)

Lampiran 1/2
No. Sertifikat : **526/ST/SRI/VII/2018**

Data Teknis Tangki Penimbun :

Pemilik / Pengguna	:	PT Dovchem Maspion Terminal
Nomor ID / Nomor Seri	:	N/A
Fabrikator	:	PT Cahaya Hidup Primakarya
Lokasi Instalasi	:	Kawasan Industri Maspion Manyar gresik – Jawa Timur
Standar Konstruksi	:	API Std 650 10th Edition 3rd Addendum
Standar Repair / Assessment / Inspeksi	:	N/A
Tahun Dibuat / Digunakan	:	2008 / 2008
Tahun Perbaikan Terakhir	:	N/A
Diameter Nominal	:	9,7 Meter
Desain Level Cairan	:	10,15 Meter
Berat Jenis	:	0,85
Tekanan Desain, kg/cm^2(psi)	:	1,03 kg/cm^2 / 14,7 Psi
Temperatur Desain, °F (°C)	:	138 °F (60 °C)
Ventilasi	:	*Free Vent*
Alat Ukur Ketinggian Permukaan Cairan	:	*Manual level gauge*
Digunakan untuk	:	*High Speed Diesel*
Atap Tangki Penimbun		
Jenis Atap	:	*Fixed Supported Cone Roof*
Material	:	JIS G3101 – SS 400
Tebal Nominal	:	5 mm
Tebal Aktual	:	4,36 mm
Tebal Minimal	:	2,29 mm
Dinding Tangki Penimbun		
Material Pondasi	:	Beton
Material Pelat	:	JIS G3101 – SS 400
Tebal Nominal	:	8 mm (Course 1), 8 mm (Course 2), 8 mm (Course 3), 6 mm (Course 4), 6 mm (Course 5), 6 mm (Course 6)

Lampiran 2/2
No. Sertifikat : **526/ST/SRI/VII/2018**

Tebal Aktual	:	6,96 mm (Course 1), 7,68 mm (Course 2), 7,71 mm (Course 3), 5,72 mm (Course 4), 5,86 mm (Course 5), 5,72 mm (Course 6)
Tebal Minimal	:	3,52 mm (Course 1), 2,92 mm (Course 2), 2,54 mm (Course 3), 2,54 mm (Course 4), 2,54 mm (Course 5), 2,54 mm (Course 6)
Dasar Tangki Penimbun		
Material Pondasi	:	Beton
Material Pelat	:	JIS G3101 – SS 400
Tebal Nominal	:	10 mm
Tebal Aktual	:	8,00 mm
Pendukung	:	Ada
Data Penilaian Umur Layan (jika ada)		
Nomor Dokumen	:	N/A
Nama Lembaga Enjiniring	:	N/A
Metode Inspeksi	:	N/A
Bagian Kritis	:	N/A
Interval Inspeksi	:	N/A
Rekomendasi	:	N/A
Pemeriksaan Keselamatan		
Laju Korosi	:	0,167 mm/tahun
Perhitungan Sisa Umur Layan	:	≥ 20 Tahun
Jenis Uji Tidak Merusak	:	UT dan Inspeksi Visual
Uji Tekan (jika ada)	:	N/A
Media Pengujian	:	N/A
Pengukuran Tahanan Pentanahan	:	0,5 Ω

Inspektur

(Amri Royan H.)

INSPECTION PLANNING PROGRAM USING RISK BASED INSPECTION API 581 FOR ABOVEGROUND STORAGE TANKS IN PT. X. GRESIK

ATTACHEMENT 3:

ABOVEGROUND STORAGE TANK INSTALLATION DATA

Rev.	Tanggal	Keterangan	Disusun Oleh:		Disetujui Oleh:	
			Nama	Paraf	Pembimbing	Paraf
			Rafli Mahadika Ariapratama		Ir. Dwi Priyanta, M.SE	
			No. Registration :		Dr. Eng. M. Badrus Zaman, S.T. , M.T.	
			04211641000014			

PT. CAHAYA HIDUP PRIMAKARYA	*DATA SHEET*

CLIENT : PT. DMP
PROJECT TITLE : PROYEK TANKI
JOB No. :
TANK No. / SERVICE : (Fuel Oil Storage Tank) / Fuel Oil
Required Nos. : 1 (one)

. DIMENSION AND TYPE

Net Working Capacity	: 1,500.0 m^3	Type of Tank	: Above Ground welded Steel tank
Nominal Capacity	: 1,523.00 m^3	Roof : - Type	: Supported Cone Roof
Tank Inside Diameter (ID)	: 13,500 mm	- Slope	: 1 : 6
Tank height (H)	: 10,640 mm	Bottom : - Type	: Appex Down
		- Slope	: 1 : 100

2. OPERATING CONDITION

Operating Pressure : - Upper : Full Liq. + 0 kg/cm² G
- Lower : Full Liq. - 0 kg/cm² G
HLL : 10,500 mm
LLL : 0 mm

PT. CAHAYA HIDUP
PRIMAKARYA

3. DESIGN CONDITION

Applicable standard	: API Std. 650 - 10th Ed, Addn. 2, w/ App. E		
Design Pressure : - Upper	: Full Liq. + 0 kg/cm² G	Design Wind Speed	: 31.5 m/sec
- Lower	: Full Liq. - 0 kg/cm² G	Seismic Data	: As per API 650 App. E
Design Sp. Gr. of contents	: 0.8600	- Ground acceleration	: 0.3
Design Max Liquid Level	: 10,640 mm	- Soil Type	: S3 (S Factor = 1.5)
Design Metal Temp, Min	: 50 °C = 122.00 °F	- Seismic Zone	: 3

C.A.: - Bottom : 1.5 mm
- Ann. Bot.P. : N/A mm
- Shell : 1.5 mm
- Roof : * Fixed : 0.0 mm
* Floating : N/A mm
- EFR Framing : N/A mm
- Column : N/A mm

4. DESIGN CONDITION OF VENTING DEVICE

Applicable standard	: API Std. 2000 - Fifth Edition, 1998		
Filling Rate. nor.	: m³/hr	Content's Flash Point	: °C (Closed Cup
Emptying Rate. nor.	: m³/hr	Content's Boiling Point	: °C

5. TEST CONDITION

Hydrostatic Test Pressure : Full Wtr. + 0 kg/cm² G

PT. CAHAYA HIDUP PRIMAKARYA	*DATA SHEET*

6. MATERIAL OF CONSTRUCTION

Bottom Plate : A-283-C Group I
Annular bottom plate : None
Shell Plate / Shell Manhole : A-283-C Group I /A-283-C
Fixed Roof PL / Manhole : A-283-C Group I /A-283-C
Floating Roof PL/ Manhole : None
Top Angle : SS 400
Wind girder : None
Fixed Roof Rafter : SS 400
Pipe Column : A106 Gr B
Internal Pipe : A 106 Gr B
Handrail : SS 400
Ladder : SS 400
Spiral Stair Way : SS 400
Sp. Stair way / Ladder Lug : SS 400
Earth Lug : SS 400
Name Plate : 304 SS
Platform : SS 400
Platform Lug : SS 400

PT. CAHAYA HIDUP PRIMAKARYA

Nozzle : - Neck : A-106 Gr. B
- Flange : A-105
- Blind Fl. : A-105
- B / N : A-193-B7 / A-194-2H
- Gasket : Non Asbestos
- Reinforc. : A-283-C

Manhole : - Neck : A-283-C
- Flange : A-283-C
- Cover : A-283-C
- B / N : A-193-B7 / A-194-2H
- Gasket : Non Asbestos
- Reinforc. : A-283-C

Foundation Bolt / Nut : A-307-B

7. PAINTING, COATING AND LINING

External Surface : -
Internal Surface : -

8. INSULATION

Shell : No
Unit weight : - Kg/m3
Insulation Type : -

Roof : No
Unit weight : - Kg/m3
Insulation Type : -

9. HEATING

Heating Coil : No
Diameter of Pipe : - inch

10. FIRE FIGHTING SYSTEM

a. Water Spray System : No
b. Foam System : No

11. TANK APPURTUNANCES

SHELL & FLOOR APPURTENANCES					ROOF APPURTENANCES				
Mk	Appurtenances	Q'ty	Size	Remarks	Mk	Appurtenances	Q'ty	Size	Remarks
GL	Earth Lugs	3 Pcs		Equally Distributed	Hr	Hand Rail	1set		
St	Stairway	1 Set							
NP	Tank Name Plate	1 Set							

12. NOZZLE SCHEDULE

Refer to General Arrangement Drawing

INSPECTION PLANNING PROGRAM USING RISK BASED INSPECTION API 581 FOR ABOVEGROUND STORAGE TANKS IN PT. X. GRESIK

ATTACHEMENT 4:

FLUID AND MATERIAL DATA OF ABOVEGROUND STORAGE TANK

Rev.	Tanggal	Keterangan	Disusun Oleh:		Disetujui Oleh:	
			Nama	Paraf	Pembimbing	Paraf
			Rafli Mahadika Ariapratama		Ir. Dwi Priyanta, M.SE	
			No. Registration :		Dr. Eng. M. Badrus Zaman, S.T. , M.T.	
			04211641000014			

Standard Specification for
Low and Intermediate Tensile Strength Carbon Steel Plates[1]

This standard is issued under the fixed designation A 283/A 283M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification[2] covers four grades (A, B, C, and D) of carbon steel plates of structural quality for general application.

1.2 When the steel is to be welded, a welding procedure suitable for the grade of steel and intended use or service is to be utilized. See Appendix X3 of Specification A 6/A 6M for information on weldability.

1.3 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exactly equivalents; therefore, each system is to be used independently of the other, without combining values in any way.

1.4 For plate produced from coil and furnished without heat treatment or with stress relieving only, the additional requirements, including additional testing requirements and the reporting of additional test results, of Specification A 6/A 6M apply.

1.5 This specification contains notes or footnotes, or both, that provide explanatory material. Such notes and footnotes, excluding those in tables and figures, do not contain any mandatory requirements.

2. Referenced Documents

2.1 *ASTM Standards:*

A 6/A 6M Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling[3]

3. General Requirements for Delivery

3.1 Plates furnished under this specification shall con-form to the requirements of the current edition of Specification A 6/A 6M, for the specific date ordered, unless a conflict exists, in which case this specification shall prevail.

3.2 Coils are excluded from qualification to this specification until they are processed into finished plates. Plates produced from coil means plates that have been cut to individual lengths from a coil. The processor directly controls, or is responsible for, the operations involved in the processing of a coil into finished plates. Such operations include decoiling, leveling, cutting to length, testing, inspection, conditioning, heat treatment (if applicable), packaging, marking, loading for shipment, and certification.

NOTE 1—For plates produced from coil and furnished without heat treatment or with stress relieving only, two test results are to be reported for each qualifying coil. Additional requirements regarding plate produced from coil are described in Specification A 6/A 6M.

4. Process

4.1 The steel shall be made by one or more of the following processes: open-hearth, basic-oxygen, or electric-furnace.

5. Chemical Requirements

5.1 The heat analysis shall conform to the requirements prescribed in Table 1.

5.2 The steel shall conform on product analysis to the requirements prescribed in Table 1, subject to the product analysis tolerances in Specification A 6/A 6M.

6. Tensile Requirements

6.1 Material as represented by the test specimens shall conform to the requirements as to tensile properties prescribed in Table 2.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys, and is the direct responsibility of Subcommittee A01.02 on Structural Steel for Bridges, Buildings, Rolling Stock, and Ships.

Current edition approved April 10, 2003. Published June 2003. Originally approved in 1946. Last previous edition approved in 2000 as A 283/A 283M – 00.

[2] For ASME Boiler and Pressure Vessel Code applications, see related Specification SA-283/SA 283M in Section II of that Code.

[3] *Annual Book of ASTM Standards,* Vol 01.04.

***A Summary of Changes section appears at the end of this standard.**

TABLE 1 Chemical Requirements

Elements	Heat Analysis, %			
	Grade A	Grade B	Grade C	Grade D
Carbon, max	0.14	0.17	0.24	0.27
Manganese, max	0.90	0.90	0.90	0.90
Phosphorus, max	0.035	0.035	0.035	0.035
Sulfur, max	0.04	0.04	0.04	0.04
Silicon				
Plates 1½ in. [40 mm] and under, max	0.40	0.40	0.40	0.40
Plates over 1½ in. [40 mm]	0.15–0.40	0.15–0.40	0.15–0.40	0.15–0.40
Copper, min % when copper is specified	0.20	0.20	0.20	0.20

TABLE 2 Tensile Requirements[A]

	Grade A	Grade B	Grade C	Grade D
Tensile strength, ksi [MPa]	45–60 [310–415]	50–65 [345–450]	55–75 [380–515]	60–80 [415–550]
Yield point, min, ksi [MPa]	24 [165]	27 [185]	30 [205]	33 [230]
Elongation in 8 in. [200 mm], min, %[B]	27	25	22	20
Elongation in 2 in. [50 mm], min, %[B]	30	28	25	23

[A] See Specimen Orientation under the Tension Tests section of Specification A 6/A 6 M.

[B] For plates wider than 24 in. [600 mm], the elongation requirement is reduced two percentage points. See elongation requirement adjustments in the Tension Tests section of Specification A 6/A 6M.

SUPPLEMENTARY REQUIREMENTS

Supplementary requirements shall not apply unless specified in the order or contract . Standardized supplementary requirements for use at the option of the purchaser are listed in Specification A 6/A 6M. Those that are considered suitable for use with this specification are listed by title:

S2. Product Analysis,

S3. Simulated Post-Weld Heat Treatment of Mechanical Test Coupons,

S5. Charpy V-Notch Impact Test,

S6. Drop Weight Test,

S8. Ultrasonic Examination, and

S15. Reduction of Area.

S97. *Limitation on Rimmed or Capped Steel:*

S97.1 The steel shall be other than rimmed or capped.

SUMMARY OF CHANGES

Committee A01 has identified the location fo the following changes to this standard since A 283/A 283M-00 that may impact the use of this standard.

(1) 1.4, 3.1, 3.1.1 (renumbered as 3.2), and Note 1 have been revised to be consistent with the terminology and requirements of Specification A 6/A 6M.

INSPECTION PLANNING PROGRAM USING RISK BASED INSPECTION API 581 FOR ABOVEGROUND STORAGE TANKS IN PT. X. GRESIK

ATTACHEMENT 5:

DAMAGE FACTOR SCREENING ABOVEGROUND STORAGE TANK

Rev.	Tanggal	Keterangan	Disusun Oleh:		Disetujui Oleh:	
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DAMAGE FACTOR SCREENING QUESTION

DETERMINATION OF PROBABILITY OF FAILURE
API 581 PART 2

I. DAMAGE FACTOR

Damage Factor(s) provides a screening tool to determine inspection priorities and optimize inspection. The basic function of the DF 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. DFs are calculated based on the 3 different techniques as mentioned below, but are not intended to reflect the actual POF for the purposes of reliability analysis. DFs reflect a relative level of concern about the component based on the stated assumptions in each of the applicable sectiion of the document.

a. Structural reliability modes

b. Statistical models based on generic data

c. Expert judgement

Table of Damage Factor Screening Questions

No	Damage Factor	Screening Criteria	Yes/No
1.	Thining	All component should be checked for thining	Yes
2.	Component Lining	If the component has organic or inorganic lining, then the component should be evaluated for lining damage	No
3.	SCC Damage Factor-Caustic Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains caustic in any concentration, then the component should be evaluated for susceptibility to caustic cracking.	No
4.	SCC Damage Factor-Amine Cracking	If the component's material of construction is carbon or low alloy steel and process environment contains acid gas treating amines (MEA, DEA, DIPA, MDEA, etc.) in any concentration, then the component should be evaluated for susceptibility to amine cracking.	No
5.	SCC Damage Factor-Sulfide Stress Cracking	If the component's material of construction contains is carbon or low alloy steel and the process environment contains water and H_2S in any concentration, then the component should be evaluated to Sulfide Ctress Cracking (SCC).	No
6.	SCC Damage Factor HIC/SOHIC-H_2S	If the component's material of construction contains is carbon or low alloy steel and the process environment contains water and H_2S in any concentration, then the component should be evaluated to HIC/SOHIC-H_2S cracking.	No

<table>
<tr><th>No</th><th>Damage Factor</th><th colspan="3">Screening Criteria</th><th>Yes/No</th></tr>
<tr><td rowspan="3">7.</td><td rowspan="3">SCC Damage Factor-Alkaline Carbonate Stress Corrosion Cracking</td><td colspan="3">If the component’s material of construction is carbon or low alloy steel and the process environment contains sour water at pH > 7.5 in any concentration, then the component should be evaluated for susceptibility to carbonate cracking.</td><td>No</td></tr>
<tr><td colspan="3">There is no data for Heat Material Balance</td><td>No</td></tr>
<tr><td colspan="3">Another trigger would be changes in FCCU feed sulfurr and nitrogen contents particularly when feed changes have reduced sulfur (low sulfur feeds or hydroprocessed feeds) or increased nitrogen.</td><td>No</td></tr>
<tr><td>8.</td><td>SCC Damage Factor-Polythionic Acid Stress Corrosion Cracking</td><td colspan="3">If the component's material of construction is an austenitic stainless steel or nickel based alloys and the components is exposed to sulfur bearing compunds, then the component should be evaluated for susceptibility to PASCC.</td><td>No</td></tr>
<tr><td rowspan="4">9.</td><td rowspan="4">SCC Damage Factor-Chloride Stress Corrosion Cracking</td><td colspan="3">If <u>ALL</u> of the following are true, then the component should evaluated for suscepibility to CLSCC cracking:</td><td rowspan="4">No</td></tr>
<tr><td>a.</td><td>The component's material of construction is an austenitic stainless</td><td>N</td></tr>
<tr><td>b.</td><td>The component is exposed or potentially exposed to chlorides and water also considering upsets and hydrotest water remaining in component, and cooling tower drift (consider both under insulation and process conditions).</td><td>Y</td></tr>
<tr><td>c.</td><td>The operating temperature is above 38^{o}C (100^{o}F)</td><td>N</td></tr>
<tr><td>10.</td><td>SCC Damage Factor-Hydrogen Stress Cracking-HF</td><td colspan="3">If the component's material of construction is ccarbon or low alloy steel and the component is exposed too hydrofluoric acid in any concentration, then the component should be evaluated for susceptibility to HSC-HF.</td><td>No</td></tr>
<tr><td>11.</td><td>SCC Damage Factor HIC/SOHIC-HF</td><td colspan="3">If the component's material of construction is ccarbon or low alloy steel and the component is exposed too hydrofluoric acid in any concentration, then the component should be evaluated for susceptibility to HIC/SOHIC-HF.</td><td>No</td></tr>
</table>

No	Damage Factor	Screening Criteria			Yes/No
12.	External Corrosion Damage Factor-Ferritic component	If the component is un-insulated and subject to any of the following , then the component should be evaluated for external damage from corrosion.			YES
		a.	Areas exposed to mist overspray from cooling towers.	Y	
		b.	Areas exposed to steam vents	Y	
		c.	Areas exposed to deluge system	Y	
		d.	Areas subject to process spills, ingress of moisture, or acid vapors.	N	
		e.	Carbon steel system, operatinng between -12°C and 177°C (10°F and 350°F). External corrosion is particulartly aggressive where operating temperatures cause frequent or continuous condensation and re-evaporation of atmospheric moisture. (Operating Temperature is 185.4 °C.	Y	
		f.	Systems that do not operating in normally temperature between -12° and 177°C (10°F and 350°F) but cool or heat into this range intermitterntly or are subjected to frequent outages.	N	
		g.	Systems with deteoriated coating and/or wrappings.	Y	
		h.	Cold service equipment consistently operating below the atmospheric dew point.	N	
		i.	Un-insulated nozzles or other prostrusions components of insulated equipment in cold service conditions.	N	

No	Damage Factor	Screening Criteria			Yes/No
13.	Corrosion Under Insulation Damage Factor-Ferritic Commponent		Specific locations and/or systems as stated below are highly suspect and should be considered during inspection program development. Examples the areas include, but are not limited to, the following:		No
		a.	Penetrations 1. All penetrations or breaches in the insulation jacketing systems, such as dead legs (vents, drains, and other similar items), hangers and other supports, valves and fittings, bolted-on pipe shoes, ladders, and platforms. 2. Steam tracer tubing penetrations. 3. Termination of insulation at flanges and other components. 4. Poorly designed insulation support rings. 5. Stiffener rings	N	
		b.	Damaged Insulation Areas 1. Damaged or missing insulation jacketing. 2. Termination of insulation in a vertical pipe or piece of equipment. 3. Caulking that has hardened, has separated, or is missing. 4. Bulges, staining of the jacketing system or missing bands (bulges may indicate corrosion product build-up). 5. Low points in systems that have a known breach in the insulation system, including low points in long unsupported piping runs. 6. Carbon or low alloy steel flanges, bolting, and other components under insulation in high alloy piping.	N	
14.	External Chloride Stress Corrosion Cracking Damage Factor-Austenitic Component		If **ALL** of the following are true, then the component should evaluated for suscepibility to CLSCC:		No
		a.	The component's material of construction is an austenitic stainless	N	
		b.	The component external surface is exposed to chloride containing fluids, mists, or solids.	N	
		c.	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.	N	

No	Damage Factor	Screening Criteria			Yes/No
15.	External Chloride Stress Corrosion Cracking Under Insulation Damage Factor-Austenitic Component	If **<u>ALL</u>** of the following are true, then the component should be evaluated for susceptibiity to CUI CLSCC:			No
		a.	The component's material of construction is an austenitic stainless	N	
		b.	The component is insulated	N	
		c.	The component external surface is exposed to chloride containing fluids, mists, or solids.	N	
		d.	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.	N	
16.	High Temperature Hydrogen Attack Damage Factor	If **<u>ALL</u>** of the following are true, then the component should be evaluated for susceptibiity to HTHA:			No
		a.	The material is carbon steel, C-$^{1}/_{2}$Mo, or a CrMo low alloy steel (such as $^{1}/_{2}$Cr-$^{1}/_{2}$Mo, 1Cr-$^{1}/_{2}$Mo, 1$^{1}/_{4}$Cr-^{1}/2Mo, 2$^{1}/_{4}$Cr-1Mo, 3Cr-1Mo, 5Cr-1Mo, 7Cr-1Mo, 9Cr-1Mo).	Y	
		b.	The operating temperature is greater than 177°C (350°F).	N	
		c.	The operating hydrogen partial presssure is greater than 0.345 Mpa (50 psia).	N	
17.	Brittle Fracture Damage Factor	If **<u>BOTH</u>** of the following are true, then the component should be evaluated for susceptibility to brittle fracture:			
		a.	The material is carbon steel or low alloy steel (see Table 20.1).	Y	
		b.	If Minimum Design Metal Temperature (MDMT), T_{MDMT}, or Minimum Allowable Metal Temperature (MAT), T_{MAT}, is unknown, or the component is known to operate at below MDMT or MAT under normal or upset conditions.	N	

No	Damage Factor	Screening Criteria			Yes/No
18.	Low Alloy Steel Embrittlement Damage Factor	If **ALL** of the following are true, then the component should be evaluated for susceptibility to low alloy steel embrittlement:			No
		a.	The material is 1Cr--0.5Mo, 1.25Cr-0.5Mo, or 3Cr-1Mo low alloy steel.	N	
		b.	The operating temperature is between 343°C and 577°C (650°F and 1070°F).	N	
19.	885°F Embrittlement Damage Factor	If **BOTH** of the following are true, then the component should be evaluated for susceptibiity to 885°F embrittlemet:			No
		a.	The material is high chromium (>12% Cr) ferritic steel	N	
		b.	The operating temperature is between 371°C and 566°C (700°F and 1050°F).	N	
20.	Sigma Phase Embrittlement Damage Factor	If **BOTH** of the following are true, then the component should be evaluated for susceptibiity to sigma phase embrittlemet:			No
		a.	The component's material of construction is an austenitic stainless steel.	N	
		b.	The operating temperature is between 593°C and 927°C (1100°F and 1700°F).	N	
21.	Piping Mechanical Fatigue Damage Factor	If **BOTH** of the following are true, then the component should be evaluated for susceptibiity to mechanical fatigue:			No
		a.	The component is pipe	N	
		b.	There have been past fatigue failure in this piping system or there is visible/audibble 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 virbration.	N	

INSPECTION PLANNING PROGRAM USING RISK BASED INSPECTION API 581 FOR ABOVEGROUND STORAGE TANKS IN PT. X. GRESIK

ATTACHMENT 6 :

PROBABILITY OF FAILURE (POF) CALCULATION OF ABOVEGROUND STORAGE TANK

Rev.	Tanggal	Keterangan	Disusun Oleh:		Disetujui Oleh:	
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			No. Registration :		Dr. Eng. M. Badrus Zaman, S.T. , M.T.	
			04211641000014			

1 GENERAL SPECIFICATION OF PRESSURE VESSEL

Tag Number	:	TANK 21	
Quantity	:	1	
Service	:	StorageTank	
Serial No.	:	-	
Manufactured by	:	PT. Cahaya Hidup Primakarya	
Type of Pressure Vessel	:	Vertical	
	:	StorageTank	
Code	:	API STD 650	
Design Pressure	:	1.03	Kg/cm2
		14,7	psi
		101	kpa
Design Temperature	:	60	℃
Operating Pressure	:	1	Kg/cm2
		98	kpa
Operating Temperature	:	30	℃
Operating Steam Flow rate	:	-	Kg/s
Vessel Volume	:	1500	m^3
Joint Efficiency (Head/Shell)	:	0.85	mm
Corrosion Allowance	:	1.50	mm
	:	0.0591	inch
Year Built	:	2008	
Material	:	ASTM 283 Grade C	
Last Inspection	:	23-Jul-18	
Allowable stress	:	137	kpa
Allowable stress	:	19870	psig
	:	136999	kpa
yield strength	:	205000	kpa
tensile strength	:	380000	kpa

THINNING DAMAGE FACTOR CALCULATION

1. RLA DATA

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1. Component types and geometry data are shown in Tables 4.2 and 4.3, respectively. The data required for determination of the thinning DF is provided in Table 4.4.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Start Date	12/01/2008		The date the component was placed in service.
Thickness	8	mm	The thickness used for DF calculation that is either the furnished thickness or the measured thickness.
Corrosion Allowance	1.50	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	60	°C	The design temperature, shell side and tube side for Aboveground Storage Tank
Design Pressure	101	kPa	The design temperature, shell side and tube side for Aboveground Storage Tank
Operating Tempearture	30	°C	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Operating Pressure	98	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Design Code	API STD 650		The designing of the component containing the component.
Equipment Type	Aboveground Storage Tank		The type of equipment.
Component Type	Aboveground Storage Tank Bottom		The type of component.
Geometry Data	-		Component geometry data depending on the type of component.
Material Specification	ASTM 283 Grade C		The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. this data is readdily available in the ASTM Code.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Yield Strength	380000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	205000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	0.85		Weld joint efficiency per the Code of construction.
Heat Tracing	No		Is the component heat traced? (Yes or No)

STEP 1 Determining the furnished thickness, t, and age for the component from the installation date.

Installation date 23/07/2008

RBI Date 29/10/2019

t = 0.31496063 inch

= 8.000 mm

age = 11.26625599 years

STEP 2 Determining the corrosion rate for base material, $C_{r,bm}$ based on the material construction and environment, and cladding/weld overlay corrosion rate, $C_{r,cm}$.

Based on the explanation from Section 4.5.2 that the corrosion rate is **MEASURED** using the data that given from the company.

1. Corrosion Rate (Cr) from the Inspection data

Cr = 0.006575 inch/year

= 0.167000 mm/year

STEP 3 Determine the time in service, age_{tk}, since the last known inspection, t_{rdi}.

Last inspection is on: 23/07/2018

RBI Date is on: 29/10/2019

Planned Date is on: 28/06/2022

t_{rdi} = 0.274015748 inch

= 6.96 mm

age_{tk} = 1.268 years. Last inspection was held on July 2018

age_{PD} = 3.932 years. Inspection is held every 4 years

STEP 4 For cladding/weld overlay pressure vessel components, calculate the age from the date starting thickness from STEP 3 required to corrode away the cladding/weld overlay material, age_{rc}, using equation below:

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

Because the Aboveground Storage Tank is not cladding/weld overlay. Then, the equation above does not need to be considered.

STEP 5 Determine the t_{min}

Actually there are 4 methods used to determine the minimum thickness of the equipment (t_{min}). Based on the condition, the method used by the author is the third method because the components is the tank bottom.

If the component is a tank bottom, use train = 0.1 in if the AST does not have a release prevention
barrier or tmin = 0.05 in if the AST has a release prevention barrier, in

t_{min} = 0.05 inch

t_{min} = 1.27 mm

So t_{min} selected for the tank shell = 1.27 mm

STEP 6 Determine the A_{rt} Parameter

For tank bottom components, calculate the A, parameter using Equation (2.12) and skip to STEP 13.

<u>A_{rt} on RBI Date:</u>

t_{min}

$$A_{rt} \max\left[\left(1 - \frac{t_{rdi} - (C_{r\,bm\,x\,agetk}}{tmin\ - CA}\right), 0.0\right] \qquad (2.12)$$

= 0

= 0

Where,

$Cr_{b.m}$: Corrosion base material = 0.167 mm/yr

age_{tk} : Component in-service time since the last inspection = 1.268 yr

t_{rdi} : Furnished thickness since last inspection = 6.96 mm

t_{min} : Minimum required thickness based on the applicable construction code = 1.27 mm

CA : Corrosion Allowance = 1.50 mm/yr

A_{rt} on Plan Date:

t_{min}

$$A_{rt}\ \max\left[\left(1-\frac{t_{rdi}-(\,C_{r,\,bm\,x\,agetk}}{tmin\ \ -CA}\right),0.0\right] \qquad (2.12)$$

$= \quad 0$

$= \quad 0$

Where,

$Cr_{b.m}$: Corrosion base material = 0.167 mm/yr

agepd : Component in-service time since the last inspection = 3.932 yr

t_{min}

t_{rdi} : Furnished thickness since last inspection = 6.96 mm

t_{min} : Minimum required thickness based on the applicable construction code = 1.27 mm

CA : Corrosion Allowance = 1.50 mm/yr

STEP 13 For tank bottom components, determine the base damage factor for thinning, Dthin , using Table

Table 4.8 — On-Line Monitoring Adjustment Factors

Thinning Mechanism	Adjustment Factors as a Function of On-Line Monitoring, Fom		
	Key Process Variable	Electrical Resistance Probes (See Note 3)	Corrosion Coupons (See Note 3)
Hydrochloric Acid (HCI) Corrosion	10 (20 if in conjunction with Probes)	10	2
High Temperature Sulfidic/Naphthenic Acid Corrosion	10	10	2
High Temperature H2S/H2 Corrosion	1	10	1

Table 4.8 — On-Line Monitoring Adjustment Factors

Thinning Mechanism	Adjustment Factors as a Function of On-Line Monitoring, Fom		
	Key Process Variable	Electrical Resistance Probes (See Note 3)	Corrosion Coupons (See Note 3)
Sulfuric Acid (H2S/H2) Corrosion - Low Velocity ≤3 ft/s for CS, ≤5 ft/s for SS, ≤7 ft/s for higher alloys 20 10 2 - High Velocity > 3 ft/s for CS, > 5 ft/s for SS, 10	20 10 (20 if in conjunction with Probes)	10 10	2 1
Hydrofluoric Acid (HF) Corrosion	10	1	1
Sour Water Corrosion Low Velocity 20 10 2 20 ft/s High Velocity > 20 ft/s	20 10	10 2	2 2
Amine - Low Velocity - High Velocity	20 10	10 10	2 1
Other Corrosion Mechanism	1	1	1

Table 4.7 - Thinning Damage Factors for AST Bottom

Art	Inspection Effectiveness	
		1 Inspection
	E	D
0	0.1	0.1
0.05	4	1
0.1	14	3
0.15	32	8
0.2	56	18
0.25	87	32
0.3	125	53
0.35	170	80
0.4	222	115
0.45	281	158
0.5	347	211
0.55	420	273
0.6	500	346
0.65	587	430
0.7	681	527
0.75	782	635
0.8	890	757
0.85	1005	893
0.9	1126	1044
0.95	1255	1209
1	1390	1390

Table 4.7 - Thinning Damage Factors for AST Bottom

Art	Inspection Effectiveness		
	1 Inspection		
	C	B	A
0	0.1	0.1	0.1
0.05	0.5	0.4	0.4
0.1	1	0.7	0.7
0.15	2	1	1
0.2	6	2	1
0.25	11	4	3
0.3	21	9	6
0.35	36	16	12
0.4	57	29	21
0.45	86	47	36
0.5	124	73	58
0.55	173	158	189
0.6	234	158	133
0.65	309	222	192
0.7	401	305	270
0.75	510	409	370
0.8	638	538	498
0.85	789	696	658
0.9	963	888	856
0.95	1163	1118	1098
1	1390	1390	1390

A_{rt} on RBI Date:

Art = 0

DfbThin = 0.1

A_{rt} on Plan Date:

Art = 0

DfbThin = 0.1

STEP 15 Determine the DF for thinning, , using equation equation below.

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} . F_{IP} . F_{DL} . F_{WD} . F_{AM} . F_{SM})}{F_{OM}}),0.1]$$

Where;

F_{IP} = DF adjustent for injection points (for piping circuit)

= 0

F_{DL} = DF adjustment for dead legs (for piping only used to intermittent service)

= 0

F_{WD} = DF adjustment for welding construction (for only AST Bottom)

= 1

F_{AM} = DF adjustment for AST maintenance per API STD 653 (for only AST)

= 1

F_{SM} = DF adjustment for settlement (for only AST Bottom)

= 1

F_{OM} = DF adjustment for online monitoring based on Table 4.9

= 1

RBI DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} . F_{IP} . F_{DL} . F_{WD} . F_{AM} . F_{SM})}{F_{OM}}),0.1]$$

= 0.1000000

PLANNED DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} . F_{IP} . F_{DL} . F_{WD} . F_{AM} . F_{SM})}{F_{OM}}),0.1]$$

= 0.1000000

DAMAGE FACTOR FOR THINNING

The governing thinning DF is determined based on the presence of an internal liner using equation below.

$D_{f-gov}^{Thin} = \min[D_f^{Thin}, D_f^{elin}]$ When internal liner is present

$D_{f-gov}^{Thin} = D_f^{Thin}$ When internal liner is not present

According to above calculaton, there is no any presence of liner, then, we can consider to use the second governing thinning DF calculation.

$$D_{f-gov}^{Thin} = D_f^{Thin}$$

RBI DATE:

Based on RLA Data

D_{f-gov}^{Thin} = 0.1000000

PLANNED DATE:

Based on RLA Data

D_{f-gov}^{Thin} = 0.1000000

TYPE OF THINNING

The type of thinning (wheter it is local or general) can be determined from table 2.B.1.2 from API RP 581 3rd Edition Part 2 - Annex 2.B, as follow:

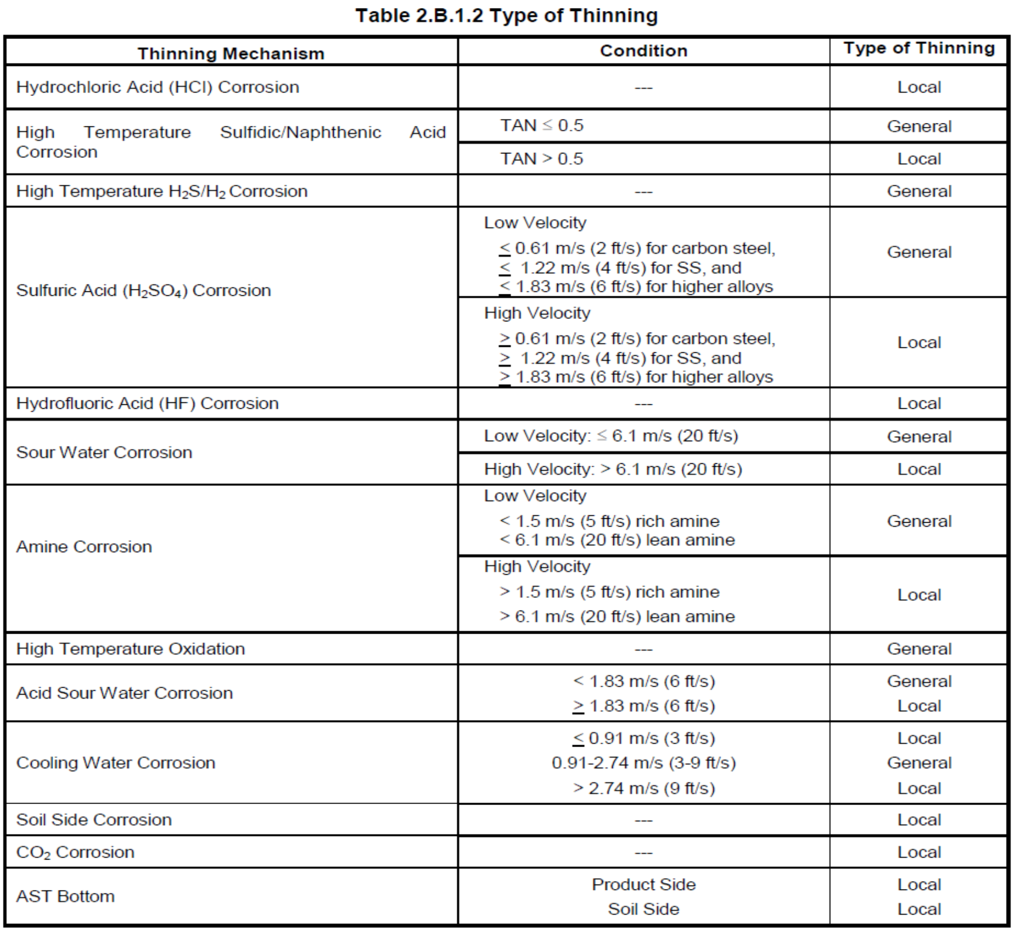


Table 2.B.1.2 Type of Thinning

Thinning Mechanism	Condition	Type of Thinning
Hydrochloric Acid (HCl) Corrosion	---	Local
High Temperature Sulfidic/Naphthenic Acid Corrosion	TAN ≤ 0.5	General
	TAN > 0.5	Local
High Temperature H_2S/H_2 Corrosion	---	General
Sulfuric Acid (H_2SO_4) Corrosion	Low Velocity ≤ 0.61 m/s (2 ft/s) for carbon steel, ≤ 1.22 m/s (4 ft/s) for SS, and ≤ 1.83 m/s (6 ft/s) for higher alloys	General
	High Velocity ≥ 0.61 m/s (2 ft/s) for carbon steel, ≥ 1.22 m/s (4 ft/s) for SS, and ≥ 1.83 m/s (6 ft/s) for higher alloys	Local
Hydrofluoric Acid (HF) Corrosion	---	Local
Sour Water Corrosion	Low Velocity: ≤ 6.1 m/s (20 ft/s)	General
	High Velocity: > 6.1 m/s (20 ft/s)	Local
Amine Corrosion	Low Velocity < 1.5 m/s (5 ft/s) rich amine < 6.1 m/s (20 ft/s) lean amine	General
	High Velocity > 1.5 m/s (5 ft/s) rich amine > 6.1 m/s (20 ft/s) lean amine	Local
High Temperature Oxidation	---	General
Acid Sour Water Corrosion	< 1.83 m/s (6 ft/s) ≥ 1.83 m/s (6 ft/s)	General Local
Cooling Water Corrosion	≤ 0.91 m/s (3 ft/s) 0.91-2.74 m/s (3-9 ft/s) > 2.74 m/s (9 ft/s)	Local General Local
Soil Side Corrosion	---	Local
CO_2 Corrosion	---	Local
AST Bottom	Product Side Soil Side	Local Local

And the thinning mechanisms AST Bottom corrosion

The type of thinning designated will be used to determine the effectiveness of inspection performed.

So, the thinning damage is designated as <u>localized</u>

THINNING DAMAGE FACTOR CALCULATION

1. RLA DATA

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1. Component types and geometry data are shown in Tables 4.2 and 4.3, respectively. The data required for determination of the thinning DF is provided in Table 4.4.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Start Date	12/01/2008		The date the component was placed in service.
Thickness	8	mm	The thickness used for DF calculation that is either the furnished thickness or the measured thickness.
Corrosion Allowance	1.50	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	60	^{o}C	The design temperature, shell side and tube side for Aboveground Storage Tank
Design Pressure	101	kPa	The design temperature, shell side and tube side for Aboveground Storage Tank
Operating Tempearture	30	^{o}C	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Operating Pressure	98	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Design Code	API STD 650		The designing of the component containing the component.
Equipment Type	Aboveground Storage Tank		The type of equipment.
Component Type	Aboveground Storage Tank Shell 1		The type of component.
Geometry Data	-		Component geometry data depending on the type of component.
Material Specification	ASTM 283 Grade C		The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. this data is readdily available in the ASTM Code.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Yield Strength	380000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	205000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	0.85		Weld joint efficiency per the Code of construction.
Heat Tracing	No		Is the component heat traced? (Yes or No)

STEP 1 Determining the furnished thickness, t, and age for the component from the installation date.

Installation date 23/07/2008

RBI Date 29/10/2019

t = 0.31496063 inch

= 8.000 mm

age = 11.26625599 years

STEP 2 Determining the corrosion rate for base material, $C_{r,bm}$ based on the material construction and environment, and cladding/weld overlay corrosion rate, $C_{r,cm}$.

Based on the explanation from Section 4.5.2 that the corrosion rate is **MEASURED** using the data that given from the company.

1. Corrosion Rate (Cr) from the Inspection data

   Cr = 0.006575 inch/year

   = 0.167000 mm/year

STEP 3 Determine the time in service, age_{tk}, since the last known inspection, t_{rdi}.

Last inspection is on: 23/07/2018

RBI Date is on: 29/10/2019

Planned Date is on: 28/06/2022

t_{rdi} = 0.274015748 inch

= 6.96 mm

age_{tk} = 1.268 years. Last inspection was held on July 2018

age_{PD} = 3.932 years. Inspection is held every 4 years

STEP 4 For cladding/weld overlay pressure vessel components, calculate the age from the date starting thickness from STEP 3 required to corrode away the cladding/weld overlay material, age_{rc}, using equation below:

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

Because the Aboveground Storage Tank is not cladding/weld overlay. Then, the equation above does not need to be considered.

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

STEP 5 Determine the t_{min}

Actually there are 4 methods used to determine the minimum thickness of the equipment (t_{min}). Based on the condition, the method used by the author is the fourth method which is specific Tmin calculated by another method and documented in the asset management program may be used at the owner-user's direction.

The Purchaser is using Standart API 650 : Welded Steel Tanks for Oil Storage Tank and using calculation of Thickness by the 1-Foot Method

From the API 653 : Tank Inspection, Repair , Alteration and Reconstruction Third Edition December 2001, the minimum acceptable thickness can be calculated by the equations bellow and not less than 1 inch or 2,54mm

$$tmin = \frac{2,6\,(H - 1)DG}{SE}$$

So t_{min} selected for the tank shell = 3.52 mm

The required minimum thickness of shell plates shall be the greater of tile values computed by tile following fornmlas:

$$tmin = \frac{4,9D\,(H - 0,3)G}{Sd} + CA$$

Shell Course	H (m)	t_d	t_t	t_{used}	t_{se} Less CA
		mm	mm	mm	mm
1	10.64	5.794	4.442	8	6.5
2	8.811	5.034	3.656	8	6.5
3	6.982	4.275	2.87	8	6.5
4	5.154	3.515	2.085	6	4.5
5	3.325	2.756	1.299	6	4.5
6	1.496	1.997	0.514	6	4.5

where : td = design shell thickness, in mm,
tt = hydrostatic test shell thickness, in mm
D = nominal tank diameter, in m
H = design liquid level, in m
G = design specific gravity of the liquid to be stored, as specified by the Purchaser
CA = Corrosion allowance, in mm, as specified by the Purchaser
= = allowable stress for tile design condition, in MPa
= = allowable stress for the hydrostatic test condition, in MPa

STEP 6 Determine the A_{rt} Parameter

For component without clading/weld overlay then use the equation following.

A_{rt} on RBI Date:

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{tk}}{t_{rdi}}$$

= 0.030415713

Where,

$Cr_{b.m}$: Corrosion base material = 0.167 mm/yr
age_{tk} : Component in-service time since the last inspection = 1.268 yr
t_{rdi} : Furnished thickness since last inspection = 6.96 mm

A_{rt} on Plan Date:

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{PD}}{t_{rdi}}$$

= 0.094334694

Where,

$Cr_{b.m}$: Corrosion base material = 0.167 mm/yr
age_{PD} : Component in-service time since the last inspection = 3.932 yr
t_{rdi} : Furnished thickness since last inspection = 6.96 mm

STEP 7 Calculate the Flow Stress, FS^{Thin}, using E from STEP 5 and equation below.

$$FS^{Thin} = \frac{(YS+TS)}{2} \cdot E.1,1$$

her

YS = 205000000 KPa
TS = 380000000 KPa
E = 0.85

ASTM 283 Grade C

$$FS^{Thin} = \frac{(YS+TS)}{2}.\ \text{E.1,1}$$

= 273487500

STEP 8 Calculate the strength ratio parameter, SR_P^{Thin} ing the appropriate equation.

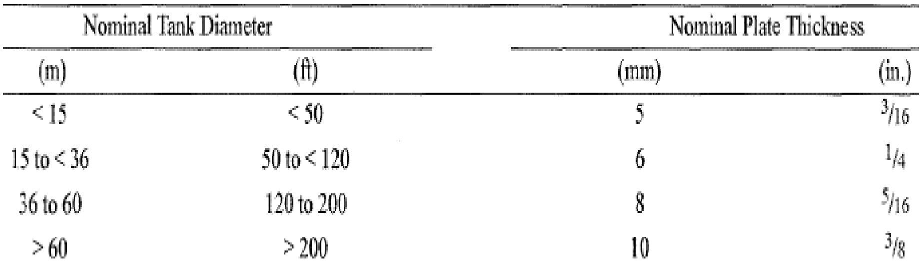
$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} \cdot \frac{Max\ (t_{min}, t_c)}{t_{rdi}}$$

Where; is the minimum structural thickness of the component base material

t_c =

= 0.1968505 inch

= 5.0000000 mm



Nominal Tank Diameter		Nominal Plate Thickness	
(m)	(ft)	(mm)	(in.)
< 15	< 50	5	$^3/_{16}$
15 to < 36	50 to < 120	6	$^1/_4$
36 to 60	120 to 200	8	$^5/_{16}$
> 60	> 200	10	$^3/_8$

Allowable stress = 136998.8812 kpa

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

= 0.000305886

STEP 9 Determine the number of inspections for each of the correspondesing inspection effectiveness, $N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$, using Section 4.5.6 of the API RP 581 Part 2 for past inspections performed during in-service time.

N_A^{Thin} = 0

N_B^{Thin} = 0

N_C^{Thin} = 0

N_D^{Thin} = 2

STEP 10 Calculate the inspection effectiveness factors, $I_1^{Thin}, I_2^{Thin}, I_3^{Thin}$ ing equation 61 below, prior probabilities, $Pr_{p1}^{Thin}, Pr_{p2}^{Thin}$ and Pr_{p3}^{Thin} , from Table 4.5. The Conditional Probabilities (for each inspection effectiveness level), , from Table 4.6, and the number of inspection, N_A^{Thin} , in each effectiveness level from STEP 9.

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

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

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

Table 4.5 - Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Conf. Data	High Conf. 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 4.6 - Conditional Probability for Inspection Effectiveness

Conditional P. 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

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

= 0.080000

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

= 0.03267000

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

= 0.0145800000

STEP 11 Calculate the Posteroir Probability, Po_{p1}^{Thin}, Po_{p2}^{Thin} and Po_{p3}^{Thin}, using equations:

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

= 0.628683694

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

= 0.256738703

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

= 0.114577603

STEP 12 Calculate the parameters, ß_1, ß_2, and ß_3 using equation 67,68,69 below and also assigning $COV_{\Delta t}$ = 0.20, COV_{sf} = 0.20, and COV_P = 0.05.

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S1}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S2}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S3}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

Where;

$COV_{\Delta t}$ = The thinning coefficient of variance ranging from 0.1 ≤ $COV_{\Delta t}$ ≤ 0.2
= 0.2

COV_{sf} = The flow stress coefficient of variance
= 0.2

COV_P = Pressure coeffficient of variance
= 0.05

D_{s1} = Damage State 1
= 1

D_{s2} = Damage State 2
= 2

D_{s3} = Damage State 3
= 4

RBI DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S1}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.9960

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S2}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.987919392

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S3}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.950988542

PLANNED DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= 4.9714$$

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= 4.868220107$$

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= 4.273984854$$

STEP 13 For tank bottom components, determine the base damage factor for thining using Table 4.8. and based on A_{rt} parameter from STEP 6.

Because component observed in this case of analysis is including into Tank Shell, then this step of calculation can be skipped.

STEP 14 For all components (excluding tank bottoms covered in STEP 13), calculate the base damage factor, .

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4}$$

RBI DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4}$$

$$= 0.354147583$$

PLANNED DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4}$$

$$= 0.354146717$$

STEP 15 Determine the DF for thinning, D_f^{Thin}, using equation equation below.

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} . F_{IP} . F_{DL} . F_{WD} . F_{AM} . F_{SM})}{F_{OM}}),0.1]$$

Where;

F_{IP} = DF adjustent for injection points (for piping circuit)

= 0

F_{DL} = DF adjustment for dead legs (for piping only used to intermittent service)

= 0

F_{WD} = DF adjustment for welding construction (for only AST)

= 1

F_{AM} = DF adjustment for AST maintenance per API STD 653 (for only AST)

= 1

F_{SM} = DF adjustment for settlement (for only AST Bottom)

= 0

F_{OM} = DF adjustment for online monitoring based on Table 4.9

= 1

RBI DATE:

<u>BASED ON CORROSION RATE FROM RLA DATA</u>

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin}\ x\ F_{am}}{F_{OM}}),0.1]$$

= 0.3541476

PLANNED DATE:

<u>BASED ON CORROSION RATE FROM RLA DATA</u>

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} x\ F_{am}.}{F_{OM}}),0.1]$$

= 0.3541467

<u>DAMAGE FACTOR FOR THINNING</u>

The governing thinning DF is determined based on the presence of an internal liner using equation below.

$D_{f-gov}^{Thin} = \text{min}[D_f^{Thin}, D_f^{elin}]$ When internal liner is present

$D_{f-gov}^{Thin} = D_f^{Thin}$ When internal liner is not present

According to above calculaton, there is no any presence of liner, then, we can consider to use the second governing thinning DF calculation.

$$D_{f-gov}^{Thin} = D_f^{Thin}$$

RBI DATE:

Based on RLA Data

D_{f-gov}^{Thin} = 0.3541476

PLANNED DATE:

Based on RLA Data

D_{f-gov}^{Thin} = 0.3541467

THINNING DAMAGE FACTOR CALCULATION

1. RLA DATA

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1. Component types and geometry data are shown in Tables 4.2 and 4.3, respectively. The data required for determination of the thinning DF is provided in Table 4.4.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Start Date	12/01/2008		The date the component was placed in service.
Thickness	8	mm	The thickness used for DF calculation that is either the furnished thickness or the measured thickness.
Corrosion Allowance	1.50	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	60	°C	The design temperature, shell side and tube side for Aboveground Storage Tank
Design Pressure	101	kPa	The design temperature, shell side and tube side for Aboveground Storage Tank
Operating Tempearture	30	°C	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Operating Pressure	98	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Design Code	API STD 650		The designing of the component containing the component.
Equipment Type	Aboveground Storage Tank		The type of equipment.
Component Type	Aboveground Storage Tank Shell 2		The type of component.
Geometry Data	-		Component geometry data depending on the type of component.
Material Specification	ASTM 283 Grade C		The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. this data is readdily available in the ASTM Code.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Yield Strength	380000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	205000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	0.85		Weld joint efficiency per the Code of construction.
Heat Tracing	No		Is the component heat traced? (Yes or No)

STEP 1 Determining the furnished thickness, t, and age for the component from the installation date.

Installation date 23/07/2008

RBI Date 29/10/2019

t = 0.31496063 inch

= 8.000 mm

age = 11.26625599 years

STEP 2 Determining the corrosion rate for base material, $C_{r,bm}$ based on the material construction and environment, and cladding/weld overlay corrosion rate, $C_{r,cm}$.

Based on the explanation from Section 4.5.2 that the corrosion rate is **MEASURED** using the data that given from the company.

1. Corrosion Rate (Cr) from the Inspection data

Cr = 0.006575 inch/year

= 0.167000 mm/year

STEP 3 Determine the time in service, age_{tk}, since the last known inspection, t_{rdi}.

Last inspection is on: 23/07/2018

RBI Date is on: 29/10/2019

Planned Date is on: 28/06/2022

t_{rdi} = 0.302362204 inch

= 7.68 mm

age_{tk} = 1.268 years. Last inspection was held on July 2018

age_{PD} = 3.932 years. Inspection is held every 4 years

STEP 4 For cladding/weld overlay pressure vessel components, calculate the age from the date starting thickness from STEP 3 required to corrode away the cladding/weld overlay material, age_{rc}, using equation below:

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

Because the Aboveground Storage Tank is not cladding/weld overlay. Then, the equation above does not need to be considered.

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

STEP 5 Determine the t_{min}

Actually there are 4 methods used to determine the minimum thickness of the equipment (t_{min}). Based on the condition, the method used by the author is the fourth method which is specific Tmin calculated by another method and documented in the asset management program may be used at the owner-user's direction.

The Purchaser is using Standart API 650 : Welded Steel Tanks for Oil Storage Tank and using calculation of Thickness by the 1-Foot Method

From the API 653 : Tank Inspection, Repair , Alteration and Reconstruction Third Edition December 2001, the minimum acceptable thickness can be calculated by the equations bellow and not less than 1 inch or 2,54mm

$$tmin = \frac{2{,}6\ (H-1)DG}{SE}$$

So t_{min} selected for the tank shell = 2.92 mm

The required minimum thickness of shell plates shall be the greater of tile values computed by tile following fornmlas:

$$tmin = \frac{4{,}9D\ (H-0{,}3)G}{Sd} + \text{CA}$$

Shell Course	H (m)	t_d	t_t	t_{used}	t_{se} Less CA
		mm	mm	mm	mm
1	10.64	5.794	4.442	8	6.5
2	8.811	5.034	3.656	8	6.5
3	6.982	4.275	2.87	8	6.5
4	5.154	3.515	2.085	6	4.5
5	3.325	2.756	1.299	6	4.5
6	1.496	1.997	0.514	6	4.5

where : td = design shell thickness, in mm,
tt = hydrostatic test shell thickness, in mm
D = nominal tank diameter, in m
H = design liquid level, in m
G = design specific gravity of the liquid to be stored, as specified by the Purchaser
CA = Corrosion allowance, in mm, as specified by the Purchaser
= = allowable stress for tile design condition, in MPa
= = allowable stress for the hydrostatic test condition, in MPa

STEP 6 Determine the A_{rt} Parameter

For component without clading/weld overlay then use the equation following.

A_{rt} on RBI Date:

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{tk}}{t_{rdi}}$$

= 0.02756424

Where,

$Cr_{b.m}$: Corrosion base material = 0.167 mm/yr
age_{tk} : Component in-service time since the last inspection = 1.268 yr
t_{rdi} : Furnished thickness since last inspection = 7.68 mm

A_{rt} on Plan Date:

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{PD}}{t_{rdi}}$$

= 0.085490817

Where,

$Cr_{b.m}$: Corrosion base material = 0.167 mm/yr
age_{PD} : Component in-service time since the last inspection = 3.932 yr
t_{rdi} : Furnished thickness since last inspection = 7.68 mm

STEP 7 Calculate the Flow Stress, FS^{Thin}, using E from STEP 5 and equation below.

$$FS^{Thin} = \frac{(YS+TS)}{2} \cdot E.1,1$$

Where;

YS = 205000000 KPa
TS = 380000000 KPa
E = 0.85

ASTM 283 Grade C

$FS^{Thin} = \frac{(YS+TS)}{2}$. E.1,1

= 273487500

STEP 8 Calculate the strength ratio parameter, SR_P^{Thin} ing the appropriate equation.

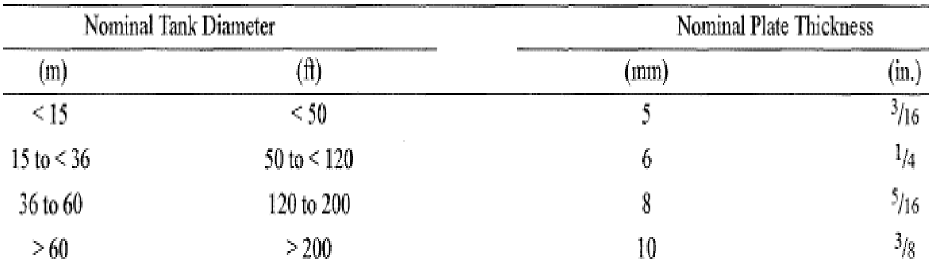
$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} \cdot \frac{Max\,(t_{min}, t_c)}{t_{rdi}}$$

Where; is the minimum structural thickness of the component base material

t_c = is the minimum structural thickness of the component base material

= 0.1968505 inch

= 5.0000000 mm



Nominal Tank Diameter		Nominal Plate Thickness	
(m)	(ft)	(mm)	(in.)
< 15	< 50	5	3/16
15 to < 36	50 to < 120	6	1/4
36 to 60	120 to 200	8	5/16
> 60	> 200	10	3/8

Allowable stress = 136998.8812 kpa

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

= 0.000277209

STEP 9 Determine the number of inspections for each of the correspondesing inspection effectiveness, $N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$, using Section 4.5.6 of the API RP 581 Part 2 for past inspections performed during in-service time.

N_A^{Thin} = 0

N_B^{Thin} = 0

N_C^{Thin} = 0

N_D^{Thin} = 2

STEP 10 Calculate the inspection effectiveness factors, $I_1^{Thin}, I_2^{Thin}, I_3^{Thin}$, using equation 61 below, prior probabilities, $Pr_{p1}^{Thin}, Pr_{p2}^{Thin}$ and Pr_{p3}^{Thin}, from Table 4.5. The Conditional Probabilities (for each inspection effectiveness level), , from Table 4.6, and the number of inspection, N_A^{Thin}, in each effectiveness level from STEP 9.

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

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

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

Table 4.5 - Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Conf. Data	High Conf. 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 4.6 - Conditional Probability for Inspection Effectiveness

Conditional P. 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

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

$$= \quad 0.080000$$

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

$$= \quad 0.03267000$$

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

$$= \quad 0.0145800000$$

STEP 11 Calculate the Posteroir Probability, $Po_{p1}^{Thin}, Po_{p2}^{Thin}$ and Po_{p3}^{Thin}, using equations:

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

$$= \quad 0.628683694$$

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

$$= \quad 0.256738703$$

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

$$= \quad 0.114577603$$

STEP 12 Calculate the parameters, ß_1, ß_2, and ß_3 using equation 67,68,69 below and also assigning $COV_{\Delta t} = 0.20$, $COV_{sf} = 0.20$, and $COV_P = 0.05$.

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S1}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S2}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S3}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

Where;

$COV_{\Delta t}$ = The thinning coefficient of variance ranging from 0.1 ≤ $COV_{\Delta t}$ ≤ 0.2
= 0.2
COV_{sf} = The flow stress coefficient of variance
= 0.2
COV_P = Pressure coeffficient of variance
= 0.05
D_{s1} = Damage State 1
= 1
D_{s2} = Damage State 2
= 2
D_{s3} = Damage State 3
= 4

RBI DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S1}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.9966

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S2}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.990046898

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S3}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.960500154

PLANNED DATE:

<u>BASED ON CORROSION RATE FROM RLA DATA</u>

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= \quad 4.9768$$

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= \quad 4.89529584$$

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= \quad 4.434810463$$

STEP 13 For tank bottom components, determine the base damage factor for thining using Table 4.8. and based on A_{rt} parameter from STEP 6.

Because component observed in this case of analysis is including into Tank Shell, then this step of calculation can be skipped.

STEP 14 For all components (excluding tank bottoms covered in STEP 13), calculate the base damage factor, .

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right)+\left(Po_{P2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right)+\left(Po_{P3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E-0.4}$$

RBI DATE:

<u>BASED ON CORROSION RATE FROM RLA DATA</u>

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right)+\left(Po_{P2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right)+\left(Po_{P3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E-0.4}$$

$$= \quad 0.354147586$$

PLANNED DATE:

<u>BASED ON CORROSION RATE FROM RLA DATA</u>

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right)+\left(Po_{P2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right)+\left(Po_{P3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E-0.4}$$

$$= \quad 0.354147167$$

STEP 15 Determine the DF for thinning, D_f^{Thin}, using equation equation below.

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} . F_{IP} . F_{DL} . F_{WD} . F_{AM} . F_{SM})}{F_{OM}}),0.1]$$

Where;

F_{IP} = DF adjustent for injection points (for piping circuit)
= 0
F_{DL} = DF adjustment for dead legs (for piping only used to intermittent service)
= 0
F_{WD} = DF adjustment for welding construction (for only AST)
= 1
F_{AM} = DF adjustment for AST maintenance per API STD 653 (for only AST)
= 1
F_{SM} = DF adjustment for settlement (for only AST Bottom)
= 0
F_{OM} = DF adjustment for online monitoring based on Table 4.9
= 1

RBI DATE:

<u>BASED ON CORROSION RATE FROM RLA DATA</u>

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} \ x \ F_{am}^{\square}}{F_{OM}}),0.1]$$

= 0.3541476

PLANNED DATE:

<u>BASED ON CORROSION RATE FROM RLA DATA</u>

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} x \ F_{am}^{\square}.}{F_{OM}}),0.1]$$

= 0.3541472

<u>DAMAGE FACTOR FOR THINNING</u>

The governing thinning DF is determined based on the presence of an internal liner using equation below.

$D_{f-gov}^{Thin} = \min[D_f^{Thin}, D_f^{elin}]$ When internal liner is present

$D_{f-gov}^{Thin} = D_f^{Thin}$ When internal liner is not present

According to above calculaton, there is no any presence of liner, then, we can consider to use the second governing thinning DF calculation.

$$D_{f-gov}^{Thin} = D_f^{Thin}$$

RBI DATE:

Based on RLA Data

D_{f-gov}^{Thin} = 0.3541476

PLANNED DATE:

Based on RLA Data

D_{f-gov}^{Thin} = 0.3541472

THINNING DAMAGE FACTOR CALCULATION

1. RLA DATA

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1. Component types and geometry data are shown in Tables 4.2 and 4.3, respectively. The data required for determination of the thinning DF is provided in Table 4.4.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Start Date	12/01/2008		The date the component was placed in service.
Thickness	8	mm	The thickness used for DF calculation that is either the furnished thickness or the measured thickness.
Corrosion Allowance	1.50	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	60	^{o}C	The design temperature, shell side and tube side for Aboveground Storage Tank
Design Pressure	101	kPa	The design temperature, shell side and tube side for Aboveground Storage Tank
Operating Tempearture	30	^{o}C	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Operating Pressure	98	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Design Code	API STD 650		The designing of the component containing the component.
Equipment Type	Aboveground Storage Tank		The type of equipment.
Component Type	Aboveground Storage Tank Shell 3		The type of component.
Geometry Data	-		Component geometry data depending on the type of component.
Material Specification	ASTM 283 Grade C		The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. this data is readdily available in the ASTM Code.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Yield Strength	380000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	205000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	0.85		Weld joint efficiency per the Code of construction.
Heat Tracing	No		Is the component heat traced? (Yes or No)

STEP 1 Determining the furnished thickness, t, and age for the component from the installation date.

Installation date 23/07/2008

RBI Date 29/10/2019

t = 0.31496063 inch

= 8.000 mm

age = 11.26625599 years

STEP 2 Determining the corrosion rate for base material, $C_{r,bm}$ based on the material construction and environment, and cladding/weld overlay corrosion rate, $C_{r,cm}$.

Based on the explanation from Section 4.5.2 that the corrosion rate is **<u>MEASURED</u>** using the data that given from the company.

1. Corrosion Rate (Cr) from the Inspection data

Cr = 0.006575 inch/year

= 0.167000 mm/year

STEP 3 Determine the time in service, age_{tk}, since the last known inspection, t_{rdi}.

Last inspection is on: 23/07/2018

RBI Date is on: 29/10/2019

Planned Date is on: 28/06/2022

t_{rdi} = 0.303543307 inch

= 7.71 mm

age_{tk} = 1.268 years. Last inspection was held on July 2018

age_{PD} = 3.932 years. Inspection is held every 4 years

STEP 4 For cladding/weld overlay pressure vessel components, calculate the age from the date starting thickness from STEP 3 required to corrode away the cladding/weld overlay material, age_{rc}, using equation below:

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

Because the Aboveground Storage Tank is not cladding/weld overlay. Then, the equation above does not need to be considered.

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

STEP 5 Determine the t_{min}

Actually there are 4 methods used to determine the minimum thickness of the equipment (t_{min}). Based on the condition, the method used by the author is the fourth method which is specific Tmin calculated by another method and documented in the asset management program may be used at the owner-user's direction.

The Purchaser is using Standart API 650 : Welded Steel Tanks for Oil Storage Tank and using calculation of Thickness by the 1-Foot Method

From the API 653 : Tank Inspection, Repair , Alteration and Reconstruction Third Edition December 2001, the minimum acceptable thickness can be calculated by the equations bellow and not less than 1 inch or 2,54mm

$$tmin = \frac{2{,}6\ (H - 1)DG}{SE}$$

So t_{min} selected for the tank shell = 2.54 mm

The required minimum thickness of shell plates shall be the greater of tile values computed by tile following fornmlas:

$$tmin = \frac{4{,}9D\ (H - 0{,}3)G}{Sd} + \text{CA}$$

Shell Course	H (m)	t_d	t_t	t_{used}	t_{se} Less CA
		mm	mm	mm	mm
1	10.64	5.794	4.442	8	6.5
2	8.811	5.034	3.656	8	6.5
3	6.982	4.275	2.87	8	6.5
4	5.154	3.515	2.085	6	4.5
5	3.325	2.756	1.299	6	4.5
6	1.496	1.997	0.514	6	4.5

where : td = design shell thickness, in mm,
tt = hydrostatic test shell thickness, in mm
D = nominal tank diameter, in m
H = design liquid level, in m
G = design specific gravity of the liquid to be stored, as specified by the Purchaser
CA = Corrosion allowance, in mm, as specified by the Purchaser
= = allowable stress for tile design condition, in MPa
= = allowable stress for the hydrostatic test condition, in MPa

STEP 6 Determine the A_{rt} Parameter

For component without clading/weld overlay then use the equation following.

A_{rt} on RBI Date:

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{tk}}{t_{rdi}}$$

$= 0.027456986$

Where,

$Cr_{b.m}$: Corrosion base material = 0.167 mm/yr
age_{tk} : Component in-service time since the last inspection = 1.268 yr
t_{rdi} : Furnished thickness since last inspection = 7.71 mm

A_{rt} on Plan Date:

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{PD}}{t_{rdi}}$$

$= 0.085158168$

Where,

$Cr_{b.m}$: Corrosion base material = 0.167 mm/yr
age_{PD} : Component in-service time since the last inspection = 3.932 yr
t_{rdi} : Furnished thickness since last inspection = 7.71 mm

STEP 7 Calculate the Flow Stress, FS^{Thin} using E from STEP 5 and equation below.

$$FS^{Thin} = \frac{(YS+TS)}{2}. E.1,1$$

Where;

YS = 205000000 KPa
TS = 380000000 KPa
E = 0.85

ASTM 283 Grade C

$$FS^{Thin} = \frac{(YS+TS)}{2}. \text{ E.1,1}$$

= 273487500

STEP 8 Calculate the strength ratio parameter, SR_P^{Thin} ing the appropriate equation.

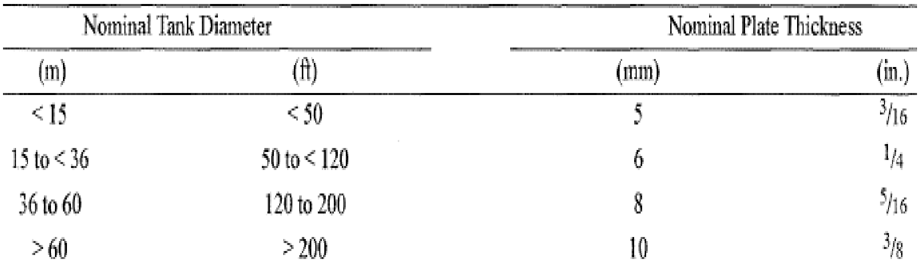
$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} \cdot \frac{Max\ (t_{min}, t_c)}{t_{rdi}}$$

Where; is the minimum structural thickness of the component base material

t_c =

= 0.1968505 inch

= 5.0000000 mm



Nominal Tank Diameter		Nominal Plate Thickness	
(m)	(ft)	(mm)	(in.)
< 15	< 50	5	3/16
15 to < 36	50 to < 120	6	1/4
36 to 60	120 to 200	8	5/16
> 60	> 200	10	3/8

Allowable stress = 136998.8812 kpa

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

= 0.00027613

STEP 9 Determine the number of inspections for each of the correspondesing inspection effectiveness, $N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$, using Section 4.5.6 of the API RP 581 Part 2 for past inspections performed during in-service time.

N_A^{Thin} = 0

N_B^{Thin} = 0

N_C^{Thin} = 0

N_D^{Thin} = 2

STEP 10 Calculate the inspection effectiveness factors, $I_1^{Thin}, I_2^{Thin}, I_3^{Thin}$ using equation 61 below, prior probabilities, $Pr_{p1}^{Thin}, Pr_{p2}^{Thin}$ and Pr_{p3}^{Thin} from Table 4.5. The Conditional Probabilities (for each inspection effectiveness level), , from Table 4.6, and the number of inspection, N_A^{Thin} , in each effectiveness level from STEP 9.

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

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

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

Table 4.5 - Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Conf. Data	High Conf. 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 4.6 - Conditional Probability for Inspection Effectiveness

Conditional P. 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

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

= 0.080000

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

= 0.03267000

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

= 0.0145800000

STEP 11 Calculate the Posteroir Probability, Po_{p1}^{Thin}, Po_{p2}^{Thin} and Po_{p3}^{Thin}, using equations:

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

= 0.628683694

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

= 0.256738703

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

= 0.114577603

STEP 12 Calculate the parameters, $ß_1$, $ß_2$, and $ß_3$ using equation 67,68,69 below and also assigning $COV_{\Delta t} = 0.20$, $COV_{sf} = 0.20$, and $COV_P = 0.05$.

$$ß_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S1}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$ß_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S2}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$ß_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S3}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

Where;

$COV_{\Delta t}$ = The thinning coefficient of variance ranging from 0.1 ≤ $COV_{\Delta t}$ ≤ 0.2
= 0.2
COV_{sf} = The flow stress coefficient of variance
= 0.2
COV_P = Pressure coeffficient of variance
= 0.05
D_{s1} = Damage State 1
= 1
D_{s2} = Damage State 2
= 2
D_{s3} = Damage State 3
= 4

RBI DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$ß_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S1}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= 4.9966$$

$$ß_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S2}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= 4.990122485$$

$$ß_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S3}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= 4.960834159$$

PLANNED DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S1}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= 4.9770$$

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S2}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= 4.896238318$$

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S3}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= 4.440380317$$

STEP 13 For tank bottom components, determine the base damage factor for thining using Table 4.8. and based on A_{rt} parameter from STEP 6.

Because component observed in this case of analysis is including into Tank Shell, then this step of calculation can be skipped.

STEP 14 For all components (excluding tank bottoms covered in STEP 13), calculate the base damage factor, .

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4}$$

RBI DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4}$$

$$= 0.354147586$$

PLANNED DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4}$$

$$= 0.354147177$$

STEP 15 Determine the DF for thinning, , D_f^{Thin} g equation equation below.

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} . F_{IP} . F_{DL} . F_{WD} . F_{AM} . F_{SM})}{F_{OM}}), 0.1]$$

Where;

F_{IP} = DF adjustent for injection points (for piping circuit)

= 0

F_{DL} = DF adjustment for dead legs (for piping only used to intermittent service)

= 0

F_{WD} = DF adjustment for welding construction (for only AST)

= 1

F_{AM} = DF adjustment for AST maintenance per API STD 653 (for only AST)

= 1

F_{SM} = DF adjustment for settlement (for only AST Bottom)

= 0

F_{OM} = DF adjustment for online monitoring based on Table 4.9

= 1

RBI DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} \; x \; F_{am}}{F_{OM}}), 0.1]$$

= 0.3541476

PLANNED DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} x \; F_{am}.}{F_{OM}}), 0.1]$$

= 0.3541472

DAMAGE FACTOR FOR THINNING

The governing thinning DF is determined based on the presence of an internal liner using equation below.

$D_{f-gov}^{Thin} = \min[D_f^{Thin}, D_f^{elin}]$ When internal liner is present

$D_{f-gov}^{Thin} = D_f^{Thin}$ When internal liner is not present

According to above calculaton, there is no any presence of liner, then, we can consider to use the second governing thinning DF calculation.

$$D_{f-gov}^{Thin} = D_f^{Thin}$$

RBI DATE:

Based on RLA Data

D_{f-gov}^{Thin} = 0.3541476

PLANNED DATE:

Based on RLA Data

D_{f-gov}^{Thin} = 0.3541472

THINNING DAMAGE FACTOR CALCULATION

1. RLA DATA

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1. Component types and geometry data are shown in Tables 4.2 and 4.3, respectively. The data required for determination of the thinning DF is provided in Table 4.4.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Start Date	12/01/2008		The date the component was placed in service.
Thickness	8	mm	The thickness used for DF calculation that is either the furnished thickness or the measured thickness.
Corrosion Allowance	1.50	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	60	^{o}C	The design temperature, shell side and tube side for Aboveground Storage Tank
Design Pressure	101	kPa	The design temperature, shell side and tube side for Aboveground Storage Tank
Operating Tempearture	30	^{o}C	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Operating Pressure	98	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Design Code	API STD 650		The designing of the component containing the component.
Equipment Type	Aboveground Storage Tank		The type of equipment.
Component Type	Aboveground Storage Tank Shell 4		The type of component.
Geometry Data	-		Component geometry data depending on the type of component.
Material Specification	ASTM 283 Grade C		The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. this data is readdily available in the ASTM Code.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	**Value**	**Unit**	**Comments**
Yield Strength	380000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	205000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	0.85		Weld joint efficiency per the Code of construction.
Heat Tracing	No		Is the component heat traced? (Yes or No)

STEP 1

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

Installation date 23/07/2008
RBI Date 29/10/2019
t = 0.236220472 inch
= 6.000 mm
age = 11.26625599 years

STEP 2

Determining the corrosion rate for base material, $C_{r,bm}$ based on the material construction and environment, and cladding/weld overlay corrosion rate, $C_{r,cm}$. Based on the explanation from Section 4.5.2 that the corrosion rate is **MEASURED** using the data that given from the company.

1. Corrosion Rate (Cr) from the Inspection data
   Cr = 0.006575 inch/year
   = 0.167000 mm/year

STEP 3

Determine the time in service, age_{tk}, since the last known inspection, t_{rdi}.

Last inspection is on: 23/07/2018
RBI Date is on: 29/10/2019
Planned Date is on: 28/06/2022
t_{rdi} = 0.22519685 inch
= 5.72 mm

age_{tk} = 1.268 years. Last inspection was held on July 2018

age_{PD} = 3.932 years. Inspection is held every 4 years

STEP 4 For cladding/weld overlay pressure vessel components, calculate the age from the date starting thickness from STEP 3 required to corrode away the cladding/weld overlay material, age$_{rc}$, using equation below:

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

Because the Aboveground Storage Tank is not cladding/weld overlay. Then, the equation above does not need to be considered.

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

STEP 5 Determine the t$_{min}$

Actually there are 4 methods used to determine the minimum thickness of the equipment (t$_{min}$). Based on the condition, the method used by the author is the fourth method which is specific Tmin calculated by another method and documented in the asset management program may be used at the owner-user's direction.

The Purchaser is using Standart API 650 : Welded Steel Tanks for Oil Storage Tank and using calculation of Thickness by the 1-Foot Method

From the API 653 : Tank Inspection, Repair , Alteration and Reconstruction Third Edition December 2001, the minimum acceptable thickness can be calculated by the equations bellow and not less than 1 inch or 2,54mm

$$tmin = \frac{2{,}6\;(H - 1)DG}{SE}$$

So t_{min} selected for the tank shell = 2.54 mm

The required minimum thickness of shell plates shall be the greater of tile values computed by tile following fornmlas:

$$tmin = \frac{4{,}9D\;(H - 0{,}3)G}{Sd} + CA$$

Shell Course	H (m)	t_d	t_t	t_{used}	t_{se} Less CA
		mm	mm	mm	mm
1	10.64	5.794	4.442	8	6.5
2	8.811	5.034	3.656	8	6.5
3	6.982	4.275	2.87	8	6.5
4	5.154	3.515	2.085	6	4.5
5	3.325	2.756	1.299	6	4.5
6	1.496	1.997	0.514	6	4.5

where : td = design shell thickness, in mm,
tt = hydrostatic test shell thickness, in mm
D = nominal tank diameter, in m
H = design liquid level, in m
G = design specific gravity of the liquid to be stored, as specified by the Purchaser
CA = Corrosion allowance, in mm, as specified by the Purchaser
= = allowable stress for tile design condition, in MPa
= = allowable stress for the hydrostatic test condition, in MPa

STEP 6 Determine the A_{rt} Parameter

For component without clading/weld overlay then use the equation following.

A_{rt} on RBI Date:

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{tk}}{t_{rdi}}$$

$$= 0.037009329$$

Where,

$Cr_{b.m}$: Corrosion base material = 0.167 mm/yr
age_{tk} : Component in-service time since the last inspection = 1.268 yr
t_{rdi} : Furnished thickness since last inspection = 5.72 mm

A_{rt} on Plan Date:

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{PD}}{t_{rdi}}$$

$$= 0.114784873$$

Where,

$Cr_{b.m}$: Corrosion base material = 0.167 mm/yr
age_{PD} : Component in-service time since the last inspection = 3.932 yr
t_{rdi} : Furnished thickness since last inspection = 5.72 mm

STEP 7 Calculate the Flow Stress, , using E from STEP 5 and equation beloFS^{Thin}

$$FS^{Thin} = \frac{(YS+TS)}{2}. \text{E.1,1}$$

Where;

YS = 205000000 KPa
TS = 380000000 KPa
E = 0.85

ASTM 283 Grade C

$$FS^{Thin} = \frac{(YS+TS)}{2}.\ \mathrm{E.1,1}$$

= 273487500

STEP 8 Calculate the strength ratio parameter, SR_P^{Thin}ing the appropriate equation.

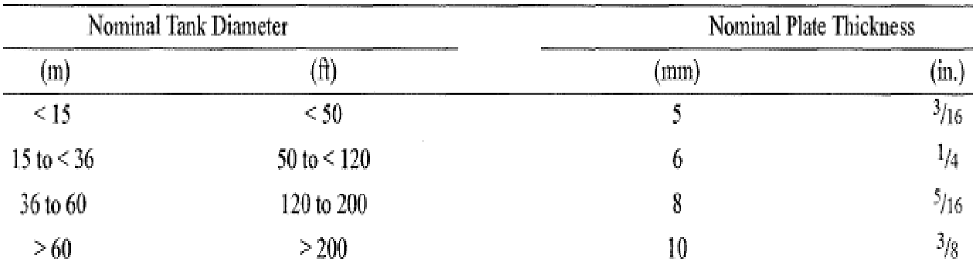
$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}}.\frac{Max\,(t_{min},t_c)}{t_{rdi}}$$

Where;

t_c = is the minimum structural thickness of the component base material

= 0.1968505 inch

= 5.0000000 mm



Nominal Tank Diameter		Nominal Plate Thickness	
(m)	(ft)	(mm)	(in.)
< 15	< 50	5	3/16
15 to < 36	50 to < 120	6	1/4
36 to 60	120 to 200	8	5/16
> 60	> 200	10	3/8

Allowable stress = 136998.8812 kpa

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

= 0.000372197

STEP 9 Determine the number of inspections for each of the correspondesing inspection effectiveness, $N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$, using Section 4.5.6 of the API RP 581 Part 2 for past inspections performed during in-service time.

N_A^{Thin} = 0

N_B^{Thin} = 0

N_C^{Thin} = 0

N_D^{Thin} = 2

STEP 10 Calculate the inspection effectiveness factors, , using equation 61 below, prior probabilities, $Pr_{p1}^{Thin}, Pr_{p2}^{Thin}$ and Pr_{p3}^{Thin} from Table 4.5. The Conditional Probabilities (for each inspection effectiveness level), , from Table 4.6, and the number of inspection, N_A^{Thin}, in each effectiveness level from STEP 9.

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

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

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

Table 4.5 - Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Conf. Data	High Conf. 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 4.6 - Conditional Probability for Inspection Effectiveness

Conditional P. 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

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

$$= \quad 0.080000$$

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

$$= \quad 0.03267000$$

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

$$= \quad 0.0145800000$$

STEP 11 Calculate the Posteroir Probability, $Po_{p1}^{Thin}, Po_{p2}^{Thin}$ and Po_{p3}^{Thin}, using equations:

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

$$= \quad 0.628683694$$

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

$$= \quad 0.256738703$$

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

$$= \quad 0.114577603$$

STEP 12 Calculate the parameters, $ß_1$, $ß_2$, and $ß_3$ using equation 67,68,69 below and also assigning $COV_{\Delta t} = 0.20$, $COV_{sf} = 0.20$, and $COV_P = 0.05$.

$$ß_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S1}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$ß_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S2}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$ß_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S3}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

Where;

$COV_{\Delta t}$ = The thinning coefficient of variance ranging from $0.1 \leq COV_{\Delta t} \leq 0.2$
= 0.2

COV_{sf} = The flow stress coefficient of variance
= 0.2

COV_P = Pressure coeffficient of variance
= 0.05

D_{s1} = Damage State 1
= 1

D_{s2} = Damage State 2
= 2

D_{s3} = Damage State 3
= 4

RBI DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$ß_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S1}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.9944

$$ß_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S2}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.982098614

$$ß_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S3}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.924033585

PLANNED DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S1}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= 4.9564$$

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S2}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= 4.789477504$$

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S3}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= 3.809131329$$

STEP 13 For tank bottom components, determine the base damage factor for thining using Table 4.8. and based on A_{rt} parameter from STEP 6.

Because component observed in this case of analysis is including into Tank Shell, then this step of calculation can be skipped.

STEP 14 For all components (excluding tank bottoms covered in STEP 13), calculate the base damage factor, .

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4}$$

RBI DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4}$$

$$= 0.354147576$$

PLANNED DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4}$$

$$= 0.354141456$$

STEP 15 Determine the DF for thinning, D_f^{Thin} using equation equation below.

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} . F_{IP} . F_{DL} .F_{WD}.F_{AM} .F_{SM})}{F_{OM}}),0.1]$$

Where;

F_{IP} = DF adjustent for injection points (for piping circuit)
= 0
F_{DL} = DF adjustment for dead legs (for piping only used to intermittent service)
= 0
F_{WD} = DF adjustment for welding construction (for only AST)
= 1
F_{AM} = DF adjustment for AST maintenance per API STD 653 (for only AST)
= 1
F_{SM} = DF adjustment for settlement (for only AST Bottom)
= 0
F_{OM} = DF adjustment for online monitoring based on Table 4.9
= 1

RBI DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin}\ x\ F_{am}^{\square}}{F_{OM}}),0.1]$$

= 0.3541476

PLANNED DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} x\ F_{am}^{\square}.}{F_{OM}}),0.1]$$

= 0.3541415

DAMAGE FACTOR FOR THINNING

The governing thinning DF is determined based on the presence of an internal liner using equation below.

$D_{f-gov}^{Thin} = \min[D_f^{Thin}, D_f^{elin}]$ When internal liner is present
$D_{f-gov}^{Thin} = D_f^{Thin}$ When internal liner is not present

According to above calculaton, there is no any presence of liner, then, we can consider to use the second governing thinning DF calculation.

$$D_{f-gov}^{Thin} = D_f^{Thin}$$

RBI DATE:

Based on RLA Data

D_{f-gov}^{Thin} = 0.3541476

PLANNED DATE:

Based on RLA Data

D_{f-gov}^{Thin} = 0.3541415

THINNING DAMAGE FACTOR CALCULATION

1. RLA DATA

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1. Component types and geometry data are shown in Tables 4.2 and 4.3, respectively. The data required for determination of the thinning DF is provided in Table 4.4.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Start Date	12/01/2008		The date the component was placed in service.
Thickness	8	mm	The thickness used for DF calculation that is either the furnished thickness or the measured thickness.
Corrosion Allowance	1.50	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	60	^{o}C	The design temperature, shell side and tube side for Aboveground Storage Tank
Design Pressure	101	kPa	The design temperature, shell side and tube side for Aboveground Storage Tank
Operating Tempearture	30	^{o}C	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Operating Pressure	98	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Design Code	API STD 650		The designing of the component containing the component.
Equipment Type	Aboveground Storage Tank		The type of equipment.
Component Type	Aboveground Storage Tank Shell 5		The type of component.
Geometry Data	-		Component geometry data depending on the type of component.
Material Specification	ASTM 283 Grade C		The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. this data is readdily available in the ASTM Code.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Yield Strength	380000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	205000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	0.85		Weld joint efficiency per the Code of construction.
Heat Tracing	No		Is the component heat traced? (Yes or No)

STEP 1 Determining the furnished thickness, t, and age for the component from the installation date.

Installation date		23/07/2008	
RBI Date		29/10/2019	
t	=	0.236220472	inch
	=	6.000	mm
age	=	11.26625599	years

STEP 2 Determining the corrosion rate for base material, $C_{r,bm}$ based on the material construction and environment, and cladding/weld overlay corrosion rate, $C_{r,cm}$. Based on the explanation from Section 4.5.2 that the corrosion rate is **MEASURED** using the data that given from the company.

1. Corrosion Rate (Cr) from the Inspection data

Cr = 0.006575 inch/year

= 0.167000 mm/year

STEP 3 Determine the time in service, age_{tk}, since the last known inspection, t_{rdi}.

Last inspection is on:		23/07/2018	
RBI Date is on:		29/10/2019	
Planned Date is on:		28/06/2022	
t_{rdi}	=	0.230708661	inch
	=	5.86	mm

age_{tk}	=	1.268	years.	Last inspection was held on July 2018
age_{PD}	=	3.932	years.	Inspection is held every 4 years

STEP 4 For cladding/weld overlay pressure vessel components, calculate the age from the date starting thickness from STEP 3 required to corrode away the cladding/weld overlay material, age_{rc}, using equation below:

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

Because the Aboveground Storage Tank is not cladding/weld overlay. Then, the equation above does not need to be considered.

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

STEP 5 Determine the t_{min}

Actually there are 4 methods used to determine the minimum thickness of the equipment (t_{min}). Based on the condition, the method used by the author is the fourth method which is specific Tmin calculated by another method and documented in the asset management program may be used at the owner-user's direction.

The Purchaser is using Standart API 650 : Welded Steel Tanks for Oil Storage Tank and using calculation of Thickness by the 1-Foot Method

From the API 653 : Tank Inspection, Repair , Alteration and Reconstruction Third Edition December 2001, the minimum acceptable thickness can be calculated by the equations bellow and not less than 1 inch or 2,54mm

$$tmin = \frac{2{,}6\ (H-1)DG}{SE}$$

So t_{min} selected for the tank shell = 2.54 mm

The required minimum thickness of shell plates shall be the greater of tile values computed by tile following fornmlas:

$$tmin = \frac{4{,}9D\ (H-0{,}3)G}{Sd} + \text{CA}$$

Shell Course	H (m)	t_d	t_t	t_{used}	t_{se} Less CA
		mm	mm	mm	mm
1	10.64	5.794	4.442	8	6.5
2	8.811	5.034	3.656	8	6.5
3	6.982	4.275	2.87	8	6.5
4	5.154	3.515	2.085	6	4.5
5	3.325	2.756	1.299	6	4.5
6	1.496	1.997	0.514	6	4.5

where : td = design shell thickness, in mm,

tt = hydrostatic test shell thickness, in mm

D = nominal tank diameter, in m

H = design liquid level, in m

G = design specific gravity of the liquid to be stored, as specified by the Purchaser

CA = Corrosion allowance, in mm, as specified by the Purchaser

= = allowable stress for tile design condition, in MPa

= = allowable stress for the hydrostatic test condition, in MPa

STEP 6 Determine the A_{rt} Parameter

For component without clading/weld overlay then use the equation following.

A_{rt} on RBI Date:

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{tk}}{t_{rdi}}$$

$$= 0.036125147$$

Where,

$Cr_{b.m}$: Corrosion base material = 0.167 mm/yr

age_{tk} : Component in-service time since the last inspection = 1.268 yr

t_{rdi} : Furnished thickness since last inspection = 5.86 mm

A_{rt} on Plan Date:

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{PD}}{t_{rdi}}$$

$$= 0.112042572$$

Where,

$Cr_{b.m}$: Corrosion base material = 0.167 mm/yr

age_{PD} : Component in-service time since the last inspection = 3.932 yr

t_{rdi} : Furnished thickness since last inspection = 5.86 mm

STEP 7 Calculate the Flow Stress, , using E from STEP 5 and equation beloFS^{Thin}

$$FS^{Thin} = \frac{(YS+TS)}{2}. \text{E.1,1}$$

Where;

YS = 205000000 KPa

TS = 380000000 KPa

E = 0.85

ASTM 283 Grade C

$$FS^{Thin} = \frac{(YS+TS)}{2}.\ E.1,1$$

= 273487500

STEP 8 Calculate the strength ratio parameter, SR_P^{Thin} ing the appropriate equation.

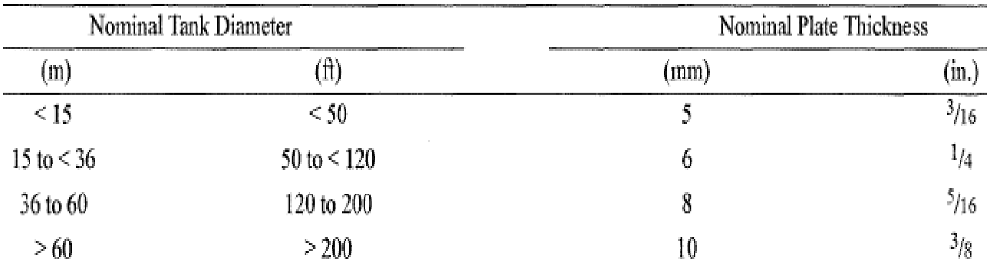
$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}}.\frac{Max\ (t_{min}, t_c)}{t_{rdi}}$$

Where; is the minimum structural thickness of the component base material

t_c =

= 0.1968505 inch

= 5.0000000 mm



Nominal Tank Diameter		Nominal Plate Thickness	
(m)	(ft)	(mm)	(in.)
< 15	< 50	5	3/16
15 to < 36	50 to < 120	6	1/4
36 to 60	120 to 200	8	5/16
> 60	> 200	10	3/8

Allowable stress = 136998.8812 kpa

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

= 0.000363305

STEP 9 Determine the number of inspections for each of the correspondesing inspection effectiveness, $N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$, using Section 4.5.6 of the API RP 581 Part 2 for past inspections performed during in-service time.

N_A^{Thin} = 0

N_B^{Thin} = 0

N_C^{Thin} = 0

N_D^{Thin} = 2

STEP 10 Calculate the inspection effectiveness factors, , using equation 61 below, prior probabilities, $Pr_{p1}^{Thin}, Pr_{p2}^{Thin}$ and Pr_{p3}^{Thin} from Table 4.5. The Conditional Probabilities (for each inspection effectiveness level), , from Table 4.6, and the number of inspection, N_A^{Thin} , in each effectiveness level from STEP 9.

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

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

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

Table 4.5 - Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Conf. Data	High Conf. 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 4.6 - Conditional Probability for Inspection Effectiveness

Conditional P. 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

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

$$= 0.080000$$

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

$$= 0.03267000$$

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

$$= 0.0145800000$$

STEP 11 Calculate the Posteroir Probability, $Po_{p1}^{Thin}, Po_{p2}^{Thin}$ and Po_{p3}^{Thin}, using equations:

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

$$= 0.628683694$$

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

$$= 0.256738703$$

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

$$= 0.114577603$$

STEP 12 Calculate the parameters, ß_1, ß_2, and ß_3 using equation 67,68,69 below and also assigning $COV_{\Delta t} = 0.20$, $COV_{sf} = 0.20$, and $COV_P = 0.05$.

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S1}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S2}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S3}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

Where;

$COV_{\Delta t}$ = The thinning coefficient of variance ranging from 0.1 ≤ $COV_{\Delta t}$ ≤ 0.2
= 0.2
COV_{sf} = The flow stress coefficient of variance
= 0.2
COV_P = Pressure coeffficient of variance
= 0.05
D_{s1} = Damage State 1
= 1
D_{s2} = Damage State 2
= 2
D_{s3} = Damage State 3
= 4

RBI DATE:

<u>BASED ON CORROSION RATE FROM RLA DATA</u>

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S1}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.9946

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S2}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.98295448

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S3}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.928072368

PLANNED DATE:

<u>BASED ON CORROSION RATE FROM RLA DATA</u>

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S1}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= \quad 4.9586$$

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S2}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= \quad 4.801433962$$

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S3}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= \quad 3.878673299$$

STEP 13 For tank bottom components, determine the base damage factor for thining using Table 4.8. and based on A_{rt} parameter from STEP 6.

Because component observed in this case of analysis is including into Tank Shell, then this step of calculation can be skipped.

STEP 14 For all components (excluding tank bottoms covered in STEP 13), calculate the base damage factor, .

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right)+\left(Po_{P2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right)+\left(Po_{P3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E-0.4}$$

RBI DATE:

<u>BASED ON CORROSION RATE FROM RLA DATA</u>

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right)+\left(Po_{P2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right)+\left(Po_{P3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E-0.4}$$

$$= \quad 0.354147577$$

PLANNED DATE:

<u>BASED ON CORROSION RATE FROM RLA DATA</u>

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right)+\left(Po_{P2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right)+\left(Po_{P3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E-0.4}$$

$$= \quad 0.354142955$$

STEP 15 Determine the DF for thinning, D_f^{Thin} , using equation equation below.

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} . F_{IP} . F_{DL} .F_{WD}.F_{AM} .F_{SM})}{F_{OM}}),0.1]$$

Where;

F_{IP} = DF adjustent for injection points (for piping circuit)

= 0

F_{DL} = DF adjustment for dead legs (for piping only used to intermittent service)

= 0

F_{WD} = DF adjustment for welding construction (for only AST)

= 1

F_{AM} = DF adjustment for AST maintenance per API STD 653 (for only AST)

= 1

F_{SM} = DF adjustment for settlement (for only AST Bottom)

= 0

F_{OM} = DF adjustment for online monitoring based on Table 4.9

= 1

RBI DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin}\ x\ F_{am}}{F_{OM}}),0.1]$$

= 0.3541476

PLANNED DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} x\ F_{am}.}{F_{OM}}),0.1]$$

= 0.3541430

DAMAGE FACTOR FOR THINNING

The governing thinning DF is determined based on the presence of an internal liner using equation below.

D_{f-gov}^{Thin} = min[D_f^{Thin}, D_f^{elin}] When internal liner is present

$D_{f-gov}^{Thin} = D_f^{Thin}$ When internal liner is not present

According to above calculaton, there is no any presence of liner, then, we can consider to use the second governing thinning DF calculation.

$$D_{f-gov}^{Thin} = D_f^{Thin}$$

RBI DATE:

Based on RLA Data

D_{f-gov}^{Thin} = 0.3541476

PLANNED DATE:

Based on RLA Data

D_{f-gov}^{Thin} = 0.3541430

THINNING DAMAGE FACTOR CALCULATION

1. RLA DATA

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1. Component types and geometry data are shown in Tables 4.2 and 4.3, respectively. The data required for determination of the thinning DF is provided in Table 4.4.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Start Date	12/01/2008		The date the component was placed in service.
Thickness	8	mm	The thickness used for DF calculation that is either the furnished thickness or the measured thickness.
Corrosion Allowance	1.50	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	60	°C	The design temperature, shell side and tube side for Aboveground Storage Tank
Design Pressure	101	kPa	The design temperature, shell side and tube side for Aboveground Storage Tank
Operating Tempearture	30	°C	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Operating Pressure	98	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Design Code	API STD 650		The designing of the component containing the component.
Equipment Type	Aboveground Storage Tank		The type of equipment.
Component Type	Aboveground Storage Tank Shell 6		The type of component.
Geometry Data	-		Component geometry data depending on the type of component.
Material Specification	ASTM 283 Grade C		The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. this data is readdily available in the ASTM Code.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Yield Strength	380000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	205000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	0.85		Weld joint efficiency per the Code of construction.
Heat Tracing	No		Is the component heat traced? (Yes or No)

STEP 1 Determining the furnished thickness, t, and age for the component from the installation date.

Installation date		23/07/2008	
RBI Date		29/10/2019	
t	=	0.236220472	inch
	=	6.000	mm
age	=	11.26625599	years

STEP 2 Determining the corrosion rate for base material, $C_{r,bm}$ based on the material construction and environment, and cladding/weld overlay corrosion rate, $C_{r,cm}$. Based on the explanation from Section 4.5.2 that the corrosion rate is **MEASURED** using the data that given from the company.

1. Corrosion Rate (Cr) from the Inspection data

Cr	=	0.006575	inch/year
	=	0.167000	mm/year

STEP 3 Determine the time in service, age_{tk}, since the last known inspection, t_{rdi}.

Last inspection is on:		23/07/2018		
RBI Date is on:		29/10/2019		
Planned Date is on:		28/06/2022		
t_{rdi}	=	0.22519685	inch	
	=	5.72	mm	
age_{tk}	=	1.268	years.	Last inspection was held on July 2018
age_{PD}	=	3.932	years.	Inspection is held every 4 years

STEP 4 For cladding/weld overlay pressure vessel components, calculate the age from the date starting thickness from STEP 3 required to corrode away the cladding/weld overlay material, age_{rc}, using equation below:

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

Because the Aboveground Storage Tank is not cladding/weld overlay. Then, the equation above does not need to be considered.

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

STEP 5 Determine the t_{min}

Actually there are 4 methods used to determine the minimum thickness of the equipment (t_{min}). Based on the condition, the method used by the author is the fourth method which is specific Tmin calculated by another method and documented in the asset management program may be used at the owner-user's direction.

The Purchaser is using Standart API 650 : Welded Steel Tanks for Oil Storage Tank and using calculation of Thickness by the 1-Foot Method

From the API 653 : Tank Inspection, Repair , Alteration and Reconstruction Third Edition December 2001, the minimum acceptable thickness can be calculated by the equations bellow and not less than 1 inch or 2,54mm

$$tmin = \frac{2{,}6\ (H - 1)DG}{SE}$$

So t_{min} selected for the tank shell = 2.54 mm

The required minimum thickness of shell plates shall be the greater of tile values computed by tile following fornmlas:

$$tmin = \frac{4{,}9D\ (H - 0{,}3)G}{Sd} + CA$$

Shell Course	H (m)	t_d	t_t	t_{used}	t_{se} Less CA
		mm	mm	mm	mm
1	10.64	5.794	4.442	8	6.5
2	8.811	5.034	3.656	8	6.5
3	6.982	4.275	2.87	8	6.5
4	5.154	3.515	2.085	6	4.5
5	3.325	2.756	1.299	6	4.5
6	1.496	1.997	0.514	6	4.5

where : td = design shell thickness, in mm,

tt = hydrostatic test shell thickness, in mm

D = nominal tank diameter, in m

H = design liquid level, in m

G = design specific gravity of the liquid to be stored, as specified by the Purchaser

CA = Corrosion allowance, in mm, as specified by the Purchaser

= = allowable stress for tile design condition, in MPa

= = allowable stress for the hydrostatic test condition, in MPa

STEP 6 Determine the A_{rt} Parameter

For component without clading/weld overlay then use the equation following.

A_{rt} on RBI Date:

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{tk}}{t_{rdi}}$$

= 0.037009329

Where,

$Cr_{b.m}$: Corrosion base material = 0.167 mm/yr

age_{tk} : Component in-service time since the last inspection = 1.268 yr

t_{rdi} : Furnished thickness since last inspection = 5.72 mm

A_{rt} on Plan Date:

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{PD}}{t_{rdi}}$$

= 0.114784873

Where,

$Cr_{b.m}$: Corrosion base material = 0.167 mm/yr

age_{PD} : Component in-service time since the last inspection = 3.932 yr

t_{rdi} : Furnished thickness since last inspection = 5.72 mm

STEP 7 Calculate the Flow Stress, , using E from STEP 5 and equation beloFS^{Thin}

$$FS^{Thin} = \frac{(YS+TS)}{2}. \text{E.1,1}$$

Where;

YS = 205000000 KPa

TS = 380000000 KPa

E = 0.85

ASTM 283 Grade C

$$FS^{Thin} = \frac{(YS+TS)}{2}. \text{ E.1,1}$$

= 273487500

STEP 8 Calculate the strength ratio parameter, SR_P^{Thin} ing the appropriate equation.

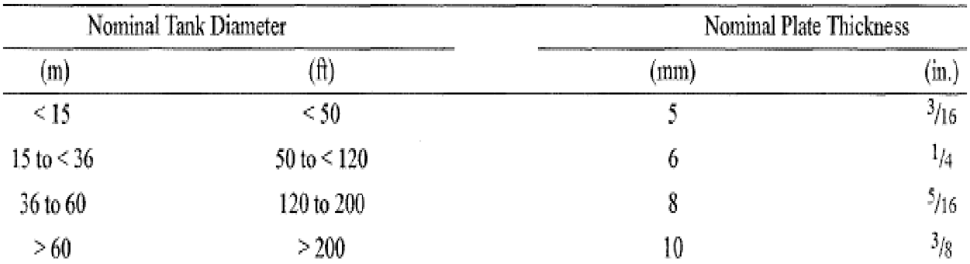
$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}}.\frac{Max\,(t_{min}, t_c)}{t_{rdi}}$$

Where; is the minimum structural thickness of the component base material

t_c =

= 0.1968505 inch

= 5.0000000 mm



Nominal Tank Diameter		Nominal Plate Thickness	
(m)	(ft)	(mm)	(in.)
< 15	< 50	5	3/16
15 to < 36	50 to < 120	6	1/4
36 to 60	120 to 200	8	5/16
> 60	> 200	10	3/8

Allowable stress = 136998.8812 kpa

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

= 0.000372197

STEP 9 Determine the number of inspections for each of the correspondesing inspection effectiveness, $N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$, using Section 4.5.6 of the API RP 581 Part 2 for past inspections performed during in-service time.

N_A^{Thin} = 0

N_B^{Thin} = 0

N_C^{Thin} = 0

N_D^{Thin} = 2

STEP 10 Calculate the inspection effectiveness factors, , using equation 61 below, prior probabilities, $Pr_{p1}^{Thin}, Pr_{p2}^{Thin}$ and Pr_{p3}^{Thin} from Table 4.5. The Conditional Probabilities (for each inspection effectiveness level), , from Table 4.6, and the number of inspection, N_A^{Thin} , in each effectiveness level from STEP 9.

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

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

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

Table 4.5 - Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Conf. Data	High Conf. 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 4.6 - Conditional Probability for Inspection Effectiveness

Conditional P. 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

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

= 0.080000

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

= 0.03267000

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

= 0.0145800000

STEP 11 Calculate the Posteroir Probability, Po_{p1}^{Thin}, Po_{p2}^{Thin} and Po_{p3}^{Thin}, using equations:

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

= 0.628683694

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

= 0.256738703

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

= 0.114577603

STEP 12 Calculate the parameters, ß_1, ß_2, and ß_3 using equation 67,68,69 below and also assigning $COV_{\Delta t} = 0.20$, $COV_{sf} = 0.20$, and $COV_P = 0.05$.

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S1}^2.A_{rt}^2.COV_{\Delta t}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S2}^2.A_{rt}^2.COV_{\Delta t}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S3}^2.A_{rt}^2.COV_{\Delta t}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

Where;

$COV_{\Delta t}$ = The thinning coefficient of variance ranging from $0.1 \le COV_{\Delta t} \le 0.2$
= 0.2
COV_{sf} = The flow stress coefficient of variance
= 0.2
COV_P = Pressure coeffficient of variance
= 0.05
D_{s1} = Damage State 1
= 1
D_{s2} = Damage State 2
= 2
D_{s3} = Damage State 3
= 4

RBI DATE:

<u>BASED ON CORROSION RATE FROM RLA DATA</u>

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S1}^2.A_{rt}^2.COV_{\Delta t}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= 4.9944$$

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S2}^2.A_{rt}^2.COV_{\Delta t}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= 4.982098614$$

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S3}^2.A_{rt}^2.COV_{\Delta t}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$= 4.924033585$$

PLANNED DATE:

<u>BASED ON CORROSION RATE FROM RLA DATA</u>

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S1}^2.A_{rt}^2.COV_{\Delta t}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.9564

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}\ .A_{rt}-SR_P^{Thin}}{\sqrt{D_{S2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.789477504

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}\ .A_{rt}-SR_P^{Thin}}{\sqrt{D_{S3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 3.809131329

STEP 13 For tank bottom components, determine the base damage factor for thining using Table 4.8. and based on A_{rt} parameter from STEP 6.

Because component observed in this case of analysis is including into Tank Shell, then this step of calculation can be skipped.

STEP 14 For all components (excluding tank bottoms covered in STEP 13), calculate the base damage factor, .

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right)+\left(Po_{P2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right)+\left(Po_{P3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E\ -0.4}$$

RBI DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right)+\left(Po_{P2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right)+\left(Po_{P3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E\ -0.4}$$

= 0.354147576

PLANNED DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right)+\left(Po_{P2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right)+\left(Po_{P3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E\ -0.4}$$

= 0.354141456

STEP 15 Determine the DF for thinning, D_f^{Thin}, using equation equation below.

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} . F_{IP} . F_{DL} . F_{WD} . F_{AM} . F_{SM})}{F_{OM}}),0.1]$$

Where;

F_{IP} = DF adjustent for injection points (for piping circuit)
= 0
F_{DL} = DF adjustment for dead legs (for piping only used to intermittent service)
= 0
F_{WD} = DF adjustment for welding construction (for only AST)
= 1
F_{AM} = DF adjustment for AST maintenance per API STD 653 (for only AST)
= 1
F_{SM} = DF adjustment for settlement (for only AST Bottom)
= 0
F_{OM} = DF adjustment for online monitoring based on Table 4.9
= 1

RBI DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin}\ x\ F_{am}}{F_{OM}}),0.1]$$

= 0.3541476

PLANNED DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} x\ F_{am}.}{F_{OM}}),0.1]$$

= 0.3541415

DAMAGE FACTOR FOR THINNING

The governing thinning DF is determined based on the presence of an internal liner using equation below.

$D_{f-gov}^{Thin} = \min[D_f^{Thin}, D_f^{elin}]$ When internal liner is present
$D_{f-gov}^{Thin} = D_f^{Thin}$ When internal liner is not present

According to above calculaton, there is no any presence of liner, then, we can consider to use the second governing thinning DF calculation.

$$D_{f-gov}^{Thin} = D_f^{Thin}$$

RBI DATE:

Based on RLA Data

D_{f-gov}^{Thin} = 0.3541476

PLANNED DATE:

Based on RLA Data

D_{f-gov}^{Thin} = 0.3541415

EXTERNAL CORROSION DAMAGE FACTOR CALCULATION

1. RLA DATA

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1. and the specific data required for determination of the DF for external corrosion is provided Table 15.1 in API RP 581 Part 2 of POF.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Start Date	12/01/2008		The date the component was placed in service.
Thickness	8	mm	The thickness used for DF calculation that is either the furnished thickness or the measured
Corrosion Allowance	1.50	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	60	^{o}C	The design temperature, shell side and tube side for Aboveground Storage Tank
Design Pressure	101	kpa	The design temperature, shell side and tube side for Aboveground Storage Tank
Operating Tempearture	30	^{o}C	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Operating Pressure	98	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage
Design Code	API STD 650		The designing of the component containing the component.
Equipment Type	Aboveground Storage Tank		The type of equipment.
Component Type	Aboveground Storage Tank shell 1		The type of component.
Geometry Data	-		Component geometry data depending on the type of component.
Material Specification	ASTM 283 Grade C		The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. Data entry is based on the material specification, grade, year, UNS Number,

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Yield Strength	380000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	205000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	0.85		Weld joint efficiency per the Code of construction.
Heat Tracing	No		Is the component heat traced? (Yes or No)

STEP 1 Determining the furnished thickness, t, and age for the component from the installation date.

t = 0.31496063 inch Installation date 23/07/2008
= 8.000 mm RBI Date 29/10/2019
age = 11.26625599 years

STEP 2 Determining the base corrosion rate, CrB based on the driver and operating temperature using Table 15.2.

Table 15.2M - Corrosion Rates for Calculation of the Damage Factor-External Corrosion

Operating Temperature (oC)	Corrosion Rate as a Function of Driver (1) (mpy)			
	Marine / Cooling	Temperat	Arid / Dry	Severe
-12	0	0	0	0
-8	0.025	0	0	0
6	0.127	0.076	0.025	0.254
32	0.127	0.076	0.025	1.254
71	0.127	0.051	0.025	2.254
107	0.025	0	0	0.051
121	0	0	0	0

t = Operating temperature
= 30 °C
= 303 K
mpy 1 = 0.127 mm/y

Because the operating temperature is normally 30°C, and there is no list of such that temperature. But, it does list values for 6°C and 32°C. Both of them have same value on marine condition.

So C_{rB} = 0.127

STEP 3 Calculate the final corrosion rate, Cr, using equation below.

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

F_{EQ} = Adjustment for equation design or fabrication
= 2

F_{IF} = Adjustment fo interface
= 1

$$C_r = C_{rB} \,.\, \max\left[\left(F_{EQ}, F_{IF}\right)\right]$$
= 0,127 . max [(2;1)]
= 0.25

But, the company has own their corrosion rate that given from the inspection that has been done for the tank before

C_r = 0.167

STEP 4 Determine the time in service, age_{tk}, since the last known inspection, t_{rde}. 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

t_{rdi} = 0.274 inch
= 6.96 mm

Last inspection is on: 23/07/2018
RBI Date is on: 29/10/2019
Planned Date is on: 28/06/2022

age_{tk} = 1.268 years. Last inspection was held on July 2018

age_{PD} = 3.932 years. Inspection is held every 4 years

STEP 5 Determine the time in-service, age_{coat}, since the coating has been installed using equation below.

$$age_{coat} = Calculation\ Date - Coating\ Installation\ Date$$

Calculation Date = 29/10/2019
Coating installation Date = 12/01/2008

$$age_{coat} = Calculation\ Date - Coating\ Installation\ Date$$
= 11.795 years

STEP 6 Determine coating adjustment, $coat_{adj}$ using one of below equations
If $Age_{tk} \geq Age_{coat}$

$Coat_{adj} = 0$ If No or Poor Coating Quality
$Coat_{adj} = \min[5, age_{coat}]$ If Medium Coating Quality
$Coat_{adj} = \min[15, age_{coat}]$ If High Coating Quality

If $Age_{tk} < Age_{coat}$

$Coat_{adj} = 0$ No / poor

$Coat_{adj} = \min[5, age_{coat}] - \min[5, age_{coat} - age_{tk}]$ Medium

$Coat_{adj} = \min[15, age_{coat}] - \min[15, age_{coat} - age_{tk}]$ High

Choose the calculation for Agetk less than the Agecoat in Medium Coating Level (painting only)

$Coat_{adj} = 0$

= 0.000

the result still 0 because the result of Agecoat and (Agecoat - Agetk) bigger than 5

STEP 7 Determine the in - service time, age, over which external corrosion may have occured uing equation below

$age = age_{tk} - Coat_{adj}$

= 1,268 - 0

= 1.268

STEP 8 Determine the allowable stress, S, weld joint efficiency, E, and minimum required thickness, t_{min}, per the original construction code or ASTM 283 or API

t_{min} = 0.1386 inch

= 3.52 mm

S = 19870 psig

= 136998881.2 Pa

= 136998.8812 Kpa

E = 0.85

STEP 9 Determine the A_{rt} Parameter

For component without clading/weld overlay then use the equation below.

<u>RBI DATE</u>

$$A_{rt} = \frac{Cr.agetk}{t_{rde}}$$

$$= \frac{0{,}167 \,.\, 1{,}268}{6{,}96}$$

= 0.030415713 (For corrosion rate based on RLA Data)

PLAN DATE

$$A_{rt} = \frac{Cr.agepd}{t_{rde}}$$

$$= \frac{0{,}167\ .\ 3{,}932}{6{,}96}$$

$= \quad 0.094334694 \quad$ (For corrosion rate based on RLA Data)

STEP 10 Calculate the Flow Stress, $FS^{extector}$, using E from STEP 5 and equation below.

$$FS^{extcorr} = \frac{(YS+TS)}{2}.\ \mathrm{E.1,1}$$

Where;

YS = 205000

TS = 380000

E = 0.85

$$FS^{extcorr} = \frac{(YS+TS)}{2}.\ \mathrm{E.1,1}$$

$$= \frac{(205000 + 380000)}{2}.\ (1)\ .1{,}1$$

$= 273487.5$

STEP 11 Calculate the strength ratio parameter, SR_P^{Thin} , using the appropriate equation.

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

Where ;

t_c = is the minimum structural thickness of the component base material

= 0.196850394 inch

= 5 mm

$$SR_P^{extcorr} = \frac{136998{,}881\ .\ 0{,}85}{273487{,}5} . \frac{Max\ (3{,}52;5\ )}{6{,}96}$$

$= \quad 0.305885739$

STEP 12 Determine the number of inspection , $N_A^{extcorr}, N_B^{extcorr}, N_C^{extcorr}, N_D^{extcorr}$, and the corresponding inspection effectiveness category using Section 15.6. 2 for past inspections performed during the in - service time.

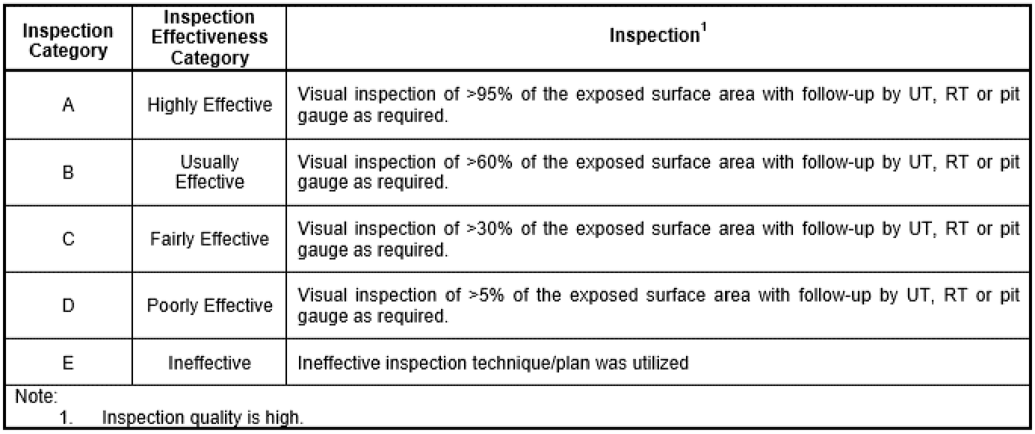
$N_A^{extcorr}$ = 0

$N_B^{extcorr}$ = 0

$N_C^{extcorr}$ = 0

$N_D^{extcorr}$ = 2

Table 2.C.10.1 - LoIE Example for External Damage



Inspection Category	Inspection Effectiveness Category	Inspection[1]
A	Highly Effective	Visual inspection of >95% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
B	Usually Effective	Visual inspection of >60% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
C	Fairly Effective	Visual inspection of >30% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
D	Poorly Effective	Visual inspection of >5% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
E	Ineffective	Ineffective inspection technique/plan was utilized

Note:

1. Inspection quality is high.

STEP 13 Determine the inspection effectiveness factors, $I_1^{extcorr}, I_2^{extcorr}, I_3^{extcorr}$, using equation below, prior probabilities, $Pr_{p1}^{extcorr}, Pr_{p2}^{extcorr}, Pr_{p3}^{extcorr}$, from Table 4.5. Conditional Probabilities (for each inspection effectiveness level) $Co_{p1}^{extcorr}, Co_{p2}^{extcorr}, Co_{p3}^{extcorr}$ fromTable 4.6, and the number of inspection, $N_A^{extcorr}, N_B^{extcorr}, N_C^{extcorr}, N_D^{extcorr}$ in each effectiveness level from STEP 12.

$$I_1^{extcorr} = Pr_{P1}^{extcorr}\left(Co_{P1}^{extcorrA}\right)^{N_A^{extcorr}}\left(Co_{P1}^{extcorrB}\right)^{N_B^{extcorr}}\left(Co_{P1}^{extcorrC}\right)^{N_C^{extcorr}}\left(Co_{P1}^{extcorrD}\right)^{N_D^{extco}}$$

$$I_2^{extcorr} = Pr_{P2}^{extcorr}\left(Co_{P2}^{extcorrA}\right)^{N_A^{extcorr}}\left(Co_{P2}^{extcorrB}\right)^{N_B^{extcorr}}\left(Co_{P2}^{extcorrC}\right)^{N_C^{extcorr}}\left(Co_{P2}^{extcorrD}\right)^{N_D^{extco}}$$

$$I_3^{extcorr} = Pr_{P3}^{extcorr}\left(Co_{P3}^{extcorrA}\right)^{N_A^{extcorr}}\left(Co_{P3}^{extcorrB}\right)^{N_B^{extcorr}}\left(Co_{P3}^{extcorrC}\right)^{N_C^{extcorr}}\left(Co_{P3}^{extcorrD}\right)^{N_D^{extco}}$$

Table 4.5 - Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Conf. 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 4.6 - Conditional Probability for Inspection Effectiveness

Conditional P. 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

$$I_1^{extcorr} = Pr_{P1}^{extcorr}(Co_{P1}^{extcorrA})^{N_A^{extcorr}}(Co_{P1}^{extcorrB})^{N_B^{extcorr}}(Co_{P1}^{extcorrC})^{N_C^{extcorr}}(Co_{P1}^{extcorrD})^{N_D^{extco}}$$

$$= \quad 0.08000$$

$$I_2^{extcorr} = Pr_{P2}^{extcorr}(Co_{P2}^{extcorrA})^{N_A^{extcorr}}(Co_{P2}^{extcorrB})^{N_B^{extcorr}}(Co_{P2}^{extcorrC})^{N_C^{extcorr}}(Co_{P2}^{extcorrD})^{N_D^{extcor}}$$

$$= \quad 0.03267$$

$$I_3^{extcorr} = Pr_{P3}^{extcorr}(Co_{P3}^{extcorrA})^{N_A^{extcorr}}(Co_{P3}^{extcorrB})^{N_B^{extcorr}}(Co_{P3}^{extcorrC})^{N_C^{extcorr}}(Co_{P3}^{extcorrD})^{N_D^{extcor}}$$

$$= \quad 0.01458$$

STEP 14 Calculate the Posteroir Probability $Po_{p1}^{extcorr}, Po_{p2}^{extcorr}, Po_{p3}^{extcorr}$, using equations

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

$$= \quad 0.6$$

$$Po_{p2}^{extcorr} = \frac{I_2^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}}$$

$$= \quad 0.256738703$$

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

$$= \quad 0.114577603$$

STEP 15 Calculate the parameters, ß$_1$, ß$_2$, and ß$_3$ using equation below and also assigning $COV_{\Delta t} = 0.20$, $COV_{sf} = 0.20$, and $COV_P = 0.05$.

$$ß_1^{extcorr} = \frac{1-D_{S1}.A_{rt}-SR_P^{extcorr}}{\sqrt{D_{S1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{extcorr})^2.(COV_P)^2}}$$

$$ß_2^{extcorr} = \frac{1-D_{S2}.A_{rt}-SR_P^{extcorr}}{\sqrt{D_{S2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{extcorr})^2.(COV_P)^2}}$$

$$ß_3^{extcorr} = \frac{1-D_{S3}.A_{rt}-SR_P^{extcorr}}{\sqrt{D_{S3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{extcorr})^2.(COV_P)^2}}$$

Where;

$COV_{\Delta t}$ = The thinning coefficient of variance ranging from $0.1 \leq COV_{\Delta t} \leq 0.2$

= 0.2

COV_{sf} = The flow stress coefficient of variance

= 0.2

COV_P = Pressure coeffficient of variance

= 0.05

D_{s1} = Damage State 1

= 1

D_{s2} = Damage State 2
= 2

D_{s3} = Damage State 3
= 4

RBI DATE

BASED ON CORROSION RATE FROM RLA

$ß_1^{extcorr}$ = 3.4103

$ß_2^{extcorr}$ = 3.3534

$ß_3^{extcorr}$ = 3.2464

PLAN DATE

BASED ON CORROSION RATE FROM RLA

$ß_1^{extcorr}$ = 3.2819

$ß_2^{extcorr}$ = 3.0213

$ß_3^{extcorr}$ = 2.5248

STEP 16 Calculate $D_f^{extcorr}$ using equation below

RBI DATE

$$D_f^{extcor} = [\frac{\left(Po_{P1}^{extcorr}\Phi\left(-\beta_1^{extcorr}\right)\right)+\left(Po_{P2}^{extcorr}\Phi\left(-\beta_2^{extcorr}\right)\right)+\left(Po_{P3}^{extcorr}\Phi\left(-\beta_3^{extcorr}\right)\right)}{1.56E-0.4}$$

$D_f^{extcorr}$ = 1.079510 **BASED ON CORROSION RATE FROM RLA**

PLAN DATE

$$D_f^{extcor} = [\frac{\left(Po_{P1}^{extcorr}\Phi\left(-\beta_1^{extcorr}\right)\right)+\left(Po_{P2}^{extcorr}\Phi\left(-\beta_2^{extcorr}\right)\right)+\left(Po_{P3}^{extcorr}\Phi\left(-\beta_3^{extcorr}\right)\right)}{1.56E-0.4}$$

$D_f^{extcorr}$ = 1.078498 **BASED ON CORROSION RATE FROM RLA**

RBI DATE

Df total = 1.433658 BASED ON CORROSION RATE FROM RLA

PLAN DATE

Df total = 1.432645 BASED ON CORROSION RATE FROM RLA

EXTERNAL CORROSION DAMAGE FACTOR CALCULATION

1. RLA DATA

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1. and the specific data required for determination of the DF for external corrosion is provided Table 15.1 in API RP 581 Part 2 of POF.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Start Date	12/01/2008		The date the component was placed in service.
Thickness	8	mm	The thickness used for DF calculation that is either the furnished thickness or the measured
Corrosion Allowance	1.50	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	60	^{o}C	The design temperature, shell side and tube side for Aboveground Storage Tank
Design Pressure	101	kpa	The design temperature, shell side and tube side for Aboveground Storage Tank
Operating Tempearture	30	^{o}C	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Operating Pressure	98	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage
Design Code	API STD 650		The designing of the component containing the component.
Equipment Type	Aboveground Storage Tank		The type of equipment.
Component Type	Aboveground Storage Tank shell 2		The type of component.
Geometry Data	-		Component geometry data depending on the type of component.
Material Specification	ASTM 283 Grade C		The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. Data entry is based on the material specification, grade, year, UNS Number,

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Yield Strength	380000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	205000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	0.85		Weld joint efficiency per the Code of construction.
Heat Tracing	No		Is the component heat traced? (Yes or No)

STEP 1

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

t = 0.31496063 inch Installation date 23/07/2008

= 8.000 mm RBI Date 29/10/2019

age = 11.26625599 years

STEP 2

Determining the base corrosion rate, CrB based on the driver and operating temperature using Table 15.2.

Table 15.2M - Corrosion Rates for Calculation of the Damage Factor-External Corrosion

Operating Temperature (oC)	Corrosion Rate as a Function of Driver (1) (mpy)			
	Marine / Cooling	Temperat	Arid / Dry	Severe
-12	0	0	0	0
-8	0.025	0	0	0
6	0.127	0.076	0.025	0.254
32	0.127	0.076	0.025	1.254
71	0.127	0.051	0.025	2.254
107	0.025	0	0	0.051
121	0	0	0	0

t = Operating temperature

= 30 ^{o}C

= 303 K

mpy 1 = 0.127 mm/y

Because the operating temperature is normally 30^{o}C, and there is no list of such that temperature. But, it does list values for 6^{o}C and 32^{o}C. Both of them have same value on marine condition.

So C_{rB} = 0.127

STEP 3 Calculate the final corrosion rate, Cr, using equation below.

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

F_{EQ} = Adjustment for equation design or fabrication
= 2

F_{IF} = Adjustment fo interface
= 1

$$C_r = C_{rB} \, . \max\left[\left(F_{EQ}, F_{IF}\right)\right]$$
= 0,127 . max [(2;1)]
= 0.25

But, the company has own their corrosion rate that given from the inspection that has been done for the tank before

C_r = 0.167

STEP 4 Determine the time in service, age_{tk}, since the last known inspection, t_{rde}. 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

t_{rdi}	=	0.3024	inch	Last inspection is on:	23/07/2018
	=	7.68	mm	RBI Date is on:	29/10/2019
				Planned Date is on:	28/06/2022
age_{tk}	=	1.268	years.	Last inspection was held on July 2018	
age_{PD}	=	3.932	years.	Inspection is held every 4 years	

STEP 5 Determine the time in-service, age_{coat}, since the coating has been installed using equation below.

$$age_{coat} = Calculation\ Date - Coating\ Installation\ Date$$

Calculation Date = 29/10/2019
Coating installation Date = 12/01/2008

$$age_{coat} = Calculation\ Date - Coating\ Installation\ Date$$
= 11.795 years

STEP 6 Determine coating adjustment, $coat_{adj}$ using one of below equations
If $Age_{tk} \geq Age_{coat}$

$Coat_{adj} = 0$	If No or Poor Coating Quality
$Coat_{adj} = \min[5, age_{coat}]$	If Medium Coating Quality
$Coat_{adj} = \min[15, age_{coat}]$	If High Coating Quality

If $Age_{tk} < Age_{coat}$

$Coat_{adj} = 0$ No / poor

$Coat_{adj} = \min[5, age_{coat}] - \min[5, age_{coat} - age_{tk}]$ Medium

$Coat_{adj} = \min[15, age_{coat}] - \min[15, age_{coat} - age_{tk}]$ High

Choose the calculation for Agetk less than the Agecoat in Medium Coating Level (painting only)

$Coat_{adj} = 0$

$= 0.000$

the result still 0 because the result of Agecoat and (Agecoat - Agetk) bigger than 5

STEP 7 Determine the in - service time, age, over which external corrosion may have occured uing equation below

$age = age_{tk} - Coat_{adj}$

$= 1{,}268 - 0$

$= 1.268$

STEP 8 Determine the allowable stress, S, weld joint efficiency, E, and minimum required thickness, t_{min}, per the original construction code or ASTM 283 or API

t_{min} = 0.1386 inch

= 3.52 mm

S = 19870 psig

= 136998881.2 Pa

= 136998.8812 Kpa

E = 0.85

STEP 9 Determine the A_{rt} Parameter

For component without clading/weld overlay then use the equation below.

RBI DATE

$$A_{rt} = \frac{Cr.agetk}{t_{rde}}$$

$$= \frac{0{,}167 \, . \, 1{,}268}{6{,}96}$$

$= 0.02756424$ (For corrosion rate based on RLA Data)

PLAN DATE

$$A_{rt} = \frac{Cr.agepd}{t_{rde}}$$

$$= \frac{0,167\ .\ 3,932}{6,96}$$

= 0.085490817 (For corrosion rate based on RLA Data)

STEP 10 Calculate the Flow Stress, $FS^{extector}$, using E from STEP 5 and equation below.

$$FS^{extcorr} = \frac{(YS+TS)}{2}.\ \mathrm{E.1,1}$$

Where;

YS = 205000

TS = 380000

E = 0.85

$$FS^{extcorr} = \frac{(YS+TS)}{2}.\ \mathrm{E.1,1}$$

$$= \frac{(205000 + 380000)}{2}.\ (1)\ .1,1$$

= 273487.5

STEP 11 Calculate the strength ratio parameter, SR_P^{Thin} , using the appropriate equation.

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

Where ;

t_c = is the minimum structural thickness of the component base material

= 0.196850394 inch

= 5 mm

$$SR_P^{extcorr} = \frac{136998,881\ .\ 0,85}{273487,5} . \frac{Max\ (3,52;5\ )}{6,96}$$

= 0.277208951

STEP 12 Determine the number of inspection , $N_A^{extcorr}, N_B^{extcorr}, N_C^{extcorr}, N_D^{extcorr}$, and the corresponding inspection effectiveness category using Section 15.6. 2 for past inspections performed during the in - service time.

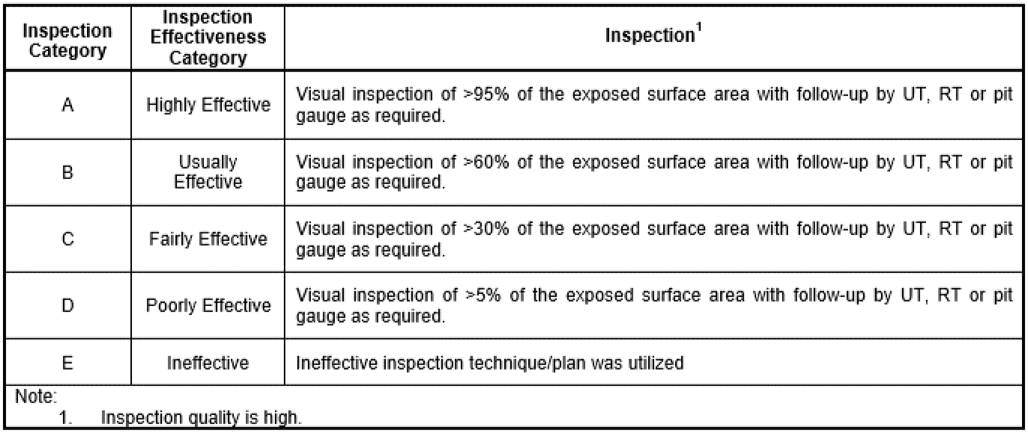
$N_A^{extcorr}$ = 0

$N_B^{extcorr}$ = 0

$N_C^{extcorr}$ = 0

$N_D^{extcorr}$ = 2

Table 2.C.10.1 - LoIE Example for External Damage



Inspection Category	Inspection Effectiveness Category	Inspection[1]
A	Highly Effective	Visual inspection of >95% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
B	Usually Effective	Visual inspection of >60% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
C	Fairly Effective	Visual inspection of >30% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
D	Poorly Effective	Visual inspection of >5% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
E	Ineffective	Ineffective inspection technique/plan was utilized

Note:

1. Inspection quality is high.

STEP 13 Determine the inspection effectiveness factors, $I_1^{extcorr}, I_2^{extcorr}, I_3^{extcorr}$, using equation below, prior probabilities $Pr_{p1}^{extcorr}, Pr_{p2}^{extcorr}, Pr_{p3}^{extcorr}$, from Table 4.5. Conditional Probabilities (for each inspection effectiveness level) $Co_{p1}^{extcorr}, Co_{p2}^{extcorr}, Co_{p3}^{extcorr}$ fromTable 4.6, and the number of inspection, $N_A^{extcorr}, N_B^{extcorr}, N_C^{extcorr}, N_D^{extcorr}$ in each effectiveness level from STEP 12.

$$I_1^{extcorr} = Pr_{P1}^{extcorr}(Co_{P1}^{extcorrA})^{N_A^{extcorr}}(Co_{P1}^{extcorrB})^{N_B^{extcorr}}(Co_{P1}^{extcorrC})^{N_C^{extcorr}}(Co_{P1}^{extcorrD})^{N_D^{extco}}$$

$$I_2^{extcorr} = Pr_{P2}^{extcorr}(Co_{P2}^{extcorrA})^{N_A^{extcorr}}(Co_{P2}^{extcorrB})^{N_B^{extcorr}}(Co_{P2}^{extcorrC})^{N_C^{extcorr}}(Co_{P2}^{extcorrD})^{N_D^{extco}}$$

$$I_3^{extcorr} = Pr_{P3}^{extcorr}(Co_{P3}^{extcorrA})^{N_A^{extcorr}}(Co_{P3}^{extcorrB})^{N_B^{extcorr}}(Co_{P3}^{extcorrC})^{N_C^{extcorr}}(Co_{P3}^{extcorrD})^{N_D^{extco}}$$

Table 4.5 - Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Conf. 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 4.6 - Conditional Probability for Inspection Effectiveness

Conditional P. 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

$$I_1^{extcorr} = Pr_{P1}^{extcorr}(Co_{P1}^{extcorrA})^{N_A^{extcorr}}(Co_{P1}^{extcorrB})^{N_B^{extcorr}}(Co_{P1}^{extcorrC})^{N_C^{extcorr}}(Co_{P1}^{extcorrD})^{N_D^{extcot}}$$

$$= \quad 0.08000$$

$$I_2^{extcorr} = Pr_{P2}^{extcorr}(Co_{P2}^{extcorrA})^{N_A^{extcorr}}(Co_{P2}^{extcorrB})^{N_B^{extcorr}}(Co_{P2}^{extcorrC})^{N_C^{extcorr}}(Co_{P2}^{extcorrD})^{N_D^{extcot}}$$

$$= \quad 0.03267$$

$$I_3^{extcorr} = Pr_{P3}^{extcorr}(Co_{P3}^{extcorrA})^{N_A^{extcorr}}(Co_{P3}^{extcorrB})^{N_B^{extcorr}}(Co_{P3}^{extcorrC})^{N_C^{extcorr}}(Co_{P3}^{extcorrD})^{N_D^{extcot}}$$

$$= \quad 0.01458$$

STEP 14 Calculate the Posteroir Probability $Po_{p1}^{extcorr}, Po_{p2}^{extcorr}, Po_{p3}^{extcorr}$, using equations

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

$$= \quad 0.6$$

$$Po_{p2}^{extcorr} = \frac{I_2^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}}$$

$$= \quad 0.256738703$$

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

$$= \quad 0.114577603$$

STEP 15 Calculate the parameters, ß_1, ß_2, and ß_3 using equation below and also assigning $COV_{\Delta t} = 0.20$, $COV_{sf} = 0.20$, and $COV_P = 0.05$.

$$\text{ß}_1^{extcorr} = \frac{1 - D_{S1}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + (1 - D_{S1}.A_{rt})^2.COV_{sf}{}^2 + (SR_P^{extcorr})^2.(COV_P)^2}}$$

$$\text{ß}_2^{extcorr} = \frac{1 - D_{S2}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + (1 - D_{S2}.A_{rt})^2.COV_{sf}{}^2 + (SR_P^{extcorr})^2.(COV_P)^2}}$$

$$\text{ß}_3^{extcorr} = \frac{1 - D_{S3}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + (1 - D_{S3}.A_{rt})^2.COV_{sf}{}^2 + (SR_P^{extcorr})^2.(COV_P)^2}}$$

Where;

$COV_{\Delta t}$ = The thinning coefficient of variance ranging from $0.1 \le COV_{\Delta t} \le 0.2$

= 0.2

COV_{sf} = The flow stress coefficient of variance

= 0.2

COV_P = Pressure coeffficient of variance

= 0.05

D_{s1} = Damage State 1

= 1

D_{s2} = Damage State 2
= 2

D_{s3} = Damage State 3
= 4

RBI DATE

BASED ON CORROSION RATE FROM RLA

$\text{ß}_1^{extcorr}$ = 3.5642

$\text{ß}_2^{extcorr}$ = 3.5177

$\text{ß}_3^{extcorr}$ = 3.4318

PLAN DATE

BASED ON CORROSION RATE FROM RLA

$\text{ß}_1^{extcorr}$ = 3.4594

$\text{ß}_2^{extcorr}$ = 3.2486

$\text{ß}_3^{extcorr}$ = 2.8778

STEP 16 Calculate $D_f^{extcorr}$ using equation below

RBI DATE

$$D_f^{extcor} = [\frac{\left(Po_{P1}^{extcorr}\Phi\left(-\beta_1^{extcorr}\right)\right)+\left(Po_{P2}^{extcorr}\Phi\left(-\beta_2^{extcorr}\right)\right)+\left(Po_{P3}^{extcorr}\Phi\left(-\beta_3^{extcorr}\right)\right)}{1.56E-0.4}$$

$D_f^{extcorr}$ = 1.079692 **BASED ON CORROSION RATE FROM RLA**

PLAN DATE

$$D_f^{extcor} = [\frac{\left(Po_{P1}^{extcorr}\Phi\left(-\beta_1^{extcorr}\right)\right)+\left(Po_{P2}^{extcorr}\Phi\left(-\beta_2^{extcorr}\right)\right)+\left(Po_{P3}^{extcorr}\Phi\left(-\beta_3^{extcorr}\right)\right)}{1.56E-0.4}$$

$D_f^{extcorr}$ = 1.079321 **BASED ON CORROSION RATE FROM RLA**

RBI DATE

Df total = 1.433840 BASED ON CORROSION RATE FROM RLA

PLAN DATE

Df total = 1.433468 BASED ON CORROSION RATE FROM RLA

EXTERNAL CORROSION DAMAGE FACTOR CALCULATION

1. RLA DATA

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1. and the specific data required for determination of the DF for external corrosion is provided Table 15.1 in API RP 581 Part 2 of POF.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Start Date	12/01/2008		The date the component was placed in service.
Thickness	8	mm	The thickness used for DF calculation that is either the furnished thickness or the measured
Corrosion Allowance	1.50	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	60	°C	The design temperature, shell side and tube side for Aboveground Storage Tank
Design Pressure	101	kpa	The design temperature, shell side and tube side for Aboveground Storage Tank
Operating Tempearture	30	°C	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Operating Pressure	98	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage
Design Code	API STD 650		The designing of the component containing the component.
Equipment Type	Aboveground Storage Tank		The type of equipment.
Component Type	Aboveground Storage Tank shell 3		The type of component.
Geometry Data	-		Component geometry data depending on the type of component.
Material Specification	ASTM 283 Grade C		The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. Data entry is based on the material specification, grade, year, UNS Number,

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Yield Strength	380000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	205000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	0.85		Weld joint efficiency per the Code of construction.
Heat Tracing	No		Is the component heat traced? (Yes or No)

STEP 1 Determining the furnished thickness, t, and age for the component from the installation date.

t = 0.31496063 inch   Installation date 23/07/2008

= 8.000 mm   RBI Date 29/10/2019

age = 11.26625599 years

STEP 2 Determining the base corrosion rate, CrB based on the driver and operating temperature using Table 15.2.

Table 15.2M - Corrosion Rates for Calculation of the Damage Factor-External Corrosion

Operating Temperature (oC)	Corrosion Rate as a Function of Driver (1) (mpy)			
	Marine / Cooling	Temperat	Arid / Dry	Severe
-12	0	0	0	0
-8	0.025	0	0	0
6	0.127	0.076	0.025	0.254
32	0.127	0.076	0.025	1.254
71	0.127	0.051	0.025	2.254
107	0.025	0	0	0.051
121	0	0	0	0

t = Operating temperature

= 30 ^{o}C

= 303 K

mpy 1 = 0.127 mm/y

Because the operating temperature is normally 30^{o}C, and there is no list of such that temperature. But, it does list values for 6^{o}C and 32^{o}C. Both of them have same value on marine condition.

So C_{rB} = 0.127

STEP 3 Calculate the final corrosion rate, Cr, using equation below.

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

F_{EQ} = Adjustment for equation design or fabrication
= 2

F_{IF} = Adjustment fo interface
= 1

$$C_r \ = \ C_{rB} \,.\max\left[\left(F_{EQ}, F_{IF}\right)\right]$$
= 0,127 . max [(2;1)]
= 0.25

But, the company has own their corrosion rate that given from the inspection that has been done for the tank before

C_r = 0.167

STEP 4 Determine the time in service, age_{tk}, since the last known inspection, t_{rde}. 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

t_{rdi} = 0.3035 inch
= 7.71 mm

Last inspection is on: 23/07/2018
RBI Date is on: 29/10/2019
Planned Date is on: 28/06/2022

age_{tk} = 1.268 years.

Last inspection was held on July 2018

age_{PD} = 3.932 years.

Inspection is held every 4 years

STEP 5 Determine the time in-service, age_{coat}, since the coating has been installed using equation below.

$$age_{coat} \ = \ Calculation\ Date \ - Coating\ Installation\ Date$$

Calculation Date = 29/10/2019
Coating installation Date = 12/01/2008

$$age_{coat} \ = \ Calculation\ Date \ - Coating\ Installation\ Date$$
= 11.795 years

STEP 6 Determine coating adjustment, coat_{adj} using one of below equations
If $\text{Age}_{tk} \geq \text{Age}_{coat}$

$Coat_{adj} = 0$ If No or Poor Coating Quality
$Coat_{adj} = \min[5, age_{coat}]$ If Medium Coating Quality
$Coat_{adj} = \min[15, age_{coat}]$ If High Coating Quality

If $\text{Age}_{tk} < \text{Age}_{coat}$

$Coat_{adj} = 0$ No / poor

$Coat_{adj} = \min[5, age_{coat}] - \min[5, age_{coat} - age_{tk}]$ Medium

$Coat_{adj} = \min[15, age_{coat}] - \min[15, age_{coat} - age_{tk}]$ High

Choose the calculation for Agetk less than the Agecoat in Medium Coating Level (painting only)

$Coat_{adj} = 0$

= 0.000

the result still 0 because the result of Agecoat and (Agecoat - Agetk) bigger than 5

STEP 7 Determine the in - service time, age, over which external corrosion may have occured uing equation below

$age = age_{tk} - Coat_{adj}$

= 1,268 - 0

= 1.268

STEP 8 Determine the allowable stress, S, weld joint efficiency, E, and minimum required thickness, t_{min}, per the original construction code or ASTM 283 or API

t_{min} = 0.1386 inch

= 3.52 mm

S = 19870 psig

= 136998881.2 Pa

= 136998.8812 Kpa

E = 0.85

STEP 9 Determine the A_{rt} Parameter

For component without clading/weld overlay then use the equation below.

RBI DATE

$$A_{rt} = \frac{Cr.agetk}{t_{rde}}$$

$$= \frac{0{,}167\ .\ 1{,}268}{6{,}96}$$

= 0.027456986 (For corrosion rate based on RLA Data)

PLAN DATE

$$A_{rt} = \frac{Cr.agepd}{t_{rde}}$$

$$= \frac{0{,}167\ .\ 3{,}932}{6{,}96}$$

$= \quad 0.085158168 \qquad$ (For corrosion rate based on RLA Data)

STEP 10 Calculate the Flow Stress, $FS^{extector}$, using E from STEP 5 and equation below.

$$FS^{extcorr} = \frac{(YS+TS)}{2}.\ \mathrm{E}.1{,}1$$

Where;

YS = 205000

TS = 380000

E = 0.85

$$FS^{extcorr} = \frac{(YS+TS)}{2}.\ \mathrm{E}.1{,}1$$

$$= \frac{(205000\ +380000)}{2}.\ (1)\ .1{,}1$$

$= \quad 273487.5$

STEP 11 Calculate the strength ratio parameter, SR_P^{Thin} , using the appropriate equation.

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

Where ;

t_c = is the minimum structural thickness of the component base material

= 0.196850394 inch

= 5 mm

$$SR_P^{extcorr} = \frac{136998{,}881\ .\ 0{,}85}{273487{,}5}.\frac{Max\ (3{,}52;5\ )}{6{,}96}$$

$= \quad 0.276130317$

STEP 12 Determine the number of inspection , $N_A^{extcorr}, N_B^{extcorr}, N_C^{extcorr}, N_D^{extcorr}$, and the corresponding inspection effectiveness category using Section 15.6. 2 for past inspections performed during the in - service time.

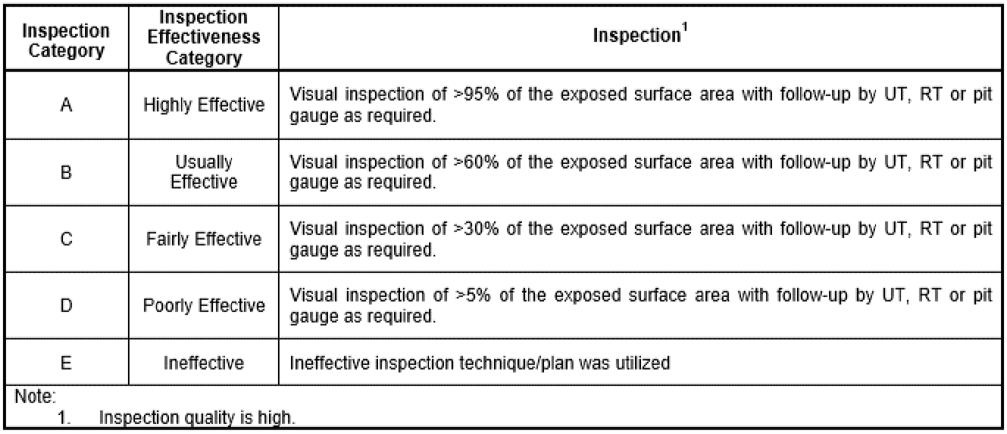
$N_A^{extcorr}$ = 0

$N_B^{extcorr}$ = 0

$N_C^{extcorr}$ = 0

$N_D^{extcorr}$ = 2

Table 2.C.10.1 - LoIE Example for External Damage



Inspection Category	Inspection Effectiveness Category	Inspection[1]
A	Highly Effective	Visual inspection of >95% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
B	Usually Effective	Visual inspection of >60% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
C	Fairly Effective	Visual inspection of >30% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
D	Poorly Effective	Visual inspection of >5% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
E	Ineffective	Ineffective inspection technique/plan was utilized

Note:

1. Inspection quality is high.

STEP 13 Determine the inspection effectiveness factors, $I_1^{extcorr}, I_2^{extcorr}, I_3^{extcorr}$, using equation below, prior probabilities, $Pr_{p1}^{extcorr}, Pr_{p2}^{extcorr}, Pr_{p3}^{extcorr}$, from Table 4.5. Conditional Probabilities (for each inspection effectiveness level) $Co_{p1}^{extcorr}, Co_{p2}^{extcorr}, Co_{p3}^{extcorr}$ fromTable 4.6, and the number of inspection, $N_A^{extcorr}, N_B^{extcorr}, N_C^{extcorr}, N_D^{extcorr}$ in each effectiveness level from STEP 12.

$$I_1^{extcorr} = Pr_{P1}^{extcorr}(Co_{P1}^{extcorrA})^{N_A^{extcorr}}(Co_{P1}^{extcorrB})^{N_B^{extcorr}}(Co_{P1}^{extcorrC})^{N_C^{extcorr}}(Co_{P1}^{extcorrD})^{N_D^{extco}}$$

$$I_2^{extcorr} = Pr_{P2}^{extcorr}(Co_{P2}^{extcorrA})^{N_A^{extcorr}}(Co_{P2}^{extcorrB})^{N_B^{extcorr}}(Co_{P2}^{extcorrC})^{N_C^{extcorr}}(Co_{P2}^{extcorrD})^{N_D^{extco}}$$

$$I_3^{extcorr} = Pr_{P3}^{extcorr}(Co_{P3}^{extcorrA})^{N_A^{extcorr}}(Co_{P3}^{extcorrB})^{N_B^{extcorr}}(Co_{P3}^{extcorrC})^{N_C^{extcorr}}(Co_{P3}^{extcorrD})^{N_D^{extco}}$$

Table 4.5 - Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Conf. 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 4.6 - Conditional Probability for Inspection Effectiveness

Conditional P. 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

$$I_1^{extcorr} = Pr_{P1}^{extcorr}(Co_{P1}^{extcorrA})^{N_A^{extcorr}}(Co_{P1}^{extcorrB})^{N_B^{extcorr}}(Co_{P1}^{extcorrC})^{N_C^{extcorr}}(Co_{P1}^{extcorrD})^{N_D^{extcot}}$$

$$= \quad 0.08000$$

$$I_2^{extcorr} = Pr_{P2}^{extcorr}(Co_{P2}^{extcorrA})^{N_A^{extcorr}}(Co_{P2}^{extcorrB})^{N_B^{extcorr}}(Co_{P2}^{extcorrC})^{N_C^{extcorr}}(Co_{P2}^{extcorrD})^{N_D^{extcot}}$$

$$= \quad 0.03267$$

$$I_3^{extcorr} = Pr_{P3}^{extcorr}(Co_{P3}^{extcorrA})^{N_A^{extcorr}}(Co_{P3}^{extcorrB})^{N_B^{extcorr}}(Co_{P3}^{extcorrC})^{N_C^{extcorr}}(Co_{P3}^{extcorrD})^{N_D^{extcot}}$$

$$= \quad 0.01458$$

STEP 14 Calculate the Posteroir Probability $Po_{p1}^{extcorr}, Po_{p2}^{extcorr}, Po_{p3}^{extcorr}$ using equations

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

$$= \quad 0.6$$

$$Po_{p2}^{extcorr} = \frac{I_2^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}}$$

$$= \quad 0.256738703$$

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

$$= \quad 0.114577603$$

STEP 15 Calculate the parameters, ß$_1$, ß$_2$, and ß$_3$ using equation below and also assigning $COV_{\Delta t} = 0.20$, $COV_{sf} = 0.20$, and $COV_P = 0.05$.

$$ß_1^{extcorr} = \frac{1 - D_{S1}.A_{rt} - SR_P^{extcorr}}{\sqrt{{D_{S1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2 + (1 - D_{S1}.A_{rt})^2.{COV_{sf}}^2 + (SR_P^{extcorr})^2.(COV_P)^2}}$$

$$ß_2^{extcorr} = \frac{1 - D_{S2}.A_{rt} - SR_P^{extcorr}}{\sqrt{{D_{S2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2 + (1 - D_{S2}.A_{rt})^2.{COV_{sf}}^2 + (SR_P^{extcorr})^2.(COV_P)^2}}$$

$$ß_3^{extcorr} = \frac{1 - D_{S3}.A_{rt} - SR_P^{extcorr}}{\sqrt{{D_{S3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2 + (1 - D_{S3}.A_{rt})^2.{COV_{sf}}^2 + (SR_P^{extcorr})^2.(COV_P)^2}}$$

Where;

$COV_{\Delta t}$ = The thinning coefficient of variance ranging from $0.1 \leq COV_{\Delta t} \leq 0.2$

= 0.2

COV_{sf} = The flow stress coefficient of variance

= 0.2

COV_P = Pressure coeffficient of variance

= 0.05

D_{s1} = Damage State 1

= 1

D_{s2} = Damage State 2
= 2

D_{s3} = Damage State 3
= 4

RBI DATE

BASED ON CORROSION RATE FROM RLA

ß$_1^{extcorr}$ = 3.5700

ß$_2^{extcorr}$ = 3.5238

ß$_3^{extcorr}$ = 3.4387

PLAN DATE

BASED ON CORROSION RATE FROM RLA

ß$_1^{extcorr}$ = 3.4660

ß$_2^{extcorr}$ = 3.2570

ß$_3^{extcorr}$ = 2.8903

STEP 16 Calculate $D_f^{extcorr}$ using equation below

RBI DATE

$$D_f^{extcor} = [\frac{\left(Po_{P1}^{extcorr}\Phi\left(-\beta_1^{extcorr}\right)\right)+\left(Po_{P2}^{extcorr}\Phi\left(-\beta_2^{extcorr}\right)\right)+\left(Po_{P3}^{extcorr}\Phi\left(-\beta_3^{extcorr}\right)\right)}{1.56E-0.4}$$

$D_f^{extcorr}$ = 1.079697 **BASED ON CORROSION RATE FROM RLA**

PLAN DATE

$$D_f^{extcor} = [\frac{\left(Po_{P1}^{extcorr}\Phi\left(-\beta_1^{extcorr}\right)\right)+\left(Po_{P2}^{extcorr}\Phi\left(-\beta_2^{extcorr}\right)\right)+\left(Po_{P3}^{extcorr}\Phi\left(-\beta_3^{extcorr}\right)\right)}{1.56E-0.4}$$

$D_f^{extcorr}$ = 1.079340 **BASED ON CORROSION RATE FROM RLA**

RBI DATE

Df total = 1.433845 BASED ON CORROSION RATE FROM RLA

PLAN DATE

Df total = 1.433487 BASED ON CORROSION RATE FROM RLA

EXTERNAL CORROSION DAMAGE FACTOR CALCULATION

1. RLA DATA

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1. and the specific data required for determination of the DF for external corrosion is provided Table 15.1 in API RP 581 Part 2 of POF.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Start Date	12/01/2008		The date the component was placed in service.
Thickness	8	mm	The thickness used for DF calculation that is either the furnished thickness or the measured
Corrosion Allowance	1.50	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	60	^{o}C	The design temperature, shell side and tube side for Aboveground Storage Tank
Design Pressure	101	kpa	The design temperature, shell side and tube side for Aboveground Storage Tank
Operating Tempearture	30	^{o}C	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Operating Pressure	98	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage
Design Code	API STD 650		The designing of the component containing the component.
Equipment Type	Aboveground Storage Tank		The type of equipment.
Component Type	Aboveground Storage Tank shell 4		The type of component.
Geometry Data	-		Component geometry data depending on the type of component.
Material Specification	ASTM 283 Grade C		The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. Data entry is based on the material specification, grade, year, UNS Number,

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Yield Strength	380000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	205000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	0.85		Weld joint efficiency per the Code of construction.
Heat Tracing	No		Is the component heat traced? (Yes or No)

STEP 1

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

t = 0.236220472 inch　　Installation date 23/07/2008

= 6.000 mm　　RBI Date 29/10/2019

age = 11.26625599 years

STEP 2

Determining the base corrosion rate, CrB based on the driver and operating temperature using Table 15.2.

Table 15.2M - Corrosion Rates for Calculation of the Damage Factor-External Corrosion

Operating Temperature (oC)	Corrosion Rate as a Function of Driver (1) (mpy)			
	Marine / Cooling	Temperat	Arid / Dry	Severe
-12	0	0	0	0
-8	0.025	0	0	0
6	0.127	0.076	0.025	0.254
32	0.127	0.076	0.025	1.254
71	0.127	0.051	0.025	2.254
107	0.025	0	0	0.051
121	0	0	0	0

t = Operating temperature

= 30 °C

= 303 K

mpy 1 = 0.127 mm/y

Because the operating temperature is normally 30°C, and there is no list of such that temperature. But, it does list values for 6°C and 32°C. Both of them have same value on marine condition.

So C_{rB} = 0.127

STEP 3 Calculate the final corrosion rate, Cr, using equation below.

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

F_{EQ} = Adjustment for equation design or fabrication

= 2

F_{IF} = Adjustment fo interface

= 1

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

= 0,127 . max [(2;1)]

= 0.25

But, the company has own their corrosion rate that given from the inspection that has been done for the tank before

C_r = 0.167

STEP 4 Determine the time in service, age_{tk}, since the last known inspection, t_{rde}. 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

t_{rdi} = 0.2252 inch

= 5.72 mm

Last inspection is on: 23/07/2018

RBI Date is on: 29/10/2019

Planned Date is on: 28/06/2022

t

age_{tk} = 1.268 years.

age_{PD} = 3.932 years.

Inspection is held every 4 years

STEP 5 Determine the time in-service, age_{coat}, since the coating has been installed using equation below.

$$age_{coat} = Calculation\ Date - Coating\ Installation\ Date$$

Calculation Date = 29/10/2019

Coating installation Date = 12/01/2008

$$age_{coat} = Calculation\ Date - Coating\ Installation\ Date$$

= 11.795 years

STEP 6 Determine coating adjustment, $coat_{adj}$ using one of below equations

If $Age_{tk} \geq Age_{coat}$

$Coat_{adj} = 0$ If No or Poor Coating Quality

$Coat_{adj} = \min[5, age_{coat}]$ If Medium Coating Quality

$Coat_{adj} = \min[15, age_{coat}]$ If High Coating Quality

If $Age_{tk} < Age_{coat}$

$Coat_{adj} = 0$ No / poor

$Coat_{adj} = \min[5, age_{coat}] - \min[5, age_{coat} - age_{tk}]$ Medium

$Coat_{adj} = \min[15, age_{coat}] - \min[15, age_{coat} - age_{tk}]$ High

Choose the calculation for Agetk less than the Agecoat in Medium Coating Level (painting only)

$Coat_{adj} = 0$

$= 0.000$

the result still 0 because the result of Agecoat and (Agecoat - Agetk) bigger than 5

STEP 7 Determine the in - service time, age, over which external corrosion may have occured uing equation below

$age = age_{tk} - Coat_{adj}$

$= 1{,}268 - 0$

$= 1.268$

STEP 8 Determine the allowable stress, S, weld joint efficiency, E, and minimum required thickness, t_{min}, per the original construction code or ASTM 283 or API

t_{min} = 0.1386 inch

= 3.52 mm

S = 19870 psig

= 136998881.2 Pa

= 136998.8812 Kpa

E = 0.85

STEP 9 Determine the A_{rt} Parameter

For component without clading/weld overlay then use the equation below.

<u>RBI DATE</u>

$$A_{rt} = \frac{Cr.agetk}{t_{rde}}$$

$$= \frac{0{,}167 \,.\, 1{,}268}{6{,}96}$$

$= 0.037009329$ (For corrosion rate based on RLA Data)

PLAN DATE

$$A_{rt} = \frac{Cr.agepd}{t_{rde}}$$

$$= \frac{0{,}167\ .\ 3{,}932}{6{,}96}$$

$= \quad 0.114784873$ (For corrosion rate based on RLA Data)

STEP 10 Calculate the Flow Stress, $FS^{extector}$, using E from STEP 5 and equation below.

$$FS^{extcorr} = \frac{(YS+TS)}{2}.\ \text{E.1,1}$$

Where;

YS = 205000

TS = 380000

E = 0.85

$$FS^{extcorr} = \frac{(YS+TS)}{2}.\ \text{E.1,1}$$

$$= \frac{(205000 + 380000)}{2}.\ (1)\ .1{,}1$$

$= 273487.5$

STEP 11 Calculate the strength ratio parameter, SR_P^{Thin} , using the appropriate equation.

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

Where ;

t_c = is the minimum structural thickness of the component base material

= 0.196850394 inch

= 5 mm

$$SR_P^{extcorr} = \frac{136998{,}881\ .\ 0{,}85}{273487{,}5} . \frac{Max\ (3{,}52;5\ )}{6{,}96}$$

$= \quad 0.372196633$

STEP 12 Determine the number of inspection , $N_A^{extcorr}, N_B^{extcorr}, N_C^{extcorr}, N_D^{extcorr}$, and the corresponding inspection effectiveness category using Section 15.6. 2 for past inspections performed during the in - service time.

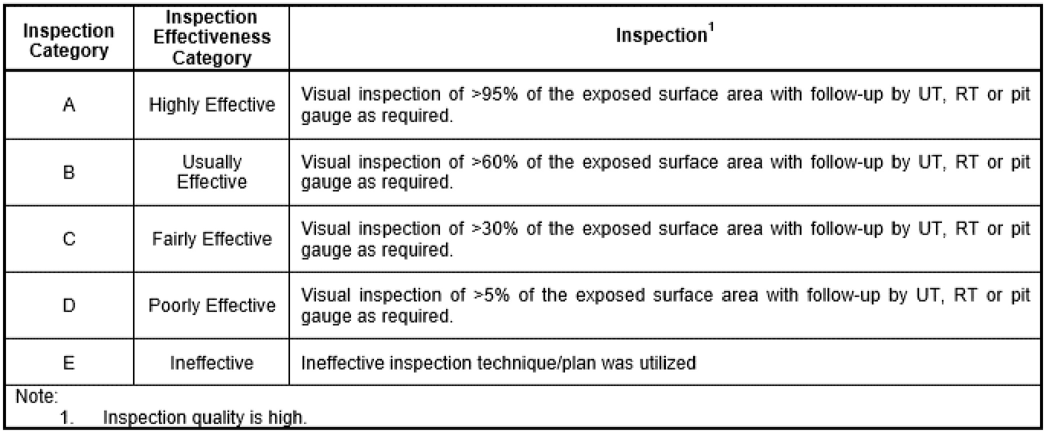
$N_A^{extcorr}$ = 0

$N_B^{extcorr}$ = 0

$N_C^{extcorr}$ = 0

$N_D^{extcorr}$ = 2

Table 2.C.10.1 - LoIE Example for External Damage



Inspection Category	Inspection Effectiveness Category	Inspection[1]
A	Highly Effective	Visual inspection of >95% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
B	Usually Effective	Visual inspection of >60% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
C	Fairly Effective	Visual inspection of >30% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
D	Poorly Effective	Visual inspection of >5% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
E	Ineffective	Ineffective inspection technique/plan was utilized

Note:
1. Inspection quality is high.

STEP 13 Determine the inspection effectiveness factors, $I_1^{extcorr}, I_2^{extcorr}, I_3^{extcorr}$, using equation below, prior probabilities, $Pr_{p1}^{extcorr}, Pr_{p2}^{extcorr}, Pr_{p3}^{extcorr}$, from Table 4.5. Conditional Probabilities (for each inspection effectiveness level) $Co_{p1}^{extcorr}, Co_{p2}^{extcorr}, Co_{p3}^{extcorr}$ fromTable 4.6, and the number of inspection, $N_A^{extcorr}, N_B^{extcorr}, N_C^{extcorr}, N_D^{extcorr}$ in each effectiveness level from STEP 12.

$$I_1^{extcorr} = Pr_{P1}^{extcorr}(Co_{P1}^{extcorrA})^{N_A^{extcorr}}(Co_{P1}^{extcorrB})^{N_B^{extcorr}}(Co_{P1}^{extcorrC})^{N_C^{extcorr}}(Co_{P1}^{extcorrD})^{N_D^{extco}}$$

$$I_2^{extcorr} = Pr_{P2}^{extcorr}(Co_{P2}^{extcorrA})^{N_A^{extcorr}}(Co_{P2}^{extcorrB})^{N_B^{extcorr}}(Co_{P2}^{extcorrC})^{N_C^{extcorr}}(Co_{P2}^{extcorrD})^{N_D^{extco}}$$

$$I_3^{extcorr} = Pr_{P3}^{extcorr}(Co_{P3}^{extcorrA})^{N_A^{extcorr}}(Co_{P3}^{extcorrB})^{N_B^{extcorr}}(Co_{P3}^{extcorrC})^{N_C^{extcorr}}(Co_{P3}^{extcorrD})^{N_D^{extco}}$$

Table 4.5 - Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Conf. 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 4.6 - Conditional Probability for Inspection Effectiveness

Conditional P. 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

$$I_1^{extcorr} = Pr_{P1}^{extcorr}(Co_{P1}^{extcorrA})^{N_A^{extcorr}}(Co_{P1}^{extcorrB})^{N_B^{extcorr}}(Co_{P1}^{extcorrC})^{N_C^{extcorr}}(Co_{P1}^{extcorrD})^{N_D^{extcot}}$$

$$= 0.08000$$

$$I_2^{extcorr} = Pr_{P2}^{extcorr}(Co_{P2}^{extcorrA})^{N_A^{extcorr}}(Co_{P2}^{extcorrB})^{N_B^{extcorr}}(Co_{P2}^{extcorrC})^{N_C^{extcorr}}(Co_{P2}^{extcorrD})^{N_D^{extcot}}$$

$$= 0.03267$$

$$I_3^{extcorr} = Pr_{P3}^{extcorr}(Co_{P3}^{extcorrA})^{N_A^{extcorr}}(Co_{P3}^{extcorrB})^{N_B^{extcorr}}(Co_{P3}^{extcorrC})^{N_C^{extcorr}}(Co_{P3}^{extcorrD})^{N_D^{extcot}}$$

$$= 0.01458$$

STEP 14 Calculate the Posteroir Probability $Po_{p1}^{extcorr}, Po_{p2}^{extcorr}, Po_{p3}^{extcorr}$, using equations

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

$$= 0.6$$

$$Po_{p2}^{extcorr} = \frac{I_2^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}}$$

$$= 0.256738703$$

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

$$= 0.114577603$$

STEP 15 Calculate the parameters, $ß_1$, $ß_2$, and $ß_3$ using equation below and also assigning $COV_{\Delta t} = 0.20$, $COV_{sf} = 0.20$, and $COV_P = 0.05$.

$$ß_1^{extcorr} = \frac{1 - D_{S1}.A_{rt} - SR_P^{extcorr}}{\sqrt{{D_{S1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2 + (1 - D_{S1}.A_{rt})^2.{COV_{sf}}^2 + (SR_P^{extcorr})^2.(COV_P)^2}}$$

$$ß_2^{extcorr} = \frac{1 - D_{S2}.A_{rt} - SR_P^{extcorr}}{\sqrt{{D_{S2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2 + (1 - D_{S2}.A_{rt})^2.{COV_{sf}}^2 + (SR_P^{extcorr})^2.(COV_P)^2}}$$

$$ß_3^{extcorr} = \frac{1 - D_{S3}.A_{rt} - SR_P^{extcorr}}{\sqrt{{D_{S3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2 + (1 - D_{S3}.A_{rt})^2.{COV_{sf}}^2 + (SR_P^{extcorr})^2.(COV_P)^2}}$$

Where;

$COV_{\Delta t}$ = The thinning coefficient of variance ranging from $0.1 \leq COV_{\Delta t} \leq 0.2$

= 0.2

COV_{sf} = The flow stress coefficient of variance

= 0.2

COV_P = Pressure coeffficient of variance

= 0.05

D_{s1} = Damage State 1

= 1

D_{s2} = Damage State 2
= 2

D_{s3} = Damage State 3
= 4

RBI DATE

BASED ON CORROSION RATE FROM RLA

$\text{ß}_1^{extcorr}$ = 3.0510

$\text{ß}_2^{extcorr}$ = 2.9659

$\text{ß}_3^{extcorr}$ = 2.7990

PLAN DATE

BASED ON CORROSION RATE FROM RLA

$\text{ß}_1^{extcorr}$ = 2.8582

$\text{ß}_2^{extcorr}$ = 2.4604

$\text{ß}_3^{extcorr}$ = 1.5366

STEP 16 Calculate $D_f^{extcorr}$ using equation below

RBI DATE

$$D_f^{extcor} = [\frac{\left(Po_{P1}^{extcorr}\Phi\left(-\beta_1^{extcorr}\right)\right)+\left(Po_{P2}^{extcorr}\Phi\left(-\beta_2^{extcorr}\right)\right)+\left(Po_{P3}^{extcorr}\Phi\left(-\beta_3^{extcorr}\right)\right)}{1.56E-0.4}$$

$D_f^{extcorr}$ = 1.078404 **BASED ON CORROSION RATE FROM RLA**

PLAN DATE

$$D_f^{extcor} = [\frac{\left(Po_{P1}^{extcorr}\Phi\left(-\beta_1^{extcorr}\right)\right)+\left(Po_{P2}^{extcorr}\Phi\left(-\beta_2^{extcorr}\right)\right)+\left(Po_{P3}^{extcorr}\Phi\left(-\beta_3^{extcorr}\right)\right)}{1.56E-0.4}$$

$D_f^{extcorr}$ = 1.068848 **BASED ON CORROSION RATE FROM RLA**

RBI DATE

Df total = 1.432552 BASED ON CORROSION RATE FROM RLA

PLAN DATE

Df total = 1.422995 BASED ON CORROSION RATE FROM RLA

EXTERNAL CORROSION DAMAGE FACTOR CALCULATION

1. RLA DATA

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1. and the specific data required for determination of the DF for external corrosion is provided Table 15.1 in API RP 581 Part 2 of POF.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Start Date	12/01/2008		The date the component was placed in service.
Thickness	8	mm	The thickness used for DF calculation that is either the furnished thickness or the measured
Corrosion Allowance	1.50	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	60	^{o}C	The design temperature, shell side and tube side for Aboveground Storage Tank
Design Pressure	101	kpa	The design temperature, shell side and tube side for Aboveground Storage Tank
Operating Tempearture	30	^{o}C	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Operating Pressure	98	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage
Design Code	API STD 650		The designing of the component containing the component.
Equipment Type	Aboveground Storage Tank		The type of equipment.
Component Type	Aboveground Storage Tank shell 5		The type of component.
Geometry Data	-		Component geometry data depending on the type of component.
Material Specification	ASTM 283 Grade C		The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. Data entry is based on the material specification, grade, year, UNS Number,

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Yield Strength	380000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	205000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	0.85		Weld joint efficiency per the Code of construction.
Heat Tracing	No		Is the component heat traced? (Yes or No)

STEP 1 Determining the furnished thickness, t, and age for the component from the installation date.

t = 0.236220472 inch   Installation date 23/07/2008

= 6.000 mm   RBI Date 29/10/2019

age = 11.26625599 years

STEP 2 Determining the base corrosion rate, CrB based on the driver and operating temperature using Table 15.2.

Table 15.2M - Corrosion Rates for Calculation of the Damage Factor-External Corrosion

Operating Temperature (oC)	Corrosion Rate as a Function of Driver (1) (mpy)			
	Marine / Cooling	Temperat	Arid / Dry	Severe
-12	0	0	0	0
-8	0.025	0	0	0
6	0.127	0.076	0.025	0.254
32	0.127	0.076	0.025	1.254
71	0.127	0.051	0.025	2.254
107	0.025	0	0	0.051
121	0	0	0	0

t = Operating temperature

= 30 °C

= 303 K

mpy 1 = 0.127 mm/y

Because the operating temperature is normally 30°C, and there is no list of such that temperature. But, it does list values for 6°C and 32°C. Both of them have same value on marine condition.

So C_{rB} = 0.127

STEP 3 Calculate the final corrosion rate, Cr, using equation below.

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

F_{EQ} = Adjustment for equation design or fabrication
= 2

F_{IF} = Adjustment fo interface
= 1

$$C_r = C_{rB} \, .\max[(F_{EQ}, F_{IF})]$$
= 0,127 . max [(2;1)]
= 0.25

But, the company has own their corrosion rate that given from the inspection that has been done for the tank before

C_r = 0.167

STEP 4 Determine the time in service, age_{tk}, since the last known inspection, t_{rde}. 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

t_{rdi} = 0.2307 inch
= 5.86 mm

Last inspection is on: 23/07/2018
RBI Date is on: 29/10/2019
Planned Date is on: 28/06/2022

Last inspection was held on July 2018

age_{tk} = 1.268 years.

age_{PD} = 3.932 years.

Inspection is held every 4 years

STEP 5 Determine the time in-service, age_{coat}, since the coating has been installed using equation below.

$$age_{coat} = Calculation\ Date - Coating\ Installation\ Date$$

Calculation Date = 29/10/2019
Coating installation Date = 12/01/2008

$$age_{coat} = Calculation\ Date - Coating\ Installation\ Date$$
= 11.795 years

STEP 6 Determine coating adjustment, $coat_{adj}$ using one of below equations

If $Age_{tk} \geq Age_{coat}$

$Coat_{adj} = 0$ If No or Poor Coating Quality
$Coat_{adj} = \min[5, age_{coat}]$ If Medium Coating Quality
$Coat_{adj} = \min[15, age_{coat}]$ If High Coating Quality

If $Age_{tk} < Age_{coat}$

$Coat_{adj} = 0$ No / poor

$Coat_{adj} = \min[5, age_{coat}] - \min[5, age_{coat} - age_{tk}]$ Medium

$Coat_{adj} = \min[15, age_{coat}] - \min[15, age_{coat} - age_{tk}]$ High

Choose the calculation for Agetk less than the Agecoat in Medium Coating Level (painting only)

$Coat_{adj} = 0$

= 0.000

the result still 0 because the result of Agecoat and (Agecoat - Agetk) bigger than 5

STEP 7 Determine the in - service time, age, over which external corrosion may have occured uing equation below

$$age = age_{tk} - Coat_{adj}$$

= 1,268 - 0

= 1.268

STEP 8 Determine the allowable stress, S, weld joint efficiency, E, and minimum required thickness, t_{min}, per the original construction code or ASTM 283 or API

t_{min} = 0.1386 inch

= 3.52 mm

S = 19870 psig

= 136998881.2 Pa

= 136998.8812 Kpa

E = 0.85

STEP 9 Determine the A_{rt} Parameter

For component without clading/weld overlay then use the equation below.

<u>RBI DATE</u>

$$A_{rt} = \frac{Cr.agetk}{t_{rde}}$$

$$= \frac{0{,}167\ .\ 1{,}268}{6{,}96}$$

= 0.036125147 (For corrosion rate based on RLA Data)

PLAN DATE

$$A_{rt} = \frac{Cr.agepd}{t_{rde}}$$

$$= \frac{0{,}167\,.\,3{,}932}{6{,}96}$$

$$= \quad 0.112042572$$ (For corrosion rate based on RLA Data)

STEP 10 Calculate the Flow Stress, $FS^{extector}$, using E from STEP 5 and equation below.

$$FS^{extcorr} = \frac{(YS+TS)}{2}.\,\mathrm{E.1{,}1}$$

Where;

YS = 205000

TS = 380000

E = 0.85

$$FS^{extcorr} = \frac{(YS+TS)}{2}.\,\mathrm{E.1{,}1}$$

$$= \frac{(205000+380000)}{2}.\ (1)\,.1{,}1$$

$$= 273487.5$$

STEP 11 Calculate the strength ratio parameter, SR_P^{Thin} , using the appropriate equation.

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

Where ;

t_c = is the

= 0.196850394 inch

= 5 mm

$$SR_P^{extcorr} = \frac{136998{,}881\,.\,0{,}85}{273487{,}5}.\frac{Max\,(3{,}52;5\,)}{6{,}96}$$

$$= \quad 0.363304564$$

STEP 12 Determine the number of inspection , $N_A^{extcorr}, N_B^{extcorr}, N_C^{extcorr}, N_D^{extcorr}$, and the corresponding inspection effectiveness category using Section 15.6. 2 for past inspections performed during the in - service time.

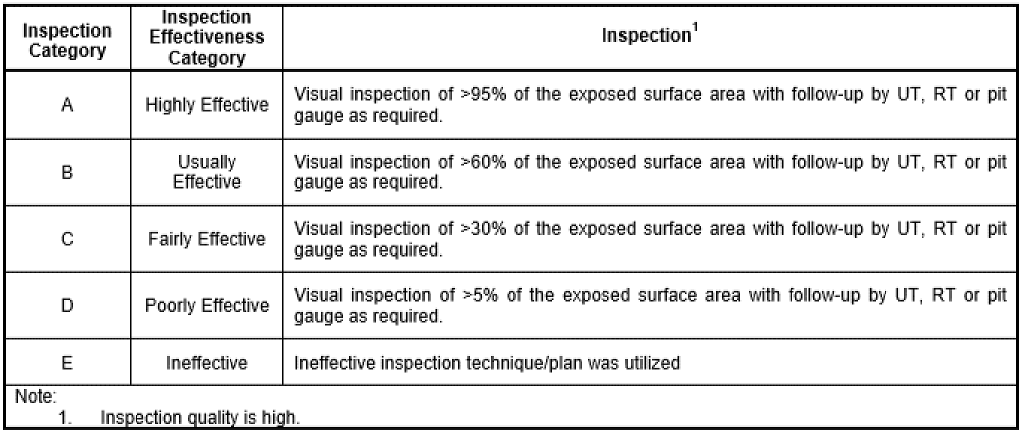
$N_A^{extcorr}$ = 0

$N_B^{extcorr}$ = 0

$N_C^{extcorr}$ = 0

$N_D^{extcorr}$ = 2

Table 2.C.10.1 - LoIE Example for External Damage



Inspection Category	Inspection Effectiveness Category	Inspection[1]
A	Highly Effective	Visual inspection of >95% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
B	Usually Effective	Visual inspection of >60% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
C	Fairly Effective	Visual inspection of >30% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
D	Poorly Effective	Visual inspection of >5% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
E	Ineffective	Ineffective inspection technique/plan was utilized

Note:

1. Inspection quality is high.

STEP 13 Determine the inspection effectiveness factors, $I_1^{extcorr}, I_2^{extcorr}, I_3^{extcorr}$, using equation below, prior probabilities, $Pr_{p1}^{extcorr}, Pr_{p2}^{extcorr}, Pr_{p3}^{extcorr}$, from Table 4.5. Conditional Probabilities (for each inspection effectiveness level) $Co_{p1}^{extcorr}, Co_{p2}^{extcorr}, Co_{p3}^{extcorr}$ fromTable 4.6, and the number of inspection, $N_A^{extcorr}, N_B^{extcorr}, N_C^{extcorr}, N_D^{extcorr}$ in each effectiveness level from STEP 12.

$$I_1^{extcorr} = Pr_{P1}^{extcorr}(Co_{P1}^{extcorrA})^{N_A^{extcorr}}(Co_{P1}^{extcorrB})^{N_B^{extcorr}}(Co_{P1}^{extcorrC})^{N_C^{extcorr}}(Co_{P1}^{extcorrD})^{N_D^{extco}}$$

$$I_2^{extcorr} = Pr_{P2}^{extcorr}(Co_{P2}^{extcorrA})^{N_A^{extcorr}}(Co_{P2}^{extcorrB})^{N_B^{extcorr}}(Co_{P2}^{extcorrC})^{N_C^{extcorr}}(Co_{P2}^{extcorrD})^{N_D^{extco}}$$

$$I_3^{extcorr} = Pr_{P3}^{extcorr}(Co_{P3}^{extcorrA})^{N_A^{extcorr}}(Co_{P3}^{extcorrB})^{N_B^{extcorr}}(Co_{P3}^{extcorrC})^{N_C^{extcorr}}(Co_{P3}^{extcorrD})^{N_D^{extco}}$$

Table 4.5 - Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Conf. 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 4.6 - Conditional Probability for Inspection Effectiveness

Conditional P. 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

$$I_1^{extcorr} = Pr_{P1}^{extcorr}(Co_{P1}^{extcorrA})^{N_A^{extcorr}}(Co_{P1}^{extcorrB})^{N_B^{extcorr}}(Co_{P1}^{extcorrC})^{N_C^{extcorr}}(Co_{P1}^{extcorrD})^{N_D^{extcot}}$$

$$= \quad 0.08000$$

$$I_2^{extcorr} = Pr_{P2}^{extcorr}(Co_{P2}^{extcorrA})^{N_A^{extcorr}}(Co_{P2}^{extcorrB})^{N_B^{extcorr}}(Co_{P2}^{extcorrC})^{N_C^{extcorr}}(Co_{P2}^{extcorrD})^{N_D^{extcot}}$$

$$= \quad 0.03267$$

$$I_3^{extcorr} = Pr_{P3}^{extcorr}(Co_{P3}^{extcorrA})^{N_A^{extcorr}}(Co_{P3}^{extcorrB})^{N_B^{extcorr}}(Co_{P3}^{extcorrC})^{N_C^{extcorr}}(Co_{P3}^{extcorrD})^{N_D^{extcot}}$$

$$= \quad 0.01458$$

STEP 14 Calculate the Posteroir Probability$Po_{p1}^{extcorr}, Po_{p2}^{extcorr}, Po_{p3}^{extcorr}$, using equations

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

$$= \quad 0.6$$

$$Po_{p2}^{extcorr} = \frac{I_2^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}}$$

$$= \quad 0.256738703$$

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

$$= \quad 0.114577603$$

STEP 15 Calculate the parameters, ß_1, ß_2, and ß_3 using equation below and also assigning $COV_{\Delta t} = 0.20$, $COV_{sf} = 0.20$, and $COV_P = 0.05$.

$$\text{ß}_1^{extcorr} = \frac{1-D_{S1}.A_{rt}-SR_P^{extcorr}}{\sqrt{D_{S1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{extcorr})^2.(COV_P)^2}}$$

$$\text{ß}_2^{extcorr} = \frac{1-D_{S2}.A_{rt}-SR_P^{extcorr}}{\sqrt{D_{S2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{extcorr})^2.(COV_P)^2}}$$

$$\text{ß}_3^{extcorr} = \frac{1-D_{S3}.A_{rt}-SR_P^{extcorr}}{\sqrt{D_{S3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{extcorr})^2.(COV_P)^2}}$$

Where;

$COV_{\Delta t}$ = The thinning coefficient of variance ranging from $0.1 \le COV_{\Delta t} \le 0.2$

= 0.2

COV_{sf} = The flow stress coefficient of variance

= 0.2

COV_P = Pressure coeffficient of variance

= 0.05

D_{s1} = Damage State 1

= 1

D_{s2} = Damage State 2
= 2

D_{s3} = Damage State 3
= 4

RBI DATE

BASED ON CORROSION RATE FROM RLA

$\text{ß}_1^{extcorr}$ = 3.0995

$\text{ß}_2^{extcorr}$ = 3.0185

$\text{ß}_3^{extcorr}$ = 2.8606

PLAN DATE

BASED ON CORROSION RATE FROM RLA

$\text{ß}_1^{extcorr}$ = 2.9161

$\text{ß}_2^{extcorr}$ = 2.5385

$\text{ß}_3^{extcorr}$ = 1.6855

STEP 16 Calculate $D_f^{extcorr}$ using equation below

RBI DATE

$$D_f^{extcor} = [\frac{\left(Po_{P1}^{extcorr}\Phi(-\beta_1^{extcorr})\right)+\left(Po_{P2}^{extcorr}\Phi(-\beta_2^{extcorr})\right)+\left(Po_{P3}^{extcorr}\Phi(-\beta_3^{extcorr})\right)}{1.56E-0.4}$$

$D_f^{extcorr}$ = 1.078642 **BASED ON CORROSION RATE FROM RLA**

PLAN DATE

$$D_f^{extcor} = [\frac{\left(Po_{P1}^{extcorr}\Phi(-\beta_1^{extcorr})\right)+\left(Po_{P2}^{extcorr}\Phi(-\beta_2^{extcorr})\right)+\left(Po_{P3}^{extcorr}\Phi(-\beta_3^{extcorr})\right)}{1.56E-0.4}$$

$D_f^{extcorr}$ = 1.071482 **BASED ON CORROSION RATE FROM RLA**

RBI DATE

Df total = 1.432789 BASED ON CORROSION RATE FROM RLA

PLAN DATE

Df total = 1.425628 BASED ON CORROSION RATE FROM RLA

EXTERNAL CORROSION DAMAGE FACTOR CALCULATION

1. RLA DATA

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1. and the specific data required for determination of the DF for external corrosion is provided Table 15.1 in API RP 581 Part 2 of POF.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Start Date	12/01/2008		The date the component was placed in service.
Thickness	8	mm	The thickness used for DF calculation that is either the furnished thickness or the measured
Corrosion Allowance	1.50	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	60	^{o}C	The design temperature, shell side and tube side for Aboveground Storage Tank
Design Pressure	101	kpa	The design temperature, shell side and tube side for Aboveground Storage Tank
Operating Tempearture	30	^{o}C	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage Tank
Operating Pressure	98	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and bottom side for Aboveground Storage
Design Code	API STD 650		The designing of the component containing the component.
Equipment Type	Aboveground Storage Tank		The type of equipment.
Component Type	Aboveground Storage Tank shell 5		The type of component.
Geometry Data	-		Component geometry data depending on the type of component.
Material Specification	ASTM 283 Grade C		The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. Data entry is based on the material specification, grade, year, UNS Number,

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Yield Strength	380000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	205000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	0.85		Weld joint efficiency per the Code of construction.
Heat Tracing	No		Is the component heat traced? (Yes or No)

STEP 1

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

t = 0.236220472 inch   Installation date 23/07/2008
= 6.000 mm   RBI Date 29/10/2019
age = 11.26625599 years

STEP 2

Determining the base corrosion rate, CrB based on the driver and operating temperature using Table 15.2.

Table 15.2M - Corrosion Rates for Calculation of the Damage Factor-External Corrosion

Operating Temperature (oC)	Corrosion Rate as a Function of Driver (1) (mpy)			
	Marine / Cooling	Temperat	Arid / Dry	Severe
-12	0	0	0	0
-8	0.025	0	0	0
6	0.127	0.076	0.025	0.254
32	0.127	0.076	0.025	1.254
71	0.127	0.051	0.025	2.254
107	0.025	0	0	0.051
121	0	0	0	0

t = Operating temperature
= 30 ^{o}C
= 303 K
mpy 1 = 0.127 mm/y

Because the operating temperature is normally 30^{o}C, and there is no list of such that temperature. But, it does list values for 6^{o}C and 32^{o}C. Both of them have same value on marine condition.

So C_{rB} = 0.127

STEP 3 Calculate the final corrosion rate, Cr, using equation below.

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

F_{EQ} = Adjustment for equation design or fabrication

= 2

F_{IF} = Adjustment fo interface

= 1

$$C_r = C_{rB} \,.\max[(F_{EQ}, F_{IF})]$$
$$= 0{,}127 \,.\, \max\,[(2;1)]$$
$$= 0.25$$

But, the company has own their corrosion rate that given from the inspection that has been done for the tank before

C_r = 0.167

STEP 4 Determine the time in service, age_{tk}, since the last known inspection, t_{rde}. 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 $age_{tk} = age$

t_{rdi} = 0.2252 inch

= 5.72 mm

Last inspection is on: 23/07/2018

RBI Date is on: 29/10/2019

Planned Date is on: 28/06/2022

age_{tk} = 1.268 years.

Last inspection was held on July 2018

age_{PD} = 3.932 years.

Inspection is held every 4 years

STEP 5 Determine the time in-service, age_{coat}, since the coating has been installed using equation below.

$$age_{coat} = Calculation\ Date\ - Coating\ Installation\ Date$$

Calculation Date = 29/10/2019

Coating installation Date = 12/01/2008

$$age_{coat} = Calculation\ Date\ - Coating\ Installation\ Date$$

= 11.795 years

STEP 6 Determine coating adjustment, $coat_{adj}$ using one of below equations

If $Age_{tk} \geq Age_{coat}$

$Coat_{adj} = 0$	If No or Poor Coating Quality
$Coat_{adj} = \min[5, age_{coat}]$	If Medium Coating Quality
$Coat_{adj} = \min[15, age_{coat}]$	If High Coating Quality

If $\text{Age}_{tk} < \text{Age}_{coat}$

$Coat_{adj} = 0$ No / poor

$Coat_{adj} = \min[5, age_{coat}] - \min[5, age_{coat} - age_{tk}]$ Medium

$Coat_{adj} = \min[15, age_{coat}] - \min[15, age_{coat} - age_{tk}]$ High

Choose the calculation for Agetk less than the Agecoat in Medium Coating Level (painting only)

$Coat_{adj} = 0$

= 0.000

the result still 0 because the result of Agecoat and (Agecoat - Agetk) bigger than 5

STEP 7 Determine the in - service time, age, over which external corrosion may have occured uing equation below

$age = age_{tk} - Coat_{adj}$

= 1,268 - 0

= 1.268

STEP 8 Determine the allowable stress, S, weld joint efficiency, E, and minimum required thickness, t_{min}, per the original construction code or ASTM 283 or API

t_{min} = 0.1386 inch

= 3.52 mm

S = 19870 psig

= 136998881.2 Pa

= 136998.8812 Kpa

E = 0.85

STEP 9 Determine the A_{rt} Parameter

For component without clading/weld overlay then use the equation below.

<u>RBI DATE</u>

$$A_{rt} = \frac{Cr.agetk}{t_{rde}}$$

$$= \frac{0{,}167\ .\ 1{,}268}{6{,}96}$$

= 0.037009329 (For corrosion rate based on RLA Data)

PLAN DATE

$$A_{rt} = \frac{Cr.agepd}{t_{rde}}$$

$$= \frac{0{,}167\ .\ 3{,}932}{6{,}96}$$

$= \quad 0.114784873 \qquad$ (For corrosion rate based on RLA Data)

STEP 10 Calculate the Flow Stress, $FS^{extector}$, using E from STEP 5 and equation below.

$$FS^{extcorr} = \frac{(YS+TS)}{2}.\ \mathrm{E.1{,}1}$$

Where;

YS = 205000 kPa

TS = 380000 kPa

E = 0.85

$$FS^{extcorr} = \frac{(YS+TS)}{2}.\ \mathrm{E.1{,}1}$$

$$= \frac{(205000 + 380000)}{2}.\ (1)\ .1{,}1$$

$= 273487.5$

STEP 11 Calculate the strength ratio parameter, SR_P^{Thin} , using the appropriate equation.

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

Where ;

t_c = is the minimum structural thickness of the component base material

= 0.196850394 inch

= 5 mm

$$SR_P^{extcorr} = \frac{136998{,}881\ .\ 0{,}85}{273487{,}5}.\ \frac{Max\ (3{,}52;5\ )}{6{,}96}$$

$= \quad 0.372196633$

STEP 12 Determine the number of inspection , $N_A^{extcorr}, N_B^{extcorr}, N_C^{extcorr}, N_D^{extcorr}$, and the corresponding inspection effectiveness category using Section 15.6. 2 for past inspections performed during the in - service time.

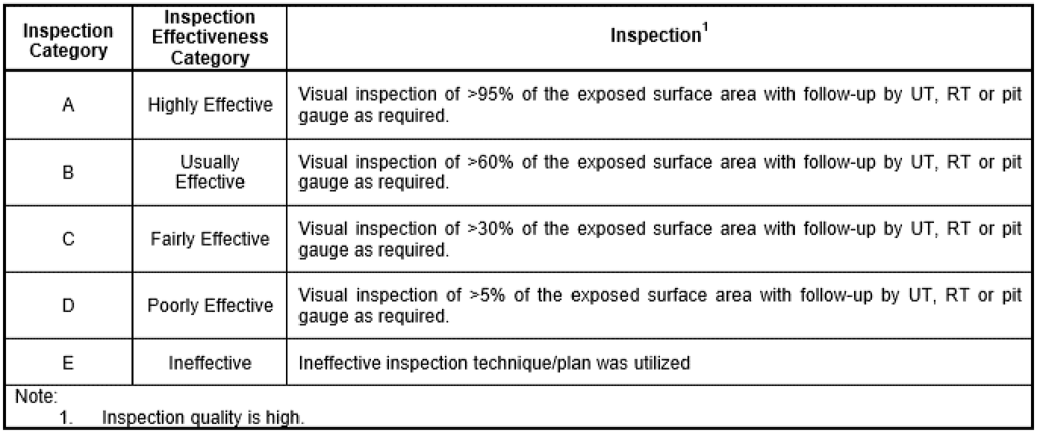
$N_A^{extcorr}$ = 0

$N_B^{extcorr}$ = 0

$N_C^{extcorr}$ = 0

$N_D^{extcorr}$ = 2

Table 2.C.10.1 - LoIE Example for External Damage



Inspection Category	Inspection Effectiveness Category	Inspection[1]
A	Highly Effective	Visual inspection of >95% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
B	Usually Effective	Visual inspection of >60% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
C	Fairly Effective	Visual inspection of >30% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
D	Poorly Effective	Visual inspection of >5% of the exposed surface area with follow-up by UT, RT or pit gauge as required.
E	Ineffective	Ineffective inspection technique/plan was utilized

Note:
1. Inspection quality is high.

STEP 13 Determine the inspection effectiveness factors, $I_1^{extcorr}, I_2^{extcorr}, I_3^{extcorr}$, using equation below, prior probabilities, $Pr_{p1}^{extcorr}, Pr_{p2}^{extcorr}, Pr_{p3}^{extcorr}$, from Table 4.5. Conditional Probabilities (for each inspection effectiveness level) $Co_{p1}^{extcorr}, Co_{p2}^{extcorr}, Co_{p3}^{extcorr}$ fromTable 4.6, and the number of inspection, $N_A^{extcorr}, N_B^{extcorr}, N_C^{extcorr}, N_D^{extcorr}$ in each effectiveness level from STEP 12.

$$I_1^{extcorr} = Pr_{P1}^{extcorr}\left(Co_{P1}^{extcorrA}\right)^{N_A^{extcorr}}\left(Co_{P1}^{extcorrB}\right)^{N_B^{extcorr}}\left(Co_{P1}^{extcorrC}\right)^{N_C^{extcorr}}\left(Co_{P1}^{extcorrD}\right)^{N_D^{extco}}$$

$$I_2^{extcorr} = Pr_{P2}^{extcorr}\left(Co_{P2}^{extcorrA}\right)^{N_A^{extcorr}}\left(Co_{P2}^{extcorrB}\right)^{N_B^{extcorr}}\left(Co_{P2}^{extcorrC}\right)^{N_C^{extcorr}}\left(Co_{P2}^{extcorrD}\right)^{N_D^{extco}}$$

$$I_3^{extcorr} = Pr_{P3}^{extcorr}\left(Co_{P3}^{extcorrA}\right)^{N_A^{extcorr}}\left(Co_{P3}^{extcorrB}\right)^{N_B^{extcorr}}\left(Co_{P3}^{extcorrC}\right)^{N_C^{extcorr}}\left(Co_{P3}^{extcorrD}\right)^{N_D^{extco}}$$

Table 4.5 - Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Conf. 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 4.6 - Conditional Probability for Inspection Effectiveness

Conditional P. 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

$$I_1^{extcorr} = Pr_{P1}^{extcorr}(Co_{P1}^{extcorrA})^{N_A^{extcorr}}(Co_{P1}^{extcorrB})^{N_B^{extcorr}}(Co_{P1}^{extcorrC})^{N_C^{extcorr}}(Co_{P1}^{extcorrD})^{N_D^{extco}}$$

$$= \quad 0.08000$$

$$I_2^{extcorr} = Pr_{P2}^{extcorr}(Co_{P2}^{extcorrA})^{N_A^{extcorr}}(Co_{P2}^{extcorrB})^{N_B^{extcorr}}(Co_{P2}^{extcorrC})^{N_C^{extcorr}}(Co_{P2}^{extcorrD})^{N_D^{extco}}$$

$$= \quad 0.03267$$

$$I_3^{extcorr} = Pr_{P3}^{extcorr}(Co_{P3}^{extcorrA})^{N_A^{extcorr}}(Co_{P3}^{extcorrB})^{N_B^{extcorr}}(Co_{P3}^{extcorrC})^{N_C^{extcorr}}(Co_{P3}^{extcorrD})^{N_D^{extco}}$$

$$= \quad 0.01458$$

STEP 14 Calculate the Posteroir Probability, $Po_{p1}^{extcorr}$, $Po_{p2}^{extcorr}$, $Po_{p3}^{extcorr}$ using equations

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

$$= \quad 0.62868369 \qquad\qquad 1.00000000$$

$$Po_{p2}^{extcorr} = \frac{I_2^{extcorr}}{I_1^{extcorr} + I_2^{extcorr} + I_3^{extcorr}}$$

$$= \quad 0.256738703$$

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

$$= \quad 0.114577603$$

STEP 15 Calculate the parameters, $ß_1$, $ß_2$, and $ß_3$ using equation below and also assigning $COV_{\Delta t} = 0.20$, $COV_{sf} = 0.20$, and $COV_P = 0.05$.

$$ß_1^{extcorr} = \frac{1-D_{S1}.A_{rt}-SR_P^{extcorr}}{\sqrt{D_{S1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{extcorr})^2.(COV_P)^2}}$$

$$ß_2^{extcorr} = \frac{1-D_{S2}.A_{rt}-SR_P^{extcorr}}{\sqrt{D_{S2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{extcorr})^2.(COV_P)^2}}$$

$$ß_3^{extcorr} = \frac{1-D_{S3}.A_{rt}-SR_P^{extcorr}}{\sqrt{D_{S3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{extcorr})^2.(COV_P)^2}}$$

Where;

$COV_{\Delta t}$ = The thinning coefficient of variance ranging from $0.1 \le COV_{\Delta t} \le 0.2$

= 0.2

COV_{sf} = The flow stress coefficient of variance

= 0.2

COV_P = Pressure coeffficient of variance

= 0.05

D_{s1} = Damage State 1

= 1

D_{s2} = Damage State 2
= 2

D_{s3} = Damage State 3
= 4

RBI DATE

BASED ON CORROSION RATE FROM RLA

ß$_1^{extcorr}$ = 3.0510

ß$_2^{extcorr}$ = 2.9659

ß$_3^{extcorr}$ = 2.7990

PLAN DATE

BASED ON CORROSION RATE FROM RLA

ß$_1^{extcorr}$ = 2.8582

ß$_2^{extcorr}$ = 2.4604

ß$_3^{extcorr}$ = 1.5366

STEP 16 Calculate $D_f^{extcorr}$ using equation below

RBI DATE

$$D_f^{extcor} = [\frac{\left(Po_{P1}^{extcorr}\Phi\left(-\beta_1^{extcorr}\right)\right)+\left(Po_{P2}^{extcorr}\Phi\left(-\beta_2^{extcorr}\right)\right)+\left(Po_{P3}^{extcorr}\Phi\left(-\beta_3^{extcorr}\right)\right)}{1.56E-0.4}$$

$D_f^{extcorr}$ = 1.078404 **BASED ON CORROSION RATE FROM RLA**

PLAN DATE

$$D_f^{extcor} = [\frac{\left(Po_{P1}^{extcorr}\Phi\left(-\beta_1^{extcorr}\right)\right)+\left(Po_{P2}^{extcorr}\Phi\left(-\beta_2^{extcorr}\right)\right)+\left(Po_{P3}^{extcorr}\Phi\left(-\beta_3^{extcorr}\right)\right)}{1.56E-0.4}$$

$D_f^{extcorr}$ = 1.068848 **BASED ON CORROSION RATE FROM RLA**

RBI DATE

Df total = 1.432552 BASED ON CORROSION RATE FROM RLA

PLAN DATE

Df total = 1.422995 BASED ON CORROSION RATE FROM RLA

PROBABILITY OF FAILURE

The probability of failure can be calculated using the equation of;

$$Pf\,(t) = gff \cdot Fms \cdot D\,f\,(t)$$

Where,

pf (t) = The PoF as a function of time

gff = General failure frequency

Fms = Management system factor

Df (t) = Total damage factor

DETERMINING DAMAGE FACTOR (Df)

In the case of multiple damage mechanisms, the combination of those damage mechanims is explained in section 3.4.2 API RP 581 Part 2 3rd Edition. Total DF, $D_{f\text{-total}}$ - If more than one damage mechanism is present, the following rules are used to combine the DFs. The total DF is given by Equation (2.2) when the external and/or thinning damage are classified as local and therefore, unlikely to occur at the same location.

$$D_{f-total} = max\left[D_{f-gov}^{thin}, D_{f-gov}^{extd}\right] + D_{f-gov}^{scc} + D_{f}^{htha} + D_{f-gov}^{brit} + D_{f}^{mfat}$$

If the external and thinning damage are general, then damage is likely to occur at the same location and the total DF is given by Equation (2.3).

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{scc} + D_{f}^{htha} + D_{f-gov}^{brit} + D_{f}^{mfat}$$

Note that the summation of DFs can be less than or equal to 1.0. This means that the component can have a POF less than the generic failure frequency.

Acccording to the observation and last inspection to Steam Scrubber equipment is categorized as local thinning and also it does not likely occur at the same location. So, we used equation correlated to local thinning.

RBI DATE:

Based on RLA Data

Shell 1 section:

$D_{f\text{-total}}$ = 1.4336580

Shell 2 section:

$D_{f\text{-total}}$ = 1.4338399

Shell 3 section:

$D_{f\text{-total}}$ = 1.4338449

Shell 4 section:

$D_{f\text{-total}}$ = 1.4325516

Bottom section:

$D_{f\text{-total}}$ = 0.10

Shell 5 section:

$D_{f\text{-total}}$ = 1.4327894

Shell 6 section:

$D_{f\text{-total}}$ = 1.4325516

PLANNED DATE:

Based on RLA Data

Shell 1 section:

$D_{f\text{-total}}$ = 1.432645

Head section:

$D_{f\text{-total}}$ = 0.10

Shell 2 section:

$D_{f\text{-total}}$ = 1.433468

Shell 5 section:

$D_{f\text{-total}}$ = 1.4256284

Shell 3 section:

$D_{f\text{-total}}$ = 1.4334868

Shell 6 section:

$D_{f\text{-total}}$ = 1.4229951

Shell 4 section:

$D_{f\text{-total}}$ = 1.4229951

DETERMINING GENERAL FAILURE FREQUENCY (gff)

To determine the value of gff, we can use the recommended list from table 3.1 of API RBI 581

Equipment Type	Component Type	gff as a function of hole size (failure/yr)			
		small	medium	Large	Rupture
Tank 650	Tank Bottom	7.20E-04	0.00E+00	0.00E+00	2.00E-06
Tank 650	Tank Shell	7.00E-05	2.50E-05	6.00E-06	1.00E-07

Equipment Type	Component Type	gff total (failure/year)
Tank 650	Tank Bottom	7.20E-04
Tank 650	Tank Shell	1.00E-04

gff bottom : 7.2E-04

gff shell : 1.00.E-04

DETERMINING MANAGEMENT SYSTEM FACTOR (fms)

To determine the value of Fms, we use a series of question and survey given by API RBI 581 to determine Fms value

For details of management system factor screening, stated in LAMPIRAN 4B: MANAGEMENT SYSTEM FACTOR

Management system factor score according from the survey, the score is

fms = 500

$$pscore = \frac{Score}{1000} . 100 \text{ [unit is 100\%]}$$

based from equation, the *pscore* is = 50 %

FMS assumption from API 581 | 500

To determine the value of Fms we can use the equation:

$$Fms = 10^{(-0.02 . pscore + 1)}$$

$$Fms = 10^{(-0.02 . 87,6 + 1)}$$

Fms = 1.0000

CALCULATING PROBABILITY OF FAILURE

Pf (t) = gff . Fms . D f (t)

RBI DATE:

Based on Corrosion Rate from RLA Data

Pf (t) = gff . Fms . D f (t)

Pf (t) = 1.43E-04 (Shell 1)

Pf (t) = gff . Fms . D f (t)

Pf (t) = 1.43E-04 (Shell 2)

Pf (t) = gff . Fms . D f (t)

Pf (t) = 1.43E-04 (Shell 3)

Pf (t) = gff . Fms . D f (t)

Pf (t) = 1.43E-04 (Shell 4)

Pf (t) = gff . Fms . D f (t)

Pf (t) = 7.20E-05 (Bottom)

Pf (t) = gff . Fms . D f (t)

Pf (t) = 1.43E-04 (Shell 5)

Pf (t) = gff . Fms . D f (t)

Pf (t) = 1.43E-04 (Shell 6)

PLANNED DATE:

Based on Corrosion Rate from RLA Data

Pf (t) = gff . Fms . D f (t)
Pf (t) = 1.43E-04 (Shell 1)

Pf (t) = gff . Fms . D f (t)
Pf (t) = 1.43E-04 (Shell 2)

Pf (t) = gff . Fms . D f (t)
Pf (t) = 1.43E-04 (Shell 3)

Pf (t) = gff . Fms . D f (t)
Pf (t) = 1.42E-04 (Shell 4)

Pf (t) = gff . Fms . D f (t)
Pf (t) = 1.00E-05 (Bottom)

Pf (t) = gff . Fms . D f (t)
Pf (t) = 1.43E-04 (Shell 5)

Pf (t) = gff . Fms . D f (t)
Pf (t) = 1.42E-04 (Shell 6)

INSPECTION PLANNING PROGRAM USING RISK BASED INSPECTION API 581 FOR ABOVEGROUND STORAGE TANKS IN PT. X. GRESIK

ATTACHMENT 7 :

CONSEQUENCES OF FAILURE (COF) CALCULATION OF ABOVEGROUND STORAGE TANK

Rev.	Tanggal	Keterangan	Disusun Oleh:		Disetujui Oleh:	
			Nama	Paraf	Pembimbing	Paraf
			Rafli Mahadika Ariapratama		Ir. Dwi Priyanta, M.SE	
			No. Registration :		Dr. Eng. M. Badrus Zaman, S.T. , M.T.	
			04211641000014			

Step 6.1 Calculation of Fluid Seepage Velocity for AST Bottom

Step 1.1

The equation that apllied for this tank was used the Level 1 so the fluid would be representative in Table 6.1

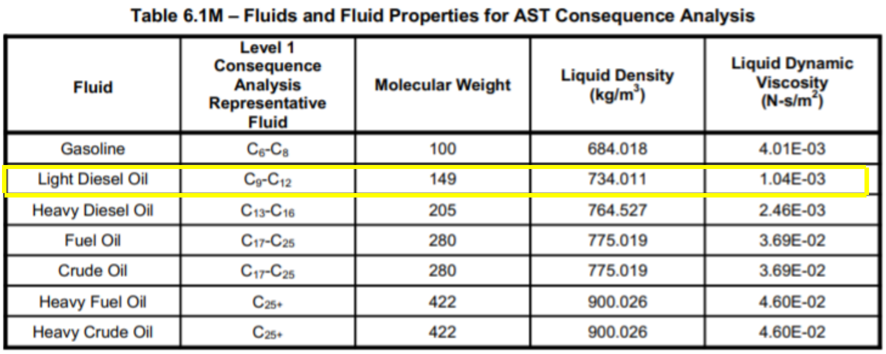


Table 6.1M – Fluids and Fluid Properties for AST Consequence Analysis

Fluid	Level 1 Consequence Analysis Representative Fluid	Molecular Weight	Liquid Density (kg/m^3)	Liquid Dynamic Viscosity (N-s/m^2)
Gasoline	C_6-C_8	100	684.018	4.01E-03
Light Diesel Oil	C_9-C_{12}	149	734.011	1.04E-03
Heavy Diesel Oil	C_{13}-C_{16}	205	764.527	2.46E-03
Fuel Oil	C_{17}-C_{25}	280	775.019	3.69E-02
Crude Oil	C_{17}-C_{25}	280	775.019	3.69E-02
Heavy Fuel Oil	C_{25+}	422	900.026	4.60E-02
Heavy Crude Oil	C_{25+}	422	900.026	4.60E-02

Step 1.2

From Table 6.1 the molecular weight, liquid density and dynamic viscosity can be determined

Molecular Weight	=	149	
Liquid Density	=	734.011	kg/m3
Liquid Dynamic Viscosity	=	0.00104	N-s/m2

Step 1.3

Calculate the hydraulic conductivity for water by averaging the upper and lower bound hydraulic conductivities provided in Table 6.2 for the soil type selected using

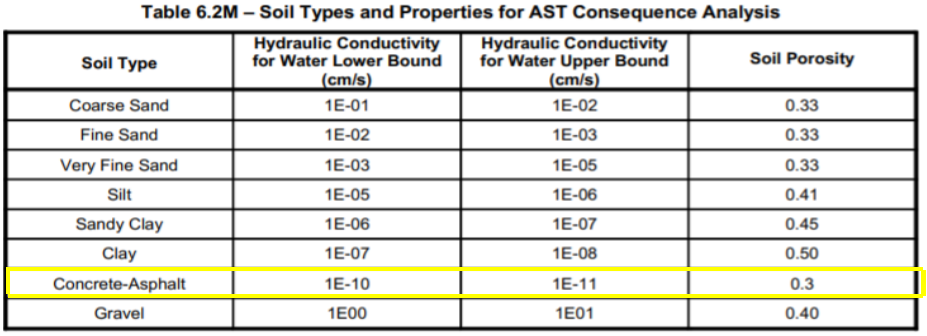


Table 6.2M – Soil Types and Properties for AST Consequence Analysis

Soil Type	Hydraulic Conductivity for Water Lower Bound (cm/s)	Hydraulic Conductivity for Water Upper Bound (cm/s)	Soil Porosity
Coarse Sand	1E-01	1E-02	0.33
Fine Sand	1E-02	1E-03	0.33
Very Fine Sand	1E-03	1E-05	0.33
Silt	1E-05	1E-06	0.41
Sandy Clay	1E-06	1E-07	0.45
Clay	1E-07	1E-08	0.50
Concrete-Asphalt	1E-10	1E-11	0.3
Gravel	1E00	1E01	0.40

$$k_{h,water} = C_{31}\left(\frac{k_{h,water-lb}+k_{h,water-ub}}{2}\right)$$

C_{31}	=	3.207	$\frac{\sec.m}{cm.day}$
$k_{h,water-lb}$	=	1E-10	cm/s
$k_{h,water-ub}$	=	1E-11	cm/s
$k_{h,water}$	=	1.76385E-10	m/day

Step 1.4

Calculate the hydraulic conductivity for fluid store inside the tank

$$k_{h,prod} = k_{h,water}(\frac{\rho_l}{\rho_w})(\frac{\pi_w}{\pi_l})$$

$k_{h,prod}$ = 9.93422E-11 m/day

Water Density = 1000 kg/m3

Water Dynamic Viscosity = 0.000798 N-s/m2

Step 1.5

Calculate the product seepage velocity for the fluid stored in AST

$$vel_{s,prod} = \left(\frac{k_{h,prod}}{P_s}\right)$$

$vel_{s,prod}$ = 3.31141E-10 m/day

Ps = 0.3

PART 2 : CALCULATION OF RELEASE HOLE SIZES

Step 2.1

Determine the release hole size, dn , from Table 6.3 for AST shell courses and from Table 6.4 for AST bottoms.

Table 6.3M - Release Hole Sizes and Areas - AST Sheel Courses

Release Hole Number	Release Hole Size	Range of Hole Diameter (mm)	Release Hole Diameter (mm)
1	small	0 - 3,175	d1 = 3,175
2	medium	> 3,175 - 6,35	d2 = 6,35
3	large	> 6,35 - 50,8	d3 = 50,8
4	rupture	> 50,8	d4 = 1000(Dtank/4)

Table 6.4M - Release Hole Sizes and Areas - AST Bottoms

Release Hole Number	Release Hole Size	Release Prevention Barrier	Range of Hole Diameter (mm)
1	small	Yes	0 - 3,175
		No	0 - 12,7
2	medium	NA	0
		NA	0
3	large	NA	0
		NA	0
4	rupture	Yes	> 3,715

Release Hole Number	Release Hole Diameter (mm)
1	d1 = 3,175
	d1 = 12,7
2	d2 = 0
3	d3 = 0
4	d4 = 1000(Dtank/4)

Step 2.2

Determine the generic failure frequency, gffn, for the nth release hole size and the total generic failure frequency from Part 2, Table 3.1

Equipment Type	**Component Type**	**gff as a function of hole size (failure/yr)**	
		small	**medium**
Tank 650	Tank Bottom	7.20E-04	0.00E+00
Tank 650	Tank Shell	7.00E-05	2.50E-05

Equipment Type	**Component Type**	**gff as a function of hole size (failure/yr)**	
		Large	**Rupture**
Tank 650	Tank Bottom	0.00E+00	2.00E-06
Tank 650	Tank Shell	6.00E-06	1.00E-07

Equipment Type	**Component Type**	**gff total (failure/year)**
Tank 650	Tank Bottom	7.20E-04
Tank 650	Tank Shell	1.00E-04

The total of generic failuure frequency (gff) can be taken from the table value or calculated using the equation below:

$$gff_{total} = \sum_{n=1}^{4} gffn$$

Because the total vallue of generic failure frequency has been availabled from the table. So, we can directly put the value from the table into the calculation.

Tank Bottom gff

gff_{total} = 0.00072 failures/year

gff_{small} = 0 failures/year

gff_{medium} = 0 failures/year

gff_{large} = 0.000002 failures/year

$gff_{rupture}$ = 0.00072 failures/year

Tank Shell gff

gff_{total} = 0.0001 failures/year

gff_{small} = 0.00007 failures/year

gff_{medium} = 0.00002 failures/year

gff_{large} = 0.000005 failures/year

$gff_{rupture}$ = 0.0000001 failures/year

SUMMARY of Step 2:

1 According to Annex 3.A Part 3 of API RP 581 committs that for pressure vessels, all of model of release hole size must be assumed.

2 The total generic failure frequency per years for every type of pressure vessel has been adjusted by the Table of 3.1 in Part 2 of API RP 581.

Tank Bottom gff

gff_{total} = 0.00072 failures/year

gff_{small} = 0 failures/year

gff_{medium} = 0 failures/year

gff_{large} = 0.000002 failures/year

$gff_{rupture}$ = 0.00072 failures/year

Tank Shell gff

gff_{total} = 0.0001 failures/year

gff_{small} = 0.00007 failures/year

gff_{medium} = 0.00002 failures/year

gff_{large} = 0.000005 failures/year

$gff_{rupture}$ = 0.0000001 failures/year

PART 3 : CALCULATION OF RELEASE RATE

Release rate calculations are provided for a leak in a AST shell course and a leak in the AST bottom plate. For the leak in the shell course, the liquid head of the product is assumed to be constant in time, and the leak is to atmospheric pressure. For the leak in the AST bottom, the liquid head is assumed to be constant in time, and the leak is into the ground that is modeled as a continuous porous media approximated by soil properties typically used for AST foundations

Calculation of Atmospheric Storage Tank Shell Course Release Rate

Step 3.1

For each release hole size, determine the height of the liquid, hliq , above the release hole size, dn

Equipment Type	Component Type	gff as a function of hole size (failure/yr)
		small
Tank 650	Tank Bottom	7.20E-04
Tank 650	Tank Shell	7.00E-05

Equipment Type	Component Type	gff as a function of hole size (failure/yr)
		medium
Tank 650	Tank Bottom	0.00E+00
Tank 650	Tank Shell	2.50E-05

Equipment Type	Component Type	gff as a function of hole size (failure/yr)
		large
Tank 650	Tank Bottom	0.00E+00
Tank 650	Tank Shell	6.00E-06

Equipment Type	Component Type	gff as a function of hole size (failure/yr)
		rupture
Tank 650	Tank Bottom	2.00E-06
Tank 650	Tank Shell	1.00E-07

Equipment Type	Component Type	gff total (failure/year)
Tank 650	Tank Bottom	7.20E-04
Tank 650	Tank Shell	1.00E-04

Release Hole Number	Release Hole Size	Range of Hole Diameter (mm)
1	small	0 - 3,175
2	medium	> 3,175 - 6,35
3	large	> 6,35 - 50,8
4	rupture	> 50,8

Release Hole Number	Release Hole Diameter (mm)
1	d1 = 3,175
2	d2 = 6,35
3	d3 = 50,8
4	d4 = 1000(Dtank/4)

h_{liq} = 10.5 m

= 10500 mm

Height of liquid above the release hole size

h_{liq} small = 10496.825 mm

= 10.496825 m

h_{liq} medium = 10493.65 mm

= 10.49365 m

h_{liq} large = 10449.2 mm

= 10.4492 m

h_{liq} rupture = 7125 mm

= 7.125 m

Step 3.2

The release hole size area can be determined by formulating below equation:

$$An = \frac{\pi dn^2}{4}$$

1). SMALL RELEASE HOLE SIZE AREA

d_1 = 3.175 mm

= 0.003175 m

π = 3.14

$$A1 = \frac{\pi d1^2}{4} = \frac{3.14\ x\ (3{,}175)^2}{4}$$

= 7.913290625 mm^2

= 0.00000791 m^2

2). MEDIUM RELEASE HOLE SIZE AREA

d_2 = 6.35 mm

= 0.00635 m

π = 3.14

$$A2 = \frac{\pi d2^2}{4} = \frac{3.14\ x\ (6{,}35)^2}{4}$$

= 31.6531625 mm^2

= 3.16532E-05 m^2

3). LARGE RELEASE HOLE SIZE AREA

d_3 = 50.8 mm

= 0.0508 m

π = 3.14

$$A3 = \frac{\pi d3^2}{4} = \frac{3.14\ x\ (50{,}8)^2}{4}$$

= 2025.8024 mm^2

= 0.002025802 m^2

4). RUPTURE RELEASE HOLE SIZE AREA

d_4 = 3375 mm

= 3.375 m

π = 3.14

$$A4 = \frac{\pi d4^2}{4} \qquad = \frac{3.14\, x\, (3375)^2}{4}$$

= 8941640.625 mm^2

= 8.941640625 m^2

Step 3.3 Determine the liquid height above theshell course where hliq is the maximum fill height in the tank and CHT is the height of each shell course

$$L\,H\,T_{above,i} = [\, h_{liq} - (\, i - 1\,)\, C\,H\,T\,]$$

h_{liq} = 10500 mm

10.5 m

C H T (1-5) = 1828 mm

1.828 m

C H T (6) = 1540 mm

1.54 m

$$L\,H\,T_{above,i} = [\, h_{liq} - (\, i - 1\,)\, C\,H\,T\,]$$

Shell 1 $L\,H\,T_{above,1}$ = 10500 mm

= 10.5 m

Shell 2 $L\,H\,T_{above,2}$ = 8672 mm

= 8.672 m

Shell 3 $L\,H\,T_{above,3}$ = 6844 mm

= 6.844 m

Shell 4 $L\,H\,T_{above,4}$ = 5016 mm

= 5.016 m

Shell 5 $L\,H\,T_{above,5}$ = 3188 mm

= 3.188 m

Shell 6 $L\,H\,T_{above,6}$ = 2800 mm

= 2.8 m

Step 3.4

For each release hole size, determine the flow rate

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

g = 9.81 m/s2

Cd = 0.61

C32 = 0.543 sec . Bbl / day . Mm2 . M

Shell 1

1). SMALL RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 37.6210517 bbl/day

2). MEDIUM RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 150.4842066 bbl/day

3). LARGE RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 9630.989225 bbl/day

4). RUPTURE RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 42509992.34 bbl/day

Shell 2

1). SMALL RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 34.1897493 bbl/day

2). MEDIUM RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 136.7589973 bbl/day

3). LARGE RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 8752.575829 bbl/day

4). RUPTURE RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 38632784.52 bbl/day

Shell 3

1). SMALL RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 30.3732512 bbl/day

2). MEDIUM RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 121.4930050 bbl/day

3). LARGE RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 7775.552318 bbl/day

4). RUPTURE RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 34320323.88 bbl/day

Shell 4

1). SMALL RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 26.0024965 bbl/day

2). MEDIUM RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 104.0099859 bbl/day

3). **LARGE RELEASE HOLE SIZE AREA**

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 6656.639095 bbl/day

4). **RUPTURE RELEASE HOLE SIZE AREA**

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 29381579.65 bbl/day

Shell 5

1). **SMALL RELEASE HOLE SIZE AREA**

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 20.7298156 bbl/day

2). **MEDIUM RELEASE HOLE SIZE AREA**

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 82.9192623 bbl/day

3). **LARGE RELEASE HOLE SIZE AREA**

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 5306.832789 bbl/day

4). RUPTURE RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 23423701.96 bbl/day

Shell 6

1). SMALL RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 19.4274275 bbl/day

2). MEDIUM RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 77.7097102 bbl/day

3). LARGE RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 4973.42145 bbl/day

4). RUPTURE RELEASE HOLE SIZE AREA

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

$$W_n = C_{32}\ x\ Cd\ x\ An\sqrt{2\ x\ g\ x\ LHT_{above,i}}$$

= 21952065.65 bbl/day

Calculation of Atmospheric Storage Tank Bottom Course Release Rate

Step 3.1 For each release hole size, determine the number of release holes from Table 6.5

AST Diameter (m(ft))	Number of Release Holes With or Without a Release Prevention Barrier		
	Small	Medium	Large
30,5 (100)	1	0	0
61 (200)	4	0	0
91,4 (300)	9	0	0

Step 3.2 Determine the hydraulic conductivity of the stored liquid from STEP 1.4

$k_{h,prod}$ = 9.93422E-11

Step 3.3 For each release hole size, determine the flow rate using equation 3.210 or 3.211 as applicable. The liquid height to use in calculation is determined as follows

The AST has an RPB = 0.0762 m

The AST doesn't have an RPB = Actual Product Height

$$C_{37} = 1.408\text{E-08} \quad \frac{m^{1,4}}{day\,.mm^{1,8}}$$

d_n (mm)	$\frac{dn^{1,8}}{C_{qo}\ x\ h_{liq}^{0,4}}$	$\left(\frac{dn^{1,8}}{C_{qo}\ x\ h_{liq}^{0,4}}\right)^{1/0,74}$	$C_{37}\ x\ \left(\frac{dn^{1,8}}{C_{qo}\ x\ h_{liq}^{0,4}}\right)^{1/0,74}$
3.175	106.6934	550.4606224	7.75049E-06
6.35	371.5279	2971.401795	4.18373E-05
50.8	15687.49	467376.3743	0.006580659
3375	29915173	12663568450	178.3030438

From this we can assume that

$$k_{h,prod} \leq C_{37} \cdot \left[\frac{d_n^{1.8}}{C_{qo} \cdot h_{liq}^{0.4}}\right]^{\frac{1}{0.74}}$$

So, the formula that we can use to determine the flow rate is :

$$W_n = C_{35}\ x\ C_{qo}\ x\ d_n^{0,2}\ \mathrm{x}\ h_{liq}^{0,9}\ x\ k_{h,prod}^{0,74}\ x\ n_{rh,n}$$

C_{35} = 29.6195

C_{qo} = 0.21

1). SMALL RELEASE HOLE SIZE AREA

$$W_n = C_{35}\ x\ C_{qo}\ x\ d_n^{0,2}\ \mathrm{x}\ h_{liq}^{0,9}\ x\ k_{h,prod}^{0,74}\ x\ n_{rh,n}$$

$$W_n = C_{35}\ x\ C_{qo}\ x\ d_n^{0,2}\ \mathrm{x}\ h_{liq}^{0,9}\ x\ k_{h,prod}^{0,74}\ x\ n_{rh,n}$$

= 3.0604425228345E-08 kg/s

2). MEDIUM RELEASE HOLE SIZE AREA

$$W_n = C_{35}\ x\ C_{qo}\ x\ d_n^{0,2}\ \mathrm{x}\ h_{liq}^{0,9}\ x\ k_{h,prod}^{0,74}\ x\ n_{rh,n}$$

$$W_n = C_{35}\ x\ C_{qo}\ x\ d_n^{0,2}\ \mathrm{x}\ h_{liq}^{0,9}\ x\ k_{h,prod}^{0,74}\ x\ n_{rh,n}$$

= 0 kg/s

3). LARGE RELEASE HOLE SIZE AREA

$$W_n = C_{35}\ x\ C_{qo}\ x\ d_n^{0,2}\ \mathrm{x}\ h_{liq}^{0,9}\ x\ k_{h,prod}^{0,74}\ x\ n_{rh,n}$$

$$W_n = C_{35}\ x\ C_{qo}\ x\ d_n^{0,2}\ \mathrm{x}\ h_{liq}^{0,9}\ x\ k_{h,prod}^{0,74}\ x\ n_{rh,n}$$

= 0 kg/s

PART 4 : CALCULATION OF ESTIMATION INVENTORY VOLUME AND MASS AVAILABLE FOR RELEASE

The amount of inventory in the AST available for release depends on the component being evaluated. For AST bottoms, the available inventory is the entire contents of the AST. For the AST shell courses, the available inventory is a function of the location of the release hole and is calculated as the volume of fluid above the release hole.

Calculation of Atmospheric Storage Tank Shell Course Inventory Mass

Step 4.1 Determine the liquid height above the shell course where, hliq , is the maximum fill height in the tank and CHT is the height of each shell course

$$LHT_{above,i} = [h_{liq} - (i-1)CHT]$$

h_{liq} = 10500 mm

10.5 m

C H T (1-5) = 1828 mm

1.828 m

C H T (6) = 1540 mm

1.54 m

$$LHT_{above,i} = [h_{liq} - (i-1)CHT]$$

Shell 1	$LHT_{above,i}$	=	10500	mm
		=	10.5	m
Shell 2	$LHT_{above,i}$	=	8672	mm
		=	8.672	m
Shell 3	$LHT_{above,i}$	=	6844	mm
		=	6.844	m
Shell 4	$LHT_{above,i}$	=	5016	mm
		=	5.016	m
Shell 5	$LHT_{above,i}$	=	3188	mm
		=	3.188	m
Shell 6	$LHT_{above,i}$	=	2800	mm
		=	2.8	m

Step 4.2

Determine the volume above the course

$$Lvol_{above,i} = \left(\frac{\pi D_{tank}^2}{4}\right) x\ LHT_{above,i}$$

π = 3.14

D_{tank} = 13.5 m

Shell 1 $Lvol_{above,1}$ = 1502.196 m^3

Shell 2 $Lvol_{above,2}$ = 1240.671 m^3

Shell 3 $Lvol_{above,3}$ = 979.1454 m^3

Shell 4 $Lvol_{above,4}$ = 717.6203 m^3

Shell 5 $Lvol_{above,5}$ = 456.0952 m^3

Shell 6 $Lvol_{above,6}$ = 400.5855 m^3

For others release hole size on each shell, the value of available release volume is same like as the small size of release hole available release volume

Step 4.3

For each release hole size, determine the location of the hole on the AST shell. Based on this location, determine the available volume of the release. Note that the release hole should be assumed to be at the bottom of the course.

$$Lvol_{avail,n} = Lvol_{above,i}$$

Shell 1 $Lvol_{avail,1} = Lvol_{above,1}$ = 1502.196 m^3

Shell 2 $Lvol_{avail,2} = Lvol_{above,2}$ = 1240.671 m^3

Shell 3 $Lvol_{avail,3} = Lvol_{above,3}$ = 979.1454 m^3

Shell 4 $Lvol_{avail,4} = Lvol_{above,4}$ = 717.6203 m^3

Shell 5 $Lvol_{avail,5} = Lvol_{above,5}$ = 456.0952 m^3

Shell 6 $Lvol_{avail,6} = Lvol_{above,6}$ = 400.5855 m^3

For others release hole size on each shell, the valuie of available release volume is same like as the small size of release hole available release volume

Step 4.4

Calculation of AST Volume in Barrels

$$BBl_{avail,n} = Lvol_{avail,n\,x}\ C_{13}$$

C_{13} = 6.29 $\frac{bbl}{m^3}$

$BBl_{avail,1} = Lvol_{avail,1\,x}\ C_{13}$

= 9448.81 bbl

$BBl_{avail,2} = Lvol_{avail,2\,x}\ C_{13}$

= 7803.818 bbl

$BBl_{avail,3} = Lvol_{avail,3\,x}\ C_{13}$

= 6158.825 bbl

$BBl_{avail,4} = Lvol_{avail,4\,x}\ C_{13}$

= 4513.832 bbl

$BBl_{avail,5} = Lvol_{avail,5\,x}\ C_{13}$

= 2868.839 bbl

$BBl_{avail,6} = Lvol_{avail,6\,x}\ C_{13}$

= 2519.683 bbl

Step 4.4

Calculation of AST Mass using Liquid Density from Table 6.1

$$Mass_{avail,n} = Lvol_{avail,n} \times \rho_l$$

ρ = 734.011 kg/m3

$$Mass_{avail,1} = Lvol_{avail,1} \times \rho_l$$

= 1102628 kg

$$Mass_{avail,2} = Lvol_{avail,2} \times \rho_l$$

= 910665.8 kg

$$Mass_{avail,3} = Lvol_{avail,3} \times \rho_l$$

= 718703.5 kg

$$Mass_{avail,4} = Lvol_{avail,4} \times \rho_l$$

= 526741.2 kg

$$Mass_{avail,5} = Lvol_{avail,5} \times \rho_l$$

= 334778.9 kg

$$Mass_{avail,6} = Lvol_{avail,6} \times \rho_l$$

= 294034.2 kg

Calculation of Atmospheric Storage Tank Bottom Inventory Mass

Step 4.1

Determine the volume inside the AST

$$Lvol_{total} = \left(\frac{\pi D_{tank}^2}{4}\right) x\ h_{liq}$$

π = 3.14

D_{tank} = 13.5 m

h_{liq} = 0.0762 m

$$Lvol_{total} = \left(\frac{\pi D_{tank}^2}{4}\right) x\ h_{liq}$$

$Lvol_{total}$ = 10.90165 m^3

Step 4.2

Calculation of AST Volume in Barrels

$$BBl_{total} = Lvol_{total\ x}\ C_{13}$$

C_{13} = 6.29 $\frac{bbl}{m^3}$

$BBl_{total} = Lvol_{total\ x}\ C_{13}$

= 68.57137 bbl

Step 4.3

Calculation of AST Mass using Liquid Density from Table 6.1

$$Mass_{total} = Lvol_{total\ x}\, \rho_l$$

ρ = 734.011 kg/m3

$Mass_{total} = Lvol_{total\ x}\, \rho_l$

= 8001.93 kg

PART 5 : DETERMINE THE TYPE OF RELEASE

The type of release for the AST Shell and the AST bottom is assumed to be continous release

PART 6 : DETERMINE THE IMPACT OF DETECTION AND ISOLATION SYSTEM ON RELEASE MAGNITUDE

Detection and isolation systems are not accounted for in the AST consequences analysis

Calculation of Atmospheric Storage Tank Bottom Release Volume

Step 7.1

For each release hole size, determine the release rate in bbls/day when the release rate is from STEP 3.3

$$Rate_n = W_n$$

Bottom

W_1 = 3.06044E-08 bbl/day
W_2 = 0 bbl/day
W_3 = 0 bbl/day

$$Rate_n = W_n$$

0.0013

$Rate_1$ = 3.06044E-08 bbl/day
$Rate_2$ = 0 bbl/day
$Rate_3$ = 0 bbl/day

$Rate_1$ = 3.97858E-11 kg/s
$Rate_2$ = 0 kg/s
$Rate_3$ = 0 kg/s

Step 7.2

Determination of leak detection time

t_{ld} = 7 days for a AST on a concrete or asphalt

t_{ld} = 30 days for a AST with RPB
t_{ld} = 30 days for a AST without RPB

Because of the AST located with concrete foundation so the leak detection time is 7 days.

Step 7.3

Determination of leak duration for each release hole sizes

$$ld_n = \min[\left(\frac{Bbl_{total}}{rate_n}\right), t_{Id}]$$

Small ld_n = 0.007119868 days
Medium ld_n = 0 days
Large ld_n = 0 days

Step 7.4

Determination of leakage volume for each release hole size

$$Bbl_n^{leak} = \min[(rate_n \; x \; Id_n), Bbl_{total}]$$

Bottom

Bbl_1^{leak} = 2.17899E-10 Barrels
Bbl_2^{leak} = 0 Barrels
Bbl_3^{leak} = 0 Barrels

$volume_1^{leak}$ = 3.46422E-11 m3
$volume_2^{leak}$ = 0 m3
$volume_3^{leak}$ = 0 m3

Step 7.5

Determination of rupture mass

$$Bbl_n^{rupture} = Bbl_{total}$$

Bottom

$Bbl_1^{rupture}$ = 68.57136749 barrels
$Bbl_2^{rupture}$ = 68.57136749 barrels
$BBl_3^{rupture}$ = 68.57136749 barrels

$volume_1^{leak}$ = 10.90164825 m3
$volume_2^{leak}$ = 10.90164825 m3
$volume_3^{leak}$ = 10.90164825 m3

ρ = 734.011 kg/m3

$mass_1^{leak}$ = 8001.929734 kg
$mass_2^{leak}$ = 8001.929734 kg
$mass_3^{leak}$ = 8001.929734 kg

PART 7 : DETERMINE THE RELEASE RATE & VOLUME FOR THE CONSEQUENCES OF FAILURE ANALYSIS

The release for the AST Shell and bottom assumed as continous. The release rate and volume neccesary for the COF are determined using a similar approach as level 2 consequences analysis with differences outlined in the procedure.

Calculation of Atmospheric Storage Tank Shell Course Release Volume

Step 7.1 For each release hole size, determine the release rate in bbls/day when the release rate is from STEP 3.3

$$Rate_n = W_n$$

Shell 1				
small	W_1	=	37.621052	bbl/day
medium	W_2	=	150.48421	bbl/day
large	W_3	=	9630.9892	bbl/day
rupture	W_4	=	42509992	bbl/day

$$Rate_n = W_n$$

0.0013

small	$Rate_1$	=	37.621052	bbl/day
medium	$Rate_2$	=	150.48421	bbl/day
large	$Rate_3$	=	9630.9892	bbl/day
rupture	$Rate_4$	=	42509992	bbl/day

small	$Rate_1$	=	0.0489074	kg/s
medium	$Rate_2$	=	0.1956295	kg/s
large	$Rate_3$	=	12.520286	kg/s
rupture	$Rate_4$	=	55262.99	kg/s

Step 7.2

Determination of leak detection time

t_{ld} = 7 days for $d_n \leq$ 3,17mm

t_{ld} = 1 days for $d_n >$ 3,17mm

Release Hole Diameter, d_n (mm)
d_1 = 3,175
d_2 = 6,35
d_3 = 50,8
d_4 = 1000[Dtank/4]

Dtank = 13.5 m

small	d1	=	3.175	mm
medium	d2	=	6.35	mm
large	d3	=	50.8	mm
rupture	d4	=	3375	mm

Release Hole Diameter, d_n	mm	t_{ld} (day)
d1	3.175	7
d2	6.35	1
d3	50.8	1
d4	3375	1

Step 7.3

Determination of leak duration for each release hole sizes

$$ld_n = \min[\left(\frac{Bbl_{avail,n}}{rate_n}\right), 7\ days\ ]$$

$$ld_1 = \min[\left(\frac{9448{,}81}{37{,}62105}\right), 7\ days\ ]$$ = 7 days

$$ld_2 = \min[\left(\frac{9448{,}81}{150{,}4842}\right), 7\ days\ ]$$ = 7 days

$$ld_3 = \min[\left(\frac{9448{,}81}{9630{,}989}\right), 7\ days\ ]$$ = 0.9810841 days

$$ld_4 = \min[\left(\frac{9448{,}81}{42509992}\right), 7\ days\ ]$$ = 0.0002223 days

Step 7.4

Determination of leakage volume for each release hole size

$$Bbl_n^{leak} = \min[\,(rate_n \; x \; Id_n), Bbl_{avail,n}]$$

Shell 1

Bbl_1^{leak}	=	263.34736	Barrels
Bbl_2^{leak}	=	1053.3894	Barrels
Bbl_3^{leak}	=	9448.8105	Barrels
Bbl_4^{leak}	=	9448.8105	Barrels

Step 7.5

Determination of leakage mass for each release hole size

$$mass_n^{leak} = Bbl_n^{leak}$$

Shell 1

$mass_1^{leak}$	=	263.34736	Barrels
$mass_2^{leak}$	=	1053.3894	Barrels
$mass_3^{leak}$	=	9448.8105	Barrels
$mass_4^{leak}$	=	9448.8105	Barrels
$volume_1^{leak}$	=	41.867625	m3
$volume_2^{leak}$	=	167.4705	m3
$volume_3^{leak}$	=	1502.1956	m3
$volume_4^{leak}$	=	1502.1956	m3
ρ	=	734.011	kg/m3
$mass_1^{leak}$	=	30731.297	kg
$mass_2^{leak}$	=	122925.19	kg
$mass_3^{leak}$	=	1102628.1	kg
$mass_4^{leak}$	=	1102628.1	kg

Step 7.6

Determination of rupture volume

$$Bbl_n^{rupture} = Bbl_{avail,n}$$

Shell 1

$Bbl_1^{rupture}$ = 9448.8105 barrels

$Bbl_2^{rupture}$ = 9448.8105 barrels

$Bbl_3^{rupture}$ = 9448.8105 barrels

$Bbl_4^{rupture}$ = 9448.8105 barrels

Step 7.7

Determination of rupture mass

$$mass_n^{rupture} = Bbl_n^{rupture}$$

Shell 1

$mass_1^{rupture}$ = 9448.8105

$mass_2^{rupture}$ = 9448.8105

$mass_3^{rupture}$ = 9448.8105

$mass_4^{rupture}$ = 9448.8105

$volume_1^{leak}$ = 1502.1956 m3

$volume_2^{leak}$ = 1502.1956 m3

$volume_3^{leak}$ = 1502.1956 m3

$volume_4^{leak}$ = 1502.1956 m3

ρ = 734.011 kg/m3

$mass_1^{leak}$ = 1102628.1 kg

$mass_2^{leak}$ = 1102628.1 kg

$mass_3^{leak}$ = 1102628.1 kg

$mass_4^{leak}$ = 1102628.1 kg

PART 7 : DETERMINE THE RELEASE RATE & VOLUME FOR THE CONSEQUENCES OF FAILURE ANALYSIS

The release for the AST Shell and bottom assumed as continous. The release rate and volume neccesary for the COF are determined using a similar approach as level 2 consequences analysis with differences outlined in the procedure.

Calculation of Atmospheric Storage Tank Shell Course Release Volume

Step 7.1

For each release hole size, determine the release rate in bbls/day when the release rate is from STEP 3.3

$$Rate_n = W_n$$

Shell 2

small	W_1	=	34.189749	bbl/day
medium	W_2	=	136.759	bbl/day
large	W_3	=	8752.5758	bbl/day
rupture	W_4	=	38632785	bbl/day

$$Rate_n = W_n$$

0.0013

small	$Rate_1$	=	34.189749	bbl/day
medium	$Rate_2$	=	136.759	bbl/day
large	$Rate_3$	=	8752.5758	bbl/day
rupture	$Rate_4$	=	38632785	bbl/day

small	$Rate_1$	=	0.0444467	kg/s
medium	$Rate_2$	=	0.1777867	kg/s
large	$Rate_3$	=	11.378349	kg/s
rupture	$Rate_4$	=	50222.62	kg/s

Step 7.2

Determination of leak detection time

t_{ld}	=	7	days	for	$d_n \leq$ 3,17mm
t_{ld}	=	1	days	for	$d_n >$ 3,17mm

Release Hole Diameter, d_n (mm)
d_1 = 3,175
d_2 = 6,35
d_3 = 50,8
d_4 = 1000[Dtank/4]

Dtank = 13.5 m

small d1 = 3.175 mm
medium d2 = 6.35 mm
large d3 = 50.8 mm
rupture d4 = 3375 mm

Release Hole Diameter, d_n	**mm**	t_{ld} **(day)**
d1	3.175	7
d2	6.35	1
d3	50.8	1
d4	3375	1

Step 7.3

Determination of leak duration for each release hole sizes

$$ld_n = \min[\left(\frac{Bbl_{avail,n}}{rate_n}\right), 7\ days\ ]$$

$$ld_1 = \min[\left(\frac{7803{,}818}{34{,}18975}\right), 7\ days\ ]$$ = 7 days

$$ld_2 = \min[\left(\frac{7803{,}818}{136{,}759}\right), 7\ days\ ]$$ = 7 days

$$ld_3 = \min[\left(\frac{7803{,}818}{8752{,}576}\right), 7\ days\ ]$$ = 0.8916024 days

$$ld_4 = \min[\left(\frac{7803{,}818}{38632785}\right), 7\ days\ ]$$ = 0.000202 days

Step 7.4

Determination of leakage volume for each release hole size

$$Bbl_n^{leak} = \min[\,(rate_n\ x\ Id_n), Bbl_{avail,n}]$$

Shell 2

Bbl_1^{leak} = 239.32825 Barrels
Bbl_2^{leak} = 957.31298 Barrels
Bbl_3^{leak} = 7803.8176 Barrels
Bbl_4^{leak} = 7803.8176 Barrels

Step 7.5

Determination of leakage mass for each release hole size

$$mass_n^{leak} = Bbl_n^{leak}$$

Shell 2

$mass_1^{leak}$ = 239.32825 Barrels
$mass_2^{leak}$ = 957.31298 Barrels
$mass_3^{leak}$ = 7803.8176 Barrels
$mass_4^{leak}$ = 7803.8176 Barrels

$volume_1^{leak}$ = 38.049006 m3
$volume_2^{leak}$ = 152.19602 m3
$volume_3^{leak}$ = 1240.6705 m3
$volume_4^{leak}$ = 1240.6705 m3

ρ = 734.011 kg/m3

$mass_1^{leak}$ = 27928.389 kg
$mass_2^{leak}$ = 111713.55 kg
$mass_3^{leak}$ = 910665.81 kg
$mass_4^{leak}$ = 910665.81 kg

Step 7.6

Determination of rupture volume

$$Bbl_n^{rupture} = Bbl_{avail,n}$$

Shell 2

$Bbl_1^{rupture}$ = 7803.8176 barrels
$Bbl_2^{rupture}$ = 7803.8176 barrels
$Bbl_3^{rupture}$ = 7803.8176 barrels
$Bbl_4^{rupture}$ = 7803.8176 barrels

Step 7.7

Determination of rupture mass

$$mass_n^{rupture} = Bbl_n^{rupture}$$

Shell 2

$mass_1^{rupture}$ = 7803.8176
$mass_2^{rupture}$ = 7803.8176
$mass_3^{rupture}$ = 7803.8176
$mass_4^{rupture}$ = 7803.8176

$volume_1^{leak}$ = 1240.6705 m3
$volume_2^{leak}$ = 1240.6705 m3
$volume_3^{leak}$ = 1240.6705 m3
$volume_4^{leak}$ = 1240.6705 m3

ρ = 734.011 kg/m3

$mass_1^{leak}$ = 910665.81 kg
$mass_2^{leak}$ = 910665.81 kg
$mass_3^{leak}$ = 910665.81 kg
$mass_4^{leak}$ = 910665.81 kg

PART 7 : DETERMINE THE RELEASE RATE & VOLUME FOR THE CONSEQUENCES OF FAILURE ANALYSIS

The release for the AST Shell and bottom assumed as continous. The release rate and volume neccesary for the COF are determined using a similar approach as level 2 consequences analysis with differences outlined in the procedure.

Calculation of Atmospheric Storage Tank Shell Course Release Volume

Step 7.1

For each release hole size, determine the release rate in bbls/day when the release rate is from STEP 3.3

$$Rate_n = W_n$$

Shell 3

small W_1 = 30.373251 bbl/day

medium W_2 = 121.493 bbl/day

large W_3 = 7775.5523 bbl/day

rupture W_4 = 34320324 bbl/day

$$Rate_n = W_n$$

0.0013

small $Rate_1$ = 30.373251 bbl/day

medium $Rate_2$ = 121.493 bbl/day

large $Rate_3$ = 7775.5523 bbl/day

rupture $Rate_4$ = 34320324 bbl/day

small $Rate_1$ = 0.0394852 kg/s

medium $Rate_2$ = 0.1579409 kg/s

large $Rate_3$ = 10.108218 kg/s

rupture $Rate_4$ = 44616.421 kg/s

Step 7.2

Determination of leak detection time

t_{ld} = 7 days for $d_n \leq$ 3,17mm

t_{ld} = 1 days for $d_n >$ 3,17mm

Release Hole Diameter, d_n (mm)
d_1 = 3,175
d_2 = 6,35
d_3 = 50,8
d_4 = 1000[Dtank/4]

Dtank = 13.5 m

small d1 = 3.175 mm
medium d2 = 6.35 mm
large d3 = 50.8 mm
rupture d4 = 3375 mm

Release Hole Diameter, d_n	**mm**	**t_{ld} (day)**
d1	3.175	7
d2	6.35	1
d3	50.8	1
d4	3375	1

Step 7.3

Determination of leak duration for each release hole sizes

$$ld_n = \min[\left(\frac{Bbl_{avail,n}}{rate_n}\right), 7\ days\ ]$$

$ld_1 = \min[\left(\frac{6158{,}825}{30{,}37325}\right), 7\ days\ ]$ = 7 days

$ld_2 = \min[\left(\frac{6158{,}825}{121{,}493}\right), 7\ days\ ]$ = 7 days

$ld_3 = \min[\left(\frac{6158{,}825}{7775{,}552}\right), 7\ days\ ]$ = 0.7920755 days

$ld_4 = \min[\left(\frac{6158{,}825}{34320324}\right), 7\ days\ ]$ = 0.0001795 days

Step 7.4

Determination of leakage volume for each release hole size

$$Bbl_n^{leak} = \min[\,(rate_n\ x\ Id_n), Bbl_{avail,n}]$$

Shell 3

Bbl_1^{leak} = 212.61276 Barrels
Bbl_2^{leak} = 850.45103 Barrels
Bbl_3^{leak} = 6158.8247 Barrels
Bbl_4^{leak} = 6158.8247 Barrels

Step 7.5

Determination of leakage mass for each release hole size

$$mass_n^{leak} = Bbl_n^{leak}$$

Shell 3

$mass_1^{leak}$ = 212.61276 Barrels
$mass_2^{leak}$ = 850.45103 Barrels
$mass_3^{leak}$ = 6158.8247 Barrels
$mass_4^{leak}$ = 6158.8247 Barrels

$volume_1^{leak}$ = 33.80171 m3
$volume_2^{leak}$ = 135.20684 m3
$volume_3^{leak}$ = 979.14542 m3
$volume_4^{leak}$ = 979.14542 m3

ρ = 734.011 kg/m3

$mass_1^{leak}$ = 24810.827 kg
$mass_2^{leak}$ = 99243.309 kg
$mass_3^{leak}$ = 718703.51 kg
$mass_4^{leak}$ = 718703.51 kg

Step 7.6

Determination of rupture volume

$$Bbl_n^{rupture} = Bbl_{avail,n}$$

Shell 3

$Bbl_1^{rupture}$ = 6158.8247 barrels
$Bbl_2^{rupture}$ = 6158.8247 barrels
$Bbl_3^{rupture}$ = 6158.8247 barrels
$Bbl_4^{rupture}$ = 6158.8247 barrels

Step 7.7

Determination of rupture mass

$$mass_n^{rupture} = Bbl_n^{rupture}$$

Shell 3

$mass_1^{rupture}$ = 6158.8247
$mass_2^{rupture}$ = 6158.8247
$mass_3^{rupture}$ = 6158.8247
$mass_4^{rupture}$ = 6158.8247

$volume_1^{leak}$ = 979.14542 m3
$volume_2^{leak}$ = 979.14542 m3
$volume_3^{leak}$ = 979.14542 m3
$volume_4^{leak}$ = 979.14542 m3

ρ = 734.011 kg/m3

$mass_1^{leak}$ = 718703.51 kg
$mass_2^{leak}$ = 718703.51 kg
$mass_3^{leak}$ = 718703.51 kg
$mass_4^{leak}$ = 718703.51 kg

PART 7 : DETERMINE THE RELEASE RATE & VOLUME FOR THE CONSEQUENCES OF FAILURE ANALYSIS

The release for the AST Shell and bottom assumed as continous. The release rate and volume neccesary for the COF are determined using a similar approach as level 2 consequences analysis with differences outlined in the procedure.

Calculation of Atmospheric Storage Tank Shell Course Release Volume

Step 7.1

For each release hole size, determine the release rate in bbls/day when the release rate is from STEP 3.3

$$Rate_n = W_n$$

Shell 4				
small	W_1	=	26.002496	bbl/day
medium	W_2	=	104.00999	bbl/day
large	W_3	=	6656.6391	bbl/day
rupture	W_4	=	29381580	bbl/day

$$Rate_n = W_n$$

0.0013

small	$Rate_1$	=	26.002496	bbl/day
medium	$Rate_2$	=	104.00999	bbl/day
large	$Rate_3$	=	6656.6391	bbl/day
rupture	$Rate_4$	=	29381580	bbl/day

small	$Rate_1$	=	0.0338032	kg/s
medium	$Rate_2$	=	0.135213	kg/s
large	$Rate_3$	=	8.6536308	kg/s
rupture	$Rate_4$	=	38196.054	kg/s

Step 7.2

Determination of leak detection time

t_{ld} = 7 days for $d_n \leq$ 3,17mm

t_{ld} = 1 days for $d_n >$ 3,17mm

Release Hole Diameter, d_n (mm)
d_1 = 3,175
d_2 = 6,35
d_3 = 50,8
d_4 = 1000[Dtank/4]

Dtank = 13.5 m

small d1 = 3.175 mm
medium d2 = 6.35 mm
large d3 = 50.8 mm
rupture d4 = 3375 mm

Release Hole Diameter, d_n	**mm**	t_{ld} **(day)**
d1	3.175	7
d2	6.35	1
d3	50.8	1
d4	3375	1

Step 7.3

Determination of leak duration for each release hole sizes

$$ld_n = \min[\left(\frac{Bbl_{avail,n}}{rate_n}\right), 7\ days\ ]$$

$$ld_1 = \min[\left(\frac{4513{,}832}{26{,}0025}\right), 7\ days\ ]$$ = 7 days

$$ld_2 = \min[\left(\frac{4513{,}832}{104{,}01}\right), 7\ days\ ]$$ = 7 days

$$ld_3 = \min[\left(\frac{4513{,}832}{6656{,}639}\right), 7\ days\ ]$$ = 0.6780947 days

$$ld_4 = \min[\left(\frac{4513{,}832}{29381580}\right), 7\ days\ ]$$ = 0.0001536 days

Step 7.4

Determination of leakage volume for each release hole size

$$Bbl_n^{leak} = \min[\,(rate_n\ x\ Id_n), Bbl_{avail,n}]$$

Shell 4

Bbl_1^{leak} = 182.01748 Barrels

Bbl_2^{leak} = 728.0699 Barrels

Bbl_3^{leak} = 4513.8317 Barrels

Bbl_4^{leak} = 4513.8317 Barrels

Step 7.5

Determination of leakage mass for each release hole size

$$mass_n^{leak} = Bbl_n^{leak}$$

Shell 4

$mass_1^{leak}$ = 182.01748 Barrels

$mass_2^{leak}$ = 728.0699 Barrels

$mass_3^{leak}$ = 4513.8317 Barrels

$mass_4^{leak}$ = 4513.8317 Barrels

$volume_1^{leak}$ = 28.937595 m3

$volume_2^{leak}$ = 115.75038 m3

$volume_3^{leak}$ = 717.62031 m3

$volume_4^{leak}$ = 717.62031 m3

ρ = 734.011 kg/m3

$mass_1^{leak}$ = 21240.513 kg

$mass_2^{leak}$ = 84962.053 kg

$mass_3^{leak}$ = 526741.2 kg

$mass_4^{leak}$ = 526741.2 kg

Step 7.6

Determination of rupture volume

$$Bbl_n^{rupture} = Bbl_{avail,n}$$

Shell 4

$Bbl_1^{rupture}$ = 4513.8317 barrels

$Bbl_2^{rupture}$ = 4513.8317 barrels

$Bbl_3^{rupture}$ = 4513.8317 barrels

$Bbl_4^{rupture}$ = 4513.8317 barrels

Step 7.7

Determination of rupture mass

$$mass_n^{rupture} = Bbl_n^{rupture}$$

Shell 4

$mass_1^{rupture}$ = 4513.8317

$mass_2^{rupture}$ = 4513.8317

$mass_3^{rupture}$ = 4513.8317

$mass_4^{rupture}$ = 4513.8317

$volume_1^{leak}$ = 717.62031 m3

$volume_2^{leak}$ = 717.62031 m3

$volume_3^{leak}$ = 717.62031 m3

$volume_4^{leak}$ = 717.62031 m3

ρ = 734.011 kg/m3

$mass_1^{leak}$ = 526741.2 kg

$mass_2^{leak}$ = 526741.2 kg

$mass_3^{leak}$ = 526741.2 kg

$mass_4^{leak}$ = 526741.2 kg

PART 7 : DETERMINE THE RELEASE RATE & VOLUME FOR THE CONSEQUENCES OF FAILURE ANALYSIS

The release for the AST Shell and bottom assumed as continous. The release rate and volume neccesary for the COF are determined using a similar approach as level 2 consequences analysis with differences outlined in the procedure.

Calculation of Atmospheric Storage Tank Shell Course Release Volume

Step 7.1

For each release hole size, determine the release rate in bbls/day when the release rate is from STEP 3.3

$$Rate_n = W_n$$

Shell 5

small	W_1	=	20.729816	bbl/day
medium	W_2	=	82.919262	bbl/day
large	W_3	=	5306.8328	bbl/day
rupture	W_4	=	23423702	bbl/day

$$Rate_n = W_n$$

0.0013

small	$Rate_1$	=	20.729816	bbl/day
medium	$Rate_2$	=	82.919262	bbl/day
large	$Rate_3$	=	5306.8328	bbl/day
rupture	$Rate_4$	=	23423702	bbl/day
small	$Rate_1$	=	0.0269488	kg/s
medium	$Rate_2$	=	0.107795	kg/s
large	$Rate_3$	=	6.8988826	kg/s
rupture	$Rate_4$	=	30450.813	kg/s

Step 7.2

Determination of leak detection time

t_{ld} = 7 days for $d_n \leq$ 3,17mm

t_{ld} = 1 days for $d_n >$ 3,17mm

Release Hole Diameter, d_n (mm)
d_1 = 3,175
d_2 = 6,35
d_3 = 50,8
d_4 = 1000[Dtank/4]

Dtank = 13.5 m

small	d1	=	3.175	mm
medium	d2	=	6.35	mm
large	d3	=	50.8	mm
rupture	d4	=	3375	mm

Release Hole Diameter, d_n	**mm**	t_{ld} **(day)**
d1	3.175	7
d2	6.35	1
d3	50.8	1
d4	3375	1

Step 7.3

Determination of leak duration for each release hole sizes

$$ld_n = \min[\left(\frac{Bbl_{avail,n}}{rate_n}\right), 7\ days\ ]$$

$$ld_1 = \min[\left(\frac{2868{,}839}{20{,}72982}\right), 7\ days\ ]$$ = 7 days

$$ld_2 = \min[\left(\frac{2868{,}839}{82{,}91926}\right), 7\ days\ ]$$ = 7 days

$$ld_3 = \min[\left(\frac{2868{,}839}{5306{,}833}\right), 7\ days\ ]$$ = 0.5405934 days

$$ld_4 = \min[\left(\frac{2868{,}839}{23423702}\right), 7\ days\ ]$$ = 0.0001225 days

Step 7.4

Determination of leakage volume for each release hole size

$$Bbl_n^{leak} = \min[\,(rate_n \ x \ Id_n), Bbl_{avail,n}]$$

Shell 5

Bbl_1^{leak} = 145.10871 Barrels
Bbl_2^{leak} = 580.43484 Barrels
Bbl_3^{leak} = 2868.8388 Barrels
Bbl_4^{leak} = 2868.8388 Barrels

Step 7.5

Determination of leakage mass for each release hole size

$$mass_n^{leak} = Bbl_n^{leak}$$

Shell 5

$mass_1^{leak}$ = 145.10871 Barrels
$mass_2^{leak}$ = 580.43484 Barrels
$mass_3^{leak}$ = 2868.8388 Barrels
$mass_4^{leak}$ = 2868.8388 Barrels

$volume_1^{leak}$ = 23.069747 m3
$volume_2^{leak}$ = 92.278988 m3
$volume_3^{leak}$ = 456.09521 m3
$volume_4^{leak}$ = 456.09521 m3

ρ = 734.011 kg/m3

$mass_1^{leak}$ = 16933.448 kg
$mass_2^{leak}$ = 67733.792 kg
$mass_3^{leak}$ = 334778.9 kg
$mass_4^{leak}$ = 334778.9 kg

Step 7.6

Determination of rupture volume

$$Bbl_n^{rupture} = Bbl_{avail,n}$$

Shell 5

$Bbl_1^{rupture}$ = 2868.8388 barrels
$Bbl_2^{rupture}$ = 2868.8388 barrels
$Bbl_3^{rupture}$ = 2868.8388 barrels
$Bbl_4^{rupture}$ = 2868.8388 barrels

Step 7.7

Determination of rupture mass

$$mass_n^{rupture} = Bbl_n^{rupture}$$

Shell 5

$mass_1^{rupture}$ = 2868.8388
$mass_2^{rupture}$ = 2868.8388
$mass_3^{rupture}$ = 2868.8388
$mass_4^{rupture}$ = 2868.8388

$volume_1^{leak}$ = 456.09521 m3
$volume_2^{leak}$ = 456.09521 m3
$volume_3^{leak}$ = 456.09521 m3
$volume_4^{leak}$ = 456.09521 m3

ρ = 734.011 kg/m3

$mass_1^{leak}$ = 334778.9 kg
$mass_2^{leak}$ = 334778.9 kg
$mass_3^{leak}$ = 334778.9 kg
$mass_4^{leak}$ = 334778.9 kg

PART 7 : DETERMINE THE RELEASE RATE & VOLUME FOR THE CONSEQUENCES OF FAILURE ANALYSIS

The release for the AST Shell and bottom assumed as continous. The release rate and volume neccesary for the COF are determined using a similar approach as level 2 consequences analysis with differences outlined in the procedure.

Calculation of Atmospheric Storage Tank Shell Course Release Volume

Step 7.1

For each release hole size, determine the release rate in bbls/day when the release rate is from STEP 3.3

$$Rate_n = W_n$$

Shell 6

small W_1 = 19.427428 bbl/day
medium W_2 = 77.70971 bbl/day
large W_3 = 4973.4215 bbl/day
rupture W_4 = 21952066 bbl/day

$$Rate_n = W_n$$

0.0013

small $Rate_1$ = 19.427428 bbl/day
medium $Rate_2$ = 77.70971 bbl/day
large $Rate_3$ = 4973.4215 bbl/day
rupture $Rate_4$ = 21952066 bbl/day

small $Rate_1$ = 0.0252557 kg/s
medium $Rate_2$ = 0.1010226 kg/s
large $Rate_3$ = 6.4654479 kg/s
rupture $Rate_4$ = 28537.685 kg/s

Step 7.2

Determination of leak detection time

t_{ld} = 7 days for $d_n \le$ 3,17mm
t_{ld} = 1 days for $d_n >$ 3,17mm

Release Hole Diameter, d_n (mm)
d_1 = 3,175
d_2 = 6,35
d_3 = 50,8
d_4 = 1000[Dtank/4]

Dtank = 13.5 m

small d1 = 3.175 mm
medium d2 = 6.35 mm
large d3 = 50.8 mm
rupture d4 = 3375 mm

Release Hole Diameter, d_n	**mm**	**t_{ld} (day)**
d1	3.175	7
d2	6.35	1
d3	50.8	1
d4	3375	1

Step 7.3

Determination of leak duration for each release hole sizes

$$ld_n = \min[\left(\frac{Bbl_{avail,n}}{rate_n}\right), 7\ days\ ]$$

$ld_1 = \min[\left(\frac{2519{,}683}{19{,}42743}\right), 7\ days\ ]$ = 7 days

$ld_2 = \min[\left(\frac{2519{,}683}{77{,}70971}\right), 7\ days\ ]$ = 7 days

$ld_3 = \min[\left(\frac{2519{,}683}{4973{,}421}\right), 7\ days\ ]$ = 0.5066297 days

$ld_4 = \min[\left(\frac{2519{,}683}{21952066}\right), 7\ days\ ]$ = 0.0001148 days

Step 7.4

Determination of leakage volume for each release hole size

$$Bbl_n^{leak} = \min[\,(rate_n \ x \ Id_n), Bbl_{avail,n}]$$

Shell 6

Bbl_1^{leak} = 135.99199 Barrels
Bbl_2^{leak} = 543.96797 Barrels
Bbl_3^{leak} = 2519.6828 Barrels
Bbl_4^{leak} = 2519.6828 Barrels

Step 7.5

Determination of leakage mass for each release hole size

$$mass_n^{leak} = Bbl_n^{leak}$$

Shell 6

$mass_1^{leak}$ = 135.99199 Barrels
$mass_2^{leak}$ = 543.96797 Barrels
$mass_3^{leak}$ = 2519.6828 Barrels
$mass_4^{leak}$ = 2519.6828 Barrels

$volume_1^{leak}$ = 21.620349 m3
$volume_2^{leak}$ = 86.481394 m3
$volume_3^{leak}$ = 400.5855 m3
$volume_4^{leak}$ = 400.5855 m3

ρ = 734.011 kg/m3

$mass_1^{leak}$ = 15869.574 kg
$mass_2^{leak}$ = 63478.295 kg
$mass_3^{leak}$ = 294034.16 kg
$mass_4^{leak}$ = 294034.16 kg

Step 7.6

Determination of rupture volume

$$Bbl_n^{rupture} = Bbl_{avail,n}$$

Shell 6

$Bbl_1^{rupture}$ = 2519.6828 barrels

$Bbl_2^{rupture}$ = 2519.6828 barrels

$Bbl_3^{rupture}$ = 2519.6828 barrels

$Bbl_4^{rupture}$ = 2519.6828 barrels

Step 7.7

Determination of rupture mass

$$mass_n^{rupture} = Bbl_n^{rupture}$$

Shell 6

$mass_1^{rupture}$ = 2519.6828

$mass_2^{rupture}$ = 2519.6828

$mass_3^{rupture}$ = 2519.6828

$mass_4^{rupture}$ = 2519.6828

$volume_1^{leak}$ = 400.5855 m3

$volume_2^{leak}$ = 400.5855 m3

$volume_3^{leak}$ = 400.5855 m3

$volume_4^{leak}$ = 400.5855 m3

ρ = 734.011 kg/m3

$mass_1^{leak}$ = 294034.16 kg

$mass_2^{leak}$ = 294034.16 kg

$mass_3^{leak}$ = 294034.16 kg

$mass_4^{leak}$ = 294034.16 kg

PART 8 : DETERMINE FLAMMABLE AND EXPLOSIVE CONSEQUENCE

8.1 CONSEQUENCE AREA EQUATIONS (Shell 1)

The following equations are used to determine the flammable consequence areas for comoponent damage and personnel injury. There are two kind of equantions explained based on its type of release, either continous release or instataneous release as mentioned below:

1). $CA_n^{CONT} = \alpha(rate_n)^b$

2). $CA_n^{INST} = \alpha(mass_n)^b$

The coefficients for those equations for component damage areas and personel injury are provided in Table 4.8 and 4.9 in API RP 581 Part 3 of COF.

STEP 8.1 Select the consequence area mitigation reduction factor, factmit, from Table 4.10

Mitigation System	**Consequence Area Adjustment**	**Consequence Area Reduction Factor, factor mit**
Inventory blowdown , couple with isolation system classification B or higher	Reduce consequence area by 25 %	0.25
Fire water deluge system and monitors	Reduce consequence area by 20%	0.2
Fire water monitor only	Reduce consequence area by 5%	0.05
Foam spray system	Reduce consequence area by 15%	0.15

Mitigation system = Fire water deluge system and monitors

Consequence Area = Reduce consequence area by 5% *

$fact_{mit}$ = 0.05

STEP 8.2 Calculate the energy efficiency, eneff$_n$, for each hole size using equation mentioned below.

$$eneff_n = 4.\,log_{10}[C_{4A}\,.mass_n] - 15$$

This correction is made for instantaneous events exceeding a release mass of 4,536 kgs (10,000 Ibs). Comparison of calculated consequence with those of actual historical releases indicates that there is need to correct large instantaneous releases for energy efficiency.

C_{4A} = 2205 1/kg

A) SMALL RELEASE HOLE SIZE AREA

$$eneff_1 = 4.\,log_{10}[C_{4A}\,.mass_1] - 15$$

$eneff_1$ = 16.32395795

B) MEDIUM RELEASE HOLE SIZE AREA

$$eneff_2 = 4.\,log_{10}[C_{4A}\,.mass_2] - 15$$

$eneff_2$ = 18.73219792

C) LARGE RELEASE HOLE SIZE AREA

$$eneff_3 = 4.\,log_{10}[C_{4A}\,.mass_3] - 15$$

$eneff_3$ = 22.54335062

D) RUPTURE RELEASE HOLE SIZE AREA

$$eneff_4 = 4.\,log_{10}[C_{4A}\,.mass_4] - 15$$

$eneff_4$ = 22.54335062

STEP 8.3 Determine the fluid type

Determine the fluid type, either TYPE 0 or TYPE 1 based on Table 4.1 of API RP 581 Part 3 of COF.

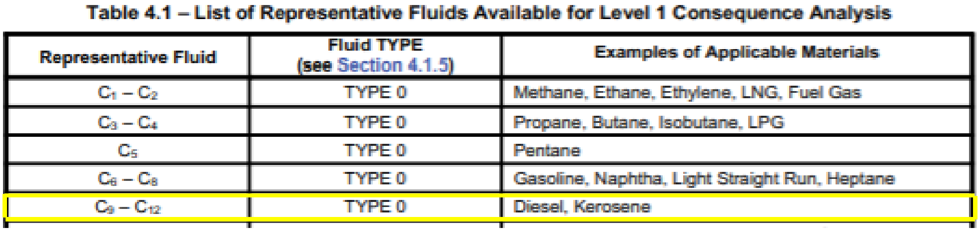


Table 4.1 – List of Representative Fluids Available for Level 1 Consequence Analysis

Representative Fluid	Fluid TYPE (see Section 4.1.5)	Examples of Applicable Materials
$C_1 - C_2$	TYPE 0	Methane, Ethane, Ethylene, LNG, Fuel Gas
$C_3 - C_4$	TYPE 0	Propane, Butane, Isobutane, LPG
C_5	TYPE 0	Pentane
$C_6 - C_8$	TYPE 0	Gasoline, Naphtha, Light Straight Run, Heptane
$C_9 - C_{12}$	TYPE 0	Diesel, Kerosene

C9-C12 = TYPE 0

MW = 149.00 (kg/kg-mol)

AIT = 208 (^oC)

AIT = 381 (K)

NBP = 184 (^oC)

ρ = 734.012 kg/m3

STEP 8.4 For each release hole size, calculate the component damage consequence areas for Auto-Ignition Not Likely, Continous Release (AINT-CONT), $CA^{AINL-CONT}$

1). Determine the appropriate constant a and b from the Table 4.8

Table 4.8M - Component Damage Flammable Consequence Equation Constants

Fluid	Continuous Release Constant							
	Auto Ignition Not Likely (CAINL)				Auto Ignition Likely (CAIL)			
	Gas		Liquid		Gas		Liquid	
	α	b	α	b	α	b	α	b
C9-C12	2.42	0.98	24.6	0.9	77	0.95	110	0.95

Fluid	Instantaneous Release Constant							
	Auto-Ignition Not Likely (IAINL)				Auto Ignition Likely (IAIL)			
	Gas		Liquid		Gas		Liquid	
	α	b	α	b	α	b	α	b
C9-C12	1.1	0.66	0.56	0.8	42	0.61	0.85	0.53

α = $\alpha_{cmd,n}^{AINL-CONT}$ = 24.6

b = $b_{cmd}^{AINL-CONT}$ = 0.90

2). Calculate the consequence of area using equation below

Shell 1

$Rate_1$ = 40.088 bbl/day

$Rate_2$ = 160.352 bbl/day

$Rate_3$ = 10262.5 bbl/day

$Rate_4$ = 4.5E+07 bbl/day

1 bbl/day = 0.0013 kg/s

Shell 1

$Rate_1$ = 0.05211 kg/s

$Rate_2$ = 0.20846 kg/s

$Rate_3$ = 13.3413 kg/s

$Rate_4$ = 58886.8 kg/s

Shell 1

$$CA^{AINL-CONT}_{cmd,n} = \alpha(rate_n)^b \, .(1 - fact_{mit})$$

A) SMALL RELEASE HOLE SIZE AREA

$$CA^{AINL-CONT}_{cmd,1} = \alpha(rate_1)^b \, .(1 - fact_{mit})$$

= 647.6967537 m^2 (use bbl/day)

= 1.636517815 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA^{AINL-CONT}_{cmd,2} = \alpha(rate_2)^b \, .(1 - fact_{mit})$$

= 2255.411095 m^2 (use bbl/day)

= 5.698686024 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$CA^{AINL-CONT}_{cmd,3} = \alpha(rate_3)^b \, .(1 - fact_{mit})$$

= 95233.04903 m^2 (use bbl/day)

= 240.6227613 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA^{AINL-CONT}_{cmd,4} = \alpha(rate_4)^b \, .(1 - fact_{mit})$$

= 181604165.5 m^2 (use bbl/day)

= 458854.3181 m^2 (use kg/s)

STEP 8.5 For ech release hole size, calculate the component damage consequence areas for Auto-Ignition Likely, Continous Release (AIL-CONT), $CA^{AIL\text{-}CONT}$

1). Determine the appropriate constant a and b from the Table 4.8

α = $\alpha^{AIL-CONT}_{cmd,n}$ = $\boxed{110.3}$

b = $b^{AIL-CONT}_{cmd}$ = $\boxed{0.95}$

2). Calculate the consequence of area using equation below

Shell 1

$$CA^{AIL-CONT}_{cmd,n} = \alpha(rate_n)^b \, .(1 - fact_{mit})$$

A) SMALL RELEASE HOLE SIZE AREA

$$CA^{AIL-CONT}_{cmd,1} = \alpha(rate_1)^b \, .(1 - fact_{mit})$$

= 3492.712579 m^2 (use bbl/day)

= 6.330077586 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA^{AIL-CONT}_{cmd,2} = \alpha(rate_2)^b \, .(1 - fact_{mit})$$

= 13035.26427 m^2 (use bbl/day)

= 23.62468491 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$CA^{AIL-CONT}_{cmd,3} = \alpha(rate_3)^b \, .(1 - fact_{mit})$$

= 677627.1768 m^2 (use bbl/day)

= 1228.109243 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA^{AIL-CONT}_{cmd,4} = \alpha(rate_4)^b \, .(1 - fact_{mit})$$

= 1965938549 m^2 (use bbl/day)

= 3563002.47 m^2 (use kg/s)

STEP 8.6 For each release hole size, calculate the component damage consequence areas for Auto-ignition Not Likely, Instaneous Release, (AINL-INST), $CA^{AINL\text{-}INST}$

1). Determine the appropriate constant a and b from the Table 4.8

α = $\alpha_{cmd,n}^{AINL-INST}$ = $\boxed{0.6}$

b = $b_{cmd}^{AINL-INST}$ = $\boxed{0.76}$

2). Calculate the consequence of area using equation below

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

From step 7, known that:

$mass_1^{leak}$ = 30731.2973 kg
$mass_2^{leak}$ = 122925.189 kg
$mass_3^{leak}$ = 1102628.11 kg
$mass_4^{leak}$ = 1102628.11 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{cmd,1}^{AINL-INST} = \alpha(mass_1)^b \cdot \left(\frac{1-fact_{mit}}{eneff_1}\right)$$

= 83.72813653 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{cmd,2}^{AINL-INST} = \alpha(mass_2)^b \cdot \left(\frac{1-fact_{mit}}{eneff_2}\right)$$

= 209.2539905 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{cmd,3}^{AINL-INST} = \alpha(mass_3)^b \cdot \left(\frac{1-fact_{mit}}{eneff_3}\right)$$

= 921.2193124 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{cmd,4}^{AINL-INST} = \alpha(mass_4)^b \cdot \left(\frac{1-fact_{mit}}{eneff_4}\right)$$

= 921.2193124 m^2

STEP 8.7 For ech release hole size, calculate the component damage consequence areas for Auto-Ignition Likely, Instataneous Release (AIL-INST), $CA^{AIL\text{-}INST}$

1). Determine the appropriate constant a and b from the Table 4.8

α = $\alpha_{cmd,n}^{AIL-INST}$ = $\boxed{0.8}$

b = $b_{cmd}^{AIL-INST}$ = $\boxed{0.53}$

2). Calculate the consequence of area using equation below

$$CA^{AIL-INST}_{cmd,n} = \alpha(mass_n)^b \cdot \left(\frac{1-fact_{mit}}{eneff_n}\right)$$

$mass^{leak}_1$ = 30731.2973 kg

$mass^{leak}_2$ = 122925.189 kg

$mass^{leak}_3$ = 1102628.11 kg

$mass^{leak}_4$ = 1102628.11 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA^{AIL-INST}_{cmd,1} = \alpha(mass_1)^b \cdot \left(\frac{1-fact_{mit}}{eneff_1}\right)$$

$$= 11.79537803 \text{ m}^2$$

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA^{AIL-INST}_{cmd,2} = \alpha(mass_2)^b \cdot \left(\frac{1-fact_{mit}}{eneff_2}\right)$$

$$= 21.43089899 \text{ m}^2$$

C) LARGE RELEASE HOLE SIZE AREA

$$CA^{AIL-INST}_{cmd,3} = \alpha(mass_3)^b \cdot \left(\frac{1-fact_{mit}}{eneff_3}\right)$$

$$= 56.96241509 \text{ m}^2$$

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA^{AIL-INST}_{cmd,4} = \alpha(mass_4)^b \cdot \left(\frac{1-fact_{mit}}{eneff_4}\right)$$

$$= 56.96241509 \text{ m}^2$$

STEP 8.8 For each release hole size, calculate the personnel injury consequence areas for Auto- $CA^{AINL-CONT}_{inj,n}$ ignition Not Likely, Continous Release (AINL-CONT),

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phas as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

Table 4.9M - Personnel Injury Flammable Consequence Equation Constants

Fluid	**Continuous Release Constant**							
	Auto Ignition Not Likely (CAINL)				**Auto Ignition Likely (CAIL)**			
	Gas		**Liquid**		**Gas**		**Liquid**	
	α	b	α	b	α	b	α	b
C9-C12	5.8	0.96	70.03	0.9	189	0.92	269.4	0.92

Fluid	Instantaneous Release Constant							
	Auto-Ignition Not Likely (IAINL)				**Auto Ignition Likely (IAIL)**			
	Gas		**Liquid**		**Gas**		**Liquid**	
	α	b	α	b	α	b	α	b
C9-C12	2.0	0.66	1.61	0.8	151	0.63	2.85	0.54

α = $\alpha_{inj,n}^{AINL-CONT}$ = 70.03

b = $b_{inj,n}^{AINL-CONT}$ = 0.89

2). Calculate the consequence of area using equation below

$$CA_{inj,n}^{AINL-CONT} = [\alpha.(rate_n^{AINL-CONT})^b].(1 - fact_{mit})$$

Shell 1

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AINL-CONT} = \left[\alpha.\left(rate_1^{AINL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 1777.01296 m^2 (use bbl/day)

= 4.798441214 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AINL-CONT} = \left[\alpha.\left(rate_2^{AINL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 6102.727629 m^2 (use bbl/day)

= 16.4791031 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AINL-CONT} = \left[\alpha.\left(rate_3^{AINL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 247186.1676 m^2 (use bbl/day)

= 667.4730692 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AINL-CONT} = \left[\alpha.\left(rate_4^{AINL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 433425121.6 m^2 (use bbl/day)

= 1170371.3 m^2 (use kg/s)

STEP 8.9 For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Likely, Continous Release (AIL-CONT), $CA_{inj,n}^{AIL-CONT}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phasE as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

α = $\alpha_{inj,n}^{AIL-CONT}$ = 269.4

b = $b_{inj,n}^{AIL-CONT}$ = 0.92

2). Calculate the consequence of area using equation below

$$CA_{inj,n}^{AIL-CONT} = [\alpha.(rate_n^{AIL-CONT})^b].(1 - fact_{mit})$$

Shell 1

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AIL-CONT} = \left[\alpha.\left(rate_1^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 7636.50242 m^2 (use bbl/day)

= 16.89360665 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AIL-CONT} = \left[\alpha.\left(rate_2^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 27339.44448 m^2 (use bbl/day)

= 60.48080595 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AIL-CONT} = \left[\alpha.\left(rate_3^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 1254513.276 m^2 (use bbl/day)

= 2775.256611 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AIL-CONT} = \left[\alpha.\left(rate_4^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 2829500540 m^2 (use bbl/day)

= 6259471.484 m^2 (use kg/s)

STEP 8.10

For each release hole size, calculate the personnel injury consequence areas for Auto-$CA_{inj,n}^{AINL-INST}$ ignition Not Likely, Instataneous Release (AINL-INST),

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phase as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

α = $\alpha_{inj,n}^{AINL-INST}$ = 1.609

b = $b_{inj,n}^{AINL-INST}$ = 0.76

2). Calculate the consequence of area using equation below

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

$mass_1^{leak}$ = 30731.2973 kg

$mass_2^{leak}$ = 122925.189 kg

$mass_3^{leak}$ = 1102628.11 kg

$mass_4^{leak}$ = 1102628.11 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AINL-INST} = \left[\alpha.\left(mass_1^{AINL-INST}\right)^b\right].\left(\frac{1 - fact_{mit}}{eneff_1}\right)$$

= 240.9992338 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AINL-INST} = \left[\alpha.\left(mass_2^{AINL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_2}\right)$$

= 602.3071031 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AINL-INST} = \left[\alpha.\left(mass_3^{AINL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_3}\right)$$

= 2651.595481 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AINL-INST} = \left[\alpha.\left(mass_4^{AINL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_4}\right)$$

= 2651.595481 m^2

STEP 8.11

For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Likely, Instataneous Release (AIL-INST), $CA_{inj,n}^{AIL-INST}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phas as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

α = $\alpha_{inj,n}^{AIL-INST}$ = 2.847

b = $b_{inj,n}^{AIL-INST}$ = 0.54

2). Calculate the consequence of area using equation below

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

$mass_1^{leak}$ = 30731.29734 kg

$mass_2^{leak}$ = 122925.1893 kg

$mass_3^{leak}$ = 1102628.113 kg

$mass_4^{leak}$ = 1102628.113 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AIL-INST} = \left[\alpha.\left(mass_1^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_1}\right)$$

= 43.91160266 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AIL-INST} = \left[\alpha.\left(mass_2^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_2}\right)$$

= 80.89625429 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AIL-INST} = \left[\alpha.\left(mass_3^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_3}\right)$$

= 219.7881633 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AIL-INST} = \left[\alpha.\left(mass_4^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_4}\right)$$

= 219.7881633 m^2

STEP 8.12 For each release hole size, calculate the instataneous/continous blending factor, $fact_n^{IC}$.

1). FOR CONTINOUS RELEASE

C_5 = 25 kg/s

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

…………………………

Shell 1

A) SMALL RELEASE HOLE SIZE AREA

$$fact_1^{IC} = \min\left[\left\{\frac{rate_1}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 0.002068032 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$fact_2^{IC} = \min\left[\left\{\frac{rate_2}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 0.008272128 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$fact_3^{IC} = \min\left[\left\{\frac{rate_3}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 0.529416204 (use kg/s)

D) **RUPTURE RELEASE HOLE SIZE AREA**

$$fact_4^{IC} = \min\left[\left\{\frac{rate_3}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 1 (use kg/s)

2). FOR INSTATANEOUS RELEASE

$fact_n^{IC} =$ 1

STEP 8.13

Calculate the AIT blending factor, fact^{AIT}, using these optional equation below.

$$fact^{AIT} = 0 \quad \text{for, } T_S + C_6 \leq AIT$$

$$fact^{AIT} = \frac{(T_s - AIT + C_6)}{2\,.\,C_6} \quad \text{for, } T_S + C_6 > AIT > T_S - C_6$$

$$fact^{AIT} = 1 \quad \text{for, } T_S - C_6 \geq AIT$$

Ts = 30 (°C)

Ts = 86 (°F)

Ts = 303 (K)

AIT = 208 (°C)

AIT = 481 (K)

C_6 = 55.6 (K)

$T_s + C_6$ = 358.6 (K)

$T_s - C_6$ = 247.4 (K)

$$\frac{(T_s - AIT + C_6)}{2\,.\,C_6} = -1 \quad \text{(K)}$$

So, $fact^{AIT}$ = 0

STEP 8.14

Calculate the continuous/instantaneous blended consequence area for the component using equation (3.53) through (3.56) based on the consequence areas calculated in $fact_n^{IC}$ previous steps

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,1}^{AIL-INST}$ = 11.80 m^2

$fact_1^{IC}$ = #######

$fact_1^{IC}$ = 1

$CA_{cmd,1}^{AIL-CONT}$ = 6.33 m^2

$CA_{cmd,1}^{AIL}$ = 18.11 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,2}^{AIL-INST}$ = 209.25 m^2

$fact_2^{IC}$ = #######

$fact_1^{IC}$ = 1

$CA_{cmd,2}^{AIL-CONT}$ = 23.62 m^2

$CA_{cmd,2}^{AIL}$ = 232.683 m^2

C) LARGE RELEASE HOLE

$CA_{cmd,3}^{AIL-INST}$ = 921.22 m^2

$fact_3^{IC}$ = 5.3E-01

$fact_1^{IC}$ = 1

$CA_{cmd,3}^{AIL-CONT}$ = 1228.11 m^2

$CA^{AIL}_{cmd,3}$ = $\underline{1499.15}$ m^2

D) RUPTURE RELEASE HOLE

$CA^{AIL-INST}_{cmd,4}$ = 921.22 m^2

$fact^{IC}_{4}$ = 1.0000 $fact^{IC}_{1}$ = 1

$CA^{AIL-CONT}_{cmd,4}$ = 3563002.47 m^2

$CA^{AIL}_{cmd,4}$ = $\underline{921.219}$ m^2

$$CA^{AIL}_{inj,n} = CA^{AIL-INST}_{inj,n} . fact^{IC}_{n} + CA^{AIL-CONT}_{inj,n} . (1 - fact^{IC}_{n})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA^{AIL-INST}_{inj,1}$ = 43.91160266 m^2

$fact^{IC}_{1}$ = 0.002068 $fact^{IC}_{1}$ = 1

$CA^{AIL-CONT}_{inj,1}$ = 16.89360665 m^2

$CA^{AIL}_{inj,1}$ = $\underline{60.77}$ m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{AIL-INST}_{inj,2}$ = 80.89625429 m^2

$fact^{IC}_{2}$ = 0.0082721 $fact^{IC}_{1}$ = 1

$CA^{AIL-CONT}_{inj,2}$ = 60.48080595 m^2

$CA^{AIL}_{inj,2}$ = $\underline{140.8767553}$ m^2

C) LARGE RELEASE HOLE

$CA^{AIL-INST}_{inj,3}$ = 219.7881633 m^2

$fact^{IC}_{3}$ = 0.529416 $fact^{IC}_{1}$ = 1

$CA^{AIL-CONT}_{inj,3}$ = 2775.256611 m^2

$CA^{AIL}_{inj,3}$ = $\underline{1525.778953}$ m^2

D) RUPTURE RELEASE HOLE

$CA^{AIL-INST}_{inj,4}$ = 219.7881633 m^2

$fact^{IC}_{4}$ = 1.0000 $fact^{IC}_{1}$ = 1

$CA^{AIL-CONT}_{inj,4}$ = 6259471.484 m^2

$CA^{AIL}_{inj,4}$ = $\underline{219.7881633}$ m^2

$$CA^{AINL}_{cmd,n} = CA^{AINL-INST}_{cmd,n} . fact^{IC}_{n} + CA^{AINL-CONT}_{cmd,n} . (1 - fact^{IC}_{n})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA^{AINL-INST}_{cmd,n}$ = 83.72813653 m^2

$fact^{IC}_{1}$ = 2.07E-03 $fact^{IC}_{1}$ = 1

$CA^{AINL-CONT}_{cmd,1}$ = 1.636517815 m^2

$CA^{AINL}_{cmd,1}$ = $\underline{85.36}$ m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{AINL-INST}_{cmd,n}$ = 209.2539905 m^2

$fact^{IC}_{2}$ = 0.008272 $fact^{IC}_{1}$ = 1

$CA^{AINL-CONT}_{cmd,2}$ = 5.698686024 m^2

$CA^{AINL}_{cmd,2}$ = $\underline{214.9055362}$ m^2

C) LARGE RELEASE HOLE

$CA^{AINL-INST}_{cmd,n}$ = 921.2193124 m^2

$fact^{IC}_{3}$ = 0.5294 $fact^{IC}_{1}$ = 1

$CA^{AINL-CONT}_{cmd,3}$ = 240.6227613 m^2

$CA^{AINL}_{cmd,3}$ = $\underline{1034.452485}$ m^2

D) RUPTURE RELEASE HOLE

$CA^{AINL-INST}_{cmd,4}$ = 921.2193124 m^2

$fact^{IC}_{4}$ = 1.0000 $fact^{IC}_{1}$ = 1

$CA^{AINL-CONT}_{cmd,4}$ = 458854.3181 m^2

$CA^{AINL}_{cmd,4}$ = $\underline{921.2193124}$ m^2

$$CA^{AINL}_{inj,n} = CA^{AINL-INST}_{inj,n} . fact^{IC}_{n} + CA^{AINL-CONT}_{inj,n} . (1 - fact^{IC}_{n})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA^{AINL-INST}_{inj,n}$ = 240.9992338 m^2

$fact^{IC}_{1}$ = 0.0021 $fact^{IC}_{1}$ = 1

$CA^{AINL-CONT}_{inj,1}.$ = 4.798441214 m^2

$CA^{AINL}_{inj,1}$ = 245.7877517 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{AINL-INST}_{inj,n}$ = 602.3071031 m^2

$fact^{IC}_2$ = 0.008272

$fact^{IC}_1$ = 1

$CA^{AINL-CONT}_{inj,2}.$ = 16.4791031 m^2

$CA^{AINL}_{inj,2}$ = 618.649889 m^2

C) LARGE RELEASE HOLE

$CA^{AINL-INST}_{inj,n}$ = 2651.595481 m^2

$fact^{IC}_3$ = 0.5294

$fact^{IC}_1$ = 1

$CA^{AINL-CONT}_{inj,3}.$ = 667.4730692 m^2

$CA^{AINL}_{inj,3}$ = 2965.697491 m^2

D) RUPTURE RELEASE HOLE

$CA^{AINL-INST}_{inj,4}$ = 2651.595481 m^2

$fact^{IC}_4$ = 1.0000

$CA^{AINL-CONT}_{inj,4}.$ = 433425121.6 m^2

$fact^{IC}_1$ = 1

$CA^{AINL}_{inj,4}$ = 2651.595481 m^2

STEP 8.15

Calculate the AIT blended consequence areas for the component using equations (3.57) and (3.58) based on the consequence areas determined in step 8.14 and the AIT blending factors, $fact^{AIT}$, calculate in step 8.13. the resulting consequence areas are the component damage and personnel injury flammable consequence areas, $CA^{flam}_{icmd,n}$ and $CA^{flam}_{inj,n}$ for each release hole size selected in step 2.2

$$CA^{flam}_{cmd,n} = CA^{AIL}_{smd,n} . fact^{AIT} + CA^{AINL}_{cmd,n} . (1 - fact^{AIT})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA^{AIL}_{cmd,1}$ = 18.11236481 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,1}$ = 85.36126998 m^2

$CA^{flam}_{cmd,1}$ = 85.36126998 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{AIL}_{cmd,2}$ = 232.6832489 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,2}$ = 214.9055362 m^2

$CA^{flam}_{cmd,2}$ = 214.9055362 m^2

C) LARGE RELEASE HOLE

$CA^{AIL}_{cmd,3}$ = 1499.15 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,3}$ = 1034.45 m^2

$CA^{flam}_{cmd,3}$ = 1034.45 m^2

D) RUPTURE RELEASE HOLE

$CA^{AIL}_{cmd,4}$ = 921.2193124 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,4}$ = 921.2193124 m^2

$CA^{flam}_{cmd,4}$ = 921.2193124 m^2

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

A) SMALL RELEASE HOLE SIZE AREA

$CA^{flam-AIL}_{inj,1}$ = 60.77027279 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{inj,1}$ = 245.7877517 m^2

$CA^{flam}_{inj,1}$ = 245.7877517 m2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{flam-AIL}_{inj,2}$ = 140.8767553 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{inj,2}$ = 618.649889 m^2

$CA_{inj,2}^{flam}$ = 618.649889 m2

C) LARGE RELEASE HOLE

$CA_{inj,3}^{flam-AIL}$ = 1525.778953 m^2

$fact^{AIT}$ = 0

$CA_{inj,3}^{AINL}$ = 2965.697491 m^2

CA_{inj3}^{flam} = 2965.697491 m^2

D) RUPTURE RELEASE HOLE

$CA_{inj,4}^{flam-AIL}$ = 219.7881633 m^2

$fact^{AIT}$ = 0

$CA_{inj,4}^{AINL}$ = 2651.595481 m^2

$CA_{inj,4}^{flam}$ = 2651.595481 m^2

STEP 8.16 Determine the consequence areas (probability weighted on release hole size) for component damage and personnel injury using equations (3.59) and (3.60) based on the consequence ara from step 8.15

Equipment Type	**Component Type**	**gff as a function of hole size (failure/yr)**				**gff total (failure/ yr)**
		Small	**Medium**	**Large**	**Rupture**	
Tank650	TANK BOTTOM	7.2E-04	0.00E+00	0.00E+00	2.00E-06	7.20E-04
Tank650	COURSE 1-10	7.0E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04

CONSEQUENCE AREA FOR COMPONENT DAMAGE

For Tank Shell

$$CA_{cmd}^{flam}=\left(\frac{\sum gff_n\;.\;CA_{cmd,n}^{flam}}{gff_{total}}\right)$$

$$CA_{cmd}^{flam}=\left(\frac{(gff_{1}.\;CA_{cmd,1}^{flam})+(gff_{2}.\;CA_{cmd,2}^{flam})+(gff_{3}.\;CA_{cmd,3}^{flam})+(gff_{4}.\;CA_{cmd,4}^{flam})}{gff_{total}}\right)$$

= 166.1231166 m^2

CONSEQUENCE AREA FOR PERSONNEL INJURY

For Tank Shell

$$CA_{inj}^{flam}=\left(\frac{\sum gff_n\;.\;CA_{inj,n}^{flam}}{gff_{total}}\right)$$

$$CA_{inj}^{flam}=\left(\frac{\left(gff_1\;.\;CA_{inj,1}^{flam}\right)+\left(gff_2\;.\;CA_{inj,2}^{flam}\right)+\left(gff_3\;.\;CA_{inj,3}^{flam}\right)+\left(gff_4\;.\;CA_{inj,4}^{flam}\right)}{gff_{total}}\right)$$

= 477.650 m^2

PART 8 : DETERMINE FLAMMABLE AND EXPLOSIVE CONSEQUENCE

8.1 CONSEQUENCE AREA EQUATIONS

(Shell 2)

The following equations are used to determine the flammable consequence areas for comoponent damage and personnel injury. There are two kind of equantions explained based on its type of release, either continous release or instataneous release as mentioned below:

1). $CA_n^{CONT} = \alpha(rate_n)^b$

2). $CA_n^{INST} = \alpha(mass_n)^b$

The coefficients for those equations for component damage areas and personel injury are provided in Table 4.8 and 4.9 in API RP 581 Part 3 of COF.

STEP 8.1 Select the consequence area mitigation reduction factor, factmit, from Table 4.10

Mitigation System	**Consequence Area Adjustment**	**Consequence Area Reduction Factor, factor mit**
Inventory blowdown , couple with isolation system classification B or higher	Reduce consequence area by 25 %	0.25
Fire water deluge system and monitors	Reduce consequence area by 20%	0.2
Fire water monitor only	Reduce consequence area by 5%	0.05
Foam spray system	Reduce consequence area by 15%	0.15

Mitigation system = Fire water deluge system and monitors

Consequence Area = Reduce consequence area by 5% *

$fact_{mit}$ = 0.05

STEP 8.2 Calculate the energy efficiency, eneff$_n$, for each hole size using equation mentioned below.

$$eneff_n = 4.\, log_{10}[C_{4A}\, .mass_n] - 15$$

This correction is made for instantaneous events exceeding a release mass of 4,536 kgs (10,000 Ibs). Comparison of calculated consequence with those of actual historical releases indicates that there is need to correct large instantaneous releases for energy efficiency.

C_{4A} = 2205 1/kg

$mass_1^{leak}$ = 27928.3887 kg

$mass_2^{leak}$ = 111713.555 kg

$mass_3^{leak}$ = 910665.809 kg

$mass_4^{leak}$ = 910665.809 kg

A) SMALL RELEASE HOLE SIZE AREA

$$eneff_1 = 4.\, log_{10}[C_{4A}\, .mass_1] - 15$$

$eneff_1$ = 16.15781789

B) MEDIUM RELEASE HOLE SIZE AREA

$$eneff_2 = 4.\, log_{10}[C_{4A}\, .mass_2] - 15$$

$eneff_2$ = 18.56605786

C) LARGE RELEASE HOLE SIZE AREA

$$eneff_3 = 4.\, log_{10}[C_{4A}\, .mass_3] - 15$$

$eneff_3$ = 22.2110705

D) RUPTURE RELEASE HOLE SIZE AREA

$$eneff_4 = 4.\, log_{10}[C_{4A}\, .mass_4] - 15$$

$eneff_4$ = 22.2110705

STEP 8.3 Determine the fluid type

Determine the fluid type, either TYPE 0 or TYPE 1 based on Table 4.1 of API RP 581 Part 3 of COF.

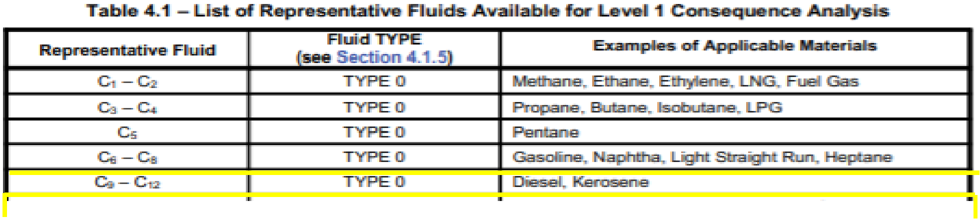


Table 4.1 – List of Representative Fluids Available for Level 1 Consequence Analysis

Representative Fluid	Fluid TYPE (see Section 4.1.5)	Examples of Applicable Materials
$C_1 - C_2$	TYPE 0	Methane, Ethane, Ethylene, LNG, Fuel Gas
$C_3 - C_4$	TYPE 0	Propane, Butane, Isobutane, LPG
C_5	TYPE 0	Pentane
$C_6 - C_8$	TYPE 0	Gasoline, Naphtha, Light Straight Run, Heptane
$C_9 - C_{12}$	TYPE 0	Diesel, Kerosene

C9-C12 = TYPE 0 NBP = 184 (^oC)

MW = 149.00 (kg/kg-mol) ρ = 734.012 kg/m3

AIT = 208 (^oC)

AIT = 381 (K)

STEP 8.4 For each release hole size, calculate the component damage consequence areas for Auto-Ignition Not Likely, Continous Release (AINT-CONT), $CA^{AINL\text{-}CONT}$

1). Determine the appropriate constant a and b from the Table 4.8

Table 4.8M - Component Damage Flammable Consequence Equation Constants

Fluid	**Continuous Release Constant**							
	Auto Ignition Not Likely (CAINL)				**Auto Ignition Likely (CAIL)**			
	Gas		**Liquid**		**Gas**		**Liquid**	
	α	b	α	b	α	b	α	b
C9-C12	2.42	0.98	24.6	0.9	77	0.95	110	0.95

Fluid	**Instantaneous Release Constant**							
	Auto-Ignition Not Likely (IAINL)				**Auto Ignition Likely (IAIL)**			
	Gas		**Liquid**		**Gas**		**Liquid**	
	α	b	α	b	α	b	α	b
C9-C12	1.1	0.66	0.56	0.8	42	0.61	0.85	0.53

$$\alpha = \alpha^{AINL-CONT}_{cmd,n} = \boxed{24.6}$$

$$b = b^{AINL-CONT}_{cmd} = \boxed{0.90}$$

2). Calculate the consequence of area using equation below

Shell 2

$Rate_1$ = 34.1897 bbl/day

$Rate_2$ = 136.759 bbl/day

$Rate_3$ = 8752.58 bbl/day

$Rate_4$ = 3.9E+07 bbl/day

1 bbl/day = 0.0013 kg/s

Shell 2

$Rate_1$ = 0.04445 kg/s

$Rate_2$ = 0.17779 kg/s

$Rate_3$ = 11.3783 kg/s

$Rate_4$ = 50222.6 kg/s

Shell 2

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,1}^{AINL-CONT} = \alpha(rate_1)^b \,.\, (1 - fact_{mit})$

= 561.2612219 m^2 (use bbl/day)

= 1.418123502 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,2}^{AINL-CONT} = \alpha(rate_2)^b \,.\, (1 - fact_{mit})$

= 1954.425092 m^2 (use bbl/day)

= 4.938192854 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$CA_{cmd,3}^{AINL-CONT} = \alpha(rate_3)^b \,.\, (1 - fact_{mit})$

= 82524.13982 m^2 (use bbl/day)

= 208.5115052 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$CA_{cmd,4}^{AINL-CONT} = \alpha(rate_4)^b \,.\, (1 - fact_{mit})$

= 157368977.5 m^2 (use bbl/day)

= 397619.9259 m^2 (use kg/s)

STEP 8.5 For ech release hole size, calculate the component damage consequence areas for Auto-Ignition Likely, Continous Release (AIL-CONT), $CA^{AIL-CONT}$

1). Determine the appropriate constant a and b from the Table 4.8

α = $\alpha_{cmd,n}^{AIL-CONT}$ = 110.3

b = $b_{cmd}^{AIL-CONT}$ = 0.95

2). Calculate the consequence of area using equation below

Shell 2

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,1}^{AIL-CONT} = \alpha(rate_1)^b \,.\, (1 - fact_{mit})$

= 3002.619071 m^2 (use bbl/day)

= 5.441848204 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,2}^{AIL-CONT} = \alpha(rate_2)^b \,.\, (1 - fact_{mit})$

= 11206.17062 m^2 (use bbl/day)

= 20.30969564 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$CA_{cmd,3}^{AIL-CONT} = \alpha(rate_3)^b \,.\, (1 - fact_{mit})$

= 582543.2919 m^2 (use bbl/day)

= 1055.782333 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$CA_{cmd,4}^{AIL-CONT} = \alpha(rate_4)^b \,.\, (1 - fact_{mit})$

= 1690080259 m^2 (use bbl/day)

= 3063045.962 m^2 (use kg/s)

STEP 8.6 For each release hole size, calculate the component damage consequence areas for Auto-ignition Not Likely, Instaneous Release, (AINL-INST), $CA^{AINL\text{-}INST}$

1). Determine the appropriate constant a and b from the Table 4.8

$\alpha = \alpha_{cmd,n}^{AINL-INST} = \boxed{0.6}$

$b = b_{cmd}^{AINL-INST} = \boxed{0.76}$

2). Calculate the consequence of area using equation below

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

From step 7, known that:

$mass_1^{leak}$ = 27928.3887 kg
$mass_2^{leak}$ = 111713.555 kg
$mass_3^{leak}$ = 910665.809 kg
$mass_4^{leak}$ = 910665.809 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{cmd,1}^{AINL-INST} = \alpha(mass_1)^b \cdot \left(\frac{1-fact_{mit}}{eneff_1}\right)$$

$= 78.65884636\ \text{m}^2$

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{cmd,2}^{AINL-INST} = \alpha(mass_2)^b \cdot \left(\frac{1-fact_{mit}}{eneff_2}\right)$$

$= 196.3252574\ \text{m}^2$

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{cmd,3}^{AINL-INST} = \alpha(mass_3)^b \cdot \left(\frac{1-fact_{mit}}{eneff_3}\right)$$

$= 808.4976955\ \text{m}^2$

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{cmd,4}^{AINL-INST} = \alpha(mass_4)^b \cdot \left(\frac{1-fact_{mit}}{eneff_4}\right)$$

$= 808.4976955\ \text{m}^2$

STEP 8.7 For ech release hole size, calculate the component damage consequence areas for Auto-Ignition Likely, Instataneous Release (AIL-INST), $CA^{AIL\text{-}INST}$

1). Determine the appropriate constant a and b from the Table 4.8

$\alpha = \alpha_{cmd,n}^{AIL-INST} = \boxed{0.8}$

$b = b_{cmd}^{AIL-INST} = \boxed{0.53}$

2). Calculate the consequence of area using equation below

$$CA^{AIL-INST}_{cmd,n} = \alpha(mass_n)^b \cdot \left(\frac{1-fact_{mit}}{eneff_n}\right)$$

$mass^{leak}_1$ = 27928.3887 kg
$mass^{leak}_2$ = 111713.555 kg
$mass^{leak}_3$ = 910665.809 kg
$mass^{leak}_4$ = 910665.809 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA^{AIL-INST}_{cmd,1} = \alpha(mass_1)^b \cdot \left(\frac{1-fact_{mit}}{eneff_1}\right)$$

$= 11.32768242 \text{ m}^2$

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA^{AIL-INST}_{cmd,2} = \alpha(mass_2)^b \cdot \left(\frac{1-fact_{mit}}{eneff_2}\right)$$

$= 20.55397716 \text{ m}^2$

C) LARGE RELEASE HOLE SIZE AREA

$$CA^{AIL-INST}_{cmd,3} = \alpha(mass_3)^b \cdot \left(\frac{1-fact_{mit}}{eneff_3}\right)$$

$= 52.24085227 \text{ m}^2$

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA^{AIL-INST}_{cmd,4} = \alpha(mass_4)^b \cdot \left(\frac{1-fact_{mit}}{eneff_4}\right)$$

$= 52.24085227 \text{ m}^2$

STEP 8.8 For each release hole size, calculate the personnel injury consequence areas for Auto-
$CA^{AINL-CONT}_{inj,n}$ ignition Not Likely, Continous Release (AINL-CONT),

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phas as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

Table 4.9M - Personnel Injury Flammable Consequence Equation Constants

Fluid	**Continuous Release Constant**							
	Auto Ignition Not Likely (CAINL)				**Auto Ignition Likely (CAIL)**			
	Gas		**Liquid**		**Gas**		**Liquid**	
	α	b	α	b	α	b	α	b
C9-C12	5.8	0.96	70.03	0.9	189	0.92	269.4	0.92

Fluid	**Instantaneous Release Constant**							
	Auto-Ignition Not Likely (IAINL)				**Auto Ignition Likely (IAIL)**			
	Gas		**Liquid**		**Gas**		**Liquid**	
	α	b	α	b	α	b	α	b
C9-C12	2.0	0.66	1.61	0.8	151	0.63	2.85	0.54

α = $\alpha_{inj,n}^{AINL-CONT}$ = 70.03

b = $b_{inj,n}^{AINL-CONT}$ = 0.89

2). Calculate the consequence of area using equation below

$$CA_{inj,n}^{AINL-CONT} = [\alpha.(rate_{n}^{AINL-CONT})^{b}].(1-fact_{mit})$$

Shell 2

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AINL-CONT} = \left[\alpha.\left(rate_{1}^{AINL-CONT}\right)^{b}\right].(1-fact_{mit})$$

= 1542.322156 m^2 (use bbl/day)

= 4.164709188 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AINL-CONT} = \left[\alpha.\left(rate_{2}^{AINL-CONT}\right)^{b}\right].(1-fact_{mit})$$

= 5296.737981 m^2 (use bbl/day)

= 14.30270145 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AINL-CONT} = \left[\alpha.\left(rate_{3}^{AINL-CONT}\right)^{b}\right].(1-fact_{mit})$$

= 214540.1928 m^2 (use bbl/day)

= 579.3196374 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AINL-CONT} = \left[\alpha.\left(rate_{4}^{AINL-CONT}\right)^{b}\right].(1-fact_{mit})$$

= 376182494.6 m^2 (use bbl/day)

= 1015799.9 m^2 (use kg/s)

STEP 8.9 For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Likely, Continous Release (AIL-CONT), $CA_{inj,n}^{AIL-CONT}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phasE as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

α = $\alpha_{inj,n}^{AIL-CONT}$ = 269.4

b = $b_{inj,n}^{AIL-CONT}$ = 0.92

2). Calculate the consequence of area using equation below

$$CA_{inj,n}^{AIL-CONT} = [\alpha.(rate_{n}^{AIL-CONT})^{b}].(1 - fact_{mit})$$

Shell 2

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AIL-CONT} = \left[\alpha.\left(rate_{1}^{AIL-CONT}\right)^{b}\right].(1 - fact_{mit})$$

= 6596.376564 m^2 (use bbl/day)
= 14.59262171 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AIL-CONT} = \left[\alpha.\left(rate_{2}^{AIL-CONT}\right)^{b}\right].(1 - fact_{mit})$$

= 23615.68961 m^2 (use bbl/day)
= 52.24304912 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AIL-CONT} = \left[\alpha.\left(rate_{3}^{AIL-CONT}\right)^{b}\right].(1 - fact_{mit})$$

= 1083642.946 m^2 (use bbl/day)
= 2397.254223 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AIL-CONT} = \left[\alpha.\left(rate_{4}^{AIL-CONT}\right)^{b}\right].(1 - fact_{mit})$$

= 2444109885 m^2 (use bbl/day)
= 5406903.414 m^2 (use kg/s)

STEP 8.10

For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Not Likely, Instataneous Release (AINL-INST), $CA_{inj,n}^{AINL-INST}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phase as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

α = $\alpha_{inj,n}^{AINL-INST}$ = 1.609

b = $b_{inj,n}^{AINL-INST}$ = 0.76

2). Calculate the consequence of area using equation below

$$CA_{inj,n}^{AINL-INST} = [\alpha.(mass_{n}^{AINL-INST})^{b}].\left(\frac{1 - fact_{mit}}{eneff_{n}}\right)$$

$mass_{1}^{leak}$ = 27928.3887 kg
$mass_{2}^{leak}$ = 111713.555 kg
$mass_{3}^{leak}$ = 910665.809 kg
$mass_{4}^{leak}$ = 910665.809 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AINL-INST} = \left[\alpha.\left(mass_{1}^{AINL-INST}\right)^{b}\right].\left(\frac{1 - fact_{mit}}{eneff_{1}}\right)$$

= 226.4080211 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AINL-INST} = \left[\alpha.\left(mass_2^{AINL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_2}\right)$$

$= \quad 565.09363 \quad \text{m}^2$

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AINL-INST} = \left[\alpha.\left(mass_3^{AINL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_3}\right)$$

$= \quad 2327.142741 \quad \text{m}^2$

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AINL-INST} = \left[\alpha.\left(mass_4^{AINL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_4}\right)$$

$= \quad 2327.142741 \quad \text{m}^2$

STEP 8.11

For each release hole size, calculate the personnel injury consequence areas for Auto-$CA_{inj,n}^{AIL-INST}$ ignition Likely, Instataneous Release (AIL-INST),

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phas as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

$\alpha \quad = \quad \alpha_{inj,n}^{AIL-INST} \quad = \quad \boxed{2.847}$

$b \quad = \quad b_{inj,n}^{AIL-INST} \quad = \quad \boxed{0.54}$

2). Calculate the consequence of area using equation below

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

$mass_1^{leak}$= 27928.38866 kg

$mass_2^{leak}$= 111713.5546 kg

$mass_3^{leak}$= 910665.8091 kg

$mass_4^{leak}$= 910665.8091 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AIL-INST} = \left[\alpha.\left(mass_1^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_1}\right)$$

$= \quad 42.1301629 \quad \text{m}^2$

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AIL-INST} = \left[\alpha.\left(mass_2^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_2}\right)$$

$= \quad 77.51192867 \quad \text{m}^2$

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AIL-INST} = \left[\alpha.\left(mass_3^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_3}\right)$$

= 201.1849358 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AIL-INST} = \left[\alpha.\left(mass_4^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_4}\right)$$

= 201.1849358 m^2

STEP 8.12 For each release hole size, calculate the instataneous/continous blending factor, $fact_n^{IC}$.

1). FOR CONTINOUS RELEASE

C_5 = 25 kg/s

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

....

Shell 2

A) SMALL RELEASE HOLE SIZE AREA

$$fact_1^{IC} = \min\left[\left\{\frac{rate_1}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 0.001763757 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$fact_2^{IC} = \min\left[\left\{\frac{rate_2}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 0.007055028 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$fact_3^{IC} = \min\left[\left\{\frac{rate_3}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 0.451521769 (use kg/s)

D) **RUPTURE RELEASE HOLE SIZE AREA**

$$fact_4^{IC} = \min\left[\left\{\frac{rate_3}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 1 (use kg/s)

2). FOR INSTATANEOUS RELEASE

$fact_n^{IC}$ = 1

STEP 8.13

Calculate the AIT blending factor, fact^{AIT}, using these optional equation below.

$fact^{AIT}$	=	0	for, $T_S + C_6 \le AIT$
$fact^{AIT}$	=	$\frac{(T_s - AIT + C_6)}{2 . C_6}$	for, $T_S + C_6 > AIT > T_S - C_6$
$fact^{AIT}$	=	1	for, $T_S - C_6 \ge AIT$

Ts	=	30	(°C)	AIT	=	208	(°C)
Ts	=	86	(°F)	AIT	=	481	(K)
Ts	=	303	(K)	C_6	=	55.6	(K)

$T_s + C_6$ = 358.6 (K)

$T_s - C_6$ = 247.4 (K)

$$\frac{(T_s - AIT + C_6)}{2 . C_6} = -1 \quad (K)$$

So, $fact^{AIT}$ = 0

STEP 8.14

Calculate the continuous/instantaneous blended consequence area for the component using equation (3.53) through (3.56) based on the consequence areas calculated in $fact_n^{IC}$ previous steps

$$CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST} . fact_n^{IC} + CA_{cmd,n}^{AIL-CONT} . (1 - fact_n^{IC})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,1}^{AIL-INST}$ = 11.33 m^2

$fact_1^{IC}$ = ####### $fact_1^{IC}$ = 1

$CA_{cmd,1}^{AIL-CONT}$ = 5.44 m^2

$CA_{cmd,1}^{AIL}$ = 16.76 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,2}^{AIL-INST}$ = 196.33 m^2

$fact_2^{IC}$ = ####### $fact_1^{IC}$ = 1

$CA_{cmd,2}^{AIL-CONT}$ = 20.31 m^2

$CA_{cmd,2}^{AIL}$ = 216.492 m^2

C) LARGE RELEASE HOLE

$CA_{cmd,3}^{AIL-INST}$ = 808.50 m^2

$fact_3^{IC}$ = 4.5E-01 $fact_1^{IC}$ = 1

$CA_{cmd,3}^{AIL-CONT}$ = 1055.78 m^2

$CA_{cmd,3}^{AIL}$ = 1387.57 m^2

D) RUPTURE RELEASE HOLE

$CA_{cmd,4}^{AIL-INST}$ = 808.50 m^2

$fact_4^{IC}$ = 1.0000 $fact_1^{IC}$ = 1

$CA_{cmd,4}^{AIL-CONT}$ = 3063045.96 m^2

$CA_{cmd,4}^{AIL}$ = 808.498 m^2

$$CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST} . fact_n^{IC} + CA_{inj,n}^{AIL-CONT} . (1 - fact_n^{IC})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA_{inj,1}^{AIL-INST}$ = 42.1301629 m^2

$fact_1^{IC}$ = 0.001764 $fact_1^{IC}$ = 1

$CA_{inj,1}^{AIL-CONT}$ = 14.59262171 m^2

$CA_{inj,1}^{AIL}$ = 56.70 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{inj,2}^{AIL-INST}$ = 77.51192867 m^2

$fact_2^{IC}$ = 0.0070550 $fact_1^{IC}$ = 1

$CA_{inj,2}^{AIL-CONT}$ = 52.24304912 m^2

$CA_{inj,2}^{AIL}$ = 129.3864016 m^2

C) LARGE RELEASE HOLE

$CA_{inj,3}^{AIL-INST}$ = 201.1849358 m^2

$fact_3^{IC}$ = 0.451522 $fact_1^{IC}$ = 1

$CA_{inj,3}^{AIL-CONT}$ = 2397.254223 m^2

$CA_{inj,3}^{AIL}$ = 1516.026691 m^2

D) RUPTURE RELEASE HOLE

$CA_{inj,4}^{AIL-INST}$ = 201.1849358 m^2

$fact_4^{IC}$ = 1.0000 $fact_1^{IC}$ = 1

$CA_{inj,4}^{AIL-CONT}$ = 5406903.414 m^2

$CA_{inj,4}^{AIL}$ = $\underline{201.1849358}$ m^2

$$CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST} . fact_n^{IC} + CA_{cmd,n}^{AINL-CONT} . (1 - fact_n^{IC})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,n}^{AINL-INST}$ = 78.65884636 m^2

$fact_1^{IC}$ = 1.76E-03 $fact_1^{IC}$ = 1

$CA_{cmd,1}^{AINL-CONT}$ = 1.418123502 m^2

$CA_{cmd,1}^{AINL}$ = $\underline{80.07}$ m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,n}^{AINL-INST}$ = 196.3252574 m^2

$fact_2^{IC}$ = 0.007055 $fact_1^{IC}$ = 1

$CA_{cmd,2}^{AINL-CONT}$ = 4.938192854 m^2

$CA_{cmd,2}^{AINL}$ = $\underline{201.2286112}$ m^2

C) LARGE RELEASE HOLE

$CA_{cmd,n}^{AINL-INST}$ = 808.4976955 m^2

$fact_3^{IC}$ = 0.4515 $fact_1^{IC}$ = 1

$CA_{cmd,3}^{AINL-CONT}$ = 208.5115052 m^2

$CA_{cmd,3}^{AINL}$ = $\underline{922.861717}$ m^2

D) RUPTURE RELEASE HOLE

$CA_{cmd,4}^{AINL-INST}$ = 808.4976955 m^2

$fact_4^{IC}$ = 1.0000 $fact_1^{IC}$ = 1

$CA_{cmd,4}^{AINL-CONT}$ = 397619.9259 m^2

$CA_{cmd,4}^{AINL}$ = $\underline{808.4976955}$ m^2

$$CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST} . fact_n^{IC} + CA_{inj,n}^{AINL-CONT} . (1 - fact_n^{IC})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA_{inj,n}^{AINL-INST}$ = 226.4080211 m^2

$fact_1^{IC}$ = 0.0018 $fact_1^{IC}$ = 1

$CA^{AINL-CONT}_{inj,1}.$ = 4.164709188 m^2

$CA^{AINL}_{inj,1}$ = 230.5653847 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{AINL-INST}_{inj,n}$ = 565.09363 m^2

$fact^{IC}_{2}$ = 0.007055 $fact^{IC}_{1}$ = 1

$CA^{AINL-CONT}_{inj,2}.$ = 14.30270145 m^2

$CA^{AINL}_{inj,2}$ = 579.2954255 m^2

C) LARGE RELEASE HOLE

$CA^{AINL-INST}_{inj,n}$ = 2327.142741 m^2

$fact^{IC}_{3}$ = 0.4515 $fact^{IC}_{1}$ = 1

$CA^{AINL-CONT}_{inj,3}.$ = 579.3196374 m^2

$CA^{AINL}_{inj,3}$ = 2644.886951 m^2

D) RUPTURE RELEASE HOLE

$CA^{AINL-INST}_{inj,4}$ = 2327.142741 m^2

$fact^{IC}_{4}$ = 1.0000

$CA^{AINL-CONT}_{inj,4}.$ = 376182494.6 m^2 $fact^{IC}_{1}$ = 1

$CA^{AINL}_{inj,4}$ = 2327.142741 m^2

STEP 8.15 Calculate the AIT blended consequence areas for the component using equations (3.57) and (3.58) based on the consequence areas determined in step 8.14 and the AIT blending factors, $fact^{AIT}$, calculate in step 8.13. the resulting consequence areas are the component damage and personnel injury flammable consequence areas, $CA^{flam}_{icmd,n}$ and $CA^{flam}_{inj,n}$ for each release hole size selected in step 2.2

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

A) SMALL RELEASE HOLE SIZE AREA

$CA^{AIL}_{cmd,1}$ = 16.75993252 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,1}$ = 80.07446864 m^2

$CA^{flam}_{cmd,1}$ = $\underline{80.07446864}$ m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{AIL}_{cmd,2}$ = 216.4916676 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,2}$ = 201.2286112 m^2

$CA^{flam}_{cmd,2}$ = $\underline{201.2286112}$ m^2

C) LARGE RELEASE HOLE

$CA^{AIL}_{cmd,3}$ = 1387.57 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,3}$ = 922.862 m^2

$CA^{flam}_{cmd,3}$ = $\underline{922.862}$ m^2

D) RUPTURE RELEASE HOLE

$CA^{AIL}_{cmd,4}$ = 808.4976955 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,4}$ = 808.4976955 m^2

$CA^{flam}_{cmd,4}$ = $\underline{808.4976955}$ m^2

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

A) SMALL RELEASE HOLE SIZE AREA

$CA^{flam-AIL}_{inj,1}$ = 56.69704677 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{inj,1}$ = 230.5653847 m^2

$CA^{flam}_{inj,1}$ = $\underline{230.5653847}$ m2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{flam-AIL}_{inj,2}$ = 129.3864016 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{inj,2}$ = 579.2954255 m^2

$CA_{inj,2}^{flam}$ = 579.2954255 m2

C) LARGE RELEASE HOLE

$CA_{inj,3}^{flam-AIL}$ = 1516.026691 m^2

$fact^{AIT}$ = 0

$CA_{inj,3}^{AINL}$ = 2644.886951 m^2

CA_{inj3}^{flam} = 2644.886951 m^2

D) RUPTURE RELEASE HOLE

$CA_{inj,4}^{flam-AIL}$ = 201.1849358 m^2

$fact^{AIT}$ = 0

$CA_{inj,4}^{AINL}$ = 2327.142741 m^2

$CA_{inj,4}^{flam}$ = 2327.142741 m^2

STEP 8.16

Determine the consequence areas (probability weighted on release hole size) for component damage and personnel injury using equations (3.59) and (3.60) based on the consequence ara from step 8.15

Equipment Type	**Component Type**	**gff as a function of hole size (failure/yr)**				**gff total (failure/yr)**
		Small	**Medium**	**Large**	**Rupture**	
Tank650	TANK BOTTOM	7.2E-04	0.00E+00	0.00E+00	2.00E-06	7.20E-04
Tank650	COURSE 1-10	7.0E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04

CONSEQUENCE AREA FOR COMPONENT DAMAGE

For Tank Shell

$$CA_{cmd}^{flam} = \left(\frac{\sum gff_n \ . CA_{cmd,n}^{flam}}{gff_{total}} \right)$$

$$CA_{cmd}^{flam} = \left(\frac{(gff_{1.}\ CA_{cmd,1}^{flam}) + (gff_{2.}\ CA_{cmd,2}^{flam}) + (gff_{3.}\ CA_{cmd,3}^{flam}) + (gff_{4.}\ CA_{cmd,4}^{flam})}{gff_{total}} \right)$$

= 153.3108644 m^2

CONSEQUENCE AREA FOR PERSONNEL INJURY

For Tank Shell

$$CA_{inj}^{flam} = \left(\frac{\sum gff_n \ . CA_{inj,n}^{flam}}{gff_{total}} \right)$$

$$CA_{inj}^{flam} = \left(\frac{\left(gff_1\ . CA_{inj,1}^{flam}\right) + \left(gff_2\ . CA_{inj,2}^{flam}\right) + \left(gff_3\ . CA_{inj,3}^{flam}\right) + \left(gff_4\ . CA_{inj,4}^{flam}\right)}{gff_{total}} \right)$$

= 440.791 m^2

PART 8 : DETERMINE FLAMMABLE AND EXPLOSIVE CONSEQUENCE

8.1 CONSEQUENCE AREA EQUATIONS (Shell 3)

The following equations are used to determine the flammable consequence areas for comoponent damage and personnel injury. There are two kind of equantions explained based on its type of release, either continous release or instataneous release as mentioned below:

1). $CA_n^{CONT} = \alpha(rate_n)^b$

2). $CA_n^{INST} = \alpha(mass_n)^b$

The coefficients for those equations for component damage areas and personel injury are provided in Table 4.8 and 4.9 in API RP 581 Part 3 of COF.

STEP 8.1 Select the consequence area mitigation reduction factor, factmit, from Table 4.10

Mitigation System	Consequence Area Adjustment	Consequence Area Reduction Factor, factor mit
Inventory blowdown , couple with isolation system classification B or higher	Reduce consequence area by 25 %	0.25
Fire water deluge system and monitors	Reduce consequence area by 20%	0.2
Fire water monitor only	Reduce consequence area by 5%	0.05
Foam spray system	Reduce consequence area by 15%	0.15

Mitigation system = Fire water deluge system and monitors

Consequence Area = Reduce consequence area by 5% *

$fact_{mit}$ = 0.05

STEP 8.2 Calculate the energy efficiency, eneff$_n$, for each hole size using equation mentioned below.

$$eneff_n = 4.\,log_{10}[C_{4A}\,.mass_n] - 15$$

This correction is made for instantaneous events exceeding a release mass of 4,536 kgs (10,000 Ibs). Comparison of calculated consequence with those of actual historical releases indicates that there is need to correct large instantaneous releases for energy efficiency.

C_{4A} = 2205 1/kg

$mass_1^{leak}$= 24810.82728 kg
$mass_2^{leak}$= 99243.30914 kg
$mass_3^{leak}$= 718703.5052 kg
$mass_4^{leak}$= 718703.5052 kg

A) SMALL RELEASE HOLE SIZE AREA

$$eneff_1 = 4.\,log_{10}[C_{4A}\,.mass_1] - 15$$

$eneff_1$ = 15.95219936

B) MEDIUM RELEASE HOLE SIZE AREA

$$eneff_2 = 4.\,log_{10}[C_{4A}\,.mass_2] - 15$$

$eneff_2$ = 18.36043932

C) LARGE RELEASE HOLE SIZE AREA

$$eneff_3 = 4.\,log_{10}[C_{4A}\,.mass_3] - 15$$

$eneff_3$ = 21.79983343

D) RUPTURE RELEASE HOLE SIZE AREA

$$eneff_4 = 4.\,log_{10}[C_{4A}\,.mass_4] - 15$$

$eneff_4$ = 21.79983343

STEP 8.3 Determine the fluid type

Determine the fluid type, either TYPE 0 or TYPE 1 based on Table 4.1 of API RP 581 Part 3 of COF.

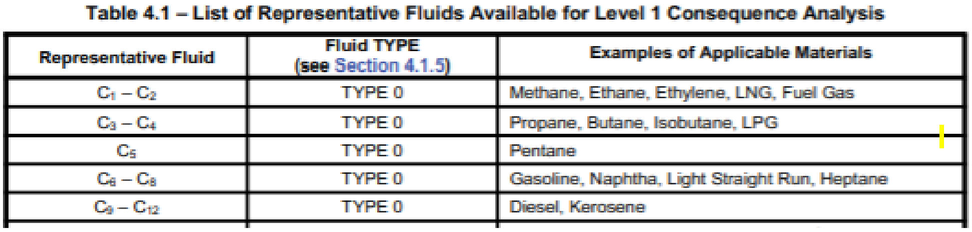


Table 4.1 – List of Representative Fluids Available for Level 1 Consequence Analysis

Representative Fluid	Fluid TYPE (see Section 4.1.5)	Examples of Applicable Materials
$C_1 - C_2$	TYPE 0	Methane, Ethane, Ethylene, LNG, Fuel Gas
$C_3 - C_4$	TYPE 0	Propane, Butane, Isobutane, LPG
C_5	TYPE 0	Pentane
$C_6 - C_8$	TYPE 0	Gasoline, Naphtha, Light Straight Run, Heptane
$C_9 - C_{12}$	TYPE 0	Diesel, Kerosene

C9-C12 = TYPE 0 NBP = 184 (^{o}C)
MW = 149.00 (kg/kg-mol) ρ = 734.012 kg/m3
AIT = 208 (^{o}C)
AIT = 381 (K)

STEP 8.4 For each release hole size, calculate the component damage consequence areas for Auto-Ignition Not Likely, Continous Release (AINT-CONT), $CA^{AINL\text{-}CONT}$

1). Determine the appropriate constant a and b from the Table 4.8

Table 4.8M - Component Damage Flammable Consequence Equation Constants

Fluid	**Continuous Release Constant**							
	Auto Ignition Not Likely (CAINL)				**Auto Ignition Likely (CAIL)**			
	Gas		**Liquid**		**Gas**		**Liquid**	
	α	b	α	b	α	b	α	b
C9-C12	2.42	0.98	24.6	0.9	77	0.95	110	0.95

Fluid	**Instantaneous Release Constant**							
	Auto-Ignition Not Likely (IAINL)				**Auto Ignition Likely (IAIL)**			
	Gas		**Liquid**		**Gas**		**Liquid**	
	α	b	α	b	α	b	α	b
C9-C12	1.1	0.66	0.56	0.8	42	0.61	0.85	0.53

$$\alpha = \alpha_{cmd,n}^{AINL-CONT} = \boxed{24.6}$$

$$b = b_{cmd}^{AINL-CONT} = \boxed{0.90}$$

2). Calculate the consequence of area using equation below

Shell 3

$Rate_1$ = 30.3733 bbl/day
$Rate_2$ = 121.493 bbl/day
$Rate_3$ = 7775.55 bbl/day
$Rate_4$ = 3.4E+07 bbl/day

1 bbl/day = 0.0013 kg/s

Shell 3

$Rate_1$ = 0.03949 kg/s
$Rate_2$ = 0.15794 kg/s
$Rate_3$ = 10.1082 kg/s
$Rate_4$ = 44616.4 kg/s

Shell 3

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,1}^{AINL-CONT} = \alpha(rate_1)^b \, .(1 - fact_{mit})$

= 504.5461153 m^2 (use bbl/day)

= 1.274822981 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,2}^{AINL-CONT} = \alpha(rate_2)^b \, .(1 - fact_{mit})$

= 1756.931619 m^2 (use bbl/day)

= 4.439191456 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$CA_{cmd,3}^{AINL-CONT} = \alpha(rate_3)^b \, .(1 - fact_{mit})$

= 74185.12546 m^2 (use bbl/day)

= 187.4415438 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$CA_{cmd,4}^{AINL-CONT} = \alpha(rate_4)^b \, .(1 - fact_{mit})$

= 141466937.6 m^2 (use bbl/day)

= 357440.6732 m^2 (use kg/s)

STEP 8.5 For ech release hole size, calculate the component damage consequence areas for Auto-Ignition Likely, Continous Release (AIL-CONT), $CA^{AIL-CONT}$

1). Determine the appropriate constant a and b from the Table 4.8

α = $\alpha_{cmd,n}^{AIL-CONT}$ = 110.3

b = $b_{cmd}^{AIL-CONT}$ = 0.95

2). Calculate the consequence of area using equation below

Shell 3

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,1}^{AIL-CONT} = \alpha(rate_1)^b \, .(1 - fact_{mit})$

= 2683.279027 m^2 (use bbl/day)

= 4.863086796 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,2}^{AIL-CONT} = \alpha(rate_2)^b \, .(1 - fact_{mit})$

= 10014.35143 m^2 (use bbl/day)

= 18.14968168 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$CA_{cmd,3}^{AIL-CONT} = \alpha(rate_3)^b \, .(1 - fact_{mit})$

= 520587.5807 m^2 (use bbl/day)

= 943.4958362 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$CA_{cmd,4}^{AIL-CONT} = \alpha(rate_4)^b \, .(1 - fact_{mit})$

= 1510333747 m^2 (use bbl/day)

= 2737279.287 m^2 (use kg/s)

STEP 8.6 For each release hole size, calculate the component damage consequence areas for Auto-ignition Not Likely, Instaneous Release, (AINL-INST), $CA^{AINL\text{-}INST}$

1). Determine the appropriate constant a and b from the Table 4.8

$\alpha = \alpha_{cmd,n}^{AINL-INST} = \boxed{0.6}$

$b = b_{cmd}^{AINL-INST} = \boxed{0.76}$

2). Calculate the consequence of area using equation below

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

From step 7, known that:

$mass_1^{leak}$ = 24810.8273 kg
$mass_2^{leak}$ = 99243.3091 kg
$mass_3^{leak}$ = 718703.505 kg
$mass_4^{leak}$ = 718703.505 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{cmd,1}^{AINL-INST} = \alpha(mass_1)^b \cdot \left(\frac{1-fact_{mit}}{eneff_1}\right)$$

$= 72.81857758 \text{ m}^2$

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{cmd,2}^{AINL-INST} = \alpha(mass_2)^b \cdot \left(\frac{1-fact_{mit}}{eneff_2}\right)$$

$= 181.4451168 \text{ m}^2$

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{cmd,3}^{AINL-INST} = \alpha(mass_3)^b \cdot \left(\frac{1-fact_{mit}}{eneff_3}\right)$$

$= 688.1134676 \text{ m}^2$

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{cmd,4}^{AINL-INST} = \alpha(mass_4)^b \cdot \left(\frac{1-fact_{mit}}{eneff_4}\right)$$

$= 688.1134676 \text{ m}^2$

STEP 8.7 For ech release hole size, calculate the component damage consequence areas for Auto-Ignition Likely, Instataneous Release (AIL-INST), $CA^{AIL\text{-}INST}$

1). Determine the appropriate constant a and b from the Table 4.8

$\alpha = \alpha_{cmd,n}^{AIL-INST} = \boxed{0.8}$

$b = b_{cmd}^{AIL-INST} = \boxed{0.53}$

2). Calculate the consequence of area using equation below

$$CA^{AIL-INST}_{cmd,n} = \alpha(mass_n)^b \cdot \left(\frac{1-fact_{mit}}{eneff_n}\right)$$

$mass^{leak}_1$ = 24810.8273 kg

$mass^{leak}_2$ = 99243.3091 kg

$mass^{leak}_3$ = 718703.505 kg

$mass^{leak}_4$ = 718703.505 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA^{AIL-INST}_{cmd,1} = \alpha(mass_1)^b \cdot \left(\frac{1-fact_{mit}}{eneff_1}\right)$$

= 10.77602894 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA^{AIL-INST}_{cmd,2} = \alpha(mass_2)^b \cdot \left(\frac{1-fact_{mit}}{eneff_2}\right)$$

= 19.52036996 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA^{AIL-INST}_{cmd,3} = \alpha(mass_3)^b \cdot \left(\frac{1-fact_{mit}}{eneff_3}\right)$$

= 46.95022272 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA^{AIL-INST}_{cmd,4} = \alpha(mass_4)^b \cdot \left(\frac{1-fact_{mit}}{eneff_4}\right)$$

= 46.95022272 m^2

STEP 8.8 For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Not Likely, Continous Release (AINL-CONT), $CA^{AINL-CONT}_{inj,n}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phas as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

Table 4.9M - Personnel Injury Flammable Consequence Equation Constants

Fluid	**Continuous Release Constant**							
	Auto Ignition Not Likely (CAINL)				**Auto Ignition Likely (CAIL)**			
	Gas		**Liquid**		**Gas**		**Liquid**	
	α	b	α	b	α	b	α	b
C9-C12	5.8	0.96	70.03	0.9	189	0.92	269.4	0.92

Fluid	Instantaneous Release Constant							
	Auto-Ignition Not Likely (IAINL)				Auto Ignition Likely (IAIL)			
	Gas		Liquid		Gas		Liquid	
	α	b	α	b	α	b	α	b
C9-C12	2.0	0.66	1.61	0.8	151	0.63	2.85	0.54

$$\alpha = \alpha_{inj,n}^{AINL-CONT} = \boxed{70.03}$$

$$b = b_{inj,n}^{AINL-CONT} = \boxed{0.89}$$

2). Calculate the consequence of area using equation below

$$CA_{inj,n}^{AINL-CONT} = [\alpha.(rate_{n}^{AINL-CONT})^{b}].(1-fact_{mit})$$

Shell 3

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AINL-CONT} = \left[\alpha.\left(rate_{1}^{AINL-CONT}\right)^{b}\right].(1-fact_{mit})$$

= 1388.113485 m^2 (use bbl/day)

= 3.748301845 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AINL-CONT} = \left[\alpha.\left(rate_{2}^{AINL-CONT}\right)^{b}\right].(1-fact_{mit})$$

= 4767.145039 m^2 (use bbl/day)

= 12.87264964 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AINL-CONT} = \left[\alpha.\left(rate_{3}^{AINL-CONT}\right)^{b}\right].(1-fact_{mit})$$

= 193089.4486 m^2 (use bbl/day)

= 521.3965171 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AINL-CONT} = \left[\alpha.\left(rate_{4}^{AINL-CONT}\right)^{b}\right].(1-fact_{mit})$$

= 338569987.7 m^2 (use bbl/day)

= 914235.4163 m^2 (use kg/s)

STEP 8.9 For each release hole size, calculate the personnel injury consequence areas for Auto-$CA_{inj,n}^{AIL-CONT}$ignition Likely, Continous Release (AIL-CONT),

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phasE as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

$$\alpha = \alpha_{inj,n}^{AIL-CONT} = \boxed{269.4}$$

$$b = b_{inj,n}^{AIL-CONT} = \boxed{0.92}$$

2). Calculate the consequence of area using equation below

$$CA_{inj,n}^{AIL-CONT} = [\alpha.(rate_n^{AIL-CONT})^b].(1 - fact_{mit})$$

Shell 3

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AIL-CONT} = \left[\alpha.\left(rate_1^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 5915.795826 m^2 (use bbl/day)
= 13.08702888 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AIL-CONT} = \left[\alpha.\left(rate_2^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 21179.14232 m^2 (use bbl/day)
= 46.8528758 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AIL-CONT} = \left[\alpha.\left(rate_3^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 971838.1527 m^2 (use bbl/day)
= 2149.917668 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AIL-CONT} = \left[\alpha.\left(rate_4^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 2191939001 m^2 (use bbl/day)
= 4849046.493 m^2 (use kg/s)

STEP 8.10

For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Not Likely, Instataneous Release (AINL-INST), $CA_{inj,n}^{AINL-INST}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phase as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

α = $\alpha_{inj,n}^{AINL-INST}$ = 1.609

b = $b_{inj,n}^{AINL-INST}$ = 0.76

2). Calculate the consequence of area using equation below

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

$mass_1^{leak}$ = 24810.8273 kg
$mass_2^{leak}$ = 99243.3091 kg
$mass_3^{leak}$ = 718703.505 kg
$mass_4^{leak}$ = 718703.505 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AINL-INST} = \left[\alpha.\left(mass_1^{AINL-INST}\right)^b\right].\left(\frac{1 - fact_{mit}}{eneff_1}\right)$$

= 209.5976589 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AINL-INST} = \left[\alpha.\left(mass_2^{AINL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_2}\right)$$

$= \quad 522.2633146 \quad m^2$

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AINL-INST} = \left[\alpha.\left(mass_3^{AINL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_3}\right)$$

$= \quad 1980.634292 \quad m^2$

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AINL-INST} = \left[\alpha.\left(mass_4^{AINL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_4}\right)$$

$= \quad 1980.634292 \quad m^2$

STEP 8.11

For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Likely, Instataneous Release (AIL-INST), $CA_{inj,n}^{AIL-INST}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phas as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

$\alpha = \alpha_{inj,n}^{AIL-INST} = \boxed{2.847}$

$b = b_{inj,n}^{AIL-INST} = \boxed{0.54}$

2). Calculate the consequence of area using equation below

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

$mass_1^{leak} = 24810.82728$ kg

$mass_2^{leak} = 99243.30914$ kg

$mass_3^{leak} = 718703.5052$ kg

$mass_4^{leak} = 718703.5052$ kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AIL-INST} = \left[\alpha.\left(mass_1^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_1}\right)$$

$= \quad 40.0310311 \quad m^2$

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AIL-INST} = \left[\alpha.\left(mass_2^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_2}\right)$$

$= \quad 73.5269704 \quad m^2$

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AIL-INST} = \left[\alpha.\left(mass_3^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_3}\right)$$

= 180.3826527 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AIL-INST} = \left[\alpha.\left(mass_4^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_4}\right)$$

= 180.3826527 m^2

STEP 8.12

For each release hole size, calculate the instataneous/continous blending factor, $fact_n^{IC}$.

1). FOR CONTINOUS RELEASE

C_5 = 25 kg/s

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

…………………………

Shell 3

A) SMALL RELEASE HOLE SIZE AREA

$$fact_1^{IC} = \min\left[\left\{\frac{rate_1}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 0.001566874 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$fact_2^{IC} = \min\left[\left\{\frac{rate_2}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 0.006267496 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$fact_3^{IC} = \min\left[\left\{\frac{rate_3}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 0.401119762 (use kg/s)

D) **RUPTURE RELEASE HOLE SIZE AREA**

$$fact_4^{IC} = \min\left[\left\{\frac{rate_3}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 1 (use kg/s)

2). FOR INSTATANEOUS RELEASE

$fact_n^{IC} =$ 1

STEP 8.13

Calculate the AIT blending factor, fact^{AIT}, using these optional equation below.

$fact^{AIT} = 0$ for, $T_S + C_6 \le AIT$

$fact^{AIT} = \dfrac{(T_s - AIT + C_6)}{2\,.\,C_6}$ for, $T_S + C_6 > AIT > T_S - C_6$

$fact^{AIT} = 1$ for, $T_S - C_6 \ge AIT$

Ts = 30 (°C)

Ts = 86 (°F)

Ts = 303 (K)

AIT = 208 (°C)

AIT = 481 (K)

C_6 = 55.6 (K)

$T_s + C_6$ = 358.6 (K)

$T_s - C_6$ = 247.4 (K)

$\dfrac{(T_s - AIT + C_6)}{2\,.\,C_6}$ = -1 (K)

So, $fact^{AIT} = 0$

STEP 8.14

Calculate the continuous/instantaneous blended consequence area for the component using equation (3.53) through (3.56) based on the consequence areas calculated in $fact_n^{IC}$ previous steps

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,1}^{AIL-INST}$ = 10.78 m^2

$fact_1^{IC}$ = #######

$fact_1^{IC}$ = 1

$CA_{cmd,1}^{AIL-CONT}$ = 4.86 m^2

$CA_{cmd,1}^{AIL}$ = 15.63 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,2}^{AIL-INST}$ = 181.45 m^2

$fact_2^{IC}$ = #######

$fact_1^{IC}$ = 1

$CA_{cmd,2}^{AIL-CONT}$ = 18.15 m^2

$CA_{cmd,2}^{AIL}$ = 199.481 m^2

C) LARGE RELEASE HOLE

$CA_{cmd,3}^{AIL-INST}$ = 688.11 m^2

$fact_3^{IC}$ = 4.0E-01

$fact_1^{IC}$ = 1

$CA_{cmd,3}^{AIL-CONT}$ = 943.50 m^2

$CA_{cmd,3}^{AIL}$ = 1253.15 m^2

D) RUPTURE RELEASE HOLE

$CA_{cmd,4}^{AIL-INST}$ = 688.11 m^2

$fact_4^{IC}$ = 1.0000 $fact_1^{IC}$ = 1

$CA_{cmd,4}^{AIL-CONT}$ = 2737279.29 m^2

$CA_{cmd,4}^{AIL}$ = 688.113 m^2

$$CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST} . fact_n^{IC} + CA_{inj,n}^{AIL-CONT} . (1 - fact_n^{IC})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA_{inj,1}^{AIL-INST}$ = 40.0310311 m^2

$fact_1^{IC}$ = 0.001567 $fact_1^{IC}$ = 1

$CA_{inj,1}^{AIL-CONT}$ = 13.08702888 m^2

$CA_{inj,1}^{AIL}$ = 53.10 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{inj,2}^{AIL-INST}$ = 73.5269704 m^2

$fact_2^{IC}$ = 0.0062675 $fact_1^{IC}$ = 1

$CA_{inj,2}^{AIL-CONT}$ = 46.8528758 m^2

$CA_{inj,2}^{AIL}$ = 120.086196 m^2

C) LARGE RELEASE HOLE

$CA_{inj,3}^{AIL-INST}$ = 180.3826527 m^2

$fact_3^{IC}$ = 0.401120 $fact_1^{IC}$ = 1

$CA_{inj,3}^{AIL-CONT}$ = 2149.917668 m^2

$CA_{inj,3}^{AIL}$ = 1467.925857 m^2

D) RUPTURE RELEASE HOLE

$CA_{inj,4}^{AIL-INST}$ = 180.3826527 m^2

$fact_4^{IC}$ = 1.0000 $fact_1^{IC}$ = 1

$CA^{AIL-CONT}_{inj,4}$ = 4849046.493 m^2

$CA^{AIL}_{inj,4}$ = $\underline{180.3826527}$ m^2

$$CA^{AINL}_{cmd,n} = CA^{AINL-INST}_{cmd,n} . fact^{IC}_{n} + CA^{AINL-CONT}_{cmd,n} . (1 - fact^{IC}_{n})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA^{AINL-INST}_{cmd,n}$ = 72.81857758 m^2

$fact^{IC}_{1}$ = 1.57E-03 $fact^{IC}_{1}$ = 1

$CA^{AINL-CONT}_{cmd,1}$ = 1.274822981 m^2

$CA^{AINL}_{cmd,1}$ = $\underline{74.09}$ m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{AINL-INST}_{cmd,n}$ = 181.4451168 m^2

$fact^{IC}_{2}$ = 0.006267 $fact^{IC}_{1}$ = 1

$CA^{AINL-CONT}_{cmd,2}$ = 4.439191456 m^2

$CA^{AINL}_{cmd,2}$ = $\underline{185.8564856}$ m^2

C) LARGE RELEASE HOLE

$CA^{AINL-INST}_{cmd,n}$ = 688.1134676 m^2

$fact^{IC}_{3}$ = 0.4011 $fact^{IC}_{1}$ = 1

$CA^{AINL-CONT}_{cmd,3}$ = 187.4415438 m^2

$CA^{AINL}_{cmd,3}$ = $\underline{800.3685039}$ m^2

D) RUPTURE RELEASE HOLE

$CA^{AINL-INST}_{cmd,4}$ = 688.1134676 m^2

$fact^{IC}_{4}$ = 1.0000 $fact^{IC}_{1}$ = 1

$CA^{AINL-CONT}_{cmd,4}$ = 357440.6732 m^2

$CA^{AINL}_{cmd,4}$ = $\underline{688.1134676}$ m^2

$$CA^{AINL}_{inj,n} = CA^{AINL-INST}_{inj,n} . fact^{IC}_{n} + CA^{AINL-CONT}_{inj,n} . (1 - fact^{IC}_{n})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA^{AINL-INST}_{inj,n}$ = 209.5976589 m^2

$fact^{IC}_{1}$ = 0.0016 $fact^{IC}_{1}$ = 1

$CA^{AINL-CONT}_{inj,1}$. = 3.748301845 m^2

$CA^{AINL}_{inj,1}$ = 213.3400876 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{AINL-INST}_{inj,n}$ = 522.2633146 m^2

$fact^{IC}_{2}$ = 0.006267 $fact^{IC}_{1}$ = 1

$CA^{AINL-CONT}_{inj,2}$. = 12.87264964 m^2

$CA^{AINL}_{inj,2}$ = 535.055285 m^2

C) LARGE RELEASE HOLE

$CA^{AINL-INST}_{inj,n}$ = 1980.634292 m^2

$fact^{IC}_{3}$ = 0.4011 $fact^{IC}_{1}$ = 1

$CA^{AINL-CONT}_{inj,3}$. = 521.3965171 m^2

$CA^{AINL}_{inj,3}$ = 2292.888362 m^2

D) RUPTURE RELEASE HOLE

$CA^{AINL-INST}_{inj,4}$ = 1980.634292 m^2

$fact^{IC}_{4}$ = 1.0000

$CA^{AINL-CONT}_{inj,4}$. = 338569987.7 m^2 $fact^{IC}_{1}$ = 1

$CA^{AINL}_{inj,4}$ = 1980.634292 m^2

STEP 8.15

Calculate the AIT blended consequence areas for the component using equations (3.57) and (3.58) based on the consequence areas determined in step 8.14 and the AIT blending factors, $fact^{AIT}$, calculate in step 8.13. the resulting consequence areas are the component damage and personnel injury flammable consequence areas, $CA^{flam}_{icmd,n}$ and $CA^{flam}_{inj,n}$ for each release hole size selected in step 2.2

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

A) SMALL RELEASE HOLE SIZE AREA

$CA^{AIL}_{cmd,1}$ = 15.63149589 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,1}$ = 74.09140308 m^2

$CA^{flam}_{cmd,1}$ = 74.09140308 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{AIL}_{cmd,2}$ = 199.4810454 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,2}$ = 185.8564856 m^2

$CA^{flam}_{cmd,2}$ = 185.8564856 m^2

C) LARGE RELEASE HOLE

$CA^{AIL}_{cmd,3}$ = 1253.15 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,3}$ = 800.369 m^2

$CA^{flam}_{cmd,3}$ = 800.369 m^2

D) RUPTURE RELEASE HOLE

$CA^{AIL}_{cmd,4}$ = 688.1134676 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,4}$ = 688.1134676 m^2

$CA^{flam}_{cmd,4}$ = 688.1134676 m^2

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

A) SMALL RELEASE HOLE SIZE AREA

$CA^{flam-AIL}_{inj,1}$ = 53.09755425 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{inj,1}$ = 213.3400876 m^2

$CA^{flam}_{inj,1}$ = 213.3400876 m2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{flam-AIL}_{inj,2}$ = 120.086196 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{inj,2}$ = 535.055285 m^2

$CA_{inj,2}^{flam}$ = 535.055285 m2

C) LARGE RELEASE HOLE

$CA_{inj,3}^{flam-AIL}$ = 1467.925857 m^2

$fact^{AIT}$ = 0

$CA_{inj,3}^{AINL}$ = 2292.888362 m^2

CA_{inj3}^{flam} = 2292.888362 m^2

D) RUPTURE RELEASE HOLE

$CA_{inj,4}^{flam-AIL}$ = 180.3826527 m^2

$fact^{AIT}$ = 0

$CA_{inj,4}^{AINL}$ = 1980.634292 m^2

$CA_{inj,4}^{flam}$ = 1980.634292 m^2

STEP 8.16

Determine the consequence areas (probability weighted on release hole size) for component damage and personnel injury using equations (3.59) and (3.60) based on the consequence ara from step 8.15

Equipment Type	**Component Type**	**gff as a function of hole size (failure/yr)**				**gff total (failure/ yr)**
		Small	**Medium**	**Large**	**Rupture**	
Tank650	TANK BOTTOM	7.2E-04	0.00E+00	0.00E+00	2.00E-06	7.20E-04
Tank650	COURSE 1-10	7.0E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04

CONSEQUENCE AREA FOR COMPONENT DAMAGE

For Tank Shell

$$CA_{cmd}^{flam} = \left(\frac{\sum gff_n \cdot CA_{cmd,n}^{flam}}{gff_{total}} \right)$$

$$CA_{cmd}^{flam} = \left(\frac{(gff_{1} \cdot CA_{cmd,1}^{flam}) + (gff_{2} \cdot CA_{cmd,2}^{flam}) + (gff_{3} \cdot CA_{cmd,3}^{flam}) + (gff_{4} \cdot CA_{cmd,4}^{flam})}{gff_{total}} \right)$$

= 139.0346422 m^2

CONSEQUENCE AREA FOR PERSONNEL INJURY

For Tank Shell

$$CA_{inj}^{flam} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{flam}}{gff_{total}} \right)$$

$$CA_{inj}^{flam} = \left(\frac{\left(gff_1 \cdot CA_{inj,1}^{flam}\right) + \left(gff_2 \cdot CA_{inj,2}^{flam}\right) + \left(gff_3 \cdot CA_{inj,3}^{flam}\right) + \left(gff_4 \cdot CA_{inj,4}^{flam}\right)}{gff_{total}} \right)$$

= 399.727 m^2

PART 8 : DETERMINE FLAMMABLE AND EXPLOSIVE CONSEQUENCE

8.1 CONSEQUENCE AREA EQUATIONS (Shell 4)

The following equations are used to determine the flammable consequence areas for comoponent damage and personnel injury. There are two kind of equantions explained based on its type of release, either continous release or instataneous release as mentioned below:

1). $CA_n^{CONT} = \alpha(rate_n)^b$

2). $CA_n^{INST} = \alpha(mass_n)^b$

The coefficients for those equations for component damage areas and personel injury are provided in Table 4.8 and 4.9 in API RP 581 Part 3 of COF.

STEP 8.1 Select the consequence area mitigation reduction factor, factmit, from Table 4.10

Mitigation System	Consequence Area Adjustment	Consequence Area Reduction Factor, factor mit
Inventory blowdown , couple with isolation system classification B or higher	Reduce consequence area by 25 %	0.25
Fire water deluge system and monitors	Reduce consequence area by 20%	0.2
Fire water monitor only	Reduce consequence area by 5%	0.05
Foam spray system	Reduce consequence area by 15%	0.15

Mitigation system = Fire water deluge system and monitors

Consequence Area = Reduce consequence area by 5% *

$fact_{mit}$ = 0.05

STEP 8.2 Calculate the energy efficiency, eneff$_n$, for each hole size using equation mentioned below.

$$eneff_n = 4.\,log_{10}[C_{4A}\,.mass_n] - 15$$

This correction is made for instantaneous events exceeding a release mass of 4,536 kgs (10,000 Ibs). Comparison of calculated consequence with those of actual historical releases indicates that there is need to correct large instantaneous releases for energy efficiency.

C_{4A} = 2205 1/kg

$mass_1^{leak}$= 21240.51336 kg
$mass_2^{leak}$= 84962.05344 kg
$mass_3^{leak}$= 526741.2014 kg
$mass_4^{leak}$= 526741.2014 kg

A) SMALL RELEASE HOLE SIZE AREA

$$eneff_1 = 4.\,log_{10}[C_{4A}\,.mass_1] - 15$$

$eneff_1$ = 15.68229441

B) MEDIUM RELEASE HOLE SIZE AREA

$$eneff_2 = 4.\,log_{10}[C_{4A}\,.mass_2] - 15$$

$eneff_2$ = 18.09053438

C) LARGE RELEASE HOLE SIZE AREA

$$eneff_3 = 4.\,log_{10}[C_{4A}\,.mass_3] - 15$$

$eneff_3$ = 21.26002353

D) RUPTURE RELEASE HOLE SIZE AREA

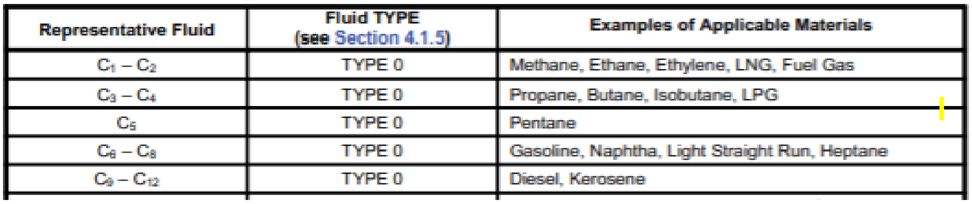
$$eneff_4 = 4.\,log_{10}[C_{4A}\,.mass_4] - 15$$

$eneff_4$ = 21.26002353

STEP 8.3 Determine the fluid type

Determine the fluid type, either TYPE 0 or TYPE 1 based on Table 4.1 of API RP 581 Part 3 of COF.

Table 4.1 – List of Representative Fluids Available for Level 1 Consequence Analysis



Representative Fluid	Fluid TYPE (see Section 4.1.5)	Examples of Applicable Materials
$C_1 - C_2$	TYPE 0	Methane, Ethane, Ethylene, LNG, Fuel Gas
$C_3 - C_4$	TYPE 0	Propane, Butane, Isobutane, LPG
C_5	TYPE 0	Pentane
$C_6 - C_8$	TYPE 0	Gasoline, Naphtha, Light Straight Run, Heptane
$C_9 - C_{12}$	TYPE 0	Diesel, Kerosene

C9-C12 = TYPE 0 NBP = 184 (°C)
MW = 149.00 (kg/kg-mol) ρ = 734.012 kg/m3
AIT = 208 (°C)
AIT = 381 (K)

STEP 8.4 For each release hole size, calculate the component damage consequence areas for Auto-Ignition Not Likely, Continous Release (AINT-CONT), $CA^{AINL-CONT}$

1). Determine the appropriate constant a and b from the Table 4.8

Table 4.8M - Component Damage Flammable Consequence Equation Constants

Fluid	Continuous Release Constant							
	Auto Ignition Not Likely (CAINL)				Auto Ignition Likely (CAIL)			
	Gas		Liquid		Gas		Liquid	
	α	b	α	b	α	b	α	b
C9-C12	2.42	0.98	24.6	0.9	77	0.95	110	0.95

Fluid	Instantaneous Release Constant							
	Auto-Ignition Not Likely (IAINL)				Auto Ignition Likely (IAIL)			
	Gas		Liquid		Gas		Liquid	
	α	b	α	b	α	b	α	b
C9-C12	1.1	0.66	0.56	0.8	42	0.61	0.85	0.53

$\alpha = \alpha_{cmd,n}^{AINL-CONT} = \boxed{24.6}$

$b = b_{cmd}^{AINL-CONT} = \boxed{0.90}$

2). Calculate the consequence of area using equation below

Shell 4

$Rate_1$ = 26.0025 bbl/day
$Rate_2$ = 104.01 bbl/day
$Rate_3$ = 6656.64 bbl/day
$Rate_4$ = 2.9E+07 bbl/day

1 bbl/day = 0.0013 kg/s

Shell 4

$Rate_1$ = 0.0338 kg/s
$Rate_2$ = 0.13521 kg/s
$Rate_3$ = 8.65363 kg/s
$Rate_4$ = 38196.1 kg/s

Shell 4

$$CA^{AINL-CONT}_{cmd,n} = \alpha(rate_n)^b\,.(1 - fact_{mit})$$

A) SMALL RELEASE HOLE SIZE AREA

$$CA^{AINL-CONT}_{cmd,1} = \alpha(rate_1)^b\,.(1 - fact_{mit})$$

= 438.7046663 m^2 (use bbl/day)

= 1.108463178 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA^{AINL-CONT}_{cmd,2} = \alpha(rate_2)^b\,.(1 - fact_{mit})$$

= 1527.658377 m^2 (use bbl/day)

= 3.859892976 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$CA^{AINL-CONT}_{cmd,3} = \alpha(rate_3)^b\,.(1 - fact_{mit})$$

= 64504.23405 m^2 (use bbl/day)

= 162.9810981 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA^{AINL-CONT}_{cmd,4} = \alpha(rate_4)^b\,.(1 - fact_{mit})$$

= 123006012.3 m^2 (use bbl/day)

= 310795.954 m^2 (use kg/s)

STEP 8.5 For ech release hole size, calculate the component damage consequence areas for Auto-Ignition Likely, Continous Release (AIL-CONT), CA$^{AIL-CONT}$

1). Determine the appropriate constant a and b from the Table 4.8

α = $\alpha^{AIL-CONT}_{cmd,n}$ = $\boxed{110.3}$

b = $b^{AIL-CONT}_{cmd}$ = $\boxed{0.95}$

2). Calculate the consequence of area using equation below

Shell 4

$$CA^{AIL-CONT}_{cmd,n} = \alpha(rate_n)^b\,.(1 - fact_{mit})$$

A) SMALL RELEASE HOLE SIZE AREA

$$CA^{AIL-CONT}_{cmd,1} = \alpha(rate_1)^b\,.(1 - fact_{mit})$$

= 2315.066185 m^2 (use bbl/day)

= 4.195749931 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA^{AIL-CONT}_{cmd,2} = \alpha(rate_2)^b\,.(1 - fact_{mit})$$

= 8640.132512 m^2 (use bbl/day)

= 15.65909244 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$CA^{AIL-CONT}_{cmd,3} = \alpha(rate_3)^b\,.(1 - fact_{mit})$$

= 449149.9736 m^2 (use bbl/day)

= 814.0246631 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{cmd,4}^{AIL-CONT} = \alpha(rate_4)^b \,.\, (1 - fact_{mit})$$

= 1303078268 m^2 (use bbl/day)

= 2361656.262 m^2 (use kg/s)

STEP 8.6 For each release hole size, calculate the component damage consequence areas for Auto-ignition Not Likely, Instaneous Release, (AINL-INST), $CA^{AINL-INST}$

1). Determine the appropriate constant a and b from the Table 4.8

$\alpha = \alpha_{cmd,n}^{AINL-INST} = \boxed{0.6}$

$b = b_{cmd}^{AINL-INST} = \boxed{0.76}$

2). Calculate the consequence of area using equation below

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

From step 7, known that:

$mass_1^{leak}$ = 21240.5134 kg
$mass_2^{leak}$ = 84962.0534 kg
$mass_3^{leak}$ = 526741.201 kg
$mass_4^{leak}$ = 526741.201 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{cmd,1}^{AINL-INST} = \alpha(mass_1)^b \,.\, \left(\frac{1-fact_{mit}}{eneff_1}\right)$$

= 65.82202167 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{cmd,2}^{AINL-INST} = \alpha(mass_2)^b \,.\, \left(\frac{1-fact_{mit}}{eneff_2}\right)$$

= 163.6420901 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{cmd,3}^{AINL-INST} = \alpha(mass_3)^b \,.\, \left(\frac{1-fact_{mit}}{eneff_3}\right)$$

= 557.1672906 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{cmd,4}^{AINL-INST} = \alpha(mass_4)^b \,.\, \left(\frac{1-fact_{mit}}{eneff_4}\right)$$

= 557.1672906 m^2

STEP 8.7 For ech release hole size, calculate the component damage consequence areas for Auto-Ignition Likely, Instataneous Release (AIL-INST), $CA^{AIL-INST}$

1). Determine the appropriate constant a and b from the Table 4.8

$\alpha = \alpha_{cmd,n}^{AIL-INST} = \boxed{0.8}$

$b = b_{cmd}^{AIL-INST} = \boxed{0.53}$

2). Calculate the consequence of area using equation below

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

$mass_1^{leak}$ = 21240.5134 kg

$mass_2^{leak}$ = 84962.0534 kg

$mass_3^{leak}$ = 526741.201 kg

$mass_4^{leak}$ = 526741.201 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{cmd,1}^{AIL-INST} = \alpha(mass_1)^b \cdot \left(\frac{1-fact_{mit}}{eneff_1}\right)$$

$$= 10.09502292 \text{ m}^2$$

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{cmd,2}^{AIL-INST} = \alpha(mass_2)^b \cdot \left(\frac{1-fact_{mit}}{eneff_2}\right)$$

$$= 18.24556481 \text{ m}^2$$

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{cmd,3}^{AIL-INST} = \alpha(mass_3)^b \cdot \left(\frac{1-fact_{mit}}{eneff_3}\right)$$

$$= 40.83215302 \text{ m}^2$$

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{cmd,4}^{AIL-INST} = \alpha(mass_4)^b \cdot \left(\frac{1-fact_{mit}}{eneff_4}\right)$$

$$= 40.83215302 \text{ m}^2$$

STEP 8.8 For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Not Likely, Continous Release (AINL-CONT), $CA_{inj,n}^{AINL-CONT}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phas as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

Table 4.9M - Personnel Injury Flammable Consequence Equation Constants

Fluid	**Continuous Release Constant**							
	Auto Ignition Not Likely (CAINL)				**Auto Ignition Likely (CAIL)**			
	Gas		**Liquid**		**Gas**		**Liquid**	
	α	b	α	b	α	b	α	b
C9-C12	5.8	0.96	70.03	0.9	189	0.92	269.4	0.92

Fluid	Instantaneous Release Constant							
	Auto-Ignition Not Likely (IAINL)				Auto Ignition Likely (IAIL)			
	Gas		Liquid		Gas		Liquid	
	α	b	α	b	α	b	α	b
C9-C12	2.0	0.66	1.61	0.8	151	0.63	2.85	0.54

$\alpha = \alpha_{inj,n}^{AINL-CONT} = \boxed{70.03}$

$b = b_{inj,n}^{AINL-CONT} = \boxed{0.89}$

2). Calculate the consequence of area using equation below

$$CA_{inj,n}^{AINL-CONT} = [\alpha.(rate_n^{AINL-CONT})^b].(1-fact_{mit})$$

Shell 4

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AINL-CONT} = \left[\alpha.\left(rate_1^{AINL-CONT}\right)^b\right].(1-fact_{mit})$$

= 1208.846403 m^2 (use bbl/day)

= 3.264229656 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AINL-CONT} = \left[\alpha.\left(rate_2^{AINL-CONT}\right)^b\right].(1-fact_{mit})$$

= 4151.494959 m^2 (use bbl/day)

= 11.21021904 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AINL-CONT} = \left[\alpha.\left(rate_3^{AINL-CONT}\right)^b\right].(1-fact_{mit})$$

= 168153.0278 m^2 (use bbl/day)

= 454.0610774 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AINL-CONT} = \left[\alpha.\left(rate_4^{AINL-CONT}\right)^b\right].(1-fact_{mit})$$

= 294845570.2 m^2 (use bbl/day)

= 796167.0331 m^2 (use kg/s)

STEP 8.9 For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Likely, Continous Release (AIL-CONT), $CA_{inj,n}^{AIL-CONT}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phasE as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

$\alpha = \alpha_{inj,n}^{AIL-CONT} = \boxed{269.4}$

$b = b_{inj,n}^{AIL-CONT} = \boxed{0.92}$

2). Calculate the consequence of area using equation below

$$CA_{inj,n}^{AIL-CONT} = [\alpha.(rate_n^{AIL-CONT})^b].(1 - fact_{mit})$$

Shell 1

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AIL-CONT} = \left[\alpha.\left(rate_1^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 5127.846769 m^2 (use bbl/day)
= 11.34391394 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AIL-CONT} = \left[\alpha.\left(rate_2^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 18358.20567 m^2 (use bbl/day)
= 40.61234952 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AIL-CONT} = \left[\alpha.\left(rate_3^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 842395.0517 m^2 (use bbl/day)
= 1863.561335 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AIL-CONT} = \left[\alpha.\left(rate_4^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 1899985675 m^2 (use bbl/day)
= 4203182.145 m^2 (use kg/s)

STEP 8.10 For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Not Likely, Instataneous Release (AINL-INST), $CA_{inj,n}^{AINL-INST}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phase as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

$\alpha = \alpha_{inj,n}^{AINL-INST} = \boxed{1.609}$

$b = b_{inj,n}^{AINL-INST} = \boxed{0.76}$

2). Calculate the consequence of area using equation below

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

$mass_1^{leak}$ = 21240.5134 kg
$mass_2^{leak}$ = 84962.0534 kg
$mass_3^{leak}$ = 526741.201 kg
$mass_4^{leak}$ = 526741.201 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AINL-INST} = \left[\alpha.\left(mass_1^{AINL-INST}\right)^b\right].\left(\frac{1 - fact_{mit}}{eneff_1}\right)$$

= 189.4590928 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AINL-INST} = \left[\alpha.\left(mass_2^{AINL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_2}\right)$$

= 471.0198979 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AINL-INST} = \left[\alpha.\left(mass_3^{AINL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_3}\right)$$

= 1603.724813 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AINL-INST} = \left[\alpha.\left(mass_4^{AINL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_4}\right)$$

= 1603.724813 m^2

STEP 8.11 For each release hole size, calculate the personnel injury consequence areas for Auto- $CA_{inj,n}^{AIL-INST}$ ignition Likely, Instataneous Release (AIL-INST),

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phas as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

α = $\alpha_{inj,n}^{AIL-INST}$ = 2.847

b = $b_{inj,n}^{AIL-INST}$ = 0.54

2). Calculate the consequence of area using equation below

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

$mass_1^{leak}$= 21240.51336 kg

$mass_2^{leak}$= 84962.05344 kg

$mass_3^{leak}$= 526741.2014 kg

$mass_4^{leak}$= 526741.2014 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AIL-INST} = \left[\alpha.\left(mass_1^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_1}\right)$$

= 37.44299453 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AIL-INST} = \left[\alpha.\left(mass_2^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_2}\right)$$

= 68.61849317 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AIL-INST} = \left[\alpha.\left(mass_3^{AIL-INST}\right)^b\right].\left(\frac{1 - fact_{mit}}{eneff_3}\right)$$

= 156.3903199 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AIL-INST} = \left[\alpha.\left(mass_4^{AIL-INST}\right)^b\right].\left(\frac{1 - fact_{mit}}{eneff_4}\right)$$

= 156.3903199 m^2

STEP 8.12

For each release hole size, calculate the instataneous/continous blending factor, $fact_n^{IC}$.

1). FOR CONTINOUS RELEASE

C_5 = 25 kg/s

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

…………………………

Shell 4

A) SMALL RELEASE HOLE SIZE AREA

$$fact_1^{IC} = \min\left[\left\{\frac{rate_1}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 0.001341399 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$fact_2^{IC} = \min\left[\left\{\frac{rate_2}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 0.005365595 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$fact_3^{IC} = \min\left[\left\{\frac{rate_3}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 0.343398049 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$fact_4^{IC} = \min\left[\left\{\frac{rate_3}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 1 (use kg/s)

2). FOR INSTATANEOUS RELEASE

$fact_n^{IC} =$ 1

STEP 8.13

Calculate the AIT blending factor, fact^{AIT}, using these optional equation below.

$$fact^{AIT} = 0 \qquad \text{for, } T_S + C_6 \leq AIT$$

$$fact^{AIT} = \frac{(T_s - AIT + C_6)}{2\,.\,C_6} \qquad \text{for, } T_S + C_6 > AIT > T_S - C_6$$

$$fact^{AIT} = 1 \qquad \text{for, } T_S - C_6 \geq AIT$$

Ts = 30 (°C)

Ts = 86 (°F)

Ts = 303 (K)

AIT = 208 (°C)

AIT = 481 (K)

C_6 = 55.6 (K)

$T_s + C_6$ = 358.6 (K)

$T_s - C_6$ = 247.4 (K)

$$\frac{(T_s - AIT + C_6)}{2\,.\,C_6} = -1 \quad (K)$$

So, $fact^{AIT} = 0$

STEP 8.14

Calculate the continuous/instantaneous blended consequence area for the component using equation (3.53) through (3.56) based on the consequence areas calculated in $fact_n^{IC}$ previous steps

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,1}^{AIL-INST}$ = 10.10 m^2

$fact_1^{IC}$ = ####### $\qquad fact_1^{IC}$ = 1

$CA_{cmd,1}^{AIL-CONT}$ = 4.20 m^2

$CA_{cmd,1}^{AIL}$ = 14.29 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,2}^{AIL-INST}$ = 163.64 m^2

$fact_2^{IC}$ = ####### $\qquad fact_1^{IC}$ = 1

$CA_{cmd,2}^{AIL-CONT}$ = 15.66 m^2

$CA_{cmd,2}^{AIL}$ = 179.217 m^2

C) LARGE RELEASE HOLE

$CA_{cmd,3}^{AIL-INST}$ = 557.17 m^2

$fact_3^{IC}$ = 3.4E-01 $\qquad fact_1^{IC}$ = 1

$CA_{cmd,3}^{AIL-CONT}$ = 814.02 m^2

$CA_{cmd,3}^{AIL}$ = 1091.66 m^2

D) RUPTURE RELEASE HOLE

$CA_{cmd,4}^{AIL-INST}$ = 557.17 m^2

$fact_4^{IC}$ = 1.0000 $fact_1^{IC}$ = 1

$CA_{cmd,4}^{AIL-CONT}$ = 2361656.26 m^2

$CA_{cmd,4}^{AIL}$ = 557.167 m^2

$$CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST} . fact_n^{IC} + CA_{inj,n}^{AIL-CONT} . (1 - fact_n^{IC})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA_{inj,1}^{AIL-INST}$ = 37.44299453 m^2

$fact_1^{IC}$ = 0.001341 $fact_1^{IC}$ = 1

$CA_{inj,1}^{AIL-CONT}$ = 11.34391394 m^2

$CA_{inj,1}^{AIL}$ = 48.77 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{inj,2}^{AIL-INST}$ = 68.61849317 m^2

$fact_2^{IC}$ = 0.0053656 $fact_1^{IC}$ = 1

$CA_{inj,2}^{AIL-CONT}$ = 40.61234952 m^2

$CA_{inj,2}^{AIL}$ = 109.0129333 m^2

C) LARGE RELEASE HOLE

$CA_{inj,3}^{AIL-INST}$ = 156.3903199 m^2

$fact_3^{IC}$ = 0.343398 $fact_1^{IC}$ = 1

$CA_{inj,3}^{AIL-CONT}$ = 1863.561335 m^2

$CA_{inj,3}^{AIL}$ = 1380.008329 m^2

D) RUPTURE RELEASE HOLE

$CA_{inj,4}^{AIL-INST}$ = 156.3903199 m^2

$fact_4^{IC}$ = 1.0000 $fact_1^{IC}$ = 1

$CA_{inj,4}^{AIL-CONT}$ = 4203182.145 m^2

$CA_{inj,4}^{AIL}$ = $\underline{156.3903199}$ m^2

$$CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST} . fact_n^{IC} + CA_{cmd,n}^{AINL-CONT} . (1 - fact_n^{IC})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,n}^{AINL-INST}$ = 65.82202167 m^2

$fact_1^{IC}$ = 1.34E-03 $fact_1^{IC}$ = 1

$CA_{cmd,1}^{AINL-CONT}$ = 1.108463178 m^2

$CA_{cmd,1}^{AINL}$ = $\underline{66.93}$ m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,n}^{AINL-INST}$ = 163.6420901 m^2

$fact_2^{IC}$ = 0.005366 $fact_1^{IC}$ = 1

$CA_{cmd,2}^{AINL-CONT}$ = 3.859892976 m^2

$CA_{cmd,2}^{AINL}$ = $\underline{167.4812724}$ m^2

C) LARGE RELEASE HOLE

$CA_{cmd,n}^{AINL-INST}$ = 557.1672906 m^2

$fact_3^{IC}$ = 0.3434 $fact_1^{IC}$ = 1

$CA_{cmd,3}^{AINL-CONT}$ = 162.9810981 m^2

$CA_{cmd,3}^{AINL}$ = $\underline{664.1809977}$ m^2

D) RUPTURE RELEASE HOLE

$CA_{cmd,4}^{AINL-INST}$ = 557.1672906 m^2

$fact_4^{IC}$ = 1.0000 $fact_1^{IC}$ = 1

$CA_{cmd,4}^{AINL-CONT}$ = 310795.954 m^2

$CA_{cmd,4}^{AINL}$ = $\underline{557.1672906}$ m^2

$$CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST} . fact_n^{IC} + CA_{inj,n}^{AINL-CONT} . (1 - fact_n^{IC})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA_{inj,n}^{AINL-INST}$ = 189.4590928 m^2

$fact_1^{IC}$ = 0.0013 $fact_1^{IC}$ = 1

$CA^{AINL-CONT}_{inj,1}$. = 3.264229656 m^2

$CA^{AINL}_{inj,1}$ = 192.7189438 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{AINL-INST}_{inj,n}$ = 471.0198979 m^2

$fact^{IC}_{2}$ = 0.005366 $fact^{IC}_{1}$ = 1

$CA^{AINL-CONT}_{inj,2}$. = 11.21021904 m^2

$CA^{AINL}_{inj,2}$ = 482.1699674 m^2

C) LARGE RELEASE HOLE

$CA^{AINL-INST}_{inj,n}$ = 1603.724813 m^2

$fact^{IC}_{3}$ = 0.3434 $fact^{IC}_{1}$ = 1

$CA^{AINL-CONT}_{inj,3}$. = 454.0610774 m^2

$CA^{AINL}_{inj,3}$ = 1901.862203 m^2

D) RUPTURE RELEASE HOLE

$CA^{AINL-INST}_{inj,4}$ = 1603.724813 m^2

$fact^{IC}_{4}$ = 1.0000

$CA^{AINL-CONT}_{inj,4}$. = 294845570.2 m^2 $fact^{IC}_{1}$ = 1

$CA^{AINL}_{inj,4}$ = 1603.724813 m^2

STEP 8.15

Calculate the AIT blended consequence areas for the component using equations (3.57) and (3.58) based on the consequence areas determined in step 8.14 and the AIT blending factors, $fact^{AIT}$, calculate in step 8.13. the resulting consequence areas are the component damage and personnel injury flammable consequence areas, $CA^{flam}_{icmd,n}$ and $CA^{flam}_{inj,n}$ for each release hole size selected in step 2.2

$$CA^{flam}_{cmd,n} = CA^{AIL}_{smd,n} . fact^{AIT} + CA^{AINL}_{cmd,n} . (1 - fact^{AIT})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA^{AIL}_{cmd,1}$ = 14.28514468 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,1}$ = 66.92899796 m^2

$CA_{cmd,1}^{flam}$ = $\underline{66.92899796}$ m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,2}^{AIL}$ = 179.2171622 m^2

$fact^{AIT}$ = 0

$CA_{cmd,2}^{AINL}$ = 167.4812724 m^2

$CA_{cmd,2}^{flam}$ = $\underline{167.4812724}$ m^2

C) LARGE RELEASE HOLE

$CA_{cmd,3}^{AIL}$ = 1091.66 m^2

$fact^{AIT}$ = 0

$CA_{cmd,3}^{AINL}$ = 664.181 m^2

$CA_{cmd,3}^{flam}$ = $\underline{664.181}$ m^2

D) RUPTURE RELEASE HOLE

$CA_{cmd,4}^{AIL}$ = 557.1672906 m^2

$fact^{AIT}$ = 0

$CA_{cmd,4}^{AINL}$ = 557.1672906 m^2

$CA_{cmd,4}^{flam}$ = $\underline{557.1672906}$ m^2

$$CA_{inj,n}^{flam} = CA_{inj,n}^{flam-AIL} \cdot fact^{AIT} + CA_{inj,n}^{AINL} \cdot (1 - fact^{AIT})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA_{inj,1}^{flam-AIL}$ = 48.77169176 m^2

$fact^{AIT}$ = 0

$CA_{inj,1}^{AINL}$ = 192.7189438 m^2

$CA_{inj,1}^{flam}$ = $\underline{192.7189438}$ m2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{inj,2}^{flam-AIL}$ = 109.0129333 m^2

$fact^{AIT}$ = 0

$CA_{inj,2}^{AINL}$ = 482.1699674 m^2

$CA_{inj,2}^{flam}$ = 482.1699674 m2

C) LARGE RELEASE HOLE

$CA_{inj,3}^{flam-AIL}$ = 1380.008329 m^2

$fact^{AIT}$ = 0

$CA_{inj,3}^{AINL}$ = 1901.862203 m^2

CA_{inj3}^{flam} = 1901.862203 m^2

D) RUPTURE RELEASE HOLE

$CA_{inj,4}^{flam-AIL}$ = 156.3903199 m^2

$fact^{AIT}$ = 0

$CA_{inj,4}^{AINL}$ = 1603.724813 m^2

$CA_{inj,4}^{flam}$ = 1603.724813 m^2

STEP 8.16

Determine the consequence areas (probability weighted on release hole size) for component damage and personnel injury using equations (3.59) and (3.60) based on the consequence ara from step 8.15

Equipment Type	**Component Type**	**gff as a function of hole size (failure/yr)**				**gff total (failure/ yr)**
		Small	**Medium**	**Large**	**Rupture**	
Tank650	TANK BOTTOM	7.2E-04	0.00E+00	0.00E+00	2.00E-06	7.20E-04
Tank650	COURSE 1-10	7.0E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04

CONSEQUENCE AREA FOR COMPONENT DAMAGE

For Tank Shell

$$CA_{cmd}^{flam} = \left(\frac{\sum gff_n \; . \; CA_{cmd,n}^{flam}}{gff_{total}} \right)$$

$$CA_{cmd}^{flam} = \left(\frac{(gff_{1} . \; CA_{cmd,1}^{flam}) + (gff_{2} . \; CA_{cmd,2}^{flam}) + (gff_{3} . \; CA_{cmd,3}^{flam}) + (gff_{4} . \; CA_{cmd,4}^{flam})}{gff_{total}} \right)$$

= 122.4868339 m^2

CONSEQUENCE AREA FOR PERSONNEL INJURY

For Tank Shell

$$CA_{inj}^{flam} = \left(\frac{\sum gff_n \; . \; CA_{inj,n}^{flam}}{gff_{total}} \right)$$

$$CA_{inj}^{flam} = \left(\frac{\left(gff_1 \; . \; CA_{inj,1}^{flam}\right) + \left(gff_2 \; . \; CA_{inj,2}^{flam}\right) + \left(gff_3 \; . \; CA_{inj,3}^{flam}\right) + \left(gff_4 \; . \; CA_{inj,4}^{flam}\right)}{gff_{total}} \right)$$

= 352.143 m^2

PART 8 : DETERMINE FLAMMABLE AND EXPLOSIVE CONSEQUENCE

8.1 CONSEQUENCE AREA EQUATIONS (Shell 5)

The following equations are used to determine the flammable consequence areas for comoponent damage and personnel injury. There are two kind of equantions explained based on its type of release, either continous release or instataneous release as mentioned below:

1). $CA_n^{CONT} = \alpha(rate_n)^b$

2). $CA_n^{INST} = \alpha(mass_n)^b$

The coefficients for those equations for component damage areas and personel injury are provided in Table 4.8 and 4.9 in API RP 581 Part 3 of COF.

STEP 8.1 Select the consequence area mitigation reduction factor, factmit, from Table 4.10

Mitigation System	**Consequence Area Adjustment**	**Consequence Area Reduction Factor, factor mit**
Inventory blowdown , couple with isolation system classification B or higher	Reduce consequence area by 25 %	0.25
Fire water deluge system and monitors	Reduce consequence area by 20%	0.2
Fire water monitor only	Reduce consequence area by 5%	0.05
Foam spray system	Reduce consequence area by 15%	0.15

Mitigation system = Fire water deluge system and monitors

Consequence Area = Reduce consequence area by 5% *

$fact_{mit}$ = 0.05

STEP 8.2 Calculate the energy efficiency, $eneff_n$, for each hole size using equation mentioned below.

$$eneff_n = 4.\, log_{10}[C_{4A}\, .mass_n] - 15$$

This correction is made for instantaneous events exceeding a release mass of 4,536 kgs (10,000 Ibs). Comparison of calculated consequence with those of actual historical releases indicates that there is need to correct large instantaneous releases for energy efficiency.

C_{4A} = 2205 1/kg

$mass_1^{leak}$= 16933.44812 kg
$mass_2^{leak}$= 67733.79246 kg
$mass_3^{leak}$= 334778.8975 kg
$mass_4^{leak}$= 334778.8975 kg

A) SMALL RELEASE HOLE SIZE AREA

$$eneff_1 = 4.\, log_{10}[C_{4A}\, .mass_1] - 15$$

$eneff_1$ = 15.28861598

B) MEDIUM RELEASE HOLE SIZE AREA

$$eneff_2 = 4.\, log_{10}[C_{4A}\, .mass_2] - 15$$

$eneff_2$ = 17.69685595

C) LARGE RELEASE HOLE SIZE AREA

$$eneff_3 = 4.\, log_{10}[C_{4A}\, .mass_3] - 15$$

$eneff_3$ = 20.47266667

D) RUPTURE RELEASE HOLE SIZE AREA

$$eneff_4 = 4.\, log_{10}[C_{4A}\, .mass_4] - 15$$

$eneff_4$ = 20.47266667

STEP 8.3 Determine the fluid type

Determine the fluid type, either TYPE 0 or TYPE 1 based on Table 4.1 of API RP 581 Part 3 of COF.

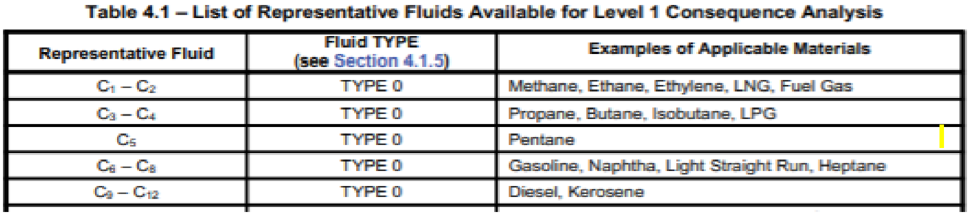


Table 4.1 – List of Representative Fluids Available for Level 1 Consequence Analysis

Representative Fluid	Fluid TYPE (see Section 4.1.5)	Examples of Applicable Materials
$C_1 - C_2$	TYPE 0	Methane, Ethane, Ethylene, LNG, Fuel Gas
$C_3 - C_4$	TYPE 0	Propane, Butane, Isobutane, LPG
C_5	TYPE 0	Pentane
$C_6 - C_8$	TYPE 0	Gasoline, Naphtha, Light Straight Run, Heptane
$C_9 - C_{12}$	TYPE 0	Diesel, Kerosene

C9-C12 = TYPE 0 NBP = 184 (^{o}C)
MW = 149.00 (kg/kg-mol) ρ = 734.012 kg/m3
AIT = 208 (^{o}C)
AIT = 381 (K)

STEP 8.4 For each release hole size, calculate the component damage consequence areas for Auto-Ignition Not Likely, Continous Release (AINT-CONT), $CA^{AINL-CONT}$

1). Determine the appropriate constant a and b from the Table 4.8

Table 4.8M - Component Damage Flammable Consequence Equation Constants

Fluid	**Continuous Release Constant**							
	Auto Ignition Not Likely (CAINL)				**Auto Ignition Likely (CAIL)**			
	Gas		**Liquid**		**Gas**		**Liquid**	
	α	b	α	b	α	b	α	b
C9-C12	2.42	0.98	24.6	0.9	77	0.95	110	0.95

Fluid	**Instantaneous Release Constant**							
	Auto-Ignition Not Likely (IAINL)				**Auto Ignition Likely (IAIL)**			
	Gas		**Liquid**		**Gas**		**Liquid**	
	α	b	α	b	α	b	α	b
C9-C12	1.1	0.66	0.56	0.8	42	0.61	0.85	0.53

α = $\alpha_{cmd,n}^{AINL-CONT}$ = $\boxed{24.6}$

b = $b_{cmd}^{AINL-CONT}$ = $\boxed{0.90}$

2). Calculate the consequence of area using equation below

Shell 5

$Rate_1$ = 20.7298 bbl/day
$Rate_2$ = 82.9193 bbl/day
$Rate_3$ = 5306.83 bbl/day
$Rate_4$ = 2.3E+07 bbl/day

1 bbl/day = 0.0013 kg/s

Shell 5

$Rate_1$ = 0.02695 kg/s
$Rate_2$ = 0.1078 kg/s
$Rate_3$ = 6.89888 kg/s
$Rate_4$ = 30450.8 kg/s

Shell 5

$$CA_{cmd,n}^{AINL-CONT} = \alpha(rate_n)^b \cdot (1 - fact_{mit})$$

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{cmd,1}^{AINL-CONT} = \alpha(rate_1)^b \cdot (1 - fact_{mit})$$

= 357.7623273 m^2 (use bbl/day)

= 0.903948366 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{cmd,2}^{AINL-CONT} = \alpha(rate_2)^b \cdot (1 - fact_{mit})$$

= 1245.800782 m^2 (use bbl/day)

= 3.147731037 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{cmd,3}^{AINL-CONT} = \alpha(rate_3)^b \cdot (1 - fact_{mit})$$

= 52603.0076 m^2 (use bbl/day)

= 132.9105921 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{cmd,4}^{AINL-CONT} = \alpha(rate_4)^b \cdot (1 - fact_{mit})$$

= 100311030.6 m^2 (use bbl/day)

= 253453.1596 m^2 (use kg/s)

STEP 8.5 For ech release hole size, calculate the component damage consequence areas for Auto-Ignition Likely, Continous Release (AIL-CONT), $CA^{AIL-CONT}$

1). Determine the appropriate constant a and b from the Table 4.8

α = $\alpha_{cmd,n}^{AIL-CONT}$ = $\boxed{110.3}$

b = $b_{cmd}^{AIL-CONT}$ = $\boxed{0.95}$

2). Calculate the consequence of area using equation below

Shell 5

$$CA_{cmd,n}^{AIL-CONT} = \alpha(rate_n)^b \cdot (1 - fact_{mit})$$

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{cmd,1}^{AIL-CONT} = \alpha(rate_1)^b \cdot (1 - fact_{mit})$$

= 1866.658122 m^2 (use bbl/day)

= 3.383069883 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{cmd,2}^{AIL-CONT} = \alpha(rate_2)^b \cdot (1 - fact_{mit})$$

= 6966.614447 m^2 (use bbl/day)

= 12.62606325 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{cmd,3}^{AIL-CONT} = \alpha(rate_3)^b \cdot (1 - fact_{mit})$$

= 362153.5539 m^2 (use bbl/day)

= 656.3552086 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA^{AIL-CONT}_{cmd,4} = \alpha(rate_4)^b \cdot (1 - fact_{mit})$$

= 1050683409 m^2 (use bbl/day)

= 1904224.109 m^2 (use kg/s)

STEP 8.6 For each release hole size, calculate the component damage consequence areas for Auto-ignition Not Likely, Instaneous Release, (AINL-INST), $CA^{AINL-INST}$

1). Determine the appropriate constant a and b from the Table 4.8

$\alpha = \alpha^{AINL-INST}_{cmd,n} = \boxed{0.6}$

$b = b^{AINL-INST}_{cmd} = \boxed{0.76}$

2). Calculate the consequence of area using equation below

$$CA^{AINL-INST}_{cmd,n} = \alpha(mass_n)^b \cdot \left(\frac{1-fact_{mit}}{eneff_n}\right)$$

From step 7, known that:

$mass^{leak}_1$ = 16933.4481 kg

$mass^{leak}_2$ = 67733.7925 kg

$mass^{leak}_3$ = 334778.898 kg

$mass^{leak}_4$ = 334778.898 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA^{AINL-INST}_{cmd,1} = \alpha(mass_1)^b \cdot \left(\frac{1-fact_{mit}}{eneff_1}\right)$$

= 56.83472279 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA^{AINL-INST}_{cmd,2} = \alpha(mass_2)^b \cdot \left(\frac{1-fact_{mit}}{eneff_2}\right)$$

= 140.815803 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA^{AINL-INST}_{cmd,3} = \alpha(mass_3)^b \cdot \left(\frac{1-fact_{mit}}{eneff_3}\right)$$

= 409.9936539 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA^{AINL-INST}_{cmd,4} = \alpha(mass_4)^b \cdot \left(\frac{1-fact_{mit}}{eneff_4}\right)$$

= 409.9936539 m^2

STEP 8.7 For ech release hole size, calculate the component damage consequence areas for Auto-Ignition Likely, Instataneous Release (AIL-INST), $CA^{AIL-INST}$

1). Determine the appropriate constant a and b from the Table 4.8

$\alpha = \alpha^{AIL-INST}_{cmd,n} = \boxed{0.8}$

$b = b^{AIL-INST}_{cmd} = \boxed{0.53}$

2). Calculate the consequence of area using equation below

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

$mass_1^{leak}$ = 16933.4481 kg

$mass_2^{leak}$ = 67733.7925 kg

$mass_3^{leak}$ = 334778.898 kg

$mass_4^{leak}$ = 334778.898 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{cmd,1}^{AIL-INST} = \alpha(mass_1)^b \cdot \left(\frac{1-fact_{mit}}{eneff_1}\right)$$

= 9.183037295 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{cmd,2}^{AIL-INST} = \alpha(mass_2)^b \cdot \left(\frac{1-fact_{mit}}{eneff_2}\right)$$

= 16.54055966 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{cmd,3}^{AIL-INST} = \alpha(mass_3)^b \cdot \left(\frac{1-fact_{mit}}{eneff_3}\right)$$

= 33.34777186 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{cmd,4}^{AIL-INST} = \alpha(mass_4)^b \cdot \left(\frac{1-fact_{mit}}{eneff_4}\right)$$

= 33.34777186 m^2

STEP 8.8 For each release hole size, calculate the personnel injury consequence areas for Auto- $CA_{inj,n}^{AINL-CONT}$ ignition Not Likely, Continous Release (AINL-CONT),

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phas as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

Table 4.9M - Personnel Injury Flammable Consequence Equation Constants

Fluid	**Continuous Release Constant**							
	Auto Ignition Not Likely (CAINL)				**Auto Ignition Likely (CAIL)**			
	Gas		**Liquid**		**Gas**		**Liquid**	
	α	b	α	b	α	b	α	b
C9-C12	5.8	0.96	70.03	0.9	189	0.92	269.4	0.92

Fluid	Instantaneous Release Constant							
	Auto-Ignition Not Likely (IAINL)				Auto Ignition Likely (IAIL)			
	Gas		Liquid		Gas		Liquid	
	α	b	α	b	α	b	α	b
C9-C12	2.0	0.66	1.61	0.8	151	0.63	2.85	0.54

α = $\alpha_{inj,n}^{AINL-CONT}$ = $\boxed{70.03}$

b = $b_{inj,n}^{AINL-CONT}$ = $\boxed{0.89}$

2). Calculate the consequence of area using equation below

$$CA_{inj,n}^{AINL-CONT} = [\alpha.(rate_n^{AINL-CONT})^b].(1 - fact_{mit})$$

Shell 5

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AINL-CONT} = \left[\alpha.\left(rate_1^{AINL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 988.0471548 m^2 (use bbl/day)

= 2.668008786 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AINL-CONT} = \left[\alpha.\left(rate_2^{AINL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 3393.212547 m^2 (use bbl/day)

= 9.162640512 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AINL-CONT} = \left[\alpha.\left(rate_3^{AINL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 137439.397 m^2 (use bbl/day)

= 371.1255247 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AINL-CONT} = \left[\alpha.\left(rate_4^{AINL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 240991184.6 m^2 (use bbl/day)

= 650744.8504 m^2 (use kg/s)

STEP 8.9 For each release hole size, calculate the personnel injury consequence areas for Auto- $CA_{inj,n}^{AIL-CONT}$ ignition Likely, Continous Release (AIL-CONT),

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phasE as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

α = $\alpha_{inj,n}^{AIL-CONT}$ = $\boxed{269.4}$

b = $b_{inj,n}^{AIL-CONT}$ = $\boxed{0.92}$

2). Calculate the consequence of area using equation below

$$CA_{inj,n}^{AIL-CONT} = [\alpha.(rate_n^{AIL-CONT})^b].(1 - fact_{mit})$$

Shell 1

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AIL-CONT} = \left[\alpha.\left(rate_1^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 4162.833109 m^2 (use bbl/day)
= 9.209093539 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AIL-CONT} = \left[\alpha.\left(rate_2^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 14903.36 m^2 (use bbl/day)
= 32.96947839 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AIL-CONT} = \left[\alpha.\left(rate_3^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 683864.0409 m^2 (use bbl/day)
= 1512.85621 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AIL-CONT} = \left[\alpha.\left(rate_4^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 1542425823 m^2 (use bbl/day)
= 3412181.875 m^2 (use kg/s)

STEP 8.10

For each release hole size, calculate the personnel injury consequence areas for Auto-$CA_{inj,n}^{AINL-INST}$ ignition Not Likely, Instataneous Release (AINL-INST),

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phase as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

α = $\alpha_{inj,n}^{AINL-INST}$ = 1.609

b = $b_{inj,n}^{AINL-INST}$ = 0.76

2). Calculate the consequence of area using equation below

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

$mass_1^{leak}$ = 16933.4481 kg
$mass_2^{leak}$ = 67733.7925 kg
$mass_3^{leak}$ = 334778.898 kg
$mass_4^{leak}$ = 334778.898 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AINL-INST} = \left[\alpha.\left(mass_1^{AINL-INST}\right)^b\right].\left(\frac{1 - fact_{mit}}{eneff_1}\right)$$

= 163.5904633 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AINL-INST} = \left[\alpha.\left(mass_2^{AINL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_2}\right)$$

= 405.3177584 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AINL-INST} = \left[\alpha.\left(mass_3^{AINL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_3}\right)$$

= 1180.106957 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AINL-INST} = \left[\alpha.\left(mass_4^{AINL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_4}\right)$$

= 1180.106957 m^2

STEP 8.11

For each release hole size, calculate the personnel injury consequence areas for Auto- $CA_{inj,n}^{AIL-INST}$ ignition Likely, Instataneous Release (AIL-INST),

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phas as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

α = $\alpha_{inj,n}^{AIL-INST}$ = $\boxed{2.847}$

b = $b_{inj,n}^{AIL-INST}$ = $\boxed{0.54}$

2). Calculate the consequence of area using equation below

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

$mass_1^{leak}$= 16933.44812 kg

$mass_2^{leak}$= 67733.79246 kg

$mass_3^{leak}$= 334778.8975 kg

$mass_4^{leak}$= 334778.8975 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AIL-INST} = \left[\alpha.\left(mass_1^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_1}\right)$$

= 33.98328964 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AIL-INST} = \left[\alpha.\left(mass_2^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_2}\right)$$

= 62.06544432 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AIL-INST} = \left[\alpha.\left(mass_3^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_3}\right)$$

= 127.1469706 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AIL-INST} = \left[\alpha.\left(mass_4^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_4}\right)$$

= 127.1469706 m^2

STEP 8.12

For each release hole size, calculate the instataneous/continous blending factor, $fact_n^{IC}$.

1). FOR CONTINOUS RELEASE

C_5 = 25 kg/s

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

…………………………

Shell 5

A) SMALL RELEASE HOLE SIZE AREA

$$fact_1^{IC} = \min\left[\left\{\frac{rate_1}{C_5}\right\}, 1.0\right]$$

= 0.822611729 (use bbl/day)

= 0.001069395 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$fact_2^{IC} = \min\left[\left\{\frac{rate_2}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 0.004277581 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$fact_3^{IC} = \min\left[\left\{\frac{rate_3}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 0.273765184 (use kg/s)

D) **RUPTURE RELEASE HOLE SIZE AREA**

$$fact_4^{IC} = \min\left[\left\{\frac{rate_3}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 1 (use kg/s)

2). FOR INSTATANEOUS RELEASE

$$fact_n^{IC} = \quad 1$$

STEP 8.13

Calculate the AIT blending factor, fact^{AIT}, using these optional equation below.

$$fact^{AIT} = 0 \qquad \text{for, } T_S + C_6 \leq AIT$$

$$fact^{AIT} = \frac{(T_s - AIT + C_6)}{2\,.\,C_6} \qquad \text{for, } T_S + C_6 > AIT > T_S - C_6$$

$$fact^{AIT} = 1 \qquad \text{for, } T_S - C_6 \geq AIT$$

Ts = 30 (°C)

Ts = 86 (°F)

Ts = 303 (K)

AIT = 208 (°C)

AIT = 481 (K)

C_6 = 55.6 (K)

$T_s + C_6$ = 358.6 (K)

$T_s - C_6$ = 247.4 (K)

$$\frac{(T_s - AIT + C_6)}{2\,.\,C_6} = -1 \quad (K)$$

So, $fact^{AIT} = 0$

STEP 8.14

Calculate the continuous/instantaneous blended consequence area for the component using equation (3.53) through (3.56) based on the consequence areas calculated in $fact_n^{IC}$ previous steps

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,1}^{AIL-INST}$ = 9.18 m^2

$fact_1^{IC}$ = ####### $\qquad fact_1^{IC}$ = 1

$CA_{cmd,1}^{AIL-CONT}$ = 3.38 m^2

$CA_{cmd,1}^{AIL}$ = $\underline{12.56}$ m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,2}^{AIL-INST}$ = 140.82 m^2

$fact_2^{IC}$ = ####### $\qquad fact_1^{IC}$ = 1

$CA_{cmd,2}^{AIL-CONT}$ = 12.63 m^2

$CA_{cmd,2}^{AIL}$ = $\underline{153.388}$ m^2

C) LARGE RELEASE HOLE

$CA_{cmd,3}^{AIL-INST}$ = 409.99 m^2

$fact_3^{IC}$ = 2.7E-01 $\qquad fact_1^{IC}$ = 1

$CA_{cmd,3}^{AIL-CONT}$ = 656.36 m^2

$CA_{cmd,3}^{AIL}$ = 886.66 m^2

D) RUPTURE RELEASE HOLE

$CA_{cmd,4}^{AIL-INST}$ = 409.99 m^2

$fact_4^{IC}$ = 1.0000 $fact_1^{IC}$ = 1

$CA_{cmd,4}^{AIL-CONT}$ = 1904224.11 m^2

$CA_{cmd,4}^{AIL}$ = 409.994 m^2

$$CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST} . fact_n^{IC} + CA_{inj,n}^{AIL-CONT} . (1 - fact_n^{IC})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA_{inj,1}^{AIL-INST}$ = 33.98328964 m^2

$fact_1^{IC}$ = 0.001069 $fact_1^{IC}$ = 1

$CA_{inj,1}^{AIL-CONT}$ = 9.209093539 m^2

$CA_{inj,1}^{AIL}$ = 43.18 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{inj,2}^{AIL-INST}$ = 62.06544432 m^2

$fact_2^{IC}$ = 0.0042776 $fact_1^{IC}$ = 1

$CA_{inj,2}^{AIL-CONT}$ = 32.96947839 m^2

$CA_{inj,2}^{AIL}$ = 94.8938931 m^2

C) LARGE RELEASE HOLE

$CA_{inj,3}^{AIL-INST}$ = 127.1469706 m^2

$fact_3^{IC}$ = 0.273765 $fact_1^{IC}$ = 1

$CA_{inj,3}^{AIL-CONT}$ = 1512.85621 m^2

$CA_{inj,3}^{AIL}$ = 1225.835823 m^2

D) RUPTURE RELEASE HOLE

$CA_{inj,4}^{AIL-INST}$ = 127.1469706 m^2

$fact_4^{IC}$ = 1.0000 $fact_1^{IC}$ = 1

$CA^{AIL-CONT}_{inj,4} = 3412181.875\ \text{m}^2$

$CA^{AIL}_{inj,4} = \underline{127.1469706}\ \text{m}^2$

$$CA^{AINL}_{cmd,n} = CA^{AINL-INST}_{cmd,n} . fact^{IC}_{n} + CA^{AINL-CONT}_{cmd,n} . (1 - fact^{IC}_{n})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA^{AINL-INST}_{cmd,n} = 56.83472279\ \text{m}^2$

$fact^{IC}_{1} = 1.07E\text{-}03$ $\quad fact^{IC}_{1} = 1$

$CA^{AINL-CONT}_{cmd,1} = 0.903948366\ \text{m}^2$

$CA^{AINL}_{cmd,1} = \underline{57.74}\ \text{m}^2$

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{AINL-INST}_{cmd,n} = 140.815803\ \text{m}^2$

$fact^{IC}_{2} = 0.004278$ $\quad fact^{IC}_{1} = 1$

$CA^{AINL-CONT}_{cmd,2} = 3.147731037\ \text{m}^2$

$CA^{AINL}_{cmd,2} = \underline{143.9500693}\ \text{m}^2$

C) LARGE RELEASE HOLE

$CA^{AINL-INST}_{cmd,n} = 409.9936539\ \text{m}^2$

$fact^{IC}_{3} = 0.2738$ $\quad fact^{IC}_{1} = 1$

$CA^{AINL-CONT}_{cmd,3} = 132.9105921\ \text{m}^2$

$CA^{AINL}_{cmd,3} = \underline{506.5179534}\ \text{m}^2$

D) RUPTURE RELEASE HOLE

$CA^{AINL-INST}_{cmd,4} = 409.9936539\ \text{m}^2$

$fact^{IC}_{4} = 1.0000$ $\quad fact^{IC}_{1} = 1$

$CA^{AINL-CONT}_{cmd,4} = 253453.1596\ \text{m}^2$

$CA^{AINL}_{cmd,4} = \underline{409.9936539}\ \text{m}^2$

$$CA^{AINL}_{inj,n} = CA^{AINL-INST}_{inj,n} . fact^{IC}_{n} + CA^{AINL-CONT}_{inj,n} . (1 - fact^{IC}_{n})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA^{AINL-INST}_{inj,n} = 163.5904633\ \text{m}^2$

$fact^{IC}_{1} = 0.0011$ $\quad fact^{IC}_{1} = 1$

$CA_{inj,1}^{AINL-CONT}.$ = 2.668008786 m^2

$CA_{inj,1}^{AINL}$ = 166.2556189 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{inj,n}^{AINL-INST}$ = 405.3177584 m^2

$fact_2^{IC}$ = 0.004278 $fact_1^{IC}$ = 1

$CA_{inj,2}^{AINL-CONT}.$ = 9.162640512 m^2

$CA_{inj,2}^{AINL}$ = 414.441205 m^2

C) LARGE RELEASE HOLE

$CA_{inj,n}^{AINL-INST}$ = 1180.106957 m^2

$fact_3^{IC}$ = 0.2738 $fact_1^{IC}$ = 1

$CA_{inj,3}^{AINL-CONT}.$ = 371.1255247 m^2

$CA_{inj,3}^{AINL}$ = 1449.631235 m^2

D) RUPTURE RELEASE HOLE

$CA_{inj,4}^{AINL-INST}$ = 1180.106957 m^2

$fact_4^{IC}$ = 1.0000

$CA_{inj,4}^{AINL-CONT}.$ = 240991184.6 m^2 $fact_1^{IC}$ = 1

$CA_{inj,4}^{AINL}$ = 1180.106957 m^2

STEP 8.15

Calculate the AIT blended consequence areas for the component using equations (3.57) and (3.58) based on the consequence areas determined in step 8.14 and the AIT blending factors, $fact^{AIT}$, calculate in step 8.13. the resulting consequence areas are the component damage and personnel injury flammable consequence areas, $CA_{icmd,n}^{flam}$ and $CA_{inj,n}^{flam}$ for each release hole size selected in step 2.2

$$CA_{cmd,n}^{flam} = CA_{smd,n}^{AIL}.\, fact^{AIT} + CA_{cmd,n}^{AINL}.\, (1 - fact^{AIT})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,1}^{AIL}$ = 12.56248934 m^2

$fact^{AIT}$ = 0

$CA_{cmd,1}^{AINL}$ = 57.73770448 m^2

$CA^{flam}_{cmd,1}$ = 57.73770448 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{AIL}_{cmd,2}$ = 153.3878572 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,2}$ = 143.9500693 m^2

$CA^{flam}_{cmd,2}$ = 143.9500693 m^2

C) LARGE RELEASE HOLE

$CA^{AIL}_{cmd,3}$ = 886.662 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,3}$ = 506.518 m^2

$CA^{flam}_{cmd,3}$ = 506.518 m^2

D) RUPTURE RELEASE HOLE

$CA^{AIL}_{cmd,4}$ = 409.9936539 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,4}$ = 409.9936539 m^2

$CA^{flam}_{cmd,4}$ = 409.9936539 m^2

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

A) SMALL RELEASE HOLE SIZE AREA

$CA^{flam-AIL}_{inj,1}$ = 43.18253502 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{inj,1}$ = 166.2556189 m^2

$CA^{flam}_{inj,1}$ = 166.2556189 m2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{flam-AIL}_{inj,2}$ = 94.8938931 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{inj,2}$ = 414.441205 m^2

$CA_{inj,2}^{flam}$ = 414.441205 m2

C) LARGE RELEASE HOLE

$CA_{inj,3}^{flam-AIL}$ = 1225.835823 m^2

$fact^{AIT}$ = 0

$CA_{inj,3}^{AINL}$ = 1449.631235 m^2

CA_{inj3}^{flam} = 1449.631235 m^2

D) RUPTURE RELEASE HOLE

$CA_{inj,4}^{flam-AIL}$ = 127.1469706 m^2

$fact^{AIT}$ = 0

$CA_{inj,4}^{AINL}$ = 1180.106957 m^2

$CA_{inj,4}^{flam}$ = 1180.106957 m^2

STEP 8.16

Determine the consequence areas (probability weighted on release hole size) for component damage and personnel injury using equations (3.59) and (3.60) based on the consequence ara from step 8.15

Equipment Type	**Component Type**	**gff as a function of hole size (failure/yr)**				**gff total (failure/ yr)**
		Small	**Medium**	**Large**	**Rupture**	
Tank650	TANK BOTTOM	7.2E-04	0.00E+00	0.00E+00	2.00E-06	7.20E-04
Tank650	COURSE 1-10	7.0E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04

CONSEQUENCE AREA FOR COMPONENT DAMAGE

For Tank Shell

$$CA_{cmd}^{flam} = \left(\frac{\sum gff_n \, . \, CA_{cmd,n}^{flam}}{gff_{total}} \right)$$

$$CA_{cmd}^{flam} = \left(\frac{(gff_{1} . \, CA_{cmd,1}^{flam}) + (gff_{2} . \, CA_{cmd,2}^{flam}) + (gff_{3} . \, CA_{cmd,3}^{flam}) + (gff_{4} . \, CA_{cmd,4}^{flam})}{gff_{total}} \right)$$

$= \quad 102.1398018 \quad m^2$

CONSEQUENCE AREA FOR PERSONNEL INJURY

For Tank Shell

$$CA_{inj}^{flam} = \left(\frac{\sum gff_n \, . \, CA_{inj,n}^{flam}}{gff_{total}} \right)$$

$$CA_{inj}^{flam} = \left(\frac{\left(gff_1 \, . \, CA_{inj,1}^{flam}\right) + \left(gff_2 \, . \, CA_{inj,2}^{flam}\right) + \left(gff_3 \, . \, CA_{inj,3}^{flam}\right) + \left(gff_4 \, . \, CA_{inj,4}^{flam}\right)}{gff_{total}} \right)$$

$= \quad 293.651 \quad m^2$

PART 8 : DETERMINE FLAMMABLE AND EXPLOSIVE CONSEQUENCE

8.1 CONSEQUENCE AREA EQUATIONS

(Shell 6)

The following equations are used to determine the flammable consequence areas for comoponent damage and personnel injury. There are two kind of equantions explained based on its type of release, either continous release or instataneous release as mentioned below:

1). $CA_n^{CONT} = \alpha(rate_n)^b$

2). $CA_n^{INST} = \alpha(mass_n)^b$

The coefficients for those equations for component damage areas and personel injury are provided in Table 4.8 and 4.9 in API RP 581 Part 3 of COF.

STEP 8.1 Select the consequence area mitigation reduction factor, factmit, from Table 4.10

Mitigation System	**Consequence Area Adjustment**	**Consequence Area Reduction Factor, factor mit**
Inventory blowdown , couple with isolation system classification B or higher	Reduce consequence area by 25 %	0.25
Fire water deluge system and monitors	Reduce consequence area by 20%	0.2
Fire water monitor only	Reduce consequence area by 5%	0.05
Foam spray system	Reduce consequence area by 15%	0.15

Mitigation system = Fire water deluge system and monitors

Consequence Area = Reduce consequence area by 5% *

$fact_{mit}$ = 0.05

STEP 8.2 Calculate the energy efficiency, $eneff_n$, for each hole size using equation mentioned below.

$$eneff_n = 4.\,log_{10}[C_{4A}\,.mass_n] - 15$$

This correction is made for instantaneous events exceeding a release mass of 4,536 kgs (10,000 Ibs). Comparison of calculated consequence with those of actual historical releases indicates that there is need to correct large instantaneous releases for energy efficiency.

C_{4A} = 2205 1/kg

$mass_1^{leak}$= 15869.57371 kg
$mass_2^{leak}$= 63478.29482 kg
$mass_3^{leak}$= 294034.1634 kg
$mass_4^{leak}$= 294034.1634 kg

A) SMALL RELEASE HOLE SIZE AREA

$$eneff_1 = 4.\,log_{10}[C_{4A}\,.mass_1] - 15$$

$eneff_1$ = 15.17589542

B) MEDIUM RELEASE HOLE SIZE AREA

$$eneff_2 = 4.\,log_{10}[C_{4A}\,.mass_2] - 15$$

$eneff_2$ = 17.58413538

C) LARGE RELEASE HOLE SIZE AREA

$$eneff_3 = 4.\,log_{10}[C_{4A}\,.mass_3] - 15$$

$eneff_3$ = 20.24722555

D) RUPTURE RELEASE HOLE SIZE AREA

$$eneff_4 = 4.\,log_{10}[C_{4A}\,.mass_4] - 15$$

$eneff_4$ = 20.24722555

STEP 8.3 Determine the fluid type

Determine the fluid type, either TYPE 0 or TYPE 1 based on Table 4.1 of API RP 581 Part 3 of COF.

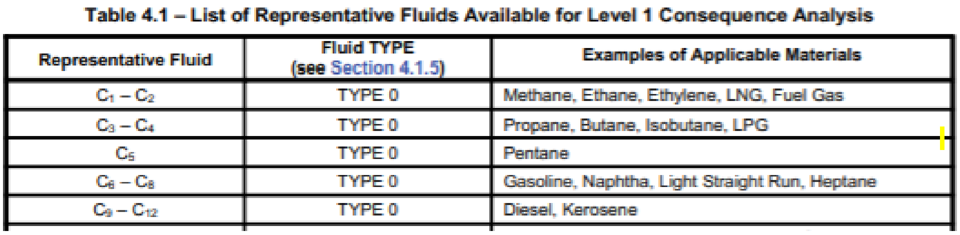


Table 4.1 – List of Representative Fluids Available for Level 1 Consequence Analysis

Representative Fluid	Fluid TYPE (see Section 4.1.5)	Examples of Applicable Materials
$C_1 – C_2$	TYPE 0	Methane, Ethane, Ethylene, LNG, Fuel Gas
$C_3 – C_4$	TYPE 0	Propane, Butane, Isobutane, LPG
C_5	TYPE 0	Pentane
$C_6 – C_8$	TYPE 0	Gasoline, Naphtha, Light Straight Run, Heptane
$C_9 – C_{12}$	TYPE 0	Diesel, Kerosene

C9-C12 = TYPE 0 NBP = 184 (°C)
MW = 149.00 (kg/kg-mol) ρ = 734.012 kg/m3
AIT = 208 (°C)
AIT = 381 (K)

STEP 8.4 For each release hole size, calculate the component damage consequence areas for Auto-Ignition Not Likely, Continous Release (AINT-CONT), $CA^{AINL-CONT}$

1). Determine the appropriate constant a and b from the Table 4.8

Table 4.8M - Component Damage Flammable Consequence Equation Constants

Fluid	**Continuous Release Constant**							
	Auto Ignition Not Likely (CAINL)				**Auto Ignition Likely (CAIL)**			
	Gas		**Liquid**		**Gas**		**Liquid**	
	α	b	α	b	α	b	α	b
C9-C12	2.42	0.98	24.6	0.9	77	0.95	110	0.95

Fluid	**Instantaneous Release Constant**							
	Auto-Ignition Not Likely (IAINL)				**Auto Ignition Likely (IAIL)**			
	Gas		**Liquid**		**Gas**		**Liquid**	
	α	b	α	b	α	b	α	b
C9-C12	1.1	0.66	0.56	0.8	42	0.61	0.85	0.53

$$\alpha = \alpha_{cmd,n}^{AINL-CONT} = \boxed{24.6}$$

$$b = b_{cmd}^{AINL-CONT} = \boxed{0.90}$$

2). Calculate the consequence of area using equation below

Shell 6

$Rate_1$ = 19.4274 bbl/day
$Rate_2$ = 77.7097 bbl/day
$Rate_3$ = 4973.42 bbl/day
$Rate_4$ = 2.2E+07 bbl/day

1 bbl/day = 0.0013 kg/s

Shell 6

$Rate_1$ = 0.02526 kg/s
$Rate_2$ = 0.10102 kg/s
$Rate_3$ = 6.46545 kg/s
$Rate_4$ = 28537.7 kg/s

Shell 6

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,1}^{AINL-CONT} = \alpha(rate_1)^b\,.(1-fact_{mit})$

= 337.4679089 m^2 (use bbl/day)

= 0.85267101 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,2}^{AINL-CONT} = \alpha(rate_2)^b\,.(1-fact_{mit})$

= 1175.131513 m^2 (use bbl/day)

= 2.969172911 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$CA_{cmd,3}^{AINL-CONT} = \alpha(rate_3)^b\,.(1-fact_{mit})$

= 49619.05047 m^2 (use bbl/day)

= 125.3711086 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$CA_{cmd,4}^{AINL-CONT} = \alpha(rate_4)^b\,.(1-fact_{mit})$

= 94620789.19 m^2 (use bbl/day)

= 239075.7809 m^2 (use kg/s)

STEP 8.5 For ech release hole size, calculate the component damage consequence areas for Auto-Ignition Likely, Continous Release (AIL-CONT), $CA^{AIL-CONT}$

1). Determine the appropriate constant a and b from the Table 4.8

α = $\alpha_{cmd,n}^{AIL-CONT}$ = $\boxed{110.3}$

b = $b_{cmd}^{AIL-CONT}$ = $\boxed{0.95}$

2). Calculate the consequence of area using equation below

Shell 6

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,1}^{AIL-CONT} = \alpha(rate_1)^b\,.(1-fact_{mit})$

= 1755.066799 m^2 (use bbl/day)

= 3.180825434 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,2}^{AIL-CONT} = \alpha(rate_2)^b\,.(1-fact_{mit})$

= 6550.140903 m^2 (use bbl/day)

= 11.87126028 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$CA_{cmd,3}^{AIL-CONT} = \alpha(rate_3)^b\,.(1-fact_{mit})$

= 340503.5293 m^2 (use bbl/day)

= 617.117415 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$CA_{cmd,4}^{AIL-CONT} = \alpha(rate_4)^b\,.(1-fact_{mit})$

= 987872147.6 m^2 (use bbl/day)

= 1790387.041 m^2 (use kg/s)

STEP 8.6 For each release hole size, calculate the component damage consequence areas for Auto-ignition Not Likely, Instaneous Release, (AINL-INST), $CA^{AINL\text{-}INST}$

1). Determine the appropriate constant a and b from the Table 4.8

$$\alpha = \alpha_{cmd,n}^{AINL-INST} = \boxed{0.6}$$

$$b = b_{cmd}^{AINL-INST} = \boxed{0.76}$$

2). Calculate the consequence of area using equation below

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

From step 7, known that:

$mass_1^{leak}$ = 15869.5737 kg
$mass_2^{leak}$ = 63478.2948 kg
$mass_3^{leak}$ = 294034.163 kg
$mass_4^{leak}$ = 294034.163 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{cmd,1}^{AINL-INST} = \alpha(mass_1)^b \cdot \left(\frac{1-fact_{mit}}{eneff_1}\right)$$

$$= 54.50177999 \text{ m}^2$$

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{cmd,2}^{AINL-INST} = \alpha(mass_2)^b \cdot \left(\frac{1-fact_{mit}}{eneff_2}\right)$$

$$= 134.8992658 \text{ m}^2$$

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{cmd,3}^{AINL-INST} = \alpha(mass_3)^b \cdot \left(\frac{1-fact_{mit}}{eneff_3}\right)$$

$$= 375.6230332 \text{ m}^2$$

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{cmd,4}^{AINL-INST} = \alpha(mass_4)^b \cdot \left(\frac{1-fact_{mit}}{eneff_4}\right)$$

$$= 375.6230332 \text{ m}^2$$

STEP 8.7 For ech release hole size, calculate the component damage consequence areas for Auto-Ignition Likely, Instataneous Release (AIL-INST), $CA^{AIL\text{-}INST}$

1). Determine the appropriate constant a and b from the Table 4.8

$$\alpha = \alpha_{cmd,n}^{AIL-INST} = \boxed{0.8}$$

$$b = b_{cmd}^{AIL-INST} = \boxed{0.53}$$

2). Calculate the consequence of area using equation below

$$CA^{AIL-INST}_{cmd,n} = \alpha(mass_n)^b \cdot \left(\frac{1-fact_{mit}}{eneff_n}\right)$$

$mass^{leak}_1$ = 15869.5737 kg

$mass^{leak}_2$ = 63478.2948 kg

$mass^{leak}_3$ = 294034.163 kg

$mass^{leak}_4$ = 294034.163 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA^{AIL-INST}_{cmd,1} = \alpha(mass_1)^b \cdot \left(\frac{1-fact_{mit}}{eneff_1}\right)$$

$$= 8.938501569 \text{ m}^2$$

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA^{AIL-INST}_{cmd,2} = \alpha(mass_2)^b \cdot \left(\frac{1-fact_{mit}}{eneff_2}\right)$$

$$= 16.0838429 \text{ m}^2$$

C) LARGE RELEASE HOLE SIZE AREA

$$CA^{AIL-INST}_{cmd,3} = \alpha(mass_3)^b \cdot \left(\frac{1-fact_{mit}}{eneff_3}\right)$$

$$= 31.47782867 \text{ m}^2$$

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA^{AIL-INST}_{cmd,4} = \alpha(mass_4)^b \cdot \left(\frac{1-fact_{mit}}{eneff_4}\right)$$

$$= 31.47782867 \text{ m}^2$$

STEP 8.8 For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Not Likely, Continous Release (AINL-CONT), $CA^{AINL-CONT}_{inj,n}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phas as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

Table 4.9M - Personnel Injury Flammable Consequence Equation Constants

Fluid	**Continuous Release Constant**							
	Auto Ignition Not Likely (CAINL)				**Auto Ignition Likely (CAIL)**			
	Gas		**Liquid**		**Gas**		**Liquid**	
	α	b	α	b	α	b	α	b
C9-C12	5.8	0.96	70.03	0.9	189	0.92	269.4	0.92

Fluid	**Instantaneous Release Constant**							
	Auto-Ignition Not Likely (IAINL)				**Auto Ignition Likely (IAIL)**			
	Gas		**Liquid**		**Gas**		**Liquid**	
	α	b	α	b	α	b	α	b
C9-C12	2.0	0.66	1.61	0.8	151	0.63	2.85	0.54

α = $\alpha_{inj,n}^{AINL-CONT}$ = $\boxed{70.03}$

b = $b_{inj,n}^{AINL-CONT}$ = $\boxed{0.89}$

2). Calculate the consequence of area using equation below

$$CA_{inj,n}^{AINL-CONT} = [\alpha.(rate_n^{AINL-CONT})^b].(1-fact_{mit})$$

Shell 6

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AINL-CONT} = \left[\alpha.\left(rate_1^{AINL-CONT}\right)^b\right].(1-fact_{mit})$$

= 932.6041564 m^2 (use bbl/day)

= 2.518296896 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AINL-CONT} = \left[\alpha.\left(rate_2^{AINL-CONT}\right)^b\right].(1-fact_{mit})$$

= 3202.806778 m^2 (use bbl/day)

= 8.648490695 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AINL-CONT} = \left[\alpha.\left(rate_3^{AINL-CONT}\right)^b\right].(1-fact_{mit})$$

= 129727.1616 m^2 (use bbl/day)

= 350.300292 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AINL-CONT} = \left[\alpha.\left(rate_4^{AINL-CONT}\right)^b\right].(1-fact_{mit})$$

= 227468273.5 m^2 (use bbl/day)

= 614229.1381 m^2 (use kg/s)

STEP 8.9 For each release hole size, calculate the personnel injury consequence areas for Auto- $CA_{inj,n}^{AIL-CONT}$ ignition Likely, Continous Release (AIL-CONT),

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phasE as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

α = $\alpha_{inj,n}^{AIL-CONT}$ = $\boxed{269.4}$

b = $b_{inj,n}^{AIL-CONT}$ = $\boxed{0.92}$

2). Calculate the consequence of area using equation below

$$CA_{inj,n}^{AIL-CONT} = [\alpha.(rate_n^{AIL-CONT})^b].(1 - fact_{mit})$$

Shell 6

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AIL-CONT} = \left[\alpha.\left(rate_1^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 3921.59979 m^2 (use bbl/day)
= 8.675432894 m^2 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AIL-CONT} = \left[\alpha.\left(rate_2^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 14039.72052 m^2 (use bbl/day)
= 31.05891976 m^2 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AIL-CONT} = \left[\alpha.\left(rate_3^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 644234.5895 m^2 (use bbl/day)
= 1425.187232 m^2 (use kg/s)

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AIL-CONT} = \left[\alpha.\left(rate_4^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 1453043306 m^2 (use bbl/day)
= 3214448.279 m^2 (use kg/s)

STEP 8.10

For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Not Likely, Instataneous Release (AINL-INST), $CA_{inj,n}^{AINL-INST}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phase as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

$\alpha = \alpha_{inj,n}^{AINL-INST} = \boxed{1.609}$

$b = b_{inj,n}^{AINL-INST} = \boxed{0.76}$

2). Calculate the consequence of area using equation below

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

$mass_1^{leak}$ = 15869.5737 kg
$mass_2^{leak}$ = 63478.2948 kg
$mass_3^{leak}$ = 294034.163 kg
$mass_4^{leak}$ = 294034.163 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AINL-INST} = \left[\alpha.\left(mass_1^{AINL-INST}\right)^b\right].\left(\frac{1 - fact_{mit}}{eneff_1}\right)$$

= 156.8754276 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AINL-INST} = \left[\alpha.\left(mass_2^{AINL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_2}\right)$$

= 388.2878688 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AINL-INST} = \left[\alpha.\left(mass_3^{AINL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_3}\right)$$

= 1081.176137 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AINL-INST} = \left[\alpha.\left(mass_4^{AINL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_4}\right)$$

= 1081.176137 m^2

STEP 8.11 For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Likely, Instataneous Release (AIL-INST), $CA_{inj,n}^{AIL-INST}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phas as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

α = $\alpha_{inj,n}^{AIL-INST}$ = 2.847

b = $b_{inj,n}^{AIL-INST}$ = 0.54

2). Calculate the consequence of area using equation below

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

$mass_1^{leak}$= 15869.57371 kg
$mass_2^{leak}$= 63478.29482 kg
$mass_3^{leak}$= 294034.1634 kg
$mass_4^{leak}$= 294034.1634 kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AIL-INST} = \left[\alpha.\left(mass_1^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_1}\right)$$

= 33.05688966 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AIL-INST} = \left[\alpha.\left(mass_2^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_2}\right)$$

= 60.31254986 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AIL-INST} = \left[\alpha.\left(mass_3^{AIL-INST}\right)^b\right].\left(\frac{1 - fact_{mit}}{eneff_3}\right)$$

= 119.8616799 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AIL-INST} = \left[\alpha.\left(mass_4^{AIL-INST}\right)^b\right].\left(\frac{1 - fact_{mit}}{eneff_4}\right)$$

= 119.8616799 m^2

STEP 8.12 For each release hole size, calculate the instataneous/continous blending factor, $fact_n^{IC}$.

1). FOR CONTINOUS RELEASE

C_5 = 25 kg/s

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

…………………………

Shell 6

A) SMALL RELEASE HOLE SIZE AREA

$$fact_1^{IC} = \min\left[\left\{\frac{rate_1}{C_5}\right\}, 1.0\right]$$

= 0.770929664 (use bbl/day)

= 0.001002209 (use kg/s)

B) MEDIUM RELEASE HOLE SIZE AREA

$$fact_2^{IC} = \min\left[\left\{\frac{rate_2}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 0.004008834 (use kg/s)

C) LARGE RELEASE HOLE SIZE AREA

$$fact_3^{IC} = \min\left[\left\{\frac{rate_3}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 0.256565392 (use kg/s)

D) **RUPTURE RELEASE HOLE SIZE AREA**

$$fact_4^{IC} = \min\left[\left\{\frac{rate_3}{C_5}\right\}, 1.0\right]$$

= 1 (use bbl/day)

= 1 (use kg/s)

2). FOR INSTATANEOUS RELEASE

$fact_n^{IC} =$ 1

STEP 8.13

Calculate the AIT blending factor, $fact^{AIT}$, using these optional equation below.

$fact^{AIT} = 0$ for, $T_S + C_6 \le AIT$

$fact^{AIT} = \dfrac{(T_s - AIT + C_6)}{2 \,.\, C_6}$ for, $T_S + C_6 > AIT > T_S - C_6$

$fact^{AIT} = 1$ for, $T_S - C_6 \ge AIT$

Ts = 30 (°C)

Ts = 86 (°F)

Ts = 303 (K)

AIT = 208 (°C)

AIT = 481 (K)

C_6 = 55.6 (K)

$T_s + C_6$ = 358.6 (K)

$T_s - C_6$ = 247.4 (K)

$\dfrac{(T_s - AIT + C_6)}{2 \,.\, C_6}$ = -1 (K)

So, $fact^{AIT}$ = 0

STEP 8.14

Calculate the continuous/instantaneous blended consequence area for the component using equation (3.53) through (3.56) based on the consequence areas calculated in $fact_n^{IC}$ previous steps

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,1}^{AIL-INST}$ = 8.94 m^2

$fact_1^{IC}$ = #######

$fact_1^{IC}$ = 1

$CA_{cmd,1}^{AIL-CONT}$ = 3.18 m^2

$CA_{cmd,1}^{AIL}$ = 12.12 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,2}^{AIL-INST}$ = 134.90 m^2

$fact_2^{IC}$ = #######

$fact_1^{IC}$ = 1

$CA_{cmd,2}^{AIL-CONT}$ = 11.87 m^2

$CA_{cmd,2}^{AIL}$ = 146.723 m^2

C) LARGE RELEASE HOLE

$CA_{cmd,3}^{AIL-INST}$ = 375.62 m^2

$fact_3^{IC}$ = 2.6E-01

$fact_1^{IC}$ = 1

$CA_{cmd,3}^{AIL-CONT}$ = 617.12 m^2

$CA_{cmd,3}^{AIL}$ = 834.41 m^2

D) RUPTURE RELEASE HOLE

$CA_{cmd,4}^{AIL-INST}$ = 375.62 m^2

$fact_4^{IC}$ = 1.0000 $fact_1^{IC}$ = 1

$CA_{cmd,4}^{AIL-CONT}$ = 1790387.04 m^2

$CA_{cmd,4}^{AIL}$ = 375.623 m^2

$$CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST} . fact_n^{IC} + CA_{inj,n}^{AIL-CONT} . (1 - fact_n^{IC})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA_{inj,1}^{AIL-INST}$ = 33.05688966 m^2

$fact_1^{IC}$ = 0.001002 $fact_1^{IC}$ = 1

$CA_{inj,1}^{AIL-CONT}$ = 8.675432894 m^2

$CA_{inj,1}^{AIL}$ = 41.72 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{inj,2}^{AIL-INST}$ = 60.31254986 m^2

$fact_2^{IC}$ = 0.0040088 $fact_1^{IC}$ = 1

$CA_{inj,2}^{AIL-CONT}$ = 31.05891976 m^2

$CA_{inj,2}^{AIL}$ = 91.24695957 m^2

C) LARGE RELEASE HOLE

$CA_{inj,3}^{AIL-INST}$ = 119.8616799 m^2

$fact_3^{IC}$ = 0.256565 $fact_1^{IC}$ = 1

$CA_{inj,3}^{AIL-CONT}$ = 1425.187232 m^2

$CA_{inj,3}^{AIL}$ = 1179.39519 m^2

D) RUPTURE RELEASE HOLE

$CA_{inj,4}^{AIL-INST}$ = 119.8616799 m^2

$fact_4^{IC}$ = 1.0000 $fact_1^{IC}$ = 1

$CA_{inj,4}^{AIL-CONT}$ = 3214448.279 m^2

$CA_{inj,4}^{AIL}$ = $\underline{119.8616799}$ m^2

$$CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST} . fact_n^{IC} + CA_{cmd,n}^{AINL-CONT} . (1 - fact_n^{IC})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,n}^{AINL-INST}$ = 54.50177999 m^2

$fact_1^{IC}$ = 1.00E-03 $fact_1^{IC}$ = 1

$CA_{cmd,1}^{AINL-CONT}$ = 0.85267101 m^2

$CA_{cmd,1}^{AINL}$ = $\underline{55.35}$ m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,n}^{AINL-INST}$ = 134.8992658 m^2

$fact_2^{IC}$ = 0.004009 $fact_1^{IC}$ = 1

$CA_{cmd,2}^{AINL-CONT}$ = 2.969172911 m^2

$CA_{cmd,2}^{AINL}$ = $\underline{137.8565358}$ m^2

C) LARGE RELEASE HOLE

$CA_{cmd,n}^{AINL-INST}$ = 375.6230332 m^2

$fact_3^{IC}$ = 0.2566 $fact_1^{IC}$ = 1

$CA_{cmd,3}^{AINL-CONT}$ = 125.3711086 m^2

$CA_{cmd,3}^{AINL}$ = $\underline{468.8282542}$ m^2

D) RUPTURE RELEASE HOLE

$CA_{cmd,4}^{AINL-INST}$ = 375.6230332 m^2

$fact_4^{IC}$ = 1.0000 $fact_1^{IC}$ = 1

$CA_{cmd,4}^{AINL-CONT}$ = 239075.7809 m^2

$CA_{cmd,4}^{AINL}$ = $\underline{375.6230332}$ m^2

$$CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST} . fact_n^{IC} + CA_{inj,n}^{AINL-CONT} . (1 - fact_n^{IC})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA_{inj,n}^{AINL-INST}$ = 156.8754276 m^2

$fact_1^{IC}$ = 0.0010 $fact_1^{IC}$ = 1

$CA^{AINL-CONT}_{inj,1}$. = 2.518296896 m^2

$CA^{AINL}_{inj,1}$ = 159.3912006 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{AINL-INST}_{inj,n}$ = 388.2878688 m^2

$fact^{IC}_{2}$ = 0.004009 $fact^{IC}_{1}$ = 1

$CA^{AINL-CONT}_{inj,2}$. = 8.648490695 m^2

$CA^{AINL}_{inj,2}$ = 396.9016891 m^2

C) LARGE RELEASE HOLE

$CA^{AINL-INST}_{inj,n}$ = 1081.176137 m^2

$fact^{IC}_{3}$ = 0.2566 $fact^{IC}_{1}$ = 1

$CA^{AINL-CONT}_{inj,3}$. = 350.300292 m^2

$CA^{AINL}_{inj,3}$ = 1341.601497 m^2

D) RUPTURE RELEASE HOLE

$CA^{AINL-INST}_{inj,4}$ = 1081.176137 m^2

$fact^{IC}_{4}$ = 1.0000

$CA^{AINL-CONT}_{inj,4}$. = 227468273.5 m^2 $fact^{IC}_{1}$ = 1

$CA^{AINL}_{inj,4}$ = 1081.176137 m^2

STEP 8.15 Calculate the AIT blended consequence areas for the component using equations (3.57) and (3.58) based on the consequence areas determined in step 8.14 and the AIT blending factors, $fact^{AIT}$, calculate in step 8.13. the resulting consequence areas are the component damage and personnel injury flammable consequence areas, $CA^{flam}_{icmd,n}$ and $CA^{flam}_{inj,n}$ for each release hole size selected in step 2.2

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

A) SMALL RELEASE HOLE SIZE AREA

$CA^{AIL}_{cmd,1}$ = 12.11613915 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,1}$ = 55.35359645 m^2

$CA^{flam}_{cmd,1}$ = $\underline{55.35359645}$ m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{AIL}_{cmd,2}$ = 146.7229361 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,2}$ = 137.8565358 m^2

$CA^{flam}_{cmd,2}$ = $\underline{137.8565358}$ m^2

C) LARGE RELEASE HOLE

$CA^{AIL}_{cmd,3}$ = 834.409 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,3}$ = 468.828 m^2

$CA^{flam}_{cmd,3}$ = $\underline{468.828}$ m^2

D) RUPTURE RELEASE HOLE

$CA^{AIL}_{cmd,4}$ = 375.6230332 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{cmd,4}$ = 375.6230332 m^2

$CA^{flam}_{cmd,4}$ = $\underline{375.6230332}$ m^2

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

A) SMALL RELEASE HOLE SIZE AREA

$CA^{flam-AIL}_{inj,1}$ = 41.72362796 m^2

$fact^{AIT}$ = 0

$CA^{AINL}_{inj,1}$ = 159.3912006 m^2

$CA^{flam}_{inj,1}$ = $\underline{159.3912006}$ m2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA^{flam-AIL}_{inj,2}$ = 91.24695957 m^2

$fact^{AIT}$ = 0

$CA_{inj,2}^{AINL}$ = 396.9016891 m^2

$CA_{inj,2}^{flam}$ = 396.9016891 m2

C) LARGE RELEASE HOLE

$CA_{inj,3}^{flam-AIL}$ = 1179.39519 m^2

$fact^{AIT}$ = 0

$CA_{inj,3}^{AINL}$ = 1341.601497 m^2

CA_{inj3}^{flam} = 1341.601497 m^2

D) RUPTURE RELEASE HOLE

$CA_{inj,4}^{flam-AIL}$ = 119.8616799 m^2

$fact^{AIT}$ = 0

$CA_{inj,4}^{AINL}$ = 1081.176137 m^2

$CA_{inj,4}^{flam}$ = 1081.176137 m^2

STEP 8.16

Determine the consequence areas (probability weighted on release hole size) for component damage and personnel injury using equations (3.59) and (3.60) based on the consequence ara from step 8.15

Equipment Type	**Component Type**	**gff as a function of hole size (failure/yr)**				**gff total (failure/ yr)**
		Small	**Medium**	**Large**	**Rupture**	
Tank650	TANK BOTTOM	7.2E-04	0.00E+00	0.00E+00	2.00E-06	7.20E-04
Tank650	COURSE 1-10	7.0E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04

CONSEQUENCE AREA FOR COMPONENT DAMAGE

For Tank Shell

$$CA_{cmd}^{flam}=\left(\frac{\sum gff_n \, . \, CA_{cmd,n}^{flam}}{gff_{total}}\right)$$

$$CA_{cmd}^{flam}=\left(\frac{(gff_{1} . \, CA_{cmd,1}^{flam})+(gff_{2} . \, CA_{cmd,2}^{flam})+(gff_{3} . \, CA_{cmd,3}^{flam})+(gff_{4} . \, CA_{cmd,4}^{flam})}{gff_{total}}\right)$$

= 97.0286872 m^2

CONSEQUENCE AREA FOR PERSONNEL INJURY

For Tank Shell

$$CA_{inj}^{flam}=\left(\frac{\sum gff_n \, . \, CA_{inj,n}^{flam}}{gff_{total}}\right)$$

$$CA_{inj}^{flam}=\left(\frac{\left(gff_1 \, . \, CA_{inj,1}^{flam}\right)+\left(gff_2 \, . \, CA_{inj,2}^{flam}\right)+\left(gff_3 \, . \, CA_{inj,3}^{flam}\right)+\left(gff_4 \, . \, CA_{inj,4}^{flam}\right)}{gff_{total}}\right)$$

= 278.961 m^2

PART 9 : DETERMINE THE TOXIC CONSEQUENCES FOR AST SHELL COURSE

Toxic consequences for AST shell courses are determined using a similar approach as implemented for Level 1 and 2 consequence analysis.

Because of the fluid that stored inside the tank is not catagorized as toxic fluid so the value becomes 0

PART 10 : DETERMINE THE NON-FLAMMABLE, NON-TOXIC CONSEQUENCES FOR AST SHELL COURSE

Non-Flammable, Non-Toxic consequences are not determined for ASTs.

PART 11 : DETERMINE THE FINAL CONSEQUENCES FOR AST SHELL COURSE

Flammable and explosive consequences for AST shell courses are determined using a similar approach as implemented for Level 2 consequence analyses

Step 11.1

Calculation the final component damage consequences area

$$CA_{cmd} = CA_{cmd}^{flam} + \max\left[psafe.CA_{cmd}^{safe}, CA_{cmd}^{nfnt}\right]$$

Shell	CA_{cmd}^{flam} (m^2)
1	166.1231
2	153.3109
3	139.0346
4	122.4868
5	102.1398
6	97.02869

CA_{cmd}^{nfnt} = 0

the consequence areas associated with non-flammable, non-toxic releases and safe events are all associated with the same probability (the probability of non-ignition, given a release) the maximum area is taken to maintain a total probability of events equal to 1.0

$psafe\,.CA_{cmd}^{safe}$ = 0

Although the consequence area of a safe release is zero, it is included in the calculation for completeness.

Shell 1

$$CA_{cmd} = CA_{cmd}^{flam} + \max\left[psafe.CA_{cmd}^{safe}, CA_{cmd}^{nfnt}\right]$$

CA_{cmd} = 166.1231 (m^2)

Shell 2

$$CA_{cmd} = CA_{cmd}^{flam} + \max\left[psafe.CA_{cmd}^{safe}, CA_{cmd}^{nfnt}\right]$$

CA_{cmd} = 153.3109 (m^2)

Shell 3

$$CA_{cmd} = CA_{cmd}^{flam} + \max\left[psafe.CA_{cmd}^{safe}, CA_{cmd}^{nfnt}\right]$$

$$CA_{cmd} \quad = \quad 139.0346\ (m^2)$$

Shell 4

$$CA_{cmd} = CA_{cmd}^{flam} + \max\left[psafe.CA_{cmd}^{safe}, CA_{cmd}^{nfnt}\right]$$

$$CA_{cmd} \quad = \quad 122.4868\ (m^2)$$

Shell 5

$$CA_{cmd} = CA_{cmd}^{flam} + \max\left[psafe.CA_{cmd}^{safe}, CA_{cmd}^{nfnt}\right]$$

$$CA_{cmd} \quad = \quad 102.1398\ (m^2)$$

Shell 6

$$CA_{cmd} = CA_{cmd}^{flam} + \max\left[psafe.CA_{cmd}^{safe}, CA_{cmd}^{nfnt}\right]$$

$$CA_{cmd} \quad = \quad 97.02869\ (m^2)$$

Step 11.2

Calculation the final personel injury consequences area

$$CA_{inj} = CA_{inj}^{flam} + \max$$

Shell	CA_{inj}^{flam} (m^2)
1	477.6504
2	440.7911
3	399.7269
4	352.1426
5	293.6509
6	278.9605

CA_{inj}^{nfnt} = 0 CA_{inj}^{tox} = 0

the consequence areas associated with non-flammable, non-toxic releases and safe events are all associated with the same probability (the probability of non-ignition, given a release) the maximum area is taken to maintain a total probability of events equal to 1.0

$psafe\,.\,CA_{inj}^{safe}$ = 0

Although the consequence area of a safe release is zero, it is included in the calculation for completeness.

Shell 1

$CA_{inj} = CA_{inj}^{flam} + \max\left[psafe\,.\,CA_{inj}^{safe}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right]$

CA_{inj} = 477.6504 (m^2)

Shell 2

$CA_{inj} = CA_{inj}^{flam} + \max\left[psafe\,.\,CA_{inj}^{safe}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right]$

CA_{inj} = 440.7911 (m^2)

Shell 3

$CA_{inj} = CA_{inj}^{flam} + \max\left[psafe\,.\,CA_{inj}^{safe}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right]$

CA_{inj} = 399.7269 (m^2)

Shell 4

$CA_{inj} = CA_{inj}^{flam} + \max\left[psafe\,.\,CA_{inj}^{safe}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right]$

CA_{inj} = 352.1426 (m^2)

Shell 5

$CA_{inj} = CA_{inj}^{flam} + \max\left[psafe\,.\,CA_{inj}^{safe}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right]$

CA_{inj} = 293.6509 (m^2)

Shell 6

$CA_{inj} = CA_{inj}^{flam} + \max\left[psafe\,.\,CA_{inj}^{safe}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right]$

CA_{inj} = 278.9605 (m^2)

Step 11.3

Calculation the final consequences area

$$CA = \max\left[CA_{cmd}, CA_{inj}\right]$$

Shell 1

$CA = \max\left[CA_{cmd}, CA_{inj}\right]$

CA = 477.6504 (m^2)

Shell 2

$CA = \max\left[CA_{cmd}, CA_{inj}\right]$

CA = 440.7911 (m^2)

Shell 3

$CA = \max\left[CA_{cmd}, CA_{inj}\right]$

CA = 399.7269 (m^2)

Shell 4

$CA = \max\left[CA_{cmd}, CA_{inj}\right]$

CA = 352.1426 (m^2)

Shell 5

$CA = \max\left[CA_{cmd}, CA_{inj}\right]$

CA = 293.6509 (m^2)

Shell 6

$CA = \max\left[CA_{cmd}, CA_{inj}\right]$

CA = 278.9605 (m^2)

INSPECTION PLANNING PROGRAM USING RISK BASED INSPECTION API 581 FOR ABOVEGROUND STORAGE TANKS IN PT. X. GRESIK

ATTACHMENT 8 :

RISK CALCULATION CALCULATION OF ABOVEGROUND STORAGE TANK

Rev.	Tanggal	Keterangan	Disusun Oleh:		Disetujui Oleh:	
			Nama	Paraf	Pembimbing	Paraf
			Rafli Mahadika Ariapratama		Ir. Dwi Priyanta, M.SE	
			No. Registration :		Dr. Eng. M. Badrus Zaman, S.T. , M.T.	
			04211641000014			

RISK CALCULATION

At RBI Date

Tank Shell

RLA Data

Shell 1	POF	=	1.43E-04
Shell 2	POF	=	1.43E-04
Shell 3	POF	=	1.43E-04
Shell 4	POF	=	1.43E-04
Shell 5	POF	=	1.43E-04
Shell 6	POF	=	1.43E-04

$$CA=\max\left[CA_{cmd}, CA_{inj}\right]$$

$$CA=\max\left[CA_{cmd}, CA_{inj}\right]$$

shell 1	CA	=	477.6503684	m^2
		=	5141.380801	ft^2
shell 2	CA	=	440.791116	m^2
		=	4744.631493	ft^2
shell 3	CA	=	399.726935	m^2
		=	4302.620756	ft^2
shell 4	CA	=	352.1425875	m^2
		=	3790.427597	ft^2
shell 5	CA	=	293.6509032	m^2
		=	3160.828957	ft^2
shell 6	CA	=	278.9605137	m^2
		=	3002.703073	ft^2

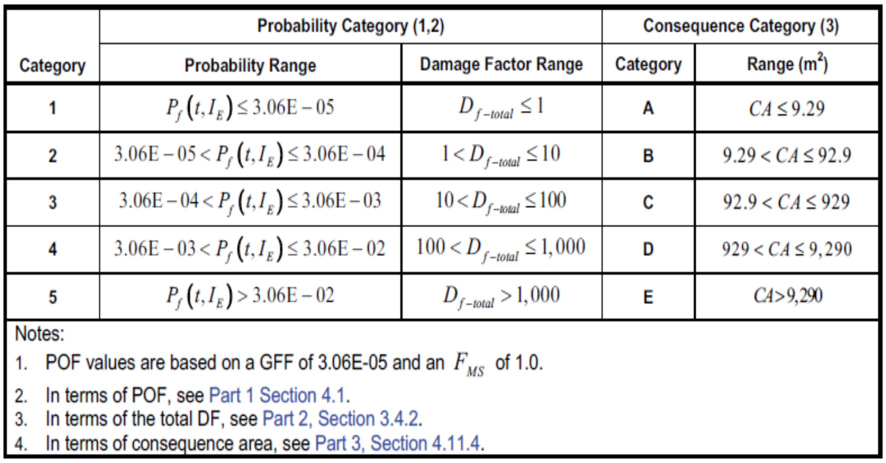
Risk

RLA Data

Shell 1	=	0.0684787	m^2	/year
		0.7370982	ft^2	/year
Shell 2	=	0.0632024	m^2	/year
		0.6803042	ft^2	/year

Shell 3	=	0.0573146	m^2	/year
		0.6169291	ft^2	/year
Shell 4	=	0.0504462	m^2	/year
		0.5429983	ft^2	/year
Shell 5	=	0.0420740	m^2	/year
		0.4528802	ft^2	/year
Shell 6	=	0.0399625	m^2	/year
		0.4301527	ft^2	/year
Risk Target	=	40	ft^2	/year
DF Target	=	10		

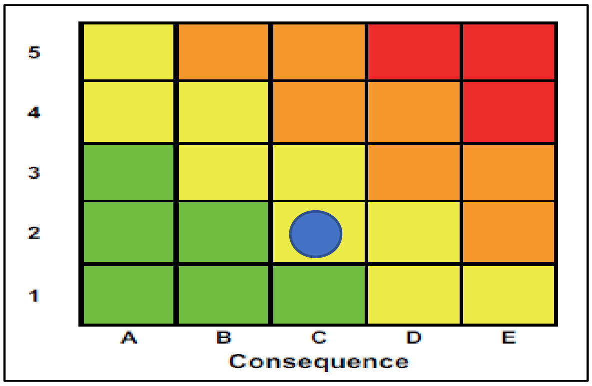
Table 4.1M – Numerical Values Associated with POF and Area-Based COF Categories



Category	Probability Category (1,2)		Consequence Category (3)	
	Probability Range	Damage Factor Range	Category	Range (m^2)
1	$P_f(t,I_E) \le 3.06E-05$	$D_{f-total} \le 1$	A	$CA \le 9.29$
2	$3.06E-05 < P_f(t,I_E) \le 3.06E-04$	$1 < D_{f-total} \le 10$	B	$9.29 < CA \le 92.9$
3	$3.06E-04 < P_f(t,I_E) \le 3.06E-03$	$10 < D_{f-total} \le 100$	C	$92.9 < CA \le 929$
4	$3.06E-03 < P_f(t,I_E) \le 3.06E-02$	$100 < D_{f-total} \le 1,000$	D	$929 < CA \le 9,290$
5	$P_f(t,I_E) > 3.06E-02$	$D_{f-total} > 1,000$	E	$CA > 9,290$

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.



At Plan Date

Tank Shell

RLA Data

Shell 1 POF = 0.0001433

Shell 2 POF = 1.43E-04

Shell 3 POF = 1.43E-04

Shell 4 POF = 1.42E-04

Shell 5 POF = 1.43E-04

Shell 6 POF = 1.42E-04

$$CA=\max\left[CA_{cmd}, CA_{inj}\right]$$

$$CA=\max\left[CA_{cmd}, CA_{inj}\right]$$

shell 1 CA = 477.6503684 m^2
= 5141.380801 ft^2

shell 2 CA = 440.791116 m^2
= 4744.631493 ft^2

shell 3 CA = 399.726935 m^2
= 4302.620756 ft^2

shell 4 CA = 352.1425875 m^2
= 3790.427597 ft^2

shell 5 CA = 293.6509032 m^2
= 3160.828957 ft^2

shell 6 CA = 278.9605137 m^2
= 3002.703073 ft^2

Risk

RLA Data

Shell 1 = 0.0684303 m^2 /year
0.7365774 ft^2 /year

Shell 2 = 0.0631860 m^2 /year
0.6801277 ft^2 /year

Shell 3 = 0.0573003 m^2 /year
0.6167750 ft^2 /year

Shell 4 = 0.0501097 m^2 /year
0.5393760 ft^2 /year

Shell 5 = 0.0418637 m^2 /year
0.4506168 ft^2 /year

Shell 6 = 0.0396959 m^2 /year
0.4272832 ft^2 /year

Risk Target = 40 ft^2 /year
DF Target = 10

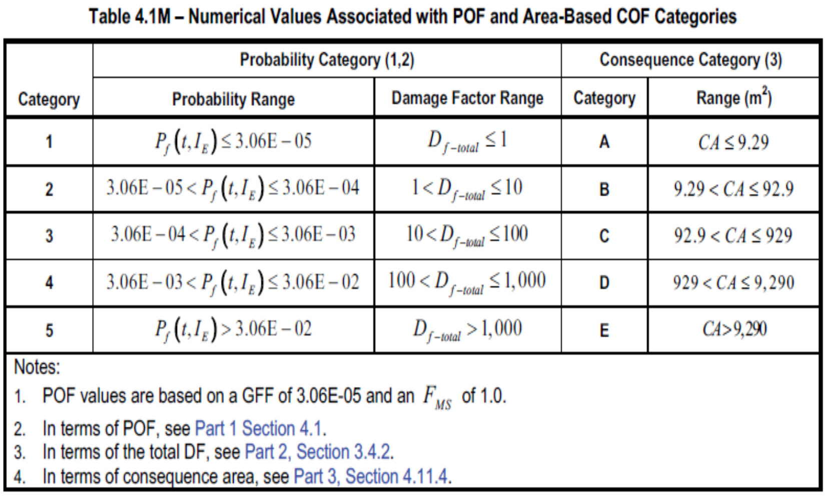
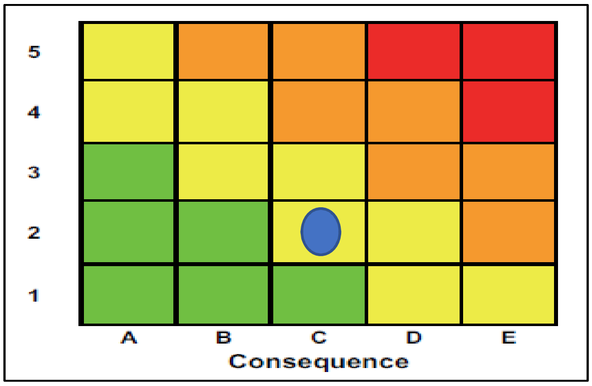


Table 4.1M – Numerical Values Associated with POF and Area-Based COF Categories

Category	Probability Category (1,2)		Consequence Category (3)	
	Probability Range	Damage Factor Range	Category	Range (m^2)
1	$P_f(t,I_E) \le 3.06E-05$	$D_{f-total} \le 1$	A	$CA \le 9.29$
2	$3.06E-05 < P_f(t,I_E) \le 3.06E-04$	$1 < D_{f-total} \le 10$	B	$9.29 < CA \le 92.9$
3	$3.06E-04 < P_f(t,I_E) \le 3.06E-03$	$10 < D_{f-total} \le 100$	C	$92.9 < CA \le 929$
4	$3.06E-03 < P_f(t,I_E) \le 3.06E-02$	$100 < D_{f-total} \le 1,000$	D	$929 < CA \le 9,290$
5	$P_f(t,I_E) > 3.06E-02$	$D_{f-total} > 1,000$	E	$CA > 9,290$

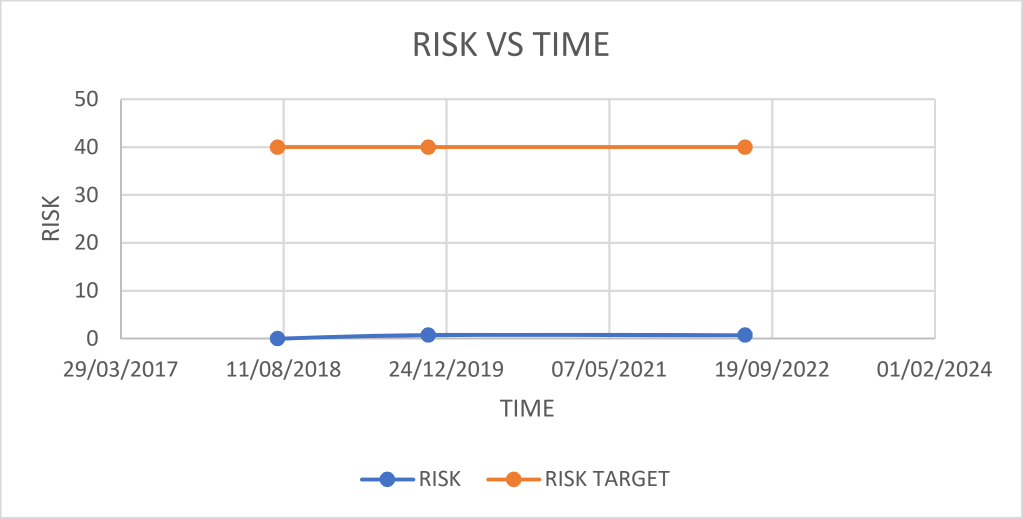
Notes:
1. POF values are based on a GFF of 3.06E-05 and an F_{MS} of 1.0.
2. In terms of POF, see Part 1 Section 4.1.
3. In terms of the total DF, see Part 2, Section 3.4.2.
4. In terms of consequence area, see Part 3, Section 4.11.4.



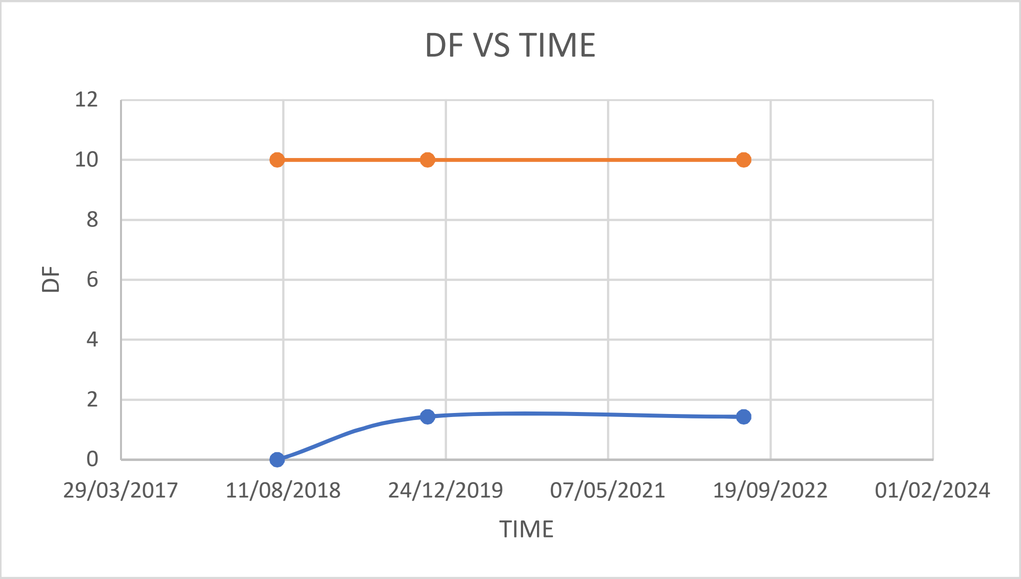
Inspection Planning

SHELL 1

	TIME	Risk (ft^2/year)	Risk target (ft^2/year)
Last insp. date	23/07/2018	0	40
RBI date	29/10/2019	0.73709816	40
Plan date	28/06/2022	0.73657737	40



	TIME	DF	DF target
Last insp. date	23/07/2018	0	10
RBI date	29/10/2019	1.43365798	10
Plan date	28/06/2022	1.43264504	10



TIME CALCULATION FOR NEXT INSPECTION

	TIME	DF	DF target
Last insp. date	23/07/2018	0	10
RBI date	29/10/2019	1.433657979	10
Plan date	28/06/2022	1.432645037	10

$$DF\ TARGET = (DF\ RBI\ Date).(Time\ Plan\ Date\ - RBI\ Date)^{n-1}$$

$$10 = (1{,}434033091).(2{,}663929)^{n-1}$$
$$6{,}97333979 = (2{,}663929)^{n-1}$$

X_1	2	Y_1	2.633929
X	x	Y	6.9733979
X_2	3	Y_2	7.09651772

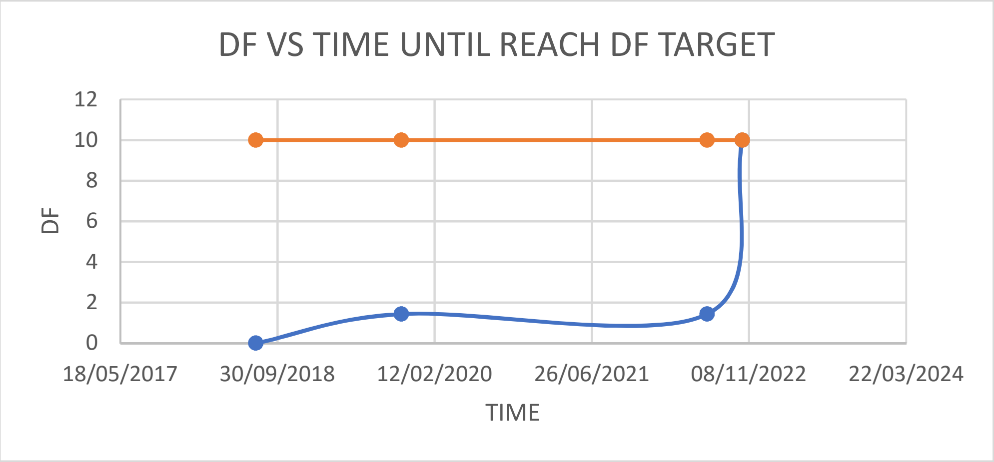
$$X = X_1 + \left(\frac{Y - Y_1}{Y_2 - Y_1}\right)(X_2 - X_1)$$

$$X = 2 + \left(\frac{6{,}9733979 - 2{,}633929}{7{,}09651772 - 2{,}633929}\right)(3 - 2)$$

X = 2.972410673 YEAR

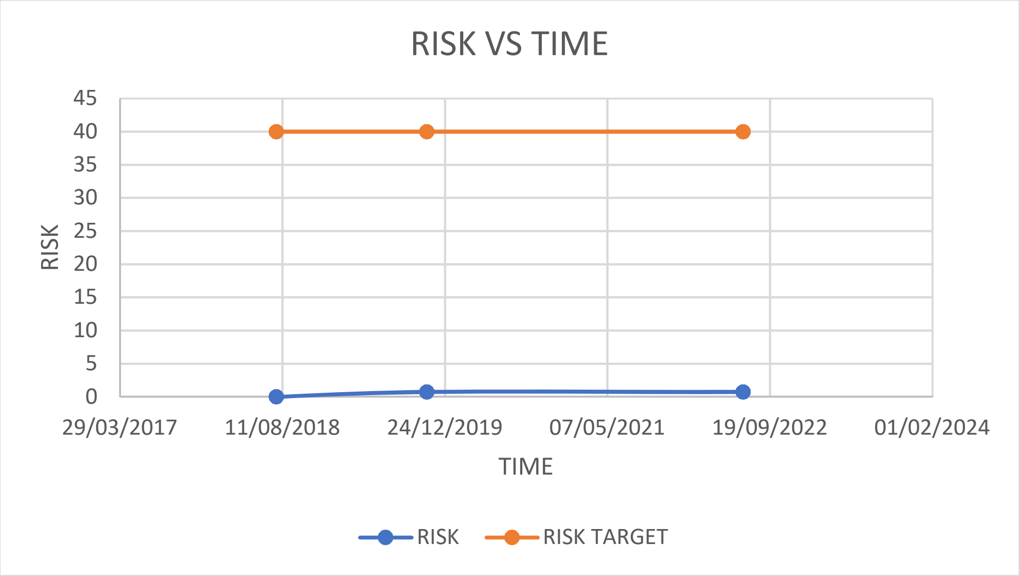
NEXT INSPECTION = 17/10/2022

	TIME	DF	DF target
Last insp. date	23/07/2018	0	10
RBI date	29/10/2019	1.433657979	10
Plan date	28/06/2022	1.432645037	10
Next Inspection	17/10/2022	10	10

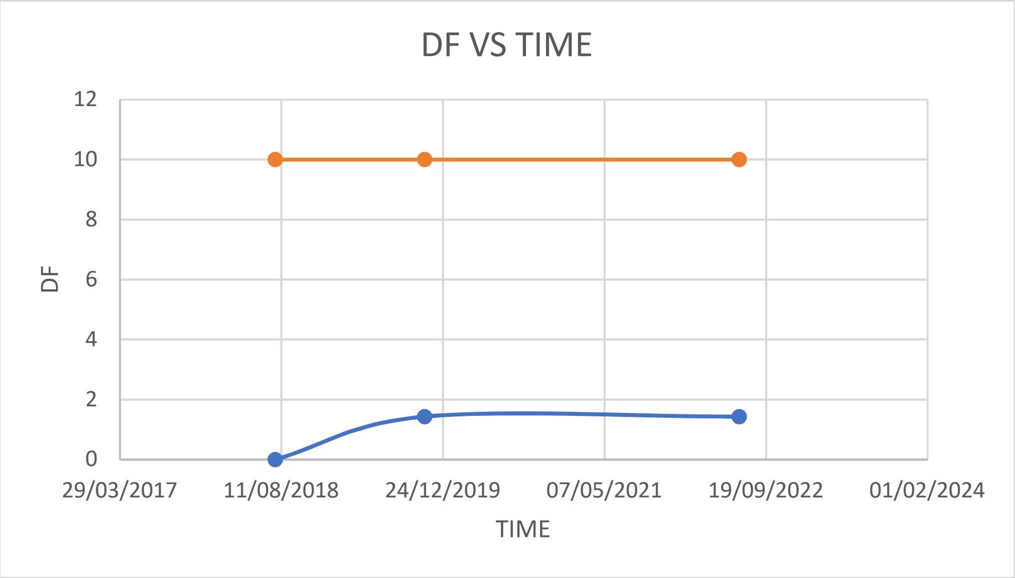


SHELL 2

	TIME	Risk (ft^2/year)	Risk target (ft^2/year)
Last insp. date	23/07/2018	0	40
RBI date	29/10/2019	0.68030417	40
Plan date	28/06/2022	0.68012775	40



	TIME	DF	DF target
Last insp. date	23/07/2018	0	10
RBI date	29/10/2019	1.43383985	10
Plan date	28/06/2022	1.43346801	10



TIME CALCULATION FOR NEXT INSPECTION

	TIME	DF	DF target
Last insp. date	23/07/2018	0	10
RBI date	29/10/2019	1.433839851	10
Plan date	28/06/2022	1.433468009	10

$$DF\ TARGET = (DF\ RBI\ Date).(Time\ Plan\ Date\ - RBI\ Date)^{n-1}$$

$$10 = (1{,}433839851).(2{,}663929)^{n-1}$$
$$6{,}99077806 = (2{,}663929)^{n-1}$$

X_1	2	Y_1	2.633929
X	x	Y	6.99077806
X_2	3	Y_2	7.09651772

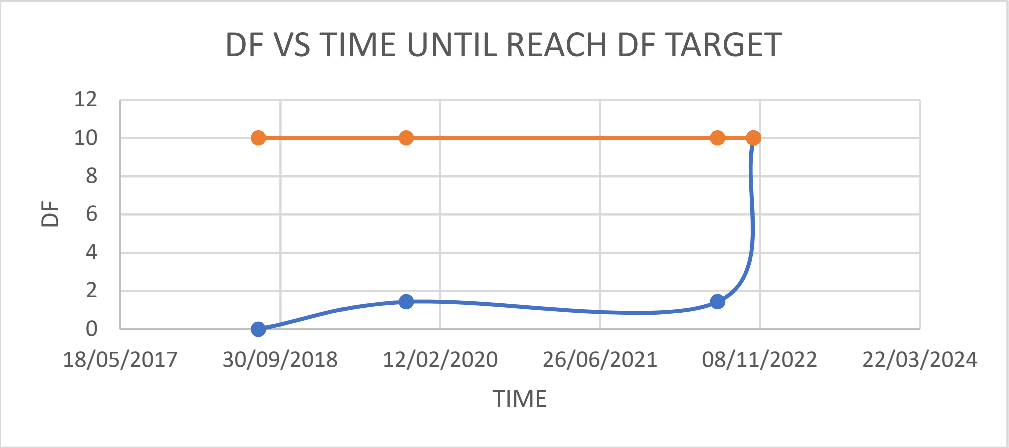
$$X = X_1 + \left(\frac{Y - Y_1}{Y_2 - Y_1}\right)(X_2 - X_1)$$

$$X = 2 + \left(\frac{6{,}99077806 - 2{,}633929}{7{,}09651772 - 2{,}633929}\right)(3 - 2)$$

X = 2.976305309 YEAR

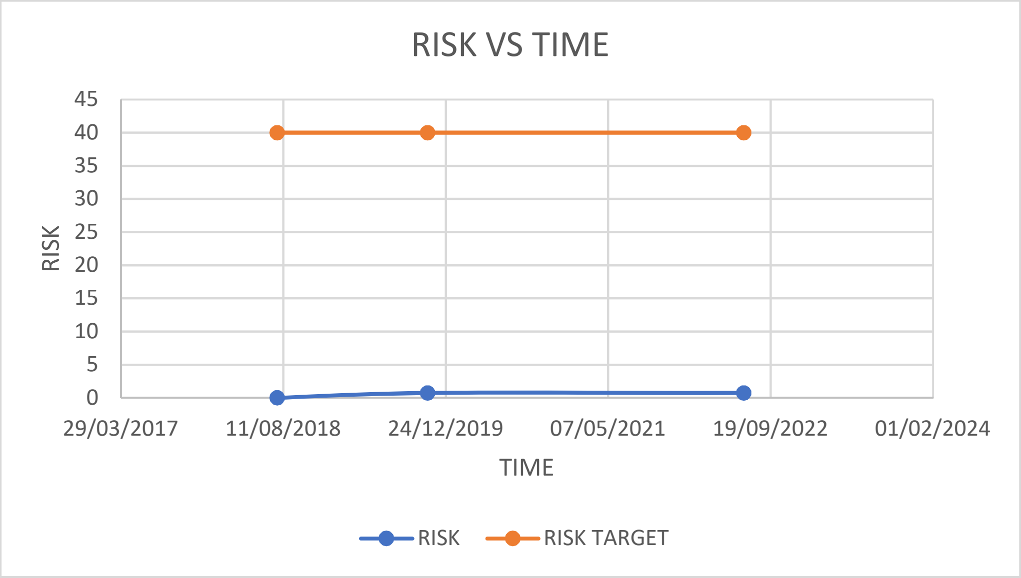
NEXT INSPECTION = 19/10/2022

	TIME	DF	DF target
Last insp. date	23/07/2018	0	10
RBI date	29/10/2019	1.433839851	10
Plan date	28/06/2022	1.433468009	10
Next Inspection	19/10/2022	10	10

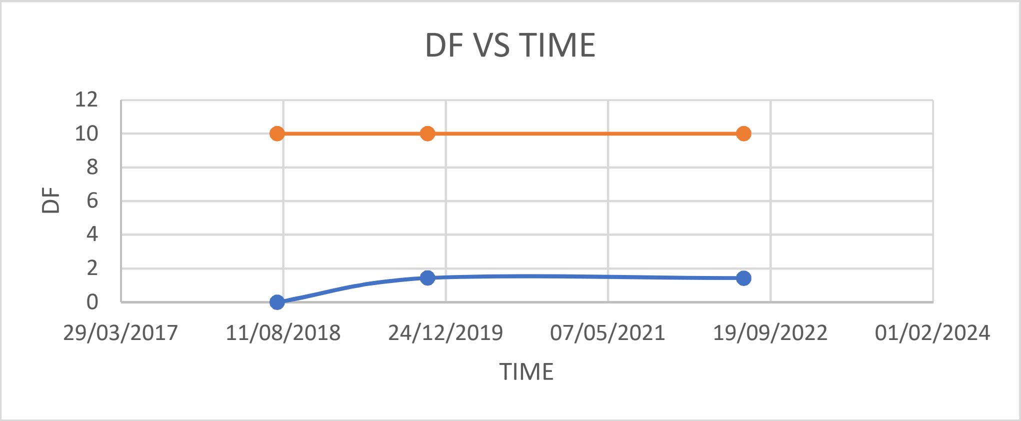


SHELL 3

	TIME	Risk (ft^2/year)	Risk target (ft^2/year)
Last insp. date	23/07/2018	0	40
RBI date	29/10/2019	0.61692906	40
Plan date	28/06/2022	0.61677501	40



	TIME	DF	DF target
Last insp. date	23/07/2018	0	10
RBI date	29/10/2019	1.43384486	10
Plan date	28/06/2022	1.43348682	10



TIME CALCULATION FOR NEXT INSPECTION

	TIME	DF	DF target
Last insp. date	23/07/2018	0	10
RBI date	29/10/2019	1.433844859	10
Plan date	28/06/2022	1.433486815	10

$$DF\ TARGET = (DF\ RBI\ Date).(Time\ Plan\ Date\ - RBI\ Date)^{n-1}$$

$$10 = (1{,}433844859).(2{,}663929)^{n-1}$$
$$6{,}97104299 = (2{,}663929)^{n-1}$$

X_1	2	Y_1	2.633929
X	x	Y	6.97104299
X_2	3	Y_2	7.09651772

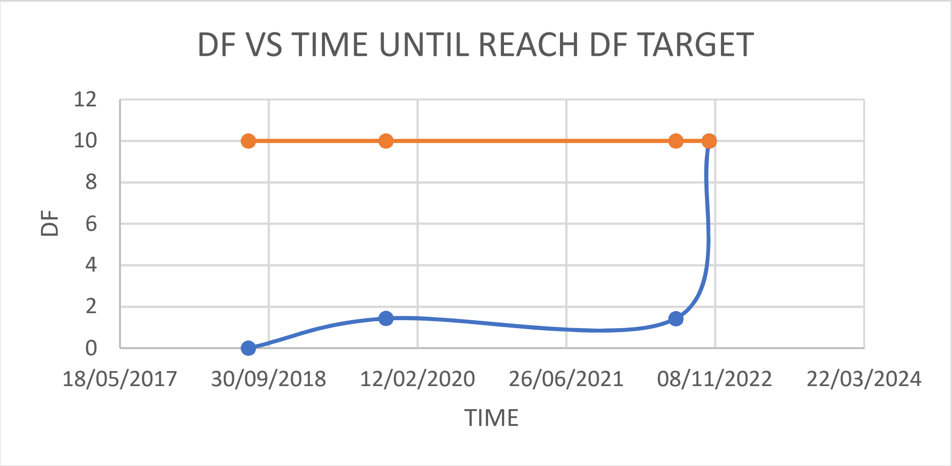
$$X = X_1 + \left(\frac{Y\ - Y_1}{Y_2 - Y_1}\right)(X_2\ - X_1)$$

$$X = 2 + \left(\frac{6{,}97104299 - 2{,}633929}{7{,}09651772 - 2{,}633929}\right)(3\ - 2)$$

X = 2.971882972 YEAR

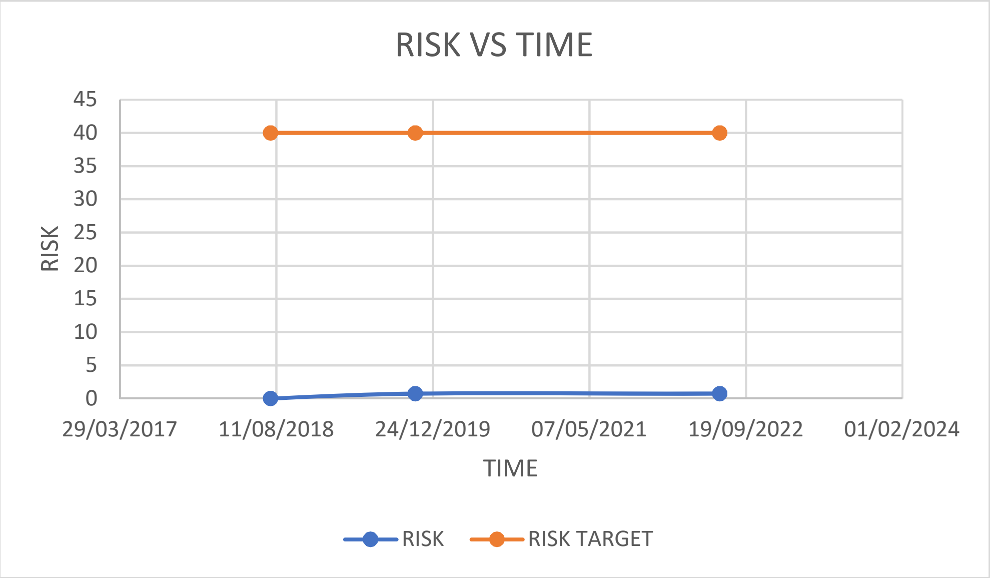
NEXT INSPECTION = 17/10/2022

	TIME	DF	DF target
Last insp. date	23/07/2018	0	10
RBI date	29/10/2019	1.433844859	10
Plan date	28/06/2022	1.433486815	10
Next Inspection	17/10/2022	10	10

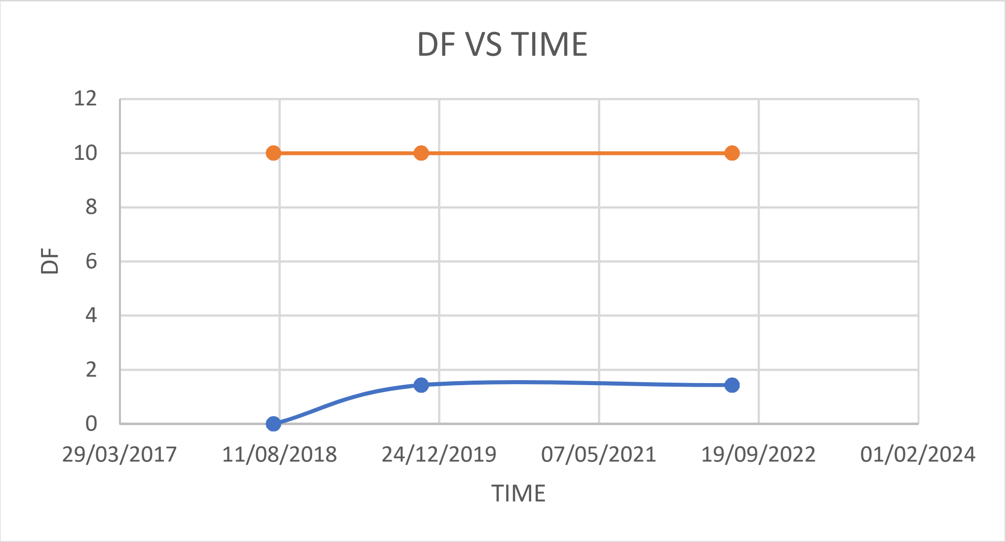


SHELL 4

	TIME	Risk (ft^2/year)	Risk target (ft^2/year)
Last insp. date	23/07/2018	0	40
RBI date	29/10/2019	0.54299830	40
Plan date	28/06/2022	0.53937599	40



	TIME	DF	DF target
Last insp. date	23/07/2018	0	10
RBI date	29/10/2019	1.43255156	10
Plan date	28/06/2022	1.42299511	10



TIME CALCULATION FOR NEXT INSPECTION

	TIME	DF	DF target
Last insp. date	23/07/2018	0	10
RBI date	29/10/2019	1.432551563	10
Plan date	28/06/2022	1.42299511	10

$$DF\ TARGET = (DF\ RBI\ Date).(Time\ Plan\ Date\ - RBI\ Date)^{n-1}$$

$$10 = (1{,}4332551563).(2{,}663929)^{n-1}$$
$$6{,}9732655 = (2{,}663929)^{n-1}$$

XX_1	2	Y_1	2.633929
X	x	Y	6.9732655
X_2	3	Y_2	7.09651772

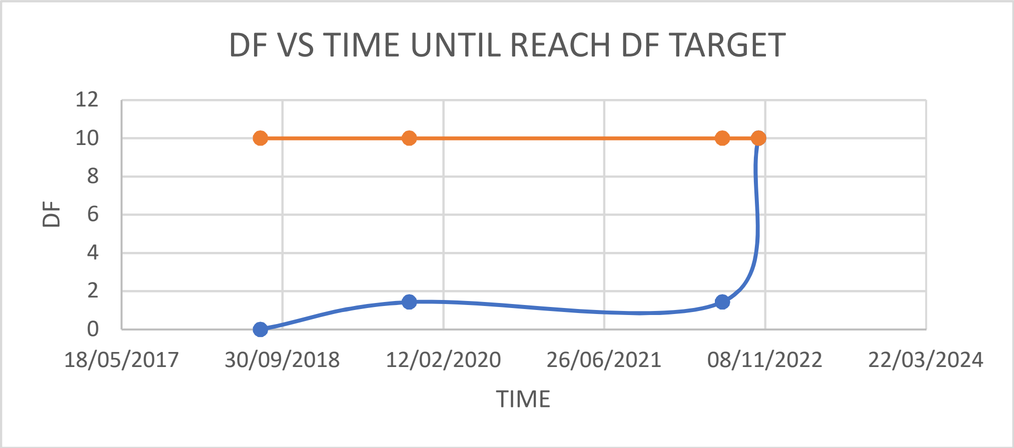
$$X = X_1 + \left(\frac{Y\ - Y_1}{Y_2 - Y_1}\right)(X_2\ - X_1)$$

$$X = 2 + \left(\frac{6{,}9732655 - 2{,}633929}{7{,}09651772 - 2{,}633929}\right)(3\ - 2)$$

X = 2.972381004 YEAR

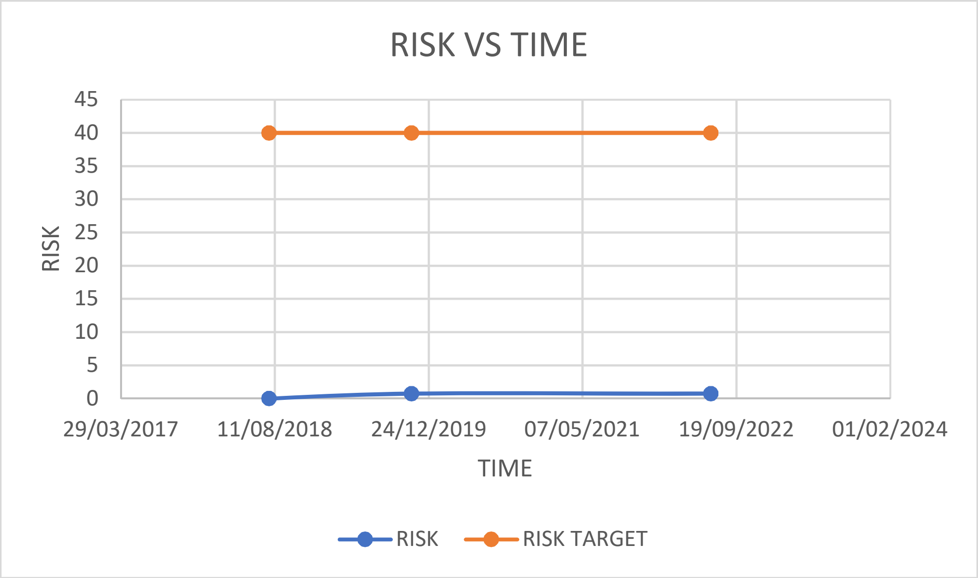
NEXT INSPECTION = 17/10/2022

	TIME	DF	DF target
Last insp. date	23/07/2018	0	10
RBI date	29/10/2019	1.432551563	10
Plan date	28/06/2022	1.42299511	10
Next Inspection	17/10/2022	10	10

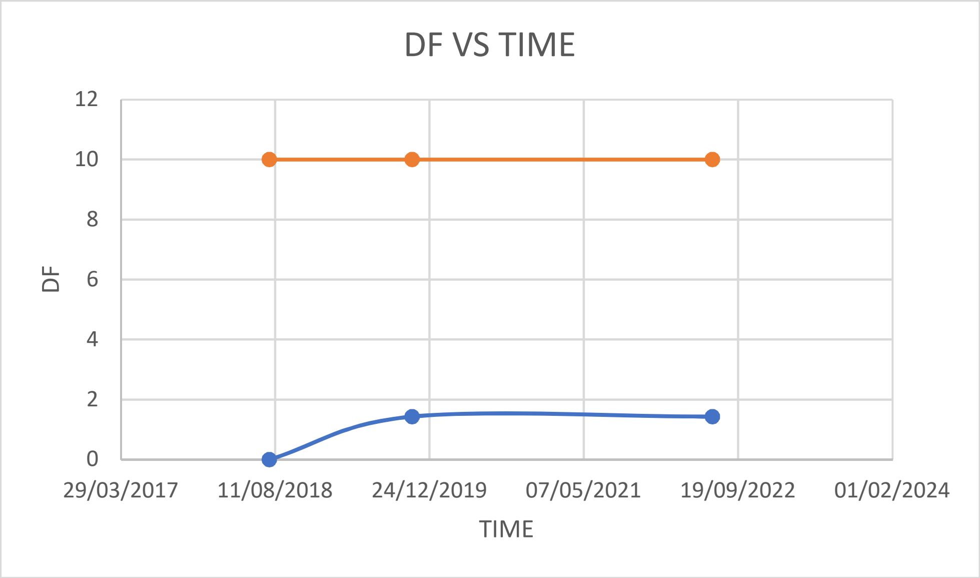


SHELL 5

	TIME	Risk (ft^2/year)	Risk target (ft^2/year)
Last insp. date	23/07/2018	0	40
RBI date	29/10/2019	0.45288021	40
Plan date	28/06/2022	0.45061677	40



	TIME	DF	DF target
Last insp. date	23/07/2018	0	10
RBI date	29/10/2019	1.43278936	10
Plan date	28/06/2022	1.42562844	10



TIME CALCULATION FOR NEXT INSPECTION

	TIME	DF	DF target
Last insp. date	23/07/2018	0	10
RBI date	29/10/2019	1.432789358	10
Plan date	28/06/2022	1.425628439	10

$$DF\ TARGET = (DF\ RBI\ Date).(Time\ Plan\ Date\ - RBI\ Date)^{n-1}$$

$$10 = (1{,}432789358).(2{,}663929)^{n-1}$$
$$6{,}9732827 = (2{,}663929)^{n-1}$$

X_1	2	Y_1	2.633929
X	x	Y	6.9732827
X_2	3	Y_2	7.09651772

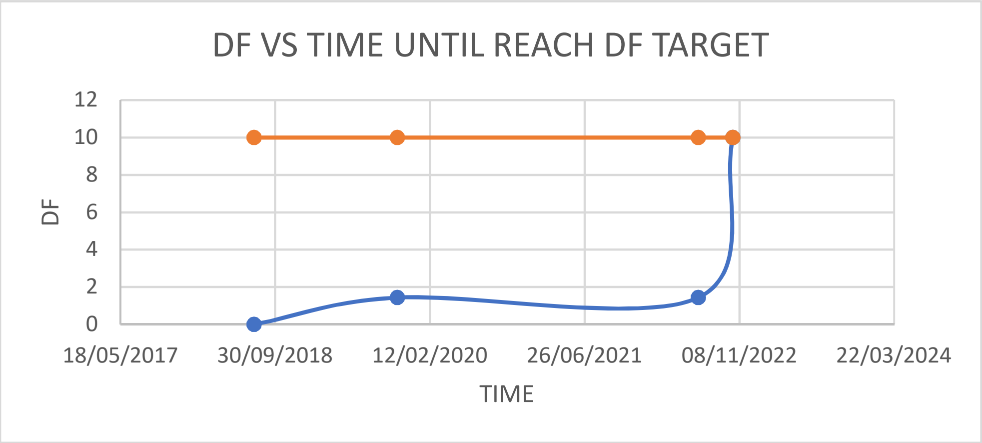
$$X = X_1 + \left(\frac{Y - Y_1}{Y_2 - Y_1}\right)(X_2 - X_1)$$

$$X = 2 + \left(\frac{6{,}9732827 - 2{,}633929}{7{,}09651772 - 2{,}633929}\right)(3 - 2)$$

X = 2.972384858 YEAR

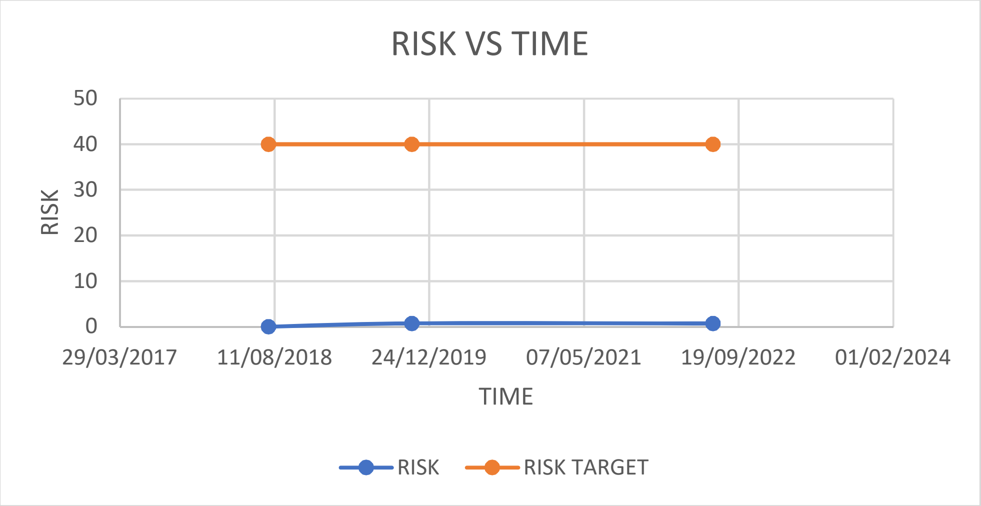
NEXT INSPECTION = 17/10/2022

	TIME	DF	DF target
Last insp. date	23/07/2018	0	10
RBI date	29/10/2019	1.432789358	10
Plan date	28/06/2022	1.425628439	10
Next Inspection	17/10/2022	10	10

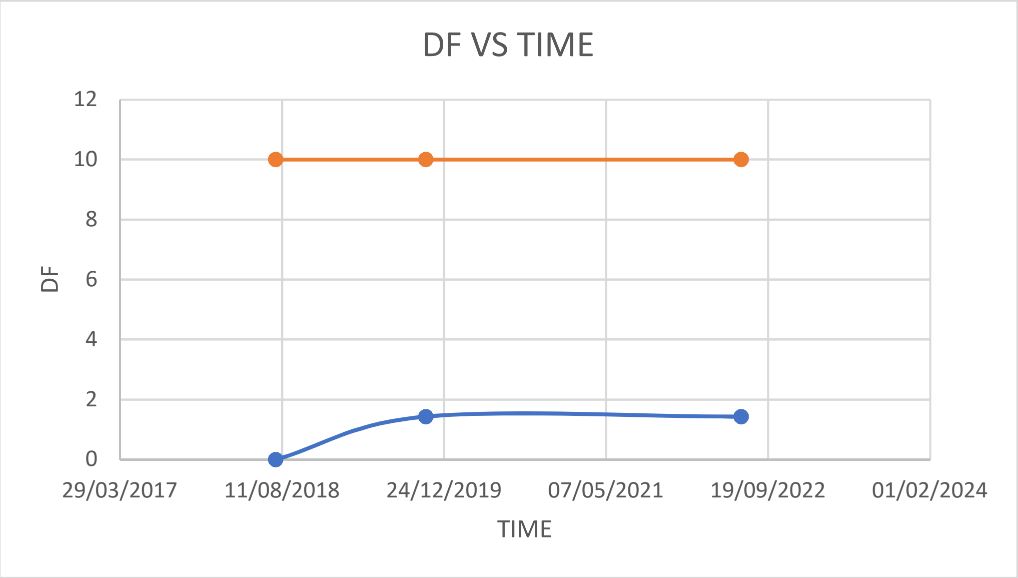


SHELL 6

	TIME	Risk (ft^2/year)	Risk target (ft^2/year)
Last insp. date	23/07/2018	0	40
RBI date	29/10/2019	0.43015270	40
Plan date	28/06/2022	0.42728318	40



	TIME	DF	DF target
Last insp. date	23/07/2018	0	10
RBI date	29/10/2019	1.43255156	10
Plan date	28/06/2022	1.42299511	10



TIME CALCULATION FOR NEXT INSPECTION

	TIME	DF	DF target
Last insp. date	23/07/2018	0	10
RBI date	29/10/2019	1.432551563	10
Plan date	28/06/2022	1.42299511	10

$$DF\ TARGET = (DF\ RBI\ Date).(Time\ Plan\ Date\ - RBI\ Date)^{n-1}$$

$$10 = (1{,}4325551563).(2{,}663929)^{n-1}$$
$$6{,}973285 = (2{,}663929)^{n-1}$$

X_1	2	Y_1	2.633929
X	x	Y	6.97328275
X_2	3	Y_2	7.09651772

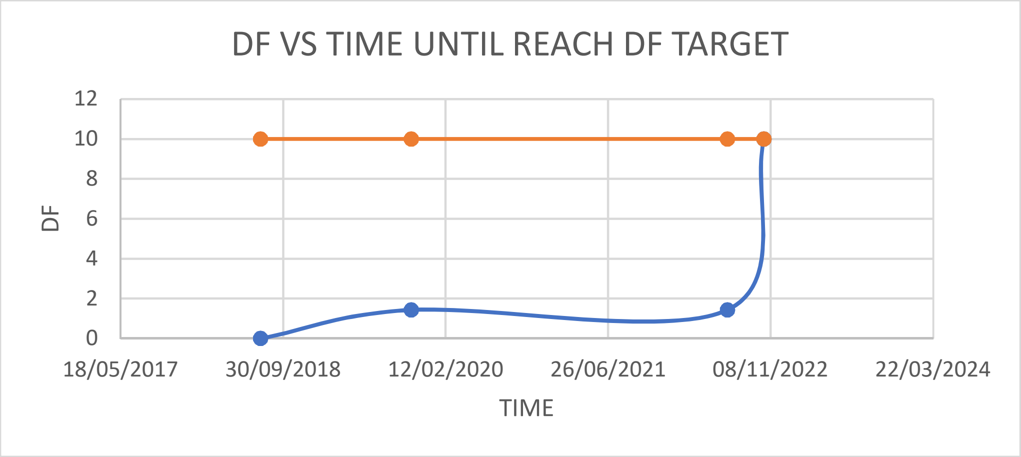
$$X = X_1 + \left(\frac{Y - Y_1}{Y_2 - Y_1}\right)(X_2 - X_1)$$

$$X = 2 + \left(\frac{6{,}973285 - 2{,}633929}{7{,}09651772 - 2{,}633929}\right)(3 - 2)$$

X = 2.972384869 YEAR

NEXT INSPECTION = 17/10/2022

	TIME	DF	DF target
Last insp. date	23/07/2018	0	10
RBI date	29/10/2019	1.432551563	10
Plan date	28/06/2022	1.42299511	10
Next Inspection	17/10/2022	10	10



INSPECTION PLANNING PROGRAM USING RISK BASED INSPECTION API 581 FOR ABOVEGROUND STORAGE TANKS IN PT. X. GRESIK

ATTACHMENT 9 :

INSPECTION RECOMMENDATION FOR ABOVEGROUND STORAGE TANK

Rev.	Tanggal	Keterangan	Disusun Oleh:		Disetujui Oleh:	
			Nama	Paraf	Pembimbing	Paraf
			Rafli Mahadika Ariapratama		Ir. Dwi Priyanta, M.SE	
			No. Registration :		Dr. Eng. M. Badrus Zaman, S.T. , M.T.	
			04211641000014			

RECOMENDATION

DAMAGE FACTOR	INSPECTION CATEGORY	INSPECTION EFFECTIVENESS CATEGORY
LOCALIZED THINNING	D	Poorly Effective

INSTRUSIVE INSPECTION	NON-INSTRUSIVE INSPECTION
>20% visual examination and 100 follow up at locally thinned areas for the total surface area	>20% Coverage the CML's using ultrasonic scanning or profile radiography for the total surface area

DAMAGE FACTOR	INSPECTION CATEGORY
EXTERNAL CORROSION	D

INSPECTION
Visual inspection of >5% of the exposed surface area with follow-up by UT, RT or pit gauge as required.