BACHELOR THESIS & COLLOQUIUM – ME1841038

RELIABILITY-CENTERED MAINTENANCE (RCM) IMPLEMENTATION FOR DETERMINING MAINTENANCE TASK OF INERT GAS SYSTEM (IGS) ON CRUDE OIL TANKER

DZILFIA QURROTUL 'AINI
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DOUBLE DEGREE PROGRAM
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SKRIPSI - ME 1841038

IMPLEMENTASI RELIABILITY-CENTERED MAINTENANCE (RCM) UNTUK MENENTUKAN TUGAS PEMELIHARAAN SISTEM GAS LEMBAM PADA CRUDE OIL TANKER

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APPROVAL SHEET

RELIABILITY-CENTERED MAINTENANCE (RCM) IMPLEMENTATION FOR DETERMINING MAINTENANCE INERT GAS SYSTEM (IGS) ON CRUDE OIL TANKER

BACHELOR THESIS

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

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DECLARATION OF HONOR

I hereby who signed below declare that:
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Surabaya, January 2020

Dzilfia Qurrotul 'Aini

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RELIABILITY-CENTERED MAINTENANCE (RCM) IMPLEMENTATION FOR DETERMINING MAINTENANCE TASK OF INERT GAS SYSTEM (IGS) ON CRUDE OIL TANKER

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ABSTRACT

PT. Z operates the largest shipping fleet in Indonesia to transport various products such as crude oil, fuel oil, gas products In line with the Government's commitment to support the domestic maritime industry and ensuring cargo transportation all over Indonesia. Transportation of oil and gas through these vessels must not be interrupted, that is why the company also has responsibility to ensuring that the vessels always in good conditions and also pay more attention to accidents that may occur on the ship, one of the accidents that can occur on a tanker is in the form of a fire and explosion in cargo area causing by flammable gas accumulation due to the absence of an inert gas system or the inert gas system not functioning on board. Fire can happen when all of the elements in fire triangle are existed. Fire triangle elements are oxidizers, fuel, and heat source. When tank cleaning, loading or discharge cargo is the most likely moment for oxygen to enter the tank, there is a risk of causing an explosion if there is a heat source around the tank. Therefore, to control the atmosphere in the tank so that the oxygen content does not reach an amount sufficient to form a fire, an inert gas system is installed, inert gas system will maintain the tank atmosphere by inserting inert gas into the tank. while inert conditions are conditions where oxygen levels in cargo tanks are maintained at a maximum level of 8% of the total volume of gas present in the tank's atmosphere. In addition, the inert gas system must be able to produce inert gas with an oxygen content of less than 5% by volume of pure inert gas (BKI, 2018) Losses that can be caused by the explosion of tanker include fatalities due to accidents, economic losses due to loss of cargo and ships, spills of oil, gas and other chemicals that cause environmental pollution, and can also result in fuel and gas scarcity. Therefore, it is very important to keep the inert gas on the ship operates as it should be. One of the solutions is by doing the maintenance of system perfectly. There is one systematic approach for determining the maintenance requirements of plant and equipment in its operation is called Reliability-

Centered Maintenance (RCM), RCM will chooses the right maintenance activities such as preventive maintenance or corrective maintenance for the right equipment at the right time to reach the most cost-efficient solution. After RCM analysis is done there are 40 tasklist, and the percentages of every maintenance types of each failure mode are 70% preventive maintenance, 22.5% condition monitoring, and 7.5% One-time change.

Key words - Crude Oil Tanker, FMECA, Inert Gas System, Reliability-Centered Maintenance

IMPLEMENTASI RELIABILITY-CENTERED MAINTENANCE (RCM) UNTUK MENENTUKAN TUGAS PEMELIHARAAN SISTEM GAS LEMBAM PADA CRUDE OIL TANKER

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ABSTRAK

PT. Z mengoperasikan armada transportasi laut untuk mengangkut berbagai produk minyak dan gas seperti minyak mentah, minyak bakar, produk gas terbesar di Indonesia. Sejalan dengan komitmen pemerintah untuk mendukung industri maritim domestik dan memastikan transportasi kargo di seluruh Indonesia. Transportasi minyak dan gas melalui kapal-kapal ini tidak boleh terputus, oleh karena itu perusahaan juga memiliki tanggung jawab untuk memastikan bahwa kapal selalu dalam kondisi baik dan juga lebih memperhatikan kecelakaan yang mungkin terjadi di kapal, salah satu kecelakaan yang bisa terjadi pada kapal tanker adalah kebakaran dan ledakan di area kargo yang disebabkan oleh akumulasi gas yang mudah terbakar karena tidak adanya sistem gas inert atau sistem gas inert yang tidak berfungsi di atas kapal. Api dapat terjadi ketika semua elemen dalam segitiga api ada. Elemen segitiga api adalah oksigen, bahan bakar, dan sumber panas. Saat pembersihan, *loading* dan *unloading* muatan adalah momen yang paling mungkin bagi oksigen untuk memasuki tangki, ada risiko menyebabkan ledakan jika ada sumber panas di sekitar tangki. Oleh karena itu, untuk mengontrol atmosfer dalam tangki sehingga kandungan oksigen tidak mencapai jumlah yang cukup untuk membentuk api, sistem gas inert dipasang, sistem gas inert akan mempertahankan atmosfer tangki dengan memasukkan gas inert ke dalam tangki. sementara kondisi lembam adalah kondisi di mana kadar oksigen dalam tangki kargo dipertahankan pada tingkat maksimum 8% dari total volume gas yang ada di atmosfer tangki. Selain itu, sistem gas inert harus mampu menghasilkan gas inert dengan kandungan oksigen kurang dari 5% volume gas inert murni (BKI, 2018) Kerugian yang dapat disebabkan oleh ledakan tanker dapat berupa korban jiwa, kerugian ekonomi karena kehilangan muatan dan kapal, tumpahan minyak, gas, dan bahan kimia lainnya dapat menyebabkan polusi lingkungan, dan juga dapat mengakibatkan kelangkaan bahan bakar dan gas karena pendistribusian yang terputus. Oleh karena itu, sangat penting untuk menjaga agar gas inert di kapal tetap beroperasi sebagaimana mestinya. Salah satu solusinya adalah dengan melakukan pemeliharaan sistem dengan sempurna. Ada satu pendekatan sistematis untuk menentukan tugas pemeliharaan yaitu Reliability-Centered Maintenance (RCM), RCM akan memilih kegiatan pemeliharaan yang tepat seperti pemeliharaan preventif atau pemeliharaan korektif untuk peralatan yang tepat pada waktu yang tepat. mencapai solusi paling hemat biaya. Berdasarkan hasil dari penelitian ini, terdapat 40 jenis task list. Dimana prosentase jenis perawatan dari masing-masing *failure mode* (*tasktype*) *Preventive Maintenance* (PM) sebesar 70%, *Condition Monitoring* (CM) sebesar 22.5%, dan *One-Time Change* 7.5%.

Key words - Crude Oil Tanker, FMECA, Inert Gas System, Reliability-Centered Maintenance

PREFACE

In the Name of Allah, the Most Gracious, the Most Merciful. All the praises and thanks be to Almighty Allah for giving the author opportunity, determination and strength to finish this bachelor thesis with the tittle "RELIABILITY-CENTERED MAINTENANCE (RCM) IMPLEMENTATION FOR DETERMINING MAINTENANCE TASK OF INERT GAS SYSTEM (IGS) ON CRUDE OIL TANKER" in order to fulfill the requirements to get a Bachelor of Engineering degree in the Department of Marine Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember Surabaya.

The author would like to express her gratitude to all those who helped, supported, and offered encouragement on this bachelor thesis writing:

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The author realizes that in writing this report there are many shortcomings, so the constructive criticisms and suggestions that the author hopes for. Hopefully this bachelor thesis can be beneficial for us. Finally, may Allah bestow His mercy and blessings for us.

Surabaya, January 2020

Author

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CHAPTER I
INTRODUCTION

1.1 Background

As a state-owned enterprise company, PT. Z is at the forefront of the effort to support the Government's program PT. Z's main focus and strategy in 2018 is to support the efforts to realize national energy security and independence. PT. Z operates the largest shipping fleet in Indonesia to transport various products such as crude oil, fuel oil, gas products In line with the Government's commitment to support the domestic maritime industry and ensuring cargo transportation all over Indonesia. Senior Vice President of Shipping, Mulyono said that "*armada kapal menjadi sangat vital sebagai urat nadi pendistribusian BBM dan LPG di Indonesia. Karenanya, transportasi BBM dan LPG melalui kapal-kapal tersebut tidak boleh terputus kendati berbagai hambatan dan kendala*" (Mulyono, 2014). Transportation of oil and gas through these vessels must not be interrupted, that is why PT. Z Shipping also has responsibility to ensuring that the vessels always in good conditions and also pay more attention to accidents that may occur on the ship so that precaution actions can be taken to reduce the possibility of accidents that will disrupt the flow of oil and gas distribution. One of the accidents that can occur on a tanker is in the form of a fire and explosion in cargo area.

Fire can happen when all of the elements in fire triangle are existed. Fire triangle elements are oxidizers, fuel, and heat source. When tank cleaning, loading or discharge cargo is the most likely moment for oxygen to enter the tank, there is a risk of causing an explosion if there is a heat source around the tank. Therefore, to control the atmosphere in the tank so that the oxygen content does not reach an amount sufficient to form a fire, an inert gas system is installed, inert gas system will maintain the tank atmosphere by inserting inert gas into the tank. while inert conditions are conditions where oxygen levels in cargo tanks are maintained at a maximum level of 8% of the total volume of gas present in the tank's atmosphere. In addition, the inert gas system must be able to produce inert gas with an oxygen content of less than 5% by volume of pure inert gas (BKI, 2018). There are so many impacts of fire / explosion caused by the accumulation of flammable gas on the ship. Flammable gas accumulation can occur due to the absence of an inert gas system or the inert gas system not functioning on board. Losses that can be caused by the explosion of tanker include fatalities due to accidents, economic losses due to loss of cargo and ships, spills of oil, gas and other chemicals that cause environmental pollution, and can also result in fuel and gas scarcity due to disruption of the flow distribution of oil, gas, and chemicals to several places, especially to places where oil and gas transportation can only be done by sea. Therefore, it is very important to keep the inert gas on the ship operates as it should be. One of the solutions is by doing the maintenance of system perfectly. There is one Systematic approach for determining the maintenance requirements of plant and equipment in its operation is called Reliability-Centered Maintenance (RCM) (Bertling, August 2005)

RCM also can be defined as a systematic method to keep balance between corrective maintenance and preventive maintenance. RCM will choose the right maintenance activities such as preventive maintenance or corrective maintenance for the right equipment at the right time to reach the most cost-efficient solution. (Bertling, August 2005) RCM is characterized by maintaining system function, identifying failure modes, prioritizing functions, and choosing efficient maintenance. The main objective of Reliability-Centered Maintenance is to reduce maintenance cost by focusing on the most important function of the system (Yssaad, et al., 2014). An RCM analysis, when properly conducted, should answer the following seven questions (Moubray, 1991) :

1. What are the system functions and associated performance standards?
2. How can the system fail to fulfill these functions?
3. What can cause a functional failure?
4. What happens when a failure occurs?
5. What might the consequence be when the failure occurs?
6. What can be done to detect and prevent the failure?
7. What should be done if a maintenance task cannot be found?

An effective and efficient maintenance strategist will improve the performance and reliability of the systems, and also can help to reduce risks that can happen in the future. The research of the implementation of RCM strategist will conducted on Inert Gas System of one of the own fleet of PT. Z Shipping.

1.2 Research Problem

Base on the background explanation on **1.1 Background,** it can be concluded that the research problems are:

a. What components are causing the failure and what is the impacts of the failures of the components of inert gas system to the ship?

b. What is the most suitable and effective maintenance type that can be done to the components of inert gas system on the ship?

c. How is the maintenance schedule of the components of inert gas system on the ship?

1.3 Research Limitation

The research can be organized and focused with limitations on the problem, which are:

a. RCM analysis process guide of this research is based on the Reliability-Centered Maintenance (RCM Guide) by the American Bureau of Shipping (ABS)

b. Research object is Inert Gas System of one of the own-fleet of PT. Z Shipping

c. The Reliability-Centered Maintenance (RCM) analysis of Inert Gas System of one of the own-fleet of PT. Z Shipping ignores the effects of natural influences and human error.

1.4 Research Objectives

Based on the problem mention on **1.2 Research Problem**, the objective of the research are:

a. To identify what components are causing the failure and what is the impacts of those failures of the components of inert gas system to the ship

b. To identify the most suitable and effective maintenance type that can be done to the components of inert gas system on the ship?

c. To know the maintenance schedule of the components of inert gas system on the ship

1.5 Research Benefits

The research is expected to give benefits for the various kind of parties. The benefits that can be obtained are:

a. Provides information about the components that are causing the failure and the impacts of those failures of the components of inert gas system to the ship

b. Provides information about the most suitable and effective maintenance type that can be done to the components of inert gas system on the ship

c. Provides information about the maintenance schedule of the components of inert gas system on the ship

1.6 Deliverable

The deliverable of this thesis is maintenance task and scheduling for Inert Gas System of Crude Oil Tanker.

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CHAPTER II
LITERATURE STUDY

2.1 Problem Overview

PT. Z operates the largest shipping fleet in Indonesia to transport various products such as crude oil, fuel oil, gas products to serve national and external demand. Senior Vice President of Shipping, Mulyono said that "*armada kapal menjadi sangat vital sebagai urat nadi pendistribusian BBM dan LPG di Indonesia. Karenanya, transportasi BBM dan LPG melalui kapal-kapal tersebut tidak boleh terputus kendati berbagai hambatan dan kendala*" (Mulyono, 2014). Transportation of oil and gas through these vessels must not be interrupted, that is why PT. Z shipping also has responsibility to ensuring that the vessels always in good conditions and also pay more attention to accidents that may occur on the ship so that precaution actions can be taken to reduce the possibility of accidents that will disrupt the flow of oil and gas distribution. One of the accidents that can occur on a tanker is in the form of a fire and explosion in cargo area.

Fire can occur when the sources of ignition exist. Ignition elements or ignition sources are consisting of oxidizers, fuels, and heat source. And these elements are called fire triangle. (Beyea, 2003) Air with the composition of oxygen only 20% are able to trigger fire when fuel and heat source are existed. (IMO, 2000) To stop a fire, one of the three elements of the fire triangle must be removed.

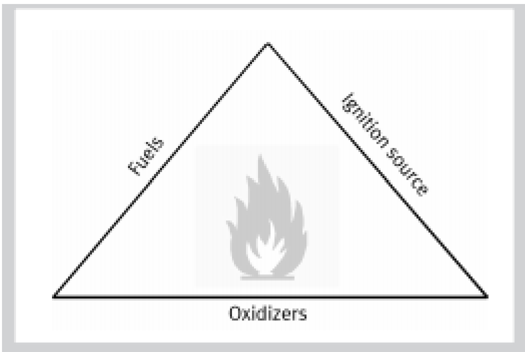

Figure 2. 1 The Fire Triangle *(Beyea, 2003)*

When tank cleaning, loading or discharge cargo is the most likely moment for oxygen to enter the tank, there is a risk of causing an explosion if there is a heat source around the tank. Therefore, to control the atmosphere in the tank so that the oxygen content does not reach an amount sufficient to form a fire, an inert gas system is installed. The inert gas system is installed as a safety system to prevent fires and also explosions in the cargo tank area by inserting inert gas into the tank so that the oxygen content is reduced. Inert gas is a gas or a mixture of various gases that can maintain oxygen levels in a low percentage, while inert conditions are conditions where oxygen levels in cargo tanks are maintained at a maximum level of 8% of the total volume of gas present in the tank's atmosphere. In addition, the inert gas system must be able to produce inert gas with an oxygen content of less than 5% by volume of pure inert gas (BKI, 2018)

The impact that can result from an explosion or fire does not only disrupt the flow of oil and gas distribution, but can cause economic losses, in the form of loss of ships and cargo; apart from that oil spills from ships can also damage the environment. and the most fatal is causing casualties.

2.1.1 Life Victims as a result of Fire / Explosion

The table below is data on accidents related to fire or explosion in the cargo area collected by OCIMF (Oil Companies International Marine Forum) from 2004-2015:

Table 2. 1 Fire/Explosion of Tanker 2004-2015 2015 *(OCIMF, 2017)*

Vessel	8000 DWT or less	8000 – 20000 DWT	20000+ DWT	Oil Cargo	Chemical Cargo	Activity
1	X			X		Tank cleaning
2	X			X		Gas freeing
3	X				X	Loading
4		X		X		Tank cleaning
5			X		X	Gas freeing
6		X			X	Discharging
7			X		X	Tank cleaning
8			X	X		Tank cleaning
9			X		X	Loading
10	X			X		Tank cleaning
11	X			X		Ballast condition
12		X		X		Tank cleaning
13			X	X		Decanting slop tank
14	X			X		Deck maintenance
15	X				X	Tank cleaning

The data above shows that during tank cleaning, loading or discharge cargo is the time of the most frequent accidents. In addition, the data also shows that the majority of accidents occur on vessels of less than 20,000 DWT. This happened because at that time, SOLAS only required to install an inert gas system on ships above 20000 DWT so that ships smaller than 20000 DWT did not install an inert gas system. (OCIMF, 2017)

OCIMF also found another fact that 2 (two) out of 15 (fifteen) ship accidents, were recorded to be over 20000 DWT in size and had installed an inert gas system, only that the tank was not conditioned in an inert condition (inert gas system was not activated) so that the accident was still happen. OCIMF also discovered the fact that of the 15 ship accidents that occurred, 30 people were declared missing and assumed dead. (OCIMF, 2017)

2.1.2 Economical losses caused by Fire/Explosion

There were 378 marine accidents that occurred from 1998 - 2010 and were registered in the GISIS system and country report. (www.gisis.imo.org, 2010) Of the 378 accidents, 61 were accidents that occurred on tankers. Table 2.2 below shows the data collected by GISIS IMO regarding the explosion accident that occurred in the oil tanker from 1998-2010.

Table 2. 2 Fire/Explosion of Tanker 1998-2010 *(www.gisis.imo.org, 2010)*

Type of Casualty			Consequences of the Casualty	
Location	**Very Serious Casualties**	**Serious Casualties**	**Death Injury**	**Economical Lost**
Open Sea	2	9	4	7
Coast	6	3	4	5
Canal	1	3	1	3
Port	21	9	18	12
Anchor	6	1	4	3
Total	**36**	**25**	**31**	**30**

Table 2.2 shows that of the 61 accidents that occurred on tankers, 31 of them resulted in fatalities, and 30 resulted in economic losses.

The results obtained from the accident analysis showed that the main factors causing the accident were the use of inappropriate hot working equipment, accumulation of excessive combustible gas, and also cargo leakage. (Ugurlu, et al., 2012) Gas accumulation is again one of the factors causing accidents.

2.1.3 Oil Spill caused by Explosion/Fire

Another loss that can be caused by an explosion is an oil spill. The diagram below is taken from the analysis of ITOPF (The International Tanker Owners Pollution Federation Limited) which shows the causes of oil spills caused by ship accidents from 1970 - 2018, ship accidents that occur are due to collision, grounding, hull & equipment failure, fire / explosion, and others.

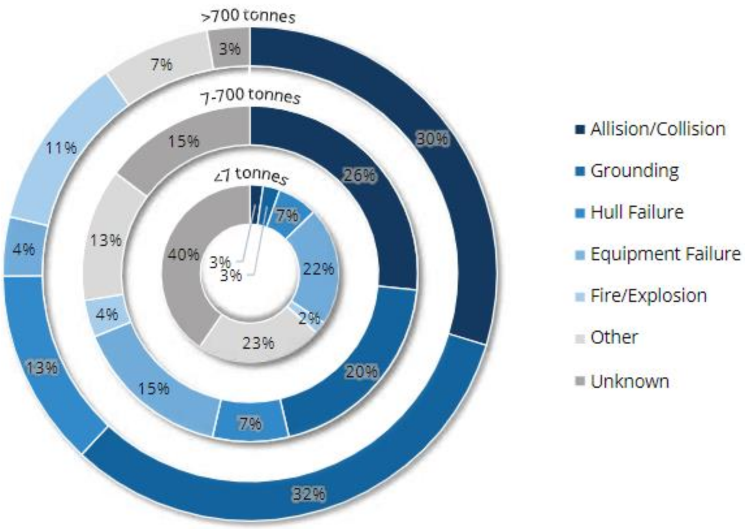

Figure 2. 2 Oil spill caused by tanker accident 1970-2018 *(ITOPF, 2019)*

Based on **Figure 2.2**, fire / explosion as the cause of oil spill does not occur very often, even though fire / explosion is also one of the causes of oil spill. On ships measuring more than 700 tones, oil spills that occur as a result of fire / explosion of 11%, this figure is quite large. From Figure 2.3 it can be seen that there were 53 accidents that occurred on ships measuring more than 700 tones. (ITOPF, 2019)

		Operations							
		At anchor (Inland/ Restricted)	At anchor (Open Water)	Underway (Inland/ Restricted)	Underway (Open Water)	Loading/ discharging	Bunkering	Other Operations/ Unknown	Total
Causes	Allision/Collision	7	5	34	67	2	0	23	138
	Grounding	5	1	46	68	2	0	28	150
	Hull Failure	2	1	0	49	0	0	8	60
	Equipment Failure	0	0	0	6	11	0	1	18
	Fire/Explosion	2	2	1	25	13	1	9	53
	Other	2	0	0	16	8	0	7	33
	Unknown	0	0	0	1	6	0	6	13
	Total	18	9	81	232	42	1	82	465
	Percentage (%)	4	2	17	50	9	0	18	

Figure 2. 3 Oil spill caused by tankers larger than 700 ton's accident 1970-2018 *(ITOPF, 2019)*

2.1.4 Explosion of Bow Mariner Chemical Tanker

Figure 2. 4 Bow Mariner Chemical Tanker *(GUARD, 2004)*

On February 28, 2004, Bow Mariner Chemical Tanker exploded while doing tank cleaning off the coast of Norfolk Harbor, Virginia, United States. Bow Mariner is a Singapore-flagged ship owned by Odfjell Asia II PTE Ltd. (GUARD, 2004)

Bow Mariner has been equipped with an inert gas generator, a nitrogen generator and also a bottled nitrogen storage unit. however, on February 28, 2004 Bow Mariner did not carry out standard procedures for tank cleaning or gas freeing. At that time the captain of the ship ordered the crew to open 22 empty cargo tank hatches which previously contained MTBE (Methyl Tert Butyl Ether) when the ship was at sea. He did not clearly explain these instructions and the crew did not question the instructions. (GUARD, 2004)

After an investigation by the USCG (United State Coast Guard), the cause of the accident was the fuel / air mixture which exceeded the flammable limits, resulting in an explosion on the deck. (GUARD, 2004)

As a result of this accident, 6 people managed to escape by entering the lifeboat which can be seen in Figure 2.5, 3 people were reported dead, and 18 people were missing and assumed dead. In addition, 3.1 million gallons of ethyl alcohol, and also 192904 gallons of HFO (Heavy Fuel Oil) and 48266 gallons of diesel fuel pollute the sea. (GUARD, 2004)

Figure 2. 5 Lifeboat Bow Mariner

2.1.5 Explosion of NCC MEKKA Chemical Tanker

Two months after the Bow Mariner Tanker accident, a similar accident occurred at the NCC MEKKA Chemical Tanker.

NCC MEKKA with a capacity of 37272 DWT departs from Brazil for the United States, the ship has just discharged some of the cargo in the form of paraffinic solvent in Santos and is on its way to deliver the remaining cargo in the form of alcohol to the United States.

The ship had just begun tank cleaning on the tank that had just been emptied in Santos when the accident occurred. The ship is equipped with IGS, but as in the case of Bow Mariner, IGS is not operated, on the pretext, the ship is not being or after carrying cargo in the form of fuel oil. The crew members also lack knowledge that the cargo they carry has a flash point of -400C. As a result of this accident, 2 crew members were declared dead.

2.1.6 Explosion non-inerted tankers

On 25 September 1993, 12101 GRT tanker called Altair exploded while proceeding on a ballast voyage from South Korea to Johor Malaysia. The explosion happened in the South China Sea, 41 nm of Tioman Island, she sank 75 minutes later. From 21 of the total crew, 18 were rescued, the others were missing and presumed dead. After investigation, it was later reported that the crew were tank cleaning at the time of explosion.

Figure 2. 6 CHASSIRON Chemical Tanker Exploded

On 13 june 2003 in the morning of southwest France, the non-inerted 9995 DWT chemical tanker named CHASSIRON was tank cleaning after discharging cargos of gas oil, a cargo of heating oil, and 98 octane gasoline. Exactly after tank cleaning of gasoline tank, whistling sound was heard and followed by explosion on gasoline tank, and then followed by explosion on gas oil tank. The investigation concluded that oxygen has entered the cargo tank during opening and discharge the tanks, resulting at least explosion on 6 across tanks, and killing one crew.

Six month later after CHASSIRON exploded, in the Inland Sea, another non-inerted 7450 DWT chemical tanker named SUN VENUS exploded. She was cleaning tanks after discharging alcohol and benzene, two ship crew were killed on board.

2.1.7 Success story of inerting

On the plus side, we began to see some of the benefits of inerting. The Venpet/Venoil was a high impact collision off South Africa between two 300,000-ton tankers, one of which was loaded. Both ships were inerted. The loaded Venpet travelling at 13.5 knots hit the Venoil in ballast, also at about 13.5 knots, just forward of the bridge. The Venoil caught fire aft; which fire spilled onto the Venpet, whose forward cargo tanks were holed. Both ships were abandoned. As the ship drifted, both fires went out. Both ships survived. two crew were killed, the great bulk of the Venpet's cargo was saved, and a 300,000 ton plus spill was averted. Contrast this with the Oswego Guardian/Texanita a somewhat similar collision in the same area. The non-inerted Texanita exploded killing 43, despite the fact that like the Venoil she was in ballast.

On the night of February 4th, 1932, the 10,950 dwt Sun Oil tanker Bidwell was cleaning tanks at Marcus Hook refinery on the Delaware River. She had carried crude oil from Texas to the refinery and was now preparing to take gasoline back. At 12:20 AM, she exploded. The first explosion was followed by three more blasts within 25 minutes. The explosions were heard 20 miles away. 18 crew including the Master were killed. The Master's wife was pulled from the frigid waters by a Sun Oil employee who swam to her rescue.

But Sun Oil had had enough. They knew that they could make tankers much safer by inerting the cargo tanks the technology was already in use in refineries, and could easily be adapted to tankers. In any event, Sun Oil reacted quickly and aggessively. By the end of 1933, all Sun Oil tankers were fitted with inert gas systems (IGS). This included the Bidwell which survived. The Bidwell was later torpedoed in 1942 while loaded 30 miles east of Cape Lookout by the U-160. The torpedo struck midships, burning oil was spilled on deck and killed the 2nd Mate; but the fire did not spread to the undamaged tanks. The crew was able to put the fire out and make port under the ship's own power. Sun Oil credits inerting for saving "many lives" on its ships during World War II, but there isn't much details. the Bidwell ended up being scrapped in 1965 at age 45.

It wasn't long after Sun had implemented inerting before they realized that proper inerting dramatically reduces steel corrosion rates in the cargo tanks. Corrosion is an oxidation process and proceeds much more slowly in an oxygen depleted environment. Sun Oil found that the need for steel renewals was drasticially reduced and in some cases eliminated. Typically, an uncoated ship in clean product service has a service life of about 12 years, and 20-25 years in dirty service, albeit with extensive steel renewals from year 15 on. But the Sun ships were different. The American Sun which had been in clean service for about four years, passed her 16 year survey without any replacement of steel, and her 20 year survey (at which point it had been in clean or partially clean service for 8.5 years) with minimal renewals due to external wastage. The Sabine Sun passed her 20-year special survey with no renewals in the cargo spaces. This ship had 2.5 years in clean service and another 7 years in part clean service.

This was not only an important economic saving, but a big safety and enviromental plus as well. Tank corrosion can easily result in cargo leaking into ballast tanks and/or pump rooms, where it becomes a major hazard. Devanney found that the single biggest cause of tanker spillage was explosions resulting from cargo being where it shouldn't be.

Based on the description above a lot of the impact of fire / explosion caused by the accumulation of flammable gas on the ship. Flammable gas accumulation can occur due to the absence of an inert gas system or the inert gas system not functioning on board.

Losses that can be caused by the explosion of tanker include fatalities due to accidents, economic losses due to loss of cargo and ships, spills of oil, gas and other chemicals that cause environmental pollution, and can also result in fuel and gas scarcity due to disruption of the flow distribution of oil, gas, and chemicals to several places, especially to places where oil and gas transportation can only be done by sea. Therefore, it is very important to keep the inert gas on the ship operates as it should be.

2.2 Inert Gas System

Tankers carry oil, gas or chemical loads with different cargo grades, which have the characteristic of being able to produce flammable vapors and gases which are flammable when loaded onto the ship or while the cargo is transported. Even though the tanker is not in a loaded condition, the cargo hold still contains dangerous combustible gas.

If the vapor produced by the oil, gas or chemical content is mixed with air whose main content is oxygen, an explosion will occur which results in damage and loss of life. Explosions can also cause pollution due to oil spills into the sea. To avoid an explosion, the Inert Gas System is used on tankers.

The Inert Gas System is an explosion prevention safety system for tankers by inserting an Inert Gas into a cargo tank to keep oxygen levels low and reduce hydrocarbons in the atmosphere of the cargo tank to safe levels.

Inert Gas is a gas or a mixture of various gases that can maintain oxygen levels in a low percentage so as to prevent explosion or fire. Whereas the Inert condition is a condition where the oxygen content in the cargo tank is maintained at 8% or less compared to the amount of gas volume in the atmosphere of the cargo tank. (BKI, 2018)

In general there are several provisions regarding the Inert Gas System according to the Indonesian Classification Bureau Regulation Vol III Section 15 Special Requirements for Tankers, (BKI, 2018) including:

- Inert gas can be produced by main or auxiliary boilers, inert gas generators with independent burner units, nitrogen generators or other equipment.
- Under normal operational conditions the Inert Gas System must prevent air from entering the tank and maintain oxygen content in the tank atmosphere at least 8% by volume.
- Inserting inert gas into an empty tank aims to reduce the hydrocarbon content to less than 2% by volume.
- Oxygen content in inert gas is not more than 5% of volume.

2.2.1 Method for Inserting Inert Gas in a Cargo Tank

There are three types of methods for introducing inert gas into cargo tanks, namely inerting, purging, and gas freeing. (Santosa, 2007) Inerting, namely the level of O2 in the tank is reduced by entering inert gas or inert gas into the tank. Purging, which is to reduce the hydrocarbon gas content in the tank by re-entering the inert gas to force the hydrocarbon gas out. Gas freeing is the process of removing a mixture of these gases, namely inert gas and hydrocarbons by entering fresh air through ventilation.

To replace the atmosphere in the tank there are 2 (two) ways that can be used (Santosa, 2007), namely:

1. Dilution process that is by mixing or mixing process. What needs to be considered in this process is that the Inert Gas that is put in the Tank must be at a high speed so that it can reach the bottom of the Tank to force out the Hydrocarbon gas. In this way there will be a mixture of gases which eventually these gas mixes are forced out with more Inert Gas. So, it should be noted about the capability of the required Inert Gas installation. For more details can be seen in **Figure 2.7**

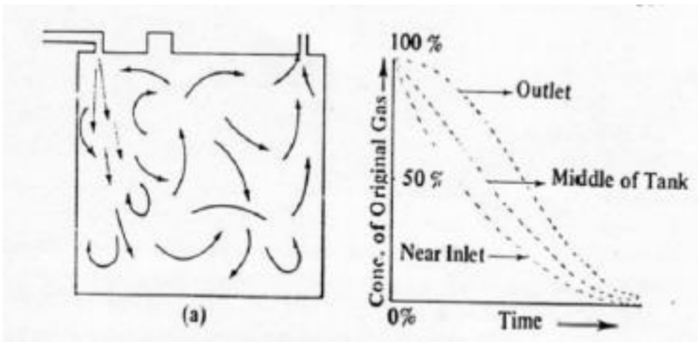

Figure 2. 7 Dilution Process *(Santosa, 2007)*

2. Displacement or with a regular replacement process that is by pushing gas regularly out of the tank. Inert Gas Displacement which is inserted in the COT (Cargo Oil Tank), is inserted horizontally so that the heavier gas in the COT will be pushed to the bottom of the Tank then regularly out of the pipe (usually a Purging pipe, see picture), until the COT is completely filled with Inert Gas . This method requires a relatively lower speed of Inert Gas to enter the tank. Therefore, it is necessary to believe

that the installation that is used can regulate gas replacement on a regular basis in all parts of the COT. For more details can be seen in **Figure 2.8**

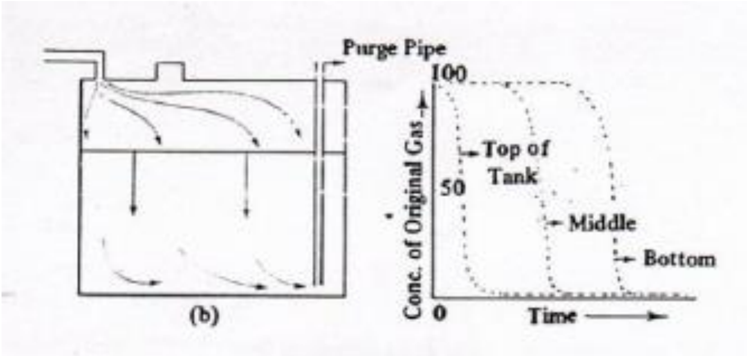

Figure 2. 8 Displacement Process (Santosa, 2007)

2.2.2 Source of Gas Inert

Inert gas as a gas from the inert gas system can be obtained from several ways, including from the boiler, and also from the inert gas generator. (Santosa, 2007)

The inert gas from the boiler is derived from the exhaust gases from the combustion boiler that flowed through the pipe after being cooled and cleaned. The inert gas produced from a boiler has many advantages, so it is widely used as the main ingredient for an inert gas system. The advantages of inert gas from boilers are:

- Oxygen content in gases is quite low, around 3-4% and some are even 2% lower than diesel engine exhaust gases.
- Boilers can continue to work when the ship is at the port, so that when loading and unloading, the supply of inert gas can be maintained.

Disadvantages of inert gas from boiler are:

- The exhaust gas produced by boiler has SO content which is corrosive
- There is a lot of dirt and ashes so it must go through a filtration process in order to reduce the content of dirt and ash in the hope of not clogging the inert gas system.
- The temperature of the exhaust gas from the boiler is quite high at around 300°C so it must be cooled before use

Inert gas from an inert gas generator. To produce better quality inert gases, special equipment, namely inert gas generators, is used instead of boilers.

How it works is similar to the inert gas combustion on a regular boiler, but this tool is made specifically for making inert gas then it is equipped with a cooling chamber to reduce levels of SO. If we use sea water for cooling it must be made from corrosion resistant materials.

The advantage of using an inert gas generator is its simple maintenance because it does not need to disassemble the main parts.

2.2.3 Atmospheric Control in Cargo Tanks

Tankers equipped with an Inert Gas System, cargo tanks must remain inerted during operation (Santosa, 2007) where:

1. Cargo Tanks and Slop Tanks whether containing Cargo, reply water or remnants of Cargo. Oxygen levels must always be maintained below 8% by volume with positive pressure in the tank. (BKI, 2018)
2. The atmosphere in the tank will change (transition) from Inert Condition to Gas Free Condition without going through the Flammable Condition area. So, in the implementation before the Tank is ventilated with fresh air for Gas Free, it must be included inert gas until the Hydrocarbon gas level in the tank is below the Critical Dilution Line, which is called Purging.
3. If the ship or tank is in a gas free state before being loaded, the first inert gas must be filled.

   So, to maintain COT in Non-Flammable conditions, the Inert Gas Plant is needed when:

   a. Loading or Ballasting.

      Inert Gas is stopped or recirculated in the Engine Room area. The Deck Master Valve for Inert Gas is closed and the Mast Safety Valve, for the Inert Gas above the Deck, is opened. When finished loading or ballasting, Inert Gas is added again in the empty tank top (Ullage Area) to restore positive pressure in the tank. This will not allow fresh air to enter the tank. Besides that, the Mast Riser is closed after loading.

   b. Unloading Cargo

      Inert Gas is run, Deck Master Valve is opened, Mast Riser is closed, and Inert Gas pressure and Oxygen levels are monitored for reasons:

      - To prevent air (oxygen) from entering the tank.

- To keep the atmosphere in the tank in the Non-Flammable Area.

  The gas helps the cargo be pressed down making it easier for the Cargo Pump to increase (Increased Head Pressure)

c. Gas Freeing

In the implementation of Gas Free, it is difficult to carry out the entire tank at the same time. Because it needs to be maintained to isolate the Tank that is being Gas Free from other Tanks, especially the ventilation systems.

Tanks that will be Gas Free must be included inert gas to reduce the levels of Hydrocarbons by means of Purging System until the levels are below 2% by volume below the Critical Dilution Line according to the Diagram, so they will not pass through the flammable Area if fresh air (O2) is being put into the Tank with Ventilation.

In planning and placing inert gas tools / components, the first thing to consider is the relationship between what is called on Non-Hazardous Area tankers, which is a less dangerous area, and Hazardous Area is the Cargo Pump Room and Cargo Tank area. where in this area the potential for danger is very high.

So do not let these tools misplaced so that they are dangerous as a result of leakage and others. Another thing that must be considered in planning a system especially when it comes to safety is that the system must:

1) Simple and uncomplicated or called Simplicity

2) Can function properly and perfectly or called reliability.

3) Easy to repair and maintain or is called Maintainability.

2.3 Maintenance Overview

Maintenance is a combination of technical, administrative and managerial actions over the lifetime of an object that is carried out to maintain or improve the object so that it is in a desired or acceptable condition. In general, an object made by humans does not exist that cannot be damaged, only by doing maintenance activities are expected to extend the life span of an object.

2.3.1 Maintenance Aims

Maintenance has several goals, and these goals can also be divided into several types, namely:

1. Economics aim or economic goals:

- Extend the work life / lifetime of an object
- Maintaining the production process or maintaining the work of the system means that with good maintenance, is expected to reduce problems that can occur on objects which can interfere with the production process or system work.
- Achieving the desired time, the intention is that with good maintenance it is expected that the production process or system work can run in accordance with the desired time
- Identifying problems early on, the intention is to maintain the company to identify what problems will occur in the future, so that it can carry out preventive activities to prevent fatal errors from happening.
- Knowing system weaknesses

2. Human aims :

- Improve work security and safety, so as to reduce the risk of loss of life due to system failure.
- Reducing the risk of pollution to the environment due to failures and system imperfections
- Comply with applicable rules such as laws, government regulations, classification bureau standards, and so on.

2.3.2 Maintenance Types

Based on the British Standard of 2010 which is the implementation of the European Rule EN 13306, maintenance is divided into two namely preventive maintenance and corrective maintenance, preventive maintenance is divided into two, namely condition based and also predetermined maintenance or can also be called planned maintenance, while corrective maintenance also divided into two namely deffered and immediate. for more details can be seen in **Figure 2.8**.

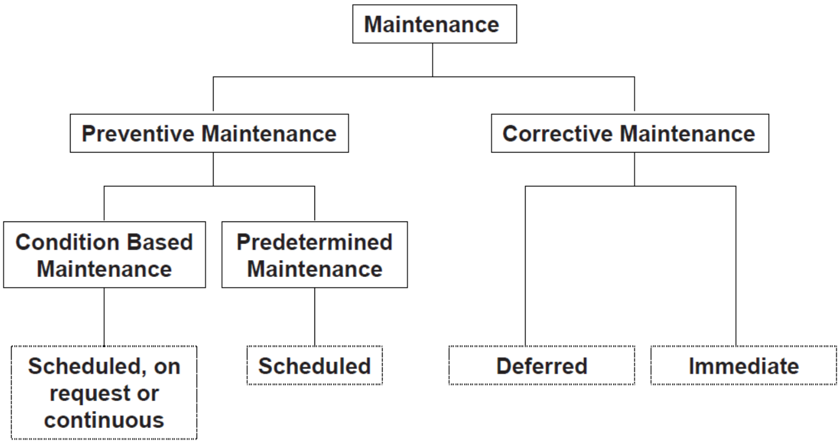

Figure 2. 9 Type of Maintenance

Corrective Maintenance is maintenance carried out after a problem with the system or object which aims to restore the system or object to the desired condition.

Preventive maintenance is carried out in accordance with the time interval or based on the frequency of use of the unit or object but without doing a condition investigation first. Predetermined maintenance is carried out at predetermined intervals or in accordance with specified criteria and is intended to reduce the possibility of failure or degradation of the function of an item. Condition based maintenance is a type of preventive maintenance which includes a combination of condition monitoring and / or inspection and / or testing, analysis and subsequent maintenance actions. monitoring and / or inspection and / or testing, analysis can be scheduled, on request or on an ongoing basis.

2.3.3 Evolution of Maintenance

According to John Moubray in 1997, the evolution of maintenance starting from the 1930s to 1997 has reached the third generation.

1. First Generation

The first generation began before the world war began. In the first generation, maintenance only focuses on repairing tasks.

2. Second Generation

The second generation began after World War II until the 1970s, second generation maintenance focused on improving maintenance planning and scheduling. The expectation of maintenance is in the form of higher equipment availability, longer equipment life, lower maintenance cost. All equipment is considered the same, ie the failure curve follows the bath-up curve. Maintenance techniques in the form of scheduled overhauls, systems for planning and controlling work using PERT, Gant and others which still use large computers and very long.

3. Third Generation

The third generation began in the 1970s until the 2010s, focusing on predicting, preventing, and avoiding the consequences of equipment failures. The expectation of maintenance is in the form of higher equipment availability & reliability, greater safety, no environmental damage, better product quality, longer equipment life, greater cost effectiveness. Failure pattern of 3rd Generation is following six basic patterns shown in **Figure 2.10**

Those failure patterns namely Failure Pattern A (bath-up curve), Failure Pattern B (wear-out curve), Failure Pattern C (fatigue curve), Failure Pattern D (initial break-in curve), Failure Pattern E (random pattern), Failure Pattern F (infant mortality).

Pattern A is often referred to in reliability literature as the bathtub curve. This type of curve has three identifiable regions:

1. An infant-mortality region, the period immediately after manufacture or overhaul in which there is a relatively high probability of failure.
2. A region of constant and relatively low failure probability.
3. A wear-out region, in which the probability of failure begins to increase rapidly with age.

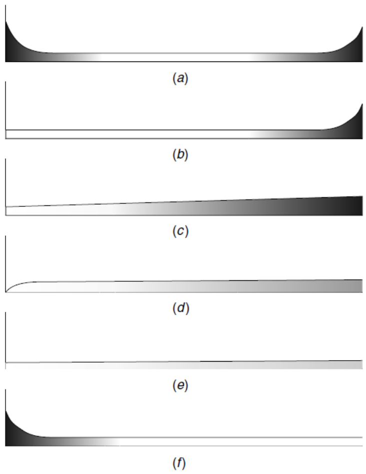

Figure 2. 10 Six Pattern of Failure *(Roberge, 2007)*

Pattern B is characterized by a constant or gradually increasing failure probability, followed by a pronounced wear-out region. Once again, an age limit may be desirable.

Pattern C shows a gradually increasing failure probability, but with no identifiable wear-out age. It is usually not desirable to impose an age limit in such cases.

Pattern D starts with a low failure probability when the item is new or just out of the shop, followed by a quick increase to a constant level.

Pattern E, which is characterized by a constant probability of failure at all ages.

Pattern F in which infant mortality is followed by a constant or very slowly increasing failure probability. This behavior is particularly applicable to electronic equipment.

The latest is the fourth generation, the fourth generation focuses on failure elimination not on failure prediction or prevention. So it will be increasingly focused on being proactive rather than reactive. Specifically, improvement in the fourth generation maintenance will concentrate on eliminating or reducing equipment failures in the Failure Pattern F of the Nowlan and Heap failure patterns. And also focuses on reducing overall levels of failure probability. (Hide, 2013)

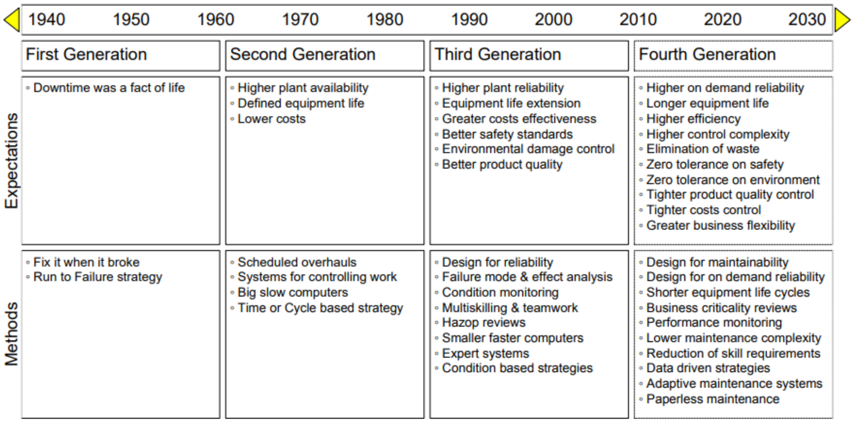

Figure 2. 11 Evolution of Maintenance

2.4 Reliability-Centered Maintenance (RCM)

2.4.1 Brief Definition of Reliability-Centered Maintenance

Systematic approach for determining the maintenance requirements of plant and equipment in its operation is called Reliability-Centered Maintenance. (Dixey, June 1993.) RCM also can be defined as a systematic methods to keep balance between corrective maintenance and preventive maintenance. RCM will chooses the right maintenance activities such as preventive maintenance or corrective maintenance for the right equipment at the right time to reach the most cost-efficient solution. (Bertling, August 2005)

RCM is characterized by maintaining system function, identifying failure modes, prioritizing functions, and choosing efficient maintenance. The main objective of Reliability-Centered Maintenance is to reduce maintenance cost by focusing on the most important function of the system (Yssaad, et al., 2014)

2.4.2 Objective of Reliability-Centered Maintenance

According to John Moubray, the objective of Reliability-Centered Maintenance is to achieve reliability for all the operating modes of a system. An RCM analysis, when properly conducted, should answer the following seven questions: (Moubray, 1991)

1) What are the **system functions** and associated performance standards?

This first question is for identifying the performance standards and function of the object or equipment. Function of an object can be identified as primary and secondary function. Primary function is the initial purpose/function for which equipment was purchased, for instance quality, speed, output, etc. secondary function is for the user satisfaction, this additional function for example comfort, aesthetics, etc. Performance standard can be explained as the user want the equipment to do anything that they want. This can be identified in two ways: the desired performance and the built-in capability. These performance standards are necessary to identify as the maintenance can only restore the asset to its initial level of capability (the designed capability or the in-built capability).

2) How can the system fail to fulfill these functions?

   This question makes the analyst to think and define **functional failure**. Functional failure is when the equipment or object can't perform a function to the acceptable and expected performance/work specification.

3) What can cause a functional failure?

   This task is known as **failure mode.**

4) What happens when a failure occurs?

   This questions helps an analyst to describe and list what happens when a failure mode occurs. These are known as **failure effects.**

5) What might the consequence be when the failure occurs?

   The fifth question lets the analyst know how much does it matter when a failure occurs. These are known as **failure consequences.**

6) What can be done to detect and prevent the failure?

   The sixth question is known as **proactive tasks,** that will provide the proactive insight by letting the analyst determine what could be done to predict or prevent failure. These are Proactive tasks are defined as the tasks that are undertaken before a failure occurs in order to prevent the asset from failing.

7) What should be done if a maintenance task cannot be found?

   This question is known as **default action.** It is identifying the task or activities that has to be done when a suitable proactive task cannot be found.

2.4.3 Success Story of Reliability Centered Maintenance Application

RCM has been applied in several companies. The first The heavy-duty hydraulic stretching machine also has been analyzed by using RCM. The result is the company saving of about 187 hours per annum in downtime from the initial total downtime 1004 hours. And cost benefit analysis results indicate that about 16.83% and 18.62% savings can be achieved in equipment downtime and associated costs respectively. (Deshpande & Modak, 2001)

And also at the Egyptian Salts & Minerals Company (Emisal), Egypt. After using RCM, the frequency of the RTF (the Run-to-Failure) decreases, the total downtime cost is also reduced by about 80% compared with previous maintenance, labor costs are reduced from 295200 $ / year to 220800 $ / year, annual spare parts cost also down about 22.17%. (Afefy, 2010)

Then in the Thai company a study was also conducted using RCM, the result was that the PPM lead from the test machine had decreased from 1087 ppm to 15 ppm (98.6%), preventive maintenance cost was reduced to 49059 Baht, and the cost of lost product was also reduced by 5343 Baht. (Supsomboon & Hongthanapach, 2014)

The RCM methodology was applied in an injection molding process. The injection molding machine is efficient, reliable, and able to process all thermostatic polymers to create a high quality melt to manufacture plastic parts. There are several failures recorded from a test of the plastic injection molding machine. The sample size is 13 failure times for the thermostatic valve. Initial replacement frequency of the thermostatic valves are done every 115 h, after RCM implementation, the replacement frequency is done every 275 h. Initial annual maintenance cost is $201,600 USD. With RCM, annual maintenance cost is $50,400 USD. savings of 75% on maintenance costs were achieved, also increasing equipment availability. (Fuentes-Huerta, et al., 2017)

2.5 Offshore Reliability Data (OREDA)

On 1988 The Offshore Reliability Data (OREDA) was established in co-operation with the Norwegian Petroleum Directorate with the initial objective was to collect reliability data for safety equipment. In 1983 the current organization as a co-operating group of several oil companies extended the scope of OREDA, the scope was extended to cover reliability data from a wide range of equipment used in oil and gas exploration and production. Offshore topside and subsea equipment are primarily covered, but some onshore E & P equipment are also included. (SINTEF, 2002)

The main objective of The Offshore Reliability Data (OREDA) project is to contribute to an improved safety and cost effectiveness in design and operation of oil and gas exploration and production facilities. Through collection and analysis of maintenance and operational data, establishment of high-quality reliability database, and exchange of reliability, availability, maintenance and safety (RAMS) technology among the participating companies.

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CHAPTER III
METHODOLOGY

methodology represents the basic framework from the research. Methodology will cover all of the activity that supports the competition of this final project. The stages of this methodology are as follows as in **Figure 3.1**

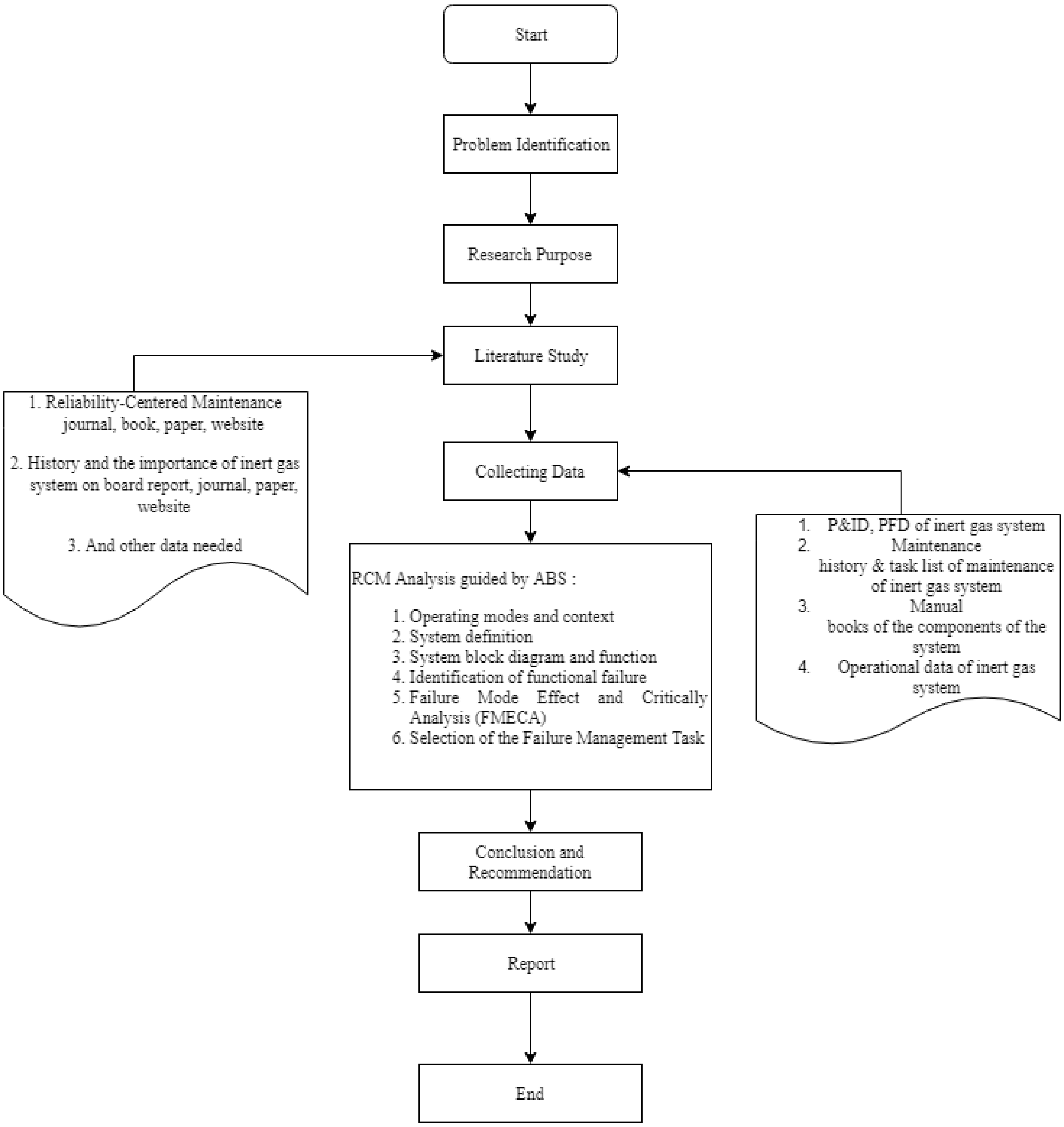

Figure 3. 1 Methodology Flowchart

3.1 Problem Identification

The first stage of this research is problem identification. The object of this research is inert gas system on one of oil tanker ship belongs to PT. Z Shipping. Inert gas system is one of the most vital instruments on tanker because the system has correlation with safety and security on board the ship.

There are so many impacts of fire / explosion caused by the accumulation of flammable gas on the ship. Flammable gas accumulation can occur due to the absence of an inert gas system or the inert gas system not functioning on board. Losses that can be caused by the explosion of tanker include fatalities due to accidents, economic losses due to loss of cargo and ships, spills of oil, gas and other chemicals that cause environmental pollution, and can also result in fuel and gas scarcity due to disruption of the flow distribution of oil, gas, and chemicals to several places, especially to places where oil and gas transportation can only be done by sea. Therefore, it is very important to keep the inert gas on the ship operates as it should be. One of the solutions is by doing the maintenance of system perfectly.

There is one Systematic approach for determining the maintenance requirements of plant and equipment in its operation is called Reliability-Centered Maintenance (RCM) (Bertling, August 2005). This research will use RCM guide based on the Reliability-Centered Maintenance (RCM Guide) by the American Bureau of Shipping (ABS).

3.2 Research Purpose

The research purpose is to find the components that are causing the failure and what is the impacts of the failures of the components of inert gas system to the ship, and find the best maintenance type for the right equipment, and also find the effective maintenance schedule for each components the inert gas system (find the right maintenance type for the right equipment at the right time to reach the most cost-efficient solution)

3.3 Literature Study

Literature study is the stages that conduct to gaining knowledges about the particular field of study related to the project including the depth of review, summarizing basic theory, general and specific reference, and obtaining other various supporting information related to the research. In this case is inert gas system, maintenance, Reliability-Centered Maintenance, etc. that obtained from books, journals, papers, handbook, the other well-done thesis, and even from the internet surfing about everything related to the research.

The discussion between author-company supervisor, and author-thesis supervisor are also can be included as an effort to get more additional information to fulfill the literature study in order the author can provide several points of view and perspective to the readers.

3.4 Data Collection

The data needed for the research analysis with the Reliability-Centered Maintenance method in is qualitative data to answer the questions that refer to RCM ABS rules. In this research the author collect data from one of the ships of PT. Z Shipping. Data required in this research are:

- General info of the ship
- Initial system design of inert gas system of the ship
- Maintenance history & task list of maintenance of inert gas system
- Manual books of the components of the system
- Operational data of inert gas system

3.5 RCM Analysis

According to the ABS Guide for Survey Based on Machinery Reliability and Maintenance Technique, here’s the procedure of RCM (ABS, 2016)

1. Operating modes and context

   properly define operating characteristics, the various operating modes for the asset or equipment are to be identified. Operating contexts are to be developed for each level of the machinery hierarchy. The typical operating mode for ship as follows: normal sea going condition at full speed, cargo handling, at sea, in congested waters, etc.

2. Partitioning system/system definition

   Each system selected for RCM analysis is to be defined. The system definition involves.

3. System block diagram

   Block diagrams are to be developed showing the functional flow sequence of the functional group, both for technical understanding of the functions and operation of the system and for subsequent analysis.

4. Identification of functional failure

Identifying functional failures for each function identified in system block and diagram is to be identified for each functional group, system, equipment item and component.

5. Failure Mode Effect and Critically Analysis (FMECA)

   The FMECA is to be considered using the bottom-up approach, starting from the lowest level of detail identified during the system partitioning. The FMECA procedure is divided into the following steps:

   a. Identify all potential failure modes and their causes;
   b. Evaluate the effects on the system of each failure mode;
   c. Identify failure detection methods;
   d. Identify corrective measures for failure modes;
   e. Assess the frequency and severity of important failures for criticality analysis, where applicable.

6. Selection of the Failure Management Task

   All causes of each failure mode are to be evaluated. The Task Type is to be identified as follows: Condition Monitoring (CM), Planned Maintenance (PM), Combination of CM and PM (CM/PM), Failure Finding (FF), One-time Change (OTC), Run-to-Failure (RTF), Any Applicable and Effective Task (AAET).

CHAPTER IV
DATA ANALYSIS

4.1 Analysis of the Collected Data

PT. Z operates a large number of tanker vessel, one type of vessel that operated by PT. Z is crude oil tanker. On **Section 3.4** the data needed for the research analysis with Reliability-Centered Maintenance method refer to RCM by ABS Standard are:

- Initial system design of inert gas system of the ship

  This design is used as a basic for making system definition and functional block diagram which are the required steps of RCM analysis by ABS Standard. From the design the author can partitioning the asset's functional groups into system, sub-systems, equipment items and components and make the narrative description of each of it. Block diagram shows the functional flow and operation of the system. The design of inert gas system on ship designed by shipyard are presented on **appendix 1**

- Maintenance history and task list maintenance of inert gas system

  This data is used as one of the references for determining failure mode of the system. This data is described further on **Section 4.2.5**

- Manual book of inert gas system

  Manual book of inert gas system is used for identifying as a basic for defining operating modes and context of each equipment of the system in order to properly define operating characteristics. And also, as a basic for identifying the function and functional failure of the system.

4.1.1 Research Object

Reliability-Centered Maintenance analysis's first step is choosing the object(s). after some considerations, the inert gas system of MT. ABC crude oil carrier was selected. **Figure 4.1** is MT. ABC picture. The general info of the ship is presented on **Table 4.1** and the inert gas system info are presented on **Appendix 2**

Figure 4.1 MT. ABC Crude Oil Carrier

Table 4.1 General Information of MT. ABC

Class	LR & BKI
Builder	Tsuneishi Holdings Corporation - Japan
Konstruksi	Double Hull
Yob	2009
Muatan	Crude Oil
Loa (m)	243.8
Bmld (m)	42
Hmld (m)	21.3
Draft (m)	14.58
DWT	107,538
GRT	60,380
NRT	32,195

4.2 RCM Analysis

4.2.1 Identification of Operating Modes and Context

The first stage of Reliability-Centered Maintenance analysis by ABS standard is identification of operating modes and context of the inert gas system. Operating contexts are the physical references of where and how the operating modes run, and the operating modes itself are the characteristics and/or the operational of the system or equipment(s) that has to be achieved. The operating modes and context of the inert gas system's equipment presented on the **Appendix 3.**

4.2.2 Partitioning system/system definition

Each system selected for RCM analysis is to be defined. The system definition involves. The hierarchy of the plant presented on **Appendix 4.**

4.2.3 System block diagram

Block diagrams are to be developed showing the functional flow sequence of the functional group, both for technical understanding of the functions and operation of the system and for subsequent analysis. System block diagram of inert gas system is presented on **Appendix 5.** The crucial data for making the system block diagram are system drawing and manual of the system.

4.2.4 Identification of functional failure

Identifying functional failures for each function identified in system block and diagram is to be identified for each functional group, system, equipment item and component. The functional and functional failure of the equipment in the inert gas system are presented on **Appendix 6.** functional failure of the system can be defined from the function of the system which can be obtained from the manual.

4.2.5 FMECA Analysis

The failure modes effects and criticality analysis (FMECA) has to be done by the following steps:

– Identification of failure modes and their causes

  This step describes the way failure occurs and its impact on the equipment or system. All the equipment item or component-related causes of the identified failure modes are to be identified. A failure mode in an equipment item or component could also be the failure cause of a system failure. After find the failure modes of the equipment the next step is to find all the potential causes for each failure mode. Next step is identified the failure characteristic for each failure mode whether it is wear-out failure, wear in, or random failure.

– Evaluate the effects on the system of each failure mode

  There are three effect of the failure that has to be identified, namely the local effect, functional failure, and the end effect. The local effect is the initial change in the component or equipment item when the failure mode occurs. The functional failure describes the effect of failure mode on the functional group or system. And the end effect describes the overall effect on the vessel addressing propulsion, directional control, environment, fire and/or explosion.

– Identification of failure detection methods

The failure detection means, such as visual or audible warning devices, automatic sensing devices, sensing instrumentation or other unique indications, if applicable. The term “evident” is to be indicated. if not evident, the term “not evident (e.g., hidden)” is to be indicated.

– Identification of corrective measures for failure modes

– Criticality analysis

The criticality analysis is used to rank the risk associated with each failure mode identified during the FMECA by assessing the severity of the End Effect and the likelihood of failure based on the best available data. The detail FMECA Analysis of the equipment in the inert gas system are presented on **Appendix 7.** The steps for determining the FMECA table on Appendix 7 are:

1. Determined the severity level of each failure mode based on its category.

According to ABS standard there are categories that has to be chosen before determining the severity level, the categories namely loss of containment, safety, explosion/fire, propulsion etc. These categories are the guide for determining severity level. The severity levels of each categories are divided into 4 level, from level 1 or minor into level 4 or catastrophic which shown in **Table 4.2.**

Table 4. 2 Consequence/Severity Level Definition Format

Severity Level	**Descriptions for Severity Level**	**Definition for Severity Level**	**Applicable to Consequence Category of**
1	Minor, Negligible	No damage to affected equipment or compartment, no significant operational delays.	Explosion/ Fire
2	Major, Marginal, Moderate	Affected equipment is damaged, operational delays	
3	Critical, Hazardous, Significant	An occurrence adversely affecting the vessel’s seaworthiness or fitness for service or route	
4	Catastrophic, Critical	Loss of vessel or results in total constructive loss	

Inert gas system is associated with flammable gas which can leads to explosion/fire, so the suitable criterion for determining severity level of each failure mode mostly explosion/fire or safety.

2. Calculate the PoF (probability of failure) of each failure mode.

Probability of failure is the prediction of how much failure occur per year. the author got the value of PoF from OREDA, OREDA presents the failure rates data of each equipment's failure mode per 10^6 hours. to calculate the PoF of those failure rates is by multiplied the failure rate with 8760 (number of hour/year) and then divided the value of it with 10^6

3. Determined the likelihood of failure from the table based on the PoF of each failure mode

Table 4. 3 Probability of Failure Criteria Example Format

Likelihood Descriptor	Description
Improbable	Fewer than 0.001 events/year
Remote	0.001 to 0.01 events/year
Occasional	0.01 to 0.1 events/year
Probable	0.1 to 1 events/year
Frequent	1 or more events/year

The are 5 descriptors of likelihood shown in **Table 4.3** namely improbable, remote, occasional, probable, and frequent. These likelihood descriptors are categorized by the value of PoF (number of events/year) of each failure mode.

4. Determined the level of current risk

The level of current risk of each failure mode can be determines by using matrix based on severity and current likelihood of each failure mode on ABS Standard. **Figure 4.2** shown the percentages of current risk level.

Table 4. 4 Risk Matrix Example Format

Severity Level	Likelihood of Failure				
	Improbable	Remote	Occasional	Probable	Frequent
4	Medium	Medium	High	High	High
3	Low	Medium	Medium	High	High
2	Low	Low	Medium	Medium	High
1	Low	Low	Low	Medium	Medium

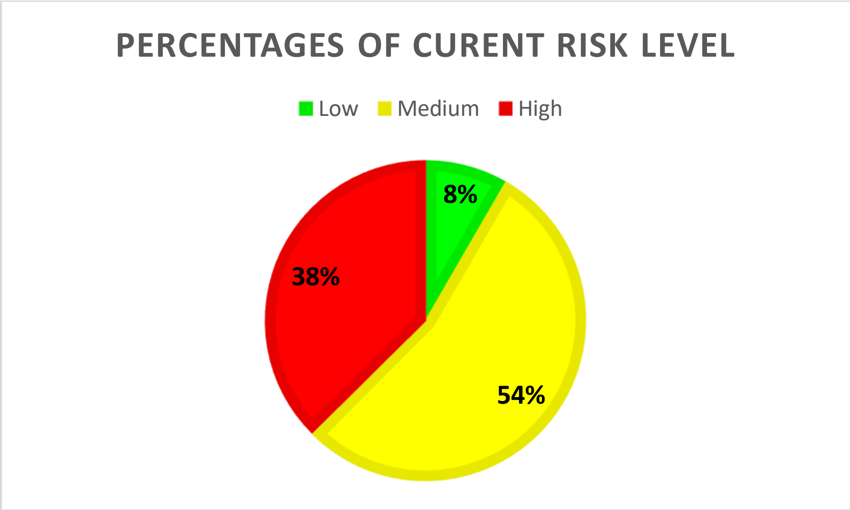

Figure 4. 2 Current Risk Level Percentages

There are 38% of high risk failure mode, 54% of medium risk failure mode, and 8% of low risk failure mode.

4.2.6 Selection of the Failure Management Task

All assessed failure modes are to be evaluated in accordance with the RCM Task Selection Flow Diagram in **Appendix 11**. The purpose of this diagram is to assist in selecting the most appropriate maintenance task strategy to prevent or detect a specific failure mode. The selection of failure management task and the detailed record of task selection are presented on **Appendix 8** and **Appendix 9.**

All manufacturers' maintenance recommendations are to be considered during the selection of the failure management tasks. If changes or deletions to the manufacturers' recommendations are made, these are to be documented in the analysis.

- Maintenance Task Allocation and Planning

The maintenance tasks identified in each step are to be organized in accordance with the following suggested categories:

- *Category A* – Can be undertaken on location (at sea, offshore) by the onboard personnel;

- *Category B* – Must be undertaken alongside by equipment vendors or with use of dockside facilities;
- *Category C* – Must be undertaken in a dry dock facility.

The Task Type is to be identified as follows: Condition Monitoring (CM), Planned Maintenance (PM), Combination of CM and PM (CM/PM), Failure Finding (FF), One-time Change (OTC), Run-to-Failure (RTF), Any Applicable and Effective Task (AAET).

Table 4. 5 Recapitulation of summary maintenance task

Percentage of Maintenance Category		
Maintenance Category	**Maintenance actions**	
	actions	**Percentage (%)**
A	18	45
B	22	55
C	0	0
Total	40	100

The RCM analysis may identify identical maintenance tasks addressing different failure modes with different intervals on the same equipment item or component. The task intervals developed may not be in alignment with the present in-use calendar-based maintenance schedule. Accordingly, the task intervals may be integrated into a common maintenance schedule as an aid to personnel scheduling efficiencies. If tasks are integrated, the RCM task intervals may only be adjusted to shorter intervals to avoid compromising of End Effects. The summary of maintenance task is presented on **Appendix 10**.

As discussed in **Section 4.2.6**, each treatment action undertaken (task list) is categorized into three categories based on the party, procedure and location of the preventive action. According to table 4.5 from the recapitulation of summary maintenance task, category A is 45% of the total maintenance tasks, and category B is 55% of the total maintenance tasks. The A category is the task list can be undertaken on location (at sea, offshore) by the onboard personnel. Most of the recommended maintenance actions to be carried out can be carried out at the same time by the vessel crew without the need to be accompanied by surveyors, vendors, complex equipment or dry dock facilities. In addition, actions included in category A are maintenance activities that are carried out regularly and continuously during its operational period. So, this is an obligation and responsibility of the ship owner which in this case is carried out by the ship's own crew.

In the summary of maintenance tasks, each maintenance action (task list) is analyzed to determine the right type of treatment (task type). Each task list is categorized into each type of treatment based on logic tree analysis in the book ABS Guidance Notes On Reliability-Centered Maintenance. **Table 4.6** are the results of determining the type of maintenance (task type) from the summary stage of task maintenance.

Table 4. 6 Recapitulation of task type of each maintenance category

Category A		
Task type	**Total**	**Percentages (%)**
Preventive Maintenance (PM)	12	30
Condition Monitoring	6	15
Total task list	**18**	**45**

Category B		
Task type	**Total**	**Percentages (%)**
Preventive Maintenance (PM)	16	40
Condition Monitoring	3	7.5
One-time-change (OTC)	3	7.5
Total task list	**24**	**55**

CHAPTER V
CONCLUSION AND SUGGESTION

5.1 Conclusion

Reliability-Centered Maintenance method is implemented in this study in order to determining maintenance task and schedule of inert gas system in MT. ABC of PT. Z. after some analysis, the following conclusion are obtained:

1. There are 2 types of maintenance activity categories (task categories performed in the task list implementation with the total 40 tasks. Category A with 18 tasks, and Category B with 22 tasks. From those categories, the percentages of each type tasks is Preventive Maintenance (PM) 70%, Condition Monitoring (CM) is 22.5%, and One-Time Change is 7.5%.
2. In Category A there are 18 types of task list obtained based on the maintenance task allocation and planning analysis. Where percentages of type maintenance of each failure mode are:
   - Planned Maintenance is 30%
   - Condition Monitoring is 15%
3. In Category B there are 22 types of task list obtained based on the maintenance task allocation and planning analysis. Where percentages of type maintenance of each failure mode are:
   - Planned Maintenance is 40%
   - Condition Monitoring is 7.5 %
   - One-time-change is 7.5 %

5.2 Suggestion

For the suggestion there are some updates to improve the more accurate research results, they are :

1. In the development of this research required more specific failure data of inert gas system of MT. ABC.
2. Further data needs to be done by discussing with the crew of PT. Z regarding RCM analysis results.
3. Further data needs to be analyzed by considering the cost aspect.

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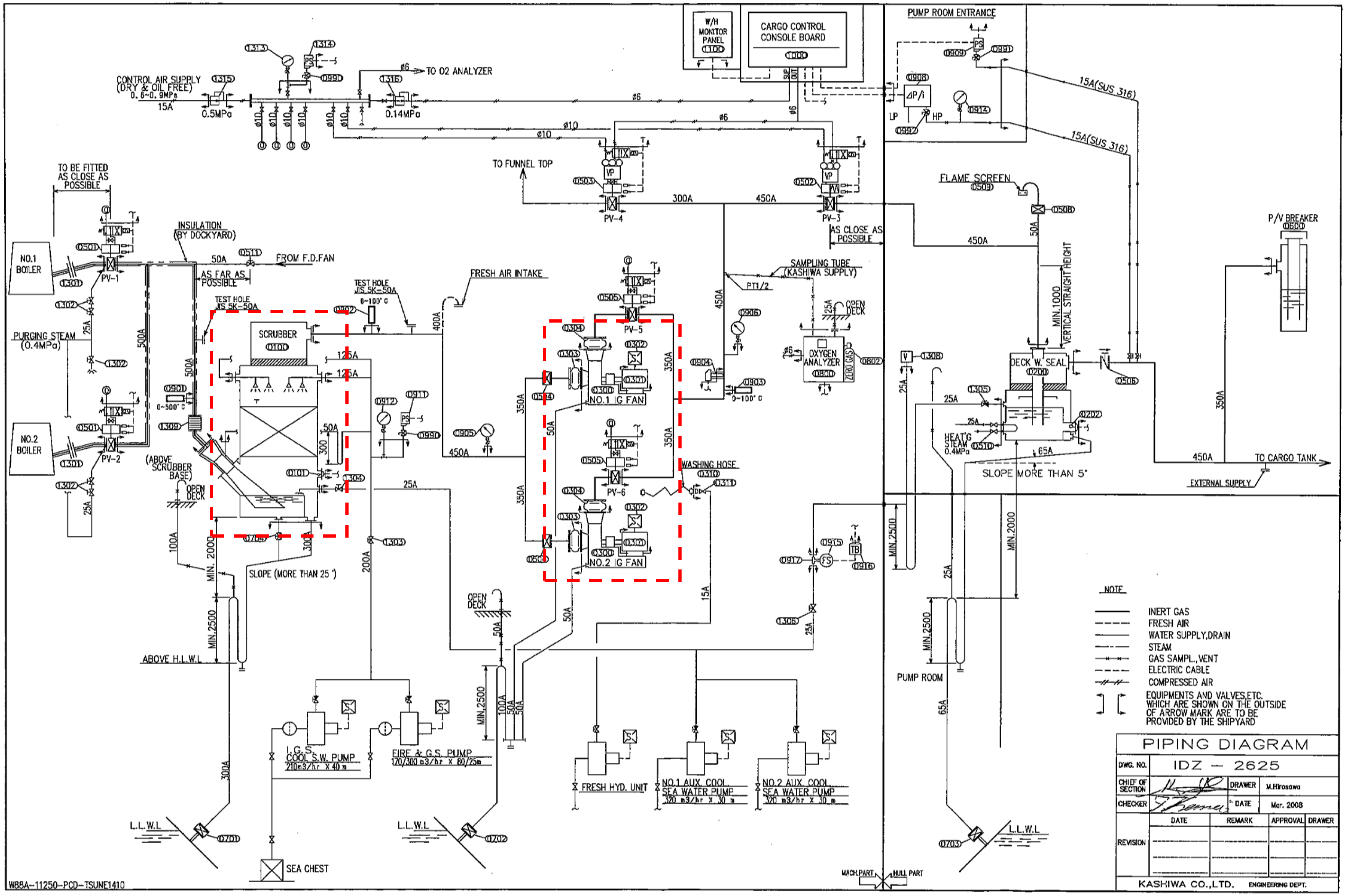
APPENDIX 1

INITIAL SYSTEM DESIGN OF INERT GAS SYSTEM



APPENDIX 2

INERT GAS SYSTEM SPECIFICATION

Inert Gas System Specification				
1	Rule(s)	:	LRS, SOLAS 1974 and it's amendments	
2	Nominal Capacity	:	11,250 m^3/hr	
3	Oxygen Contents	:	Less than 5%	
4	Inert Gas Temperature	:	Boiler Uptake :	450°C (Max)
			Inert Gas Main Line :	65°C (Max)
			Scrubber Outlet :	Sea Water Temperature Plus Within 5°C
5	Gas Composition	:		
			At Venturi Inlet	At Inert Gas Main Line
	O2	(vol %)	3.0	No Change
	CO2	(vol %)	13.0	No Change
	SO2	(vol %)	0.3	Less than 0.03
	N2	(vol %)	Balance	Balance
	Solid Particles	(mg/Nm^3)	250	Less than 7.5 (greater than one micron diameter particle)
6	Scrubbing Efficiency	:		
	1. Dust Removal	:	Greater than 97% (against the particles bigger than 1.0 micron)	
	2. Sulphur Removal	:	Greater than 90% (at sea water temperature 32°C)	
	3. Water Mist Removal	:	Greater than 98% (against the particles bigger than 5.0 micron)	
7	Utility Requirement	:		
	1. Sea Water (at Plant Inlet)		Scrubber Cooling Water :	204 m^3/h at 0.1 MPa
			Scrubber Seal Water :	1.0 m^3/h at 0.1 MPa
			Deck Seal Water :	1.9 m^3/h at 0.1 MPa
	2. Fresh Water (at Plant Inlet) Fan Cleaning Water		:	
	3. Electricity	IG Fan Motor :	AC440V, 60Hz, 3 Phase, 75 kW x 2 sets	
		Control System :	AC440V, 60Hz, Single Phase, 0.8 kW	
			DC24V, 50 W (Emergency Alarm Only)	
	4. Control Air	: 600Nl/min		
	5. Steam	: Deck Water Seal Heating Coil	:	0.9 MPa
8	Inert Gas Fan	:		
	1. Main IG Fan		: 5,625 m^3/hr x 18.6 kPa	x 2 sets
9	Pressure Resistance			
	1. Scrubber		: 5.5 kPa	
	2. Deck Water Seal		: 2.0 kPa	

APPENDIX 3

OPERATING MODES AND CONTEXT OF INERT GAS SYSTEM

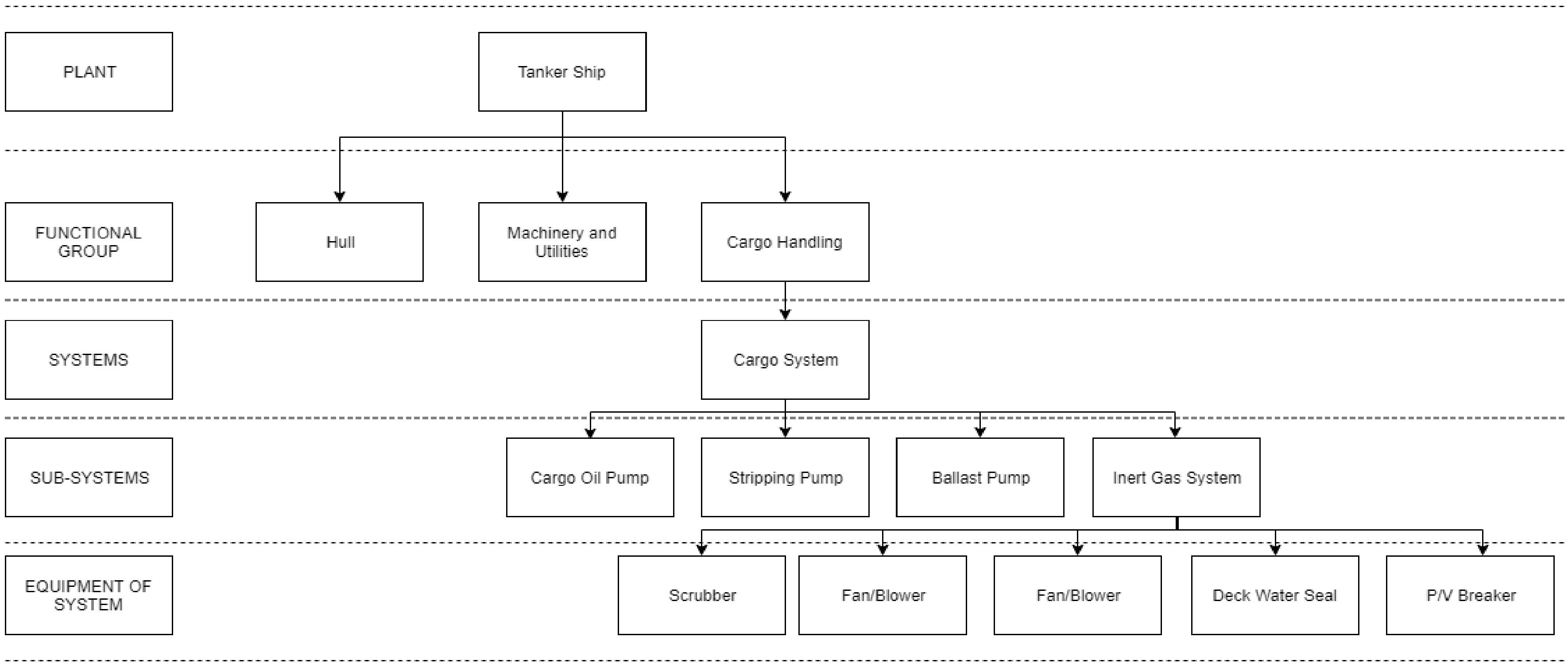
Operating Context of Scrubber			
Scrubber is one of the equipment of inert gas system which has function to cooled and cleaned exhaust gas from boiler for removing soot particles and sulphur dioxide and water mist content to produce inert gas. There are 2 main part of the scrubber, 1). Venturi, has main function as dust removal and primary cooling, 2). Packed tower, as desulfurization, secondary cooling, and colleting seawater mist.			
Common Characteristics	**Operating Modes**		
	Inert Gas	**Gas Free**	**Navigation**
Environmental Parameters	Maximal temperature of gas from boiler uptake is 450^{o}c; Gas composition (% of total volume): O_2 3%, CO_2 13%, SO_2 0.3%; Solid particle content 250 mg/Nm^3	not used	not used
Manner of Use	Inert gas system of the ship only has one scrubber, and it is proceeding exhaust gas that coming from boiler for removing and reducing soot particles, sulphur dioxide and water mist content and also cooled down the gas.	not used	not used
Performance Capability	Capacity : 11250 m^3/h; Pressure resistance : 5.5 kpa; Cooled down exhaust gas from 450^{o}c(max) until the temperature of gas similar to sea water temperature plus within 5^{o}c; Sulphur dioxide is reduced to less than 10%	not used	not used

APPENDIX 3

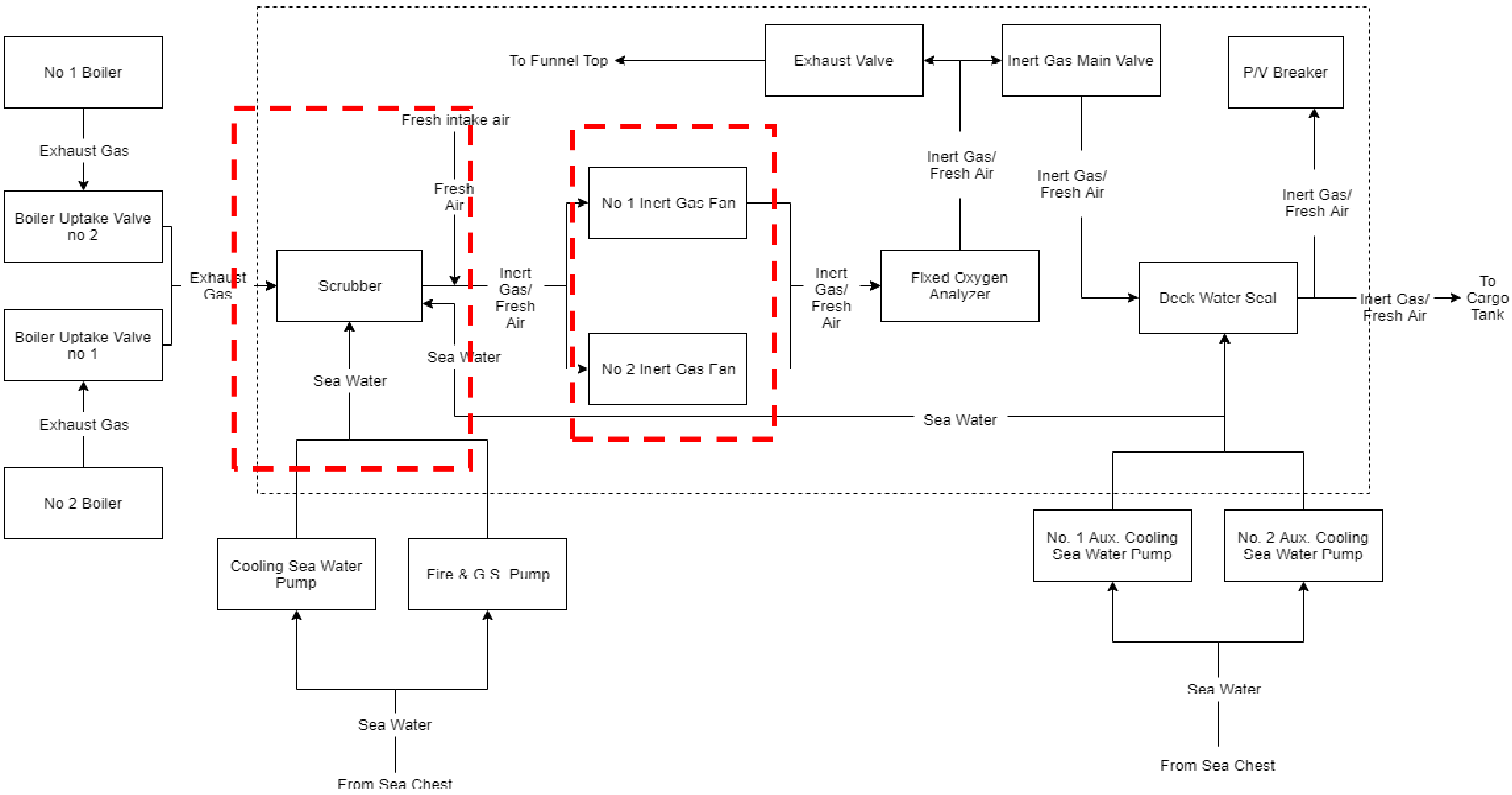
OPERATING MODES AND CONTEXT OF INERT GAS SYSTEM

Operating Context of Inert Gas Fan			
IG Fans are provided to blow the inert gas into cargo oil tank. NSSC170 (high Chromium Stainless Steel) is selected for the impeller material. The fan are rotated by motor AC 440V, 60 Hz, 3 Phase, 75 kW each.			
Common Characteristics	**Operating Modes**		
	Inert Gas	**Gas Free**	**Navigation**
Environmental Parameters	Range of pressure gauge of fan inlet: -25 to +25 kPa	Range of pressure gauge of fan inlet: -25 to +25 kPa	not used
Manner of Use	there are 2 sets of IG Fans in inert gas system that cannot be operated simultaneously, the no. 1 fan is operated 100%, when the fan no.2 is standby	there are 2 sets of IG Fans in inert gas system that cannot be operated simultaneously, the no. 1 fan is operated 100%, when the fan no.2 is standby	not used
Performance Capability	Capacity 5625 m^3/h x 18.6kPa	Capacity 5625 m^3/h x 18.6kPa	not used

APPENDIX 4
SYSTEM DEFNITION



APPENDIX 5
FUNCTIONAL BLOCK DIAGRAM



APPENDIX 6

IDENTIFICATION OF FUNCTIONAL FAILURES

Equipment Item: Scrubber				
Function			Functional Failure	
Item No.	Function Statement	Function Type	Item No.	Functional Failure Statement
1	To absorb sulfur dioxide content of exhaust gas until less than 0.03% of the total volume of gas, to cool down the temperature of gas to sea water temperature plus within 5°C, to remove particles (dust) if its larger than 1.0 micron.	Primary	1.1	Unable to absorb sulfur dioxide content of exhaust gas until less than 0.03% of the total volume of gas
		Primary	1.2	Unable to cool down exhaust gas until the temperature of gas similar to sea water temperature plus within 5°C;
		Primary	1.3	unable to remove particles (dust) which larger than 1.0 micron
		Primary	1.4	Unable to operate or unable to complete all of the fuctions

APPENDIX 6

<u>IDENTIFICATION OF FUNCTIONAL FAILURES</u>

Equipment Item: Inert Gas Fan				
Function			**Functional Failure**	
Item No.	**Function Statement**	**Function Type**	**Item No.**	**Functional Failure Statement**
2	To blow the inert gas into cargo oil tank with the capacity 5625 m3/h and 18.6 kPa	Primary	2.1	Unable to blow inert gas into cargo oil tank
			2.2	transmit less than 5625 m3/h of inert gas
			2.3	transmit less than 18.6 kPa of inert gas into cargo oil tank

APPENDIX 7
FMECA ANALYSIS

BOTTOM-UP FMECA WORKSHEET											
1. SCRUBBER											
Function	**Functional Failure**	**Failure mode**	**Causes**	**Failure Characteristic**	**Local Effects**	**End Effects**	**Matrix**	**Severity**	**Current Likehood**	**Current Risk**	**Failure Detection/ Corrective Measures**
To cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5°C;	Unable to cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5°C;	1.1 Leakage in body/ shell	Corrosion caused by the natrium chloride in sea water which act like a catalyst, accelerating the corrosion of the metal and also by the substances of exhaust gas which are acid such as SOx	Wear out	release seawater in engine room, insufficient amount of water inside scrubber	Can't reach the certain temperature of cooled gas, if the temperature of gas in inert gas main line is too hot, the system will shut down, and the worst case is it can leads to explosion in cargo tank due to the existance of ignition sources.	Explosion/ Fire	4	Occasional	High	Fluid drip out at a certain place
		1.2 Venturi spray nozzle plugged/choked	accumulation of dust or dirt or other substance from sea water	Wear-out	Cannot produce and distribute the sea-water mist over entire throat section of venturi	Function of spray nozzle in venturi is for cooling down the gas from about 450°C to 60°C - 70°C, if the certain temperature cannot be fulfilled, the temperature of gas inside inert gas main line is too hot the system will automatically shut down. This situation can leads to the worst scenario caused by the existance of ignition sources inside the cargo tank, explosion.	Explosion/ Fire	4	Remote	Medium	Temperature of IG main line is too hot (>65°C)

APPENDIX 7

FMECA ANALYSIS

BOTTOM-UP FMECA WORKSHEET											
1. SCRUBBER											
Function	**Functional Failure**	**Failure mode**	**Causes**	**Failure Characteristic**	**Local Effects**	**End Effects**	**Matrix**	**Severity**	**Current Likehood**	**Current Risk**	**Failure Detection/ Corrective Measures**
To cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5°C;	Unable to cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5°C;	1.3 Plugged/chocked in scrubber cooling sea water inlet valve	accumulation of dust or dirt or other substance from seea water	Wear-out	Cannot deliver the sufficient amount of scrubber cooling sea water to the nozzles inside the srubber	Cannot cooled down the gas to sea water temperature plus within 5°C by the sea water when the temperature of gas in inert gas main line is too hot, the system will automatically shut down, and the worst case explosion in cargo tank due to the existance of ignition sources.	Explosion/ Fire	4	Remote	Medium	
		1.4 Scrubber drain valve leakage	Corrosion caused by the natrium chloride in sea water which act like a catalyst, accelerating the corrosion of the metal.	Wear-out	Release scrubber seal water	Low scrubber water level, can't reach the certain temperature of cooled gas, if the temperature of gas in inert gas main line is too hot, the system will shut down, and also can leads to explosion in cargo tank due to the existance of ignition sources.	Explosion/ Fire	3	Occasional	Medium	Seawater drip out from valve

APPENDIX 7

<u>FMECA ANALYSIS</u>

BOTTOM-UP FMECA WORKSHEET											
1. SCRUBBER											
Function	**Functional Failure**	**Failure mode**	**Causes**	**Failure Characteristic**	**Local Effects**	**End Effects**	**Matrix**	**Severity**	**Current Likehood**	**Current Risk**	**Failure Detection/ Corrective**
		1.5 Scrubber drain valve leakage	- Looseness	Wear-in	Release scrubber seal water	Low scrubber water level, can't reach the certain temperature of cooled gas, if the temperature of gas in inert gas main line is too hot, the system will shut down, and also can leads to explosion in cargo tank due to the existance of ignition sources.	Explosion/ Fire	4	Occasional	high	Seawater drip out from valve
To cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5^{o}C;	Unable to cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5^{o}C;	1.6 Plugged/ choked in tower spray nozzles	accumulation of dust or dirt or other substance	Wear-out	Cannot produce and distribute the sea-water mist at the upper part of packed tower	function of the tower spray is doing the 2nd cooling, spray tower will produces sea water mist to cooled down the gas to sea water temperature plus within 5^{o}C . If the outlet temperature of gas from the scrubber is higher than 65oC, the system will shut down, further case it can leads to explosion/fire caused by the existance of ignition sources because the atmosphere of the cargo tank is not regulated.	Explosion/ Fire	4	Remote	Medium	

APPENDIX 7
FMECA ANALYSIS

BOTTOM-UP FMECA WORKSHEET											
1. SCRUBBER											
Function	**Functional Failure**	**Failure mode**	**Causes**	**Failure Characteristic**	**Local Effects**	**End Effects**	**Matrix**	**Severity**	**Current Likehood**	**Current Risk**	**Failure Detection/ Corrective Measures**
To absorbs sulfur dioxide content of exhaust gas until less than 0.03% of the total volume of gas	Unable to absorbs sulfur dioxide content of exhaust gas until less than 0.03% of the total volume of gas	2.1 Plugged/ choked in tower spray nozzles	Accumulation of dust or dirt or other substance from sea water	Wear-out	Cannot produce and distribute the sea-water mist at the upper part of packed tower	the SO contained in gas is absorbed by the sea water mist, if it is not, then the SO will be released into the atmosfer, and very dangerous for the environment. Or if it is streaming towards the cargo tank, it will be dangerous for the personnel. If the concentration is more than 5 ppm-3 mg/m3, when inhale, crew get poisoned.	safety	4	Remote	Medium	

APPENDIX 7
FMECA ANALYSIS

BOTTOM-UP FMECA WORKSHEET											
1. SCRUBBER											
Function	**Functional Failure**	**Failure mode**	**Causes**	**Failure Characteristic**	**Local Effects**	**End Effects**	**Matrix**	**Severity**	**Current Likehood**	**Current Risk**	**Failure Detection/ Corrective Measures**
To absorbs sulfur dioxide content of exhaust gas until less than 0.03% of the total volume of gas	Unable to absorbs sulfur dioxide content of exhaust gas until less than 0.03% of the total volume of gas	2.2 Leakage in body/ shell	Corrosion	Wear-out	Release exhaust gas to engine room	if the sulfur is released to engine room which is closed space and the concentration is more than 5 ppm-3 mg/m3, when inhale, crew get poisoned.	safety	4	Remote	Medium	From combustible gas detector (Portable or fixed)
		2.3 Scrubber cooling sea water inlet valve plugged/ chocked	Accumulation of dust or dirt or other substance	Wear-out	When valve not completely plugged it the flow and pressure of scrubber cooling water will be increasing before entering the nozzles	can break the nozzle tip. then, the spray pattern becomes irregular and liquid drops become larger and cannot collect SO2 contents of gas. SO2 will pollute the atmosfer and it is dangerous for the environment	safety	4	Remote	Medium	
		2.4 Structural deficiency of tower spray nozzles	Gradual removal of metal because of daily use	Wear-out	Nozzle tip enlargement gradually	flow usually increases, pressure may decrease, the spray pattern becomes irregular and liquid drops become larger and cannot collect SO2 contents of gas. SO2 will pollute the atmosfer and it is dangerous for the environment	safety	4	Remote	Medium	

APPENDIX 7
FMECA ANALYSIS

BOTTOM-UP FMECA WORKSHEET											
1. SCRUBBER											
Function	**Functional Failure**	**Failure mode**	**Causes**	**Failure Characteristic**	**Local Effects**	**End Effects**	**Matrix**	**Severity**	**Current Likehood**	**Current Risk**	**Failure Detection/ Corrective Measures**
To removes particles (dust) which larger than 1.0 micron	unable to removes particles (dust) which larger than 1.0 micron	3.1 Venturi spray nozzle structural deficiency	Erosion/ wear because of daily use	Wear-out	the spray pattern becomes irregular and liquid drops become larger and cannot collect SO2 contents of gas.	Liquid drops become larger and unable to collected the particles contents in exhaust gas. and also can't reach the certain temperature of cooled gas, if the temperature of gas in inert gas main line is too hot, the system will shut down, and also can leads to explosion in cargo tank due to the existance of ignition sources.	Explosion/ Fire	4	Remote	Medium	
		3.2 Scrubber cooling sea water inlet valve plugged/choked	Accumulation of dust or dirt or other substance	Wear-out	When valve not completely plugged it the flow and pressure of scrubber cooling water will be increasing before entering the nozzles	can break the nozzle tip. then, the spray pattern becomes irregular and liquid drops become larger and cannot collect large particle contents of gas. And also if the nozzle tip broken, it can produces water mist to cooled down the gas. so the cooled gas can't reach the certain temperature, if the temperature of gas in inert gas main line is too hot, the system will shut down, and also can leads to explosion in cargo tank due to the existance of ignition sources.	Explosion/ Fire	4	Remote	Medium	

APPENDIX 7

FMECA ANALYSIS

1. SCRUBBER											
Function	**Functional Failure**	**Failure mode**	**Causes**	**Failure Characteristic**	**Local Effects**	**End Effects**	**Matrix**	**Severity**	**Current Likehood**	**Current Risk**	**Failure Detection/ Corrective Measures**
To removes particles (dust) which larger than 1.0 micron	unable to removes particles (dust) which larger than 1.0 micron	3.3 Scrubber cooling sea water inlet valve structural deficiency	Gradual removal of metal because of daily use & cavitation	Wear-out	Unable to open or closed completely or not	the spray pattern becomes irregular and liquid drops become larger and cannot collect particles contents of gas. if the certain temperature cannot be fulfilled, the temperature of gas inside inert gas main line is too hot the system will automatically shut down. This situation can leads to the worst scenario caused by the existance of ignition sources inside the cargo tank, explosion.	Explosion/ Fire	1	Remote	Low	

APPENDIX 7

FMECA ANALYSIS

BOTTOM-UP FMECA WORKSHEET											
1. SCRUBBER											
Function	**Functional Failure**	**Failure mode**	**Causes**	**Failure Characteristic**	**Local Effects**	**End Effects**	**Matrix**	**Severity**	**Current Likehood**	**Current Risk**	**Failure Detection/ Corrective Measures**
To removes particles (dust) which larger than 1.0 micron	unable to removes particles (dust) which larger than 1.0 micron	3.4 Venturi spray nozzle plugged/choked	accumulation of dust or dirt or other substance	Wear-out	Cannot produce and distribute the sea-water mist over entire throat section of venturi	Produces large liquid drops which are unable to collected the particles contents in exhaust gas	Explosion/ Fire	1	Remote	Low	
To operates or to completes all of the fuctions	Unable to operates or unable to completes all of the fuctions	4.1 Scrubber drain valve plugged/ choked	Accumulation of dust or dirt or other substance	Wear-out	Unable to released scrubber seal water level	High scrubber seal water level, system shutdown	Explosion/ Fire	4	Remote	Medium	By looking at the sea water flow come out from drain valve
		4.2 Abnormal instrument pressure reading	Corrosion, clogging	Wear-out	gauge readings unreliable	when the gauge misread the pressure of system is in high pressure, the system will shutdown	Explosion/ Fire	4	Occasional	High	Measured value in pressure gauge is abnormal (too high or too low or even unchanged)
			Sudden stress	Random failure	gauge readings unreliable	when the gauge misread the pressure of system is in high pressure, the system will shutdown	Explosion/ Fire	4	Occasional	High	

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FMECA ANALYSIS

BOTTOM-UP FMECA WORKSHEET											
1. SCRUBBER											
Function	**Functional Failure**	**Failure mode**	**Causes**	**Failure Characteristic**	**Local Effects**	**End Effects**	**Matrix**	**Severity**	**Current Likehood**	**Current Risk**	**Failure Detection/ Corrective Measures**
To operates or to completes all of the fuctions	Unable to operates or unable to completes all of the fuctions	4.3 Instrument pressure leakage	Wear, corrosion	Wear-out	gauge readings unreliable	when the gauge misread the pressure of system is in high pressure, the system will shutdown, further case it can leads to explosion/fire caused by the existance of ignition sources because the atmosphere of the cargo tank is not regulated (inert gas not operated).	Explosion/ Fire	4	Remote	Medium	Measured value in pressure gauge is abnormal (too high or too low or even unchanged)
		4.4 structural deficiency of body/shell	- Deformation - Corrosion - Cavitation - Fatigue	Wear-out	Structural strength decreases	for long time the body can collapsed. It means that inert gas system is not operating which can leads to explosion/fire caused by the existance of ignition sources because the atmosphere of the cargo tank is not regulated.	Explosion/ Fire	4	Occasional	High	Do some inspection of the body
		4.5 structural deficiency of support	- Corrosion - Fatigue	wear-out	Decreases of structural strength	Collapsed, support will collapsed, the worst case is explosion because at that time inert gas system will not operated. So there is no control on cargo tank atmosphere	Explosion/ Fire	4	Remote	Medium	Inspection

APPENDIX 7

FMECA ANALYSIS

BOTTOM-UP FMECA WORKSHEET											
1. SCRUBBER											
Function	**Functional Failure**	**Failure mode**	**Causes**	**Failure Characteristic**	**Local Effects**	**End Effects**	**Matrix**	**Severity**	**Current Likehood**	**Current Risk**	**Failure Detection/ Corrective Measures**
To operates or to completes all of the fuctions	Unable to operates or unable to completes all of the fuctions	4.6 Abnormal instrument level reading	Corrosion	Wear-out	Faulty level switch	High scrubber water level, then shutdown. And it can leads to explosion in cargo tank due to the existance of ignition sources.	Explosion/ Fire	4	Probable	High	Unable to switch off/on

APPENDIX 7

FMECA ANALYSIS

BOTTOM -UP FMECA WORKSHEET											
2. INERT GAS FAN											
Item	**Failure Mode**	**Cause(s)**	**Failure Characteristic**	**Local Effects**	**Functional Failures**	**End Effects**	**Matrix**	**Severity**	**Current Likehood**	**Current Risk**	**Failure Detection/ Corrective Measures**
1.1	Minor in Service Problem	- Breakage - Clearance/ alignment failure - Electrical failures - Looseness - Mechanical failure - Vibration - Wear	Wear-out, wear-in, random	unable to start	unable to blow inert gas into cargo tank	system shutdown	Explosion/ Fire	4	Probable	High	Alarm
1.2	Insuficient gas transfer	- breakage - clearance/ alignment failure - earth/ isolation failure - electrical failure - looseness - material failure - mechanical failure - miscellaneous - open circuit - wear	Wear-out, wear-in, random	low pressure in IG deck main pipe	transmit less than 18.6 kPa and less than 5625 m3/h of inert gas into cargo oil tank	system shutdown	Explosion/ Fire	4	Probable	High	Alarm

APPENDIX 7

FMECA ANALYSIS

BOTTOM -UP FMECA WORKSHEET											
Inert Gas Fan											
Item	**Failure Mode**	**Cause(s)**	**Failure Characteristic**	**Local Effects**	**Functional Failures**	**End Effects**	**Matrix**	**Severity**	**Current Likehood**	**Current Risk**	**Failure Detection/ Corrective Measures**
1.3	Abnormal instrument reading	Instrument failure	random	false alarm	unable to blow inert gas into cargo tank	system shutdown	Explosion/ Fire	4	Occasional	High	Alarm

APPENDIX 8

SELECTION OF THE FAILURE MANAGEMENT TASK

1. SCRUBBER													
Function	***Functional Failure***	***Failure Mode***	***Failure Char.***	***Hidden/ Evident***	***Effects***		***Risk Characterization***			***Task Selection***			
					Local	***End***	***S***	***CL***	***CR***	***Proposed Action(s)***	***PL***	***PR***	***Disposition***
To cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5°C;	Unable to cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5°C;	1.1 Leakage in body/ shell	Wear out	Evident	release seawater in engine room, insufficient amount of water inside scrubber	Can't reach the certain temperature of cooled gas, if the temperature of gas in inert gas main line is too hot, the system will shut down, and the worst case is it can leads to explosion in cargo tank due to the existance of ignition sources.	4	Ocassional	High	- Optically check for external leakage weekly - Monitor the record of corrosion sensor (high level of potential noise & current noise are indicative of massive pitting attack) daily - Check corrosion condition of shell thoroughly yearly	Improbable	Medium	
		1.2 Venturi spray nozzle plugged/ choked	Wear-out	Hidden	Cannot produce and distribute the sea-water mist over entire throat section of venturi	Function of spray nozzle in venturi is for cooling down the gas from about 450°C to 60°C - 70°C, if the certain temperature cannot be fulfilled, the temperature of gas inside inert gas main line is too hot the system will automatically shut down. This situation can leads to the worst scenario caused by the existance of ignition sources inside the cargo tank, explosion.	4	Remote	Medium	- Remove all nozzles from header to check and clean or replace yearly	Improbable	Medium	

APPENDIX 8

SELECTION OF THE FAILURE MANAGEMENT TASK

1. SCRUBBER													
Function	***Functional Failure***	***Failure Mode***	***Failure Char.***	***Hidden / Evident***	***Effects***		***Risk Characterization***			***Task Selection***			
					Local	***End***	***S***	***CL***	***CR***	***Proposed Action(s)***	***PL***	***PR***	***Dispositi on***
To cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5°C;	Unable to cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5°C;	1.3 Plugged/ choked in scrubber cooling sea water inlet valve	Wear-out	Hidden	Cannot deliver the sufficient amount of scrubber cooling sea water to the nozzles inside the srubber	Cannot cooled down the gas to sea water temperature plus within 5°C by the sea water when the temperature of gas in inert gas main line is too hot, the system will automatically shut down, and the worst case explosion in cargo tank due to the existance of ignition sources.	4	Remot e	Medium	Remove the valve to check and clean from fouling & dirt or replace yearly	Improb able	Mediu m	
		1.4 Scrubber drain valve leakage	Wear-out	Evident	Release scrubber seal water	Low scrubber water level, can't reach the certain temperature of cooled gas, if the temperature of gas in inert gas main line is too hot, the system will shut down, and also can leads to explosion in cargo tank due to the existance of ignition sources.	3	Occasi onal	Medium	Remove the valve to check and clean from fouling & dirt or replace yearly	Remot e	Mediu m	

APPENDIX 8

SELECTION OF THE FAILURE MANAGEMENT TASK

1. SCRUBBER														
Function	***Functional Failure***	***Failure Mode***	***Failure Char.***	***Hidden / Evident***	***Effects***		***Risk Characterization***			***Task Selection***				
					Local	***End***	***S***	***CL***	***CR***	***Proposed Action(s)***	***PL***	***PR***	***Dispositi on***
		1.5 Scrubber drain valve leakage	Wear-in	Evident	Release scrubber seal water	Low scrubber water level, can't reach the certain temperature of cooled gas, if the temperature of gas in inert gas main line is too hot, the system will shut down, and also can leads to explosion in cargo tank due to the existance of ignition sources.	4	Occasi onal	High	optically check for external leakage weekly, check corrosion condition of scrubber drain valve yearly; Remove the valve to check and clean from fouling & dirt or replace yearly;	Remot e	Mediu m	
To cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5°C;	Unable to cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5°C;	1.6 Plugged/ choked in tower spray nozzles	Wear-out	Hidden	Cannot produce and distribute the sea-water mist at the upper part of packed tower	function of the tower spray is doing the 2nd cooling, spray tower will produces sea water mist to cooled down the gas to sea water temperature plus within 5°C . If the outlet temperature of gas from the scrubber is higher than 65oC, the system will shut down, further case it can leads to explosion/fire caused by the existance of ignition sources because the atmosphere of the cargo tank is not regulated.	4	Remot e	Medium	Remove all nozzles from header to check and clean or replace yearly	Improb able	Mediu m	

APPENDIX 8

SELECTION OF THE FAILURE MANAGEMENT TASK

1. SCRUBBER													
Function	***Functional Failure***	***Failure Mode***	***Failure Char.***	***Hidden / Evident***	***Effects***		***Risk Characterization***			***Task Selection***			
					Local	***End***	***S***	***CL***	***CR***	***Proposed Action(s)***	***PL***	***PR***	***Disposition***
To absorbs sulfur dioxide content of exhaust gas until less than 0.03% of the total volume of gas	Unable to absorbs sulfur dioxide content of exhaust gas until less than 0.03% of the total volume of gas	2.1 Plugged/ choked in tower spray nozzles	Wear-out	Hidden	Cannot produce and distribute the sea-water mist at the upper part of packed tower	the SO contained in gas is absorbed by the sea water mist, if it is not, then the SO will be released into the atmosfer, and very dangerous for the environment. Or if it is streaming towards the cargo tank, it will be dangerous for the personnel. If the concentration is more than 5 ppm-3 mg/m3, when inhale, crew get poisoned.	4	Remote	Medium	- Remove all nozzles from header to check and clean or replace yearly	Improbable	Medium	
		2.2 Leakage in body/ shell	Wear-out	Evident	Release exhaust gas to engine room	if the sulfur is released to engine room which is closed space and the concentration is more than 5 ppm-3 mg/m3, when inhale, crew get poisoned.	4	Remote	Medium	Check corrosion condition of shell thoroughly yearly	Improbable	Medium	

APPENDIX 8

SELECTION OF THE FAILURE MANAGEMENT TASK

1. SCRUBBER														
Function	Functional Failure	Failure Mode	Failure Char.	Hidden / Evident	Effects		Risk Characterization			Task Selection			
					Local	End	S	CL	CR	Proposed Action(s)	PL	PR	Disposition
To absorbs sulfur dioxide content of exhaust gas until less than 0.03% of the total volume of gas	Unable to absorbs sulfur dioxide content of exhaust gas until less than 0.03% of the total volume of gas	2.3 Scrubber cooling sea water inlet valve plugged/ chocked	Wear-out	Hidden	When valve not completely plugged it the flow and pressure of scrubber cooling water will be increasing before entering the nozzles	can break the nozzle tip. then, the spray pattern becomes irregular and liquid drops become larger and cannot collect SO2 contents of gas. SO2 will pollute the atmosfer and it is dangerous for the environment	4	Remote	Medium	Remove the valve to check and clean from fouling & dirt or replace yearly	Improbable	Medium	
		2.4 Structural deficiency of tower spray nozzles	Wear-out	Hidden	Nozzle tip enlargement gradually	flow usually increases, pressure may decrease, the spray pattern becomes irregular and liquid drops become larger and cannot collect SO2 contents of gas. SO2 will pollute the atmosfer and it is dangerous for the environment	4	Remote	Medium	Remove all nozzles from header to check and clean or replace yearly	Improbable	Medium	
To removes particles (dust) which larger than 1.0 micron	unable to removes particles (dust) which larger than 1.0 micron	3.1 Venturi spray nozzle structural deficiency	Wear-out	Hidden	the spray pattern becomes irregular and liquid drops become larger and cannot collect SO2 contents of gas.	Liquid drops become larger and unable to collected the particles contents in exhaust gas. and also can't reach the certain temperature of cooled gas, if the temperature of gas in inert gas main line is too hot, the system will shut down, and also can leads to explosion in cargo tank due to the existance of ignition sources.	4	Remote	Medium	Remove all nozzles from header to check and clean or replace yearly	Improbable	Medium	

APPENDIX 8

<u>SELECTION OF THE FAILURE MANAGEMENT TASK</u>

1. SCRUBBER														
Function	***Functional Failure***	***Failure Mode***	***Failure Char.***	***Hidden/ Evident***	***Effects***		***Risk Characterization***			***Task Selection***			
					Local	***End***	***S***	***CL***	***CR***	***Proposed Action(s)***	***PL***	***PR***	***Dispositi on***
To removes particles (dust) which larger than 1.0 micron	unable to removes particles (dust) which larger than 1.0 micron	3.2 Scrubber cooling sea water inlet valve plugged/chok ed	Wear-out	Hidden	When valve not completely plugged it the flow and pressure of scrubber cooling water will be increasing before entering the nozzles	can break the nozzle tip. then, the spray pattern becomes irregular and liquid drops become larger and cannot collect large particle contents of gas. And also if the nozzle tip broken, it can produces water mist to cooled down the gas. so the cooled gas can't reach the certain temperature, if the temperature of gas in inert gas main line is too hot, the system will shut down, and also can leads to explosion in cargo tank due to the existance of ignition sources.	4	Remot e	Medium	Remove the valve to check and clean from fouling & dirt or replace yearly	Improb able	Mediu m	
		3.3 Scrubber cooling sea water inlet valve structural deficiency	Wear-out	Hidden	Unable to open or closed completely or not	the spray pattern becomes irregular and liquid drops become larger and cannot collect particles contents of gas. if the certain temperature cannot be fulfilled, the temperature of gas inside inert gas main line is too hot the system will automatically shut down. This situation can leads to the worst scenario caused by the existance of ignition sources inside the cargo tank, explosion.	1	Remot e	Low	'Remove the valve to check and clean from fouling & dirt or replace yearly	Improb able	Low	

APPENDIX 8

SELECTION OF THE FAILURE MANAGEMENT TASK

1. SCRUBBER													
Function	***Functional Failure***	***Failure Mode***	***Failure Char.***	***Hidden /Evident***	***Effects***		***Risk Characterization***			***Task Selection***			
					Local	***End***	***S***	***CL***	***CR***	***Proposed Action(s)***	***PL***	***PR***	***Disposition***
To removes particles (dust) which larger than 1.0 micron	unable to removes particles (dust) which larger than 1.0 micron	3.4 Venturi spray nozzle plugged/choked	Wear-out	Hidden	Cannot produce and distribute the sea-water mist over entire throat section of venturi	Produces large liquid drops which are unable to collected the particles contents in exhaust gas	1	Remote	Low	Remove all nozzles from header to check and clean or replace yearly	Improbable	Low	
To operates or to completes all of the fuctions	Unable to operates or unable to completes all of the fuctions	4.1 Scrubber drain valve plugged/ choked	Wear-out	Hidden	Unable to released scrubber seal water level	High scrubber seal water level, system shutdown	4	Remote	Medium	Remove the valve to check and clean from fouling & dirt or replace yearly	Improbable	Medium	
		4.2 Abnormal instrument pressure reading	Wear-out	Evident	gauge readings unreliable	when the gauge misread the pressure of system is in high pressure, the system will shutdown	4	Occasional	High	- Calibration of instrument at every measurement - Check the instrument monthly	Remote	Medium	
			Random failure	Evident	gauge readings unreliable	when the gauge misread the pressure of system is in high pressure, the system will shutdown	4	Occasional	High		Remote	Medium	
		4.3 Instrument pressure leakage	Wear-out	Evident	gauge readings unreliable	when the gauge misread the pressure of system is in high pressure, the system will shutdown, further case it can leads to explosion/fire caused by the existance of ignition sources because the atmosphere of the cargo tank is not regulated (inert gas not operated).	4	Remote	Medium	- Calibration of instrument at every measurement - Check the instrument monthly	Improbable	Medium	

APPENDIX 8

<u>SELECTION OF THE FAILURE MANAGEMENT TASK</u>

1. SCRUBBER

Function	Functional Failure	Failure Mode	Failure Char.	Hidden /Evident	*Effects*		*Risk Characterization*			*Task Selection*			
					Local	*End*	*S*	*CL*	*CR*	*Proposed Action(s)*	*PL*	*PR*	*Disposition*
To operates or to completes all of the fuctions	Unable to operates or unable to completes all of the fuctions	4.4 structural deficiency of body/shell	Wear-out	Hidden	Structural strength decreases	for long time the body can collapsed. It means that inert gas system is not operating which can leads to explosion/fire caused by the existance of ignition sources because the atmosphere of the cargo tank is not regulated.	4	Occasional	High	- Optically check for external leakage weekly - Monitor the record of corrosion sensor (high level of potential noise & current noise are indicative of massive pitting attack) daily - Check corrosion condition of shell thoroughly yearly	Remote	Medium	
		4.5 structural deficiency of support	wear-out	Hidden	Decreases of structural strength	Collapsed, support will collapsed, the worst case is explosion because at that time inert gas system will not operated. So there is no control on cargo tank atmosphere.	4	Remote	Medium	Check corrosion condition of structure thoroughly yearly	Improbable	Medium	
		4.6 Abnormal instrument level reading	Wear-out	Evident	Faulty level switch	High scrubber water level, then shutdown. And it can leads to explosion in cargo tank due to the existance of ignition sources.	4	Probable	High	- Calibration of instrument at every measurement - Check the instrument monthly	Occasional	High	

APPENDIX 8

SELECTION OF THE FAILURE MANAGEMENT TASK

2. INERT GAS FAN													
Function	***Functional Failure***	***Failure Mode***	***Failure Char.***	***Hidden / Evident***	***Effects***		***Risk Characterization***			***Task Selection***			
					Local	***End***	***S***	***CL***	***CR***	***Proposed Action(s)***	***PL***	***PR***	***Disposition***
To blow the inert gas into cargo oil tank with the capacity 5625 m3/h and 18.6 kPa	unable to blow inert gas into cargo tank	1.1 Minor in Service Problem	Wear-out, wear-in, random	Evident	unable to start	system shutdown	4	Probable	High	- Washing of impeller during after fans stop operation (10~15min) until the impeller completely stops. - Confirm that the shaft rotation part is not sticked by turning the fan every week - Grease up the bearing at both sides of motor every 6 months - Open the inspection hole of fan casing and check the coating of inner surface on fan every 6 months - Check the wear and soiled condition every 6 months - Open the stuffing box for inspection every year - Check the inside of bearing housing & replace LO or grease every year - Grease up the bearing every 2000 hrs	Occasional	High	

APPENDIX 8

SELECTION OF THE FAILURE MANAGEMENT TASK

2. INERT GAS FAN													
Function	***Functional Failure***	***Failure Mode***	***Failure Char.***	***Hidden / Evident***	***Effects***		***Risk Characterization***			***Task Selection***			
					Local	***End***	***S***	***CL***	***CR***	***Proposed Action(s)***	***PL***	***PR***	***Disposition***
To blow the inert gas into cargo oil tank with the capacity 5625 m3/h and 18.6 kPa	transmit less than 18.6 kPa and less than 5625 m3/h of inert gas into cargo oil tank	1.2 Insuficient gas transfer	Wear-out, random	Evident	low pressure in IG deck main pipe	system shutdown	4	Probable	High	- Washing of impeller during after fans stop operation (10~15min) until the impeller completely stops. - Confirm that the shaft rotation part is not sticked by turning the fan every week - Grease up the bearing at both sides of motor every 6 months - Open the inspection hole of fan casing and check the coating of inner surface on fan every 6 months - Check the wear and soiled condition every 6 months - Open the stuffing box for inspection every year - Check the inside of bearing housing & replace LO or grease every year - Grease up the bearing every 2000 hrs	Occasional	High	

APPENDIX 8

SELECTION OF THE FAILURE MANAGEMENT TASK

2. INERT GAS FAN													
Function	***Functional Failure***	***Failure Mode***	***Failure Char.***	***Hidden / Evident***	***Effects***		***Risk Characterization***			***Task Selection***			
					Local	***End***	***S***	***CL***	***CR***	***Proposed Action(s)***	***PL***	***PR***	***Disposition***
To blow the inert gas into cargo oil tank with the capacity 5625 m3/h and 18.6 kPa	unable to blow inert gas into cargo tank	1.3 Abnormal instrument reading	Wear-out, random	Evident	false alarm	system shutdown	4	Occasional	High	- Calibration of instrument at every measurement - Check the instrument monthly	Remote	Medium	

APPENDIX 9

FMECA TASK SELECTION FLOW DIAGRAM RECORD

1. SCRUBBER

Function	*Functional Failure*	*Failure Mode*	*Failure Char.*	*Hidden / Evident*	*Effects*		*Risk Characterization*			*Task Selection Flow Diagram Record*												
					Local	*End*	*S*	*CL*	*CR*	*A1*	*A2*	*B1*	*B2*	*B3*	*B4*	*B5*	*B6*	*B7*	*C1*	*C2*	*C3*	*Result*
To cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5^{o}C;	Unable to cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5^{o}C;	1.1 Leakage in body/ shell	Wear out	Evident	release seawater in engine room, insufficient amount of water inside scrubber	Can't reach the certain temperature of cooled gas, if the temperature of gas in inert gas main line is too hot, the system will shut down, and the worst case is it can leads to explosion in cargo tank due to the existance of ignition sources.	4	Ocassio nal	High	Y	N	N	N	-	-	-	-	Y	-	-	-	Specify the task at the appropriate interval to achieve the tolerance risk
		1.2 Venturi spray nozzle plugged/ choked	Wear-out	Hidden	Cannot produce and distribute the sea-water mist over entire throat section of venturi	Function of spray nozzle in venturi is for cooling down the gas from about 450^{o}C to 60^{o}C - 70^{o}C, if the certain temperature cannot be fulfilled, the temperature of gas inside inert gas main line is too hot the system will automatically shut down. This situation can leads to the worst scenario caused by the existance of ignition sources inside the cargo tank, explosion.	4	Remote	Medium	N	-	N	Y	-	Y	-	-	-	-	-	-	Specify planned maintenance at the appropriate life limit

1. SCRUBBER																							
Function	***Functional Failure***	***Failure Mode***	***Failure Char.***	***Hidden / Evident***	***Effects***		***Risk Characterization***			***Task Selection Flow Diagram Record***													
					Local	***End***	***S***	***CL***	***CR***	***A1***	***A2***	***B1***	***B2***	***B3***	***B4***	***B5***	***B6***	***B7***	***C1***	***C2***	***C3***	***Result***
To cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5^{o}C;	Unable to cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5^{o}C;	1.3 Plugged/ choked in scrubber cooling sea water inlet valve	Wear-out	Hidden	Cannot deliver the sufficient amount of scrubber cooling sea water to the nozzles inside the srubber	Cannot cooled down the gas to sea water temperature plus within 5^{o}C by the sea water when the temperature of gas in inert gas main line is too hot, the system will automatically shut down, and the worst case explosion in cargo tank due to the existance of ignition sources.	4	Remote	Medium	N	-	N	Y	-	Y	-	-	-	-	-	-	Specify planned maintenance at the appropriate life limit
		1.4 Scrubber drain valve leakage	Wear-out	Evident	Release scrubber seal water	Low scrubber water level, can't reach the certain temperature of cooled gas, if the temperature of gas in inert gas main line is too hot, the system will shut down, and also can leads to explosion in cargo tank due to the existance of ignition sources.	3	Occasional	Medium	N	-	N	Y	-	Y	-	-	-	-	-	-	Specify planned maintenance at the appropriate life limit

1. SCRUBBER

Function	*Functional Failure*	*Failure Mode*	*Failure Char.*	*Hidden / Evident*	*Effects*		*Risk Characterization*			*Task Selection Flow Diagram Record*												
					Local	*End*	*S*	*CL*	*CR*	*A1*	*A2*	*B1*	*B2*	*B3*	*B4*	*B5*	*B6*	*B7*	*C1*	*C2*	*C3*	*Result*
To cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5^{o}C;	Unable to cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5^{o}C;	1.5 Scrubber drain valve leakage	Wear-in	Evident	Release scrubber seal water	Low scrubber water level, can't reach the certain temperature of cooled gas, if the temperature of gas in inert gas main line is too hot, the system will shut down, and also can leads to explosion in cargo tank due to the existance of ignition sources.	4	Occasional	High	Y	N	N	N	-	-	-	-	Y	-	-	-	Specify the task at the appropriate interval to achieve the tolerance risk
To cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5^{o}C;	Unable to cools down exhaust gas until the temperature of gas similar to sea water temperature plus within 5^{o}C;	1.6 Plugged/ choked in tower spray nozzles	Wear-out	Hidden	Cannot produce and distribute the sea-water mist at the upper part of packed tower	function of the tower spray is doing the 2nd cooling, spray tower will produces sea water mist to cooled down the gas to sea water temperature plus within 5^{o}C . If the outlet temperature of gas from the scrubber is higher than 65oC, the system will shut down, further case it can leads to explosion/fire caused by the existance of ignition sources because the atmosphere of the cargo tank is not regulated.	4	Remote	Medium	N	-	N	Y	-	Y	-	-	-	-	-	-	Specify planned maintenance at the appropriate life limit

1. SCRUBBER																								
Function	***Functional Failure***	***Failure Mode***	***Failure Char.***	***Hidden / Evident***	***Effects***		***Risk Characterization***			***Task Selection Flow Diagram Record***														
					Local	***End***	***S***	***CL***	***CR***	***A1***	***A2***	***B1***	***B2***	***B3***	***B4***	***B5***	***B6***	***B7***	***C1***	***C2***	***C3***	***Result***		
To absorbs sulfur dioxide content of exhaust gas until less than 0.03% of the total volume of gas	Unable to absorbs sulfur dioxide content of exhaust gas until less than 0.03% of the total volume of gas	2.1 Plugged/ choked in tower spray nozzles	Wear-out	Hidden	Cannot produce and distribute the sea-water mist at the upper part of packed tower	the SO contained in gas is absorbed by the sea water mist, if it is not, then the SO will be released into the atmosfer, and very dangerous for the environment. Or if it is streaming towards the cargo tank, it will be dangerous for the personnel. If the concentration is more than 5 ppm-3 mg/m3, when inhale, crew get poisoned.	4	Remote	Medium	N	-	N	Y	-	Y	-	-	-	-	-	-	Specify planned maintenance at the appropriate life limit		
		2.2 Leakage in body/ shell	Wear-out	Evident	Release exhaust gas to engine room	if the sulfur is released to engine room which is closed space and the concentration is more than 5 ppm-3 mg/m3, when inhale, crew get poisoned.	4	Remote	Medium	N	-	N	Y	-	Y	-	-	-	-	-	-	Specify planned maintenance at the appropriate life limit		

1. SCRUBBER																						
Function	***Functional Failure***	***Failure Mode***	***Failure Char.***	***Hidden / Evident***	***Effects***		***Risk Characterization***			***Task Selection Flow Diagram Record***												
					Local	***End***	***S***	***CL***	***CR***	***A1***	***A2***	***B1***	***B2***	***B3***	***B4***	***B5***	***B6***	***B7***	***C1***	***C2***	***C3***	***Result***
To absorbs sulfur dioxide content of exhaust gas until less than 0.03% of the total volume of gas	Unable to absorbs sulfur dioxide content of exhaust gas until less than 0.03% of the total volume of gas	2.3 Scrubber cooling sea water inlet valve plugged/ chocked	Wear-out	Hidden	When valve not completely plugged it the flow and pressure of scrubber cooling water will be increasing before entering the nozzles.	can break the nozzle tip. then, the spray pattern becomes irregular and liquid drops become larger and cannot collect SO2 contents of gas. SO2 will pollute the atmosfer and it is dangerous for the environment	4	Remote	Medium	N	-	N	Y	-	Y	-	-	-	-	-	-	Specify planned maintenance at the appropriate life limit
		2.4 Structural deficiency of tower spray nozzles	Wear-out	Hidden	Nozzle tip enlargement gradually	flow usually increases, pressure may decrease, the spray pattern becomes irregular and liquid drops become larger and cannot collect SO2 contents of gas. SO2 will pollute the atmosfer and it is dangerous for the environment	4	Remote	Medium	N	-	N	Y	-	Y	-	-	-	-	-	-	Specify planned maintenance at the appropriate life limit

1. SCRUBBER																						
Function	***Functional Failure***	***Failure Mode***	***Failure Char.***	***Hidden / Evident***	***Effects***		***Risk Characterization***			***Task Selection Flow Diagram Record***												
					Local	***End***	***S***	***CL***	***CR***	***A1***	***A2***	***B1***	***B2***	***B3***	***B4***	***B5***	***B6***	***B7***	***C1***	***C2***	***C3***	***Result***
To removes particles (dust) which larger than 1.0 micron	unable to removes particles (dust) which larger than 1.0 micron	3.1 Venturi spray nozzle structural deficiency	Wear-out	Hidden	the spray pattern becomes irregular and liquid drops become larger and cannot collect SO2 contents of gas.	Liquid drops become larger and unable to collected the particles contents in exhaust gas. and also can't reach the certain temperature of cooled gas, if the temperature of gas in inert gas main line is too hot, the system will shut down, and also can leads to explosion in cargo tank due to the existance of ignition sources.	4	Remote	Medium	N	-	N	Y	-	Y	-	-	-	-	-	-	Specify planned maintenance at the appropriate life limit
To removes particles (dust) which larger than 1.0 micron	unable to removes particles (dust) which larger than 1.0 micron	3.2 Scrubber cooling sea water inlet valve plugged/ choked	Wear-out	Hidden	When valve not completely plugged it the flow and pressure of scrubber cooling water will be increasing before entering the nozzles	can break the nozzle tip. then, the spray pattern becomes irregular and liquid drops become larger and cannot collect large particle contents of gas. And also if the nozzle tip broken, it can produces water mist to cooled down the gas. so the cooled gas can't reach the certain temperature, if the temperature of gas in inert gas main line is too hot, the system will shut down, and also can leads to explosion in cargo tank due to the existance of ignition sources.	4	Remote	Medium	N	-	N	Y	-	Y	-	-	-	-	-	-	Specify planned maintenance at the appropriate life limit

1. SCRUBBER

Function	*Functional Failure*	*Failure Mode*	*Failure Char.*	*Hidden / Evident*	*Effects*		*Risk Characterization*			*Task Selection Flow Diagram Record*												
					Local	*End*	*S*	*CL*	*CR*	*A1*	*A2*	*B1*	*B2*	*B3*	*B4*	*B5*	*B6*	*B7*	*C1*	*C2*	*C3*	*Result*
To removes particles (dust) which larger than 1.0 micron	unable to removes particles (dust) which larger than 1.0 micron	3.3 Scrubber cooling sea water inlet valve structural deficiency	Wear-out	Hidden	Unable to open or closed completely or not	the spray pattern becomes irregular and liquid drops become larger and cannot collect particles contents of gas. if the certain temperature cannot be fulfilled, the temperature of gas inside inert gas main line is too hot the system will automatically shut down. This situation can leads to the worst scenario caused by the existance of ignition sources inside the cargo tank, explosion.	1	Remote	Low	Y	Y	-	-	-	-	-	-	-	-	-	-	Specify run-to failure strategy
		3.4 Venturi spray nozzle plugged/ choked	Wear-out	Hidden	Cannot produce and distribute the sea-water mist over entire throat section of venturi	Produces large liquid drops which are unable to collected the particles contents in exhaust gas	1	Remote	Low	Y	Y	-	-	-	-	-	-	-	-	-	-	Specify run-to failure strategy
To operates or to completes all of the fuctions	Unable to operates or unable to completes all of the fuctions	4.1 Scrubber drain valve plugged/ choked	Wear-out	Hidden	Unable to released scrubber seal water level	High scrubber seal water level, system shutdown	4	Remote	Medium	N	-	N	Y	-	Y	-	-	-	-	-	-	Specify planned maintenance at the appropriate life limit
		4.2 Abnormal instrument pressure reading	Wear-out	Evident	gauge readings unreliable	when the gauge misread the pressure of system is in high pressure, the system will shutdown	4	Occasional	High	Y	N	N	N	-	-	-	-	Y	-	-	-	Specify the task at the appropriate interval to achieve the tolerance risk

1. SCRUBBER																						
Function	***Functional Failure***	***Failure Mode***	***Failure Char.***	***Hidden / Evident***	***Effects***		***Risk Characterization***			***Task Selection Flow Diagram Record***												
					Local	***End***	***S***	***CL***	***CR***	***A1***	***A2***	***B1***	***B2***	***B3***	***B4***	***B5***	***B6***	***B7***	***C1***	***C2***	***C3***	***Result***
To operates or to completes all of the fuctions	Unable to operates or unable to completes all of the fuctions	4.2 Abnormal instrument pressure reading	Random failure	Evident	gauge readings unreliable	when the gauge misread the pressure of system is in high pressure, the system will shutdown	4	Occasional	High	Y	N	N	N	-	-	-	-	Y	-	-	-	Specify the task at the appropriate interval to achieve the tolerance risk
		4.3 Instrument pressure leakage	Wear-out	Evident	gauge readings unreliable	when the gauge misread the pressure of system is in high pressure, the system will shutdown, further case it can leads to explosion/fire caused by the existance of ignition sources because the atmosphere of the cargo tank is not regulated (inert gas not operated).	4	Remote	Medium	N	-	N	Y	-	Y	-	-	-	-	-	-	Specify planned maintenance at the appropriate life limit
		4.4 structural deficiency of body/shell	Wear-out	Hidden	Structural strength decreases	for long time the body can collapsed. It means that inert gas system is not operating which can leads to explosion/fire caused by the existance of ignition sources because the atmosphere of the cargo tank is not regulated.	4	Occasional	High	Y	N	N	N	-	-	-	-	Y	-	-	-	Specify the task at the appropriate interval to achieve the tolerance risk

2. INERT GAS FAN

Function	Functional Failure	Failure Mode	Failure Char.	Hidden / Evident	Effects		Risk Characterization			Task Selection Flow Diagram Record												
					Local	End	S	CL	CR	A1	A2	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	Result
To operates or to completes all of the fuctions	Unable to operates or unable to completes all of the fuctions	4.5 structural deficiency of support	wear-out	Hidden	Decreases of structural strength	Collapsed, support will collapsed, the worst case is explosion because at that time inert gas system will not operated. So there is no control on cargo tank atmosphere.	4	Remote	Medium	N	-	N	Y	-	Y	-	-	-	-	-	-	Specify planned maintenance at the appropriate life limit
		4.6 Abnormal instrument level reading	Wear-out	Evident	Faulty level switch	High scrubber water level, then shutdown. And it can leads to explosion in cargo tank due to the existance of ignition sources.	4	Probable	High	Y	N	N	N	-	-	-	-	Y	-	-	-	Specify the task at the appropriate interval to achieve the tolerance risk
To blow the inert gas into cargo oil tank with the capacity 5625 m3/h and 18.6 kPa	unable to blow inert gas into cargo tank	1.1 Minor in Service Problem	Wear-out, wear-in, random	Evident	unable to start	system shutdown	4	Probable	High	Y	N	N	N	-	-	-	-	Y	-	-	-	Specify the task at the appropriate interval to achieve the tolerance risk
	transmit less than 18.6 kPa and less than 5625 m3/h of inert gas into cargo oil tank	1.2 Insuficient gas transfer	Wear-out, random	Evident	low pressure in IG deck main pipe	system shutdown	4	Probable	High	Y	N	N	N	-	-	-	-	Y	-	-	-	Specify the task at the appropriate interval to achieve the tolerance risk

2. INERT GAS FAN																						
Function	***Functional Failure***	***Failure Mode***	***Failure Char.***	***Hidden / Evident***	***Effects***		***Risk Characterization***			***Task Selection Flow Diagram Record***												
					Local	***End***	***S***	***CL***	***CR***	***A1***	***A2***	***B1***	***B2***	***B3***	***B4***	***B5***	***B6***	***B7***	***C1***	***C2***	***C3***	***Result***
To blow the inert gas into cargo oil tank with the capacity 5625 m3/h and 18.6 kPa	unable to blow inert gas into cargo tank	1.3 Abnormal instrument reading	Wear-out, random	Evident	false alarm	system shutdown	4	Occasional	High	Y	N	N	N	-	-	-	-	Y	-	-	-	Specify the task at the appropriate interval to achieve the tolerance risk

APPENDIX 10
SUMMARY OF MAINTENANCE TASK

Maintenance Category : **Category A**
Fuctional Group : **Cargo handling**
System : **Cargo system**
Sub-System : **Inert gas system**
Equipment of System : **Scrubber**

Task	Task Type	Item No.	Risk		Frequency	Procedure No. or Class References	Comments
			Unmitigated	Mitigated			
Optically check for external leakage	CM	1.1	High	Medium	Once a day		by onboard personnel
Monitor the record of corrosion sensor	CM	1.1	High	Medium	every day		by onboard personnel
Optically check for external leakage	PM	1.5	Medium	Medium	Once a week		by onboard personnel
Calibration of instrument	PM	4.2	High	Medium	At every measurement		by onboard personnel
Check the instrument	PM	4.2	High	Medium	Once a month		by onboard personnel
Calibration of instrument	PM	4.3	Medium	Medium	At every measurement		by onboard personnel
Check the instrument	PM	4.3	Medium	Medium	Once a month		by onboard personnel
Optically check for external leakage	CM	4.4	High	Medium	Once a week		by onboard personnel
Monitor the record of corrosion sensor	CM	4.4	High	Medium	every day		by onboard personnel
Check the instrument	PM	4.6	High	High	Once a month		by onboard personnel
Calibration of instrument	PM	4.6	High	High	At every measurement		by onboard personnel

APPENDIX 10
SUMMARY OF MAINTENANCE TASK

Maintenance Category : **Category A**
Fuctional Group : **Cargo handling**
System : **Cargo system**
Sub-System : **Inert gas system**
Equipment of System : **Inert Gas Fan**

Task	Task Type	Item No.	Risk		Frequency	Procedure No. or Class References	Comments
			Unmitigated	Mitigated			
Washing impeller after fans stop operation	PM	1.1	High	High	After every operation		by onboard personnel
Confirm that the shaft rotation part is not sticked by turning the fan	CM	1.1	High	High	Every Week		by onboard personnel
Grease up the bearing at both sides of motor	PM	1.1	High	High	Every 6 Months		by onboard personnel
Grease up the bearing	PM	1.1	High	High	Every ~2000 hrs		by onboard personnel
Check the inside of bearing housing & replace LO or grease	PM	1.1	High	High	Every year		by onboard personnel
Washing impeller after fans stop operation	PM	1.2	High	High	After every operation		by onboard personnel
Confirm that the shaft rotation part is not sticked by turning the fan	CM	1.2	High	High	Every Week		by onboard personnel
Grease up the bearing at both sides of motor	PM	1.2	High	High	Every 6 Months		by onboard personnel
Grease up the bearing	PM	1.2	High	High	Every ~2000 hrs		by onboard personnel
Check the inside of bearing housing & replace LO or grease	PM	1.2	High	High	Every year		by onboard personnel
Calibrating of instrument at every measurement	PM	1.3	High	High	At every measurement		by onboard personnel
Check the instrument	PM	1.3	High	High	Every month		by onboard personnel

APPENDIX 10

SUMMARY OF MAINTENANCE TASK

Maintenance Category : Category B
Fuctional Group : Cargo handling
System : Cargo system
Sub-System : Inert gas system
Equipment of System : Scrubber

Task	Task Type	Item No.	Risk		Frequency	Procedure No. or Class References	Comments
			Unmitigated	Mitigated			
Check corrosion condition of shell thoroughly	CM	1.1	High	Medium	Once a year		undertaken alongside by equipment vendors or with use of dockside facilities
Remove all nozzles from header to check and clean or replace yearly	PM	1.2	Medium	Medium	Once a year		
Remove the scrubber coolong sea water inlet valve to check and clean from fouling & dirt or replace yearly	PM	1.3	Medium	Medium	Once a year		
Remove the valve to check and clean from fouling & dirt or replace yearly	PM	1.4	Medium	Medium	Once a year		
check corrosion condition of scrubber drain valve	CM	1.5	High	Medium	Once a year		
Remove all nozzles from header to check and clean or replace	PM	1.5	High	Medium	Once a year		
Remove all nozzles from header to check and clean or replace	PM	1.6	Medium	Medium	Once a year		

APPENDIX 10

SUMMARY OF MAINTENANCE TASK

Maintenance Category	**: Category B**						
Fuctional Group	**: Cargo handling**						
System	**: Cargo system**						
Sub-System	**: Inert gas system**						
Equipment of System	**: Scrubber**						
Task	**Task Type**	**Item No.**	**Risk**		**Frequency**	**Procedure No. or Class References**	**Comments**
			Unmitigated	**Mitigated**			
Remove all nozzles from header to check and clean or replace	PM	2.1	Medium	Medium	Once a year		undertaken alongside by equipment vendors or with use of dockside facilities
Check corrosion condition of shell thoroughly	PM	2.2	Medium	Medium	Once a year		
Remove the valve to check and clean from fouling & dirt or replace	PM	2.3	Medium	Medium	Once a year		
Remove all nozzles from header to check and clean or replace	PM	2.4	Medium	Medium	Once a year		
Remove all nozzles from header to check and clean or replace	PM	3.1	Medium	Medium	Once a year		
Remove the valve to check and clean from fouling & dirt or replace	PM	3.2	Medium	Medium	Once a year		

APPENDIX 10
SUMMARY OF MAINTENANCE TASK

Maintenance Category : **Category B**
Fuctional Group : **Cargo handling**
System : **Cargo system**
Sub-System : **Inert gas system**
Equipment of System : **Scrubber**

Task	Task Type	Item No.	Risk		Frequency	Procedure No. or Class References	Comments
			Unmitigated	Mitigated			
Remove the valve to check and clean from fouling & dirt or replace	PM	4.1	Medium	Medium	Once a year		undertaken alongside by equipment vendors or with use of dockside facilities
Check corrosion condition of shell thoroughly	CM	4.4	High	Medium	Once a year		
Check corrosion condition of support thoroughly	PM	4.5	Medium	Medium	Once a year		

APPENDIX 10

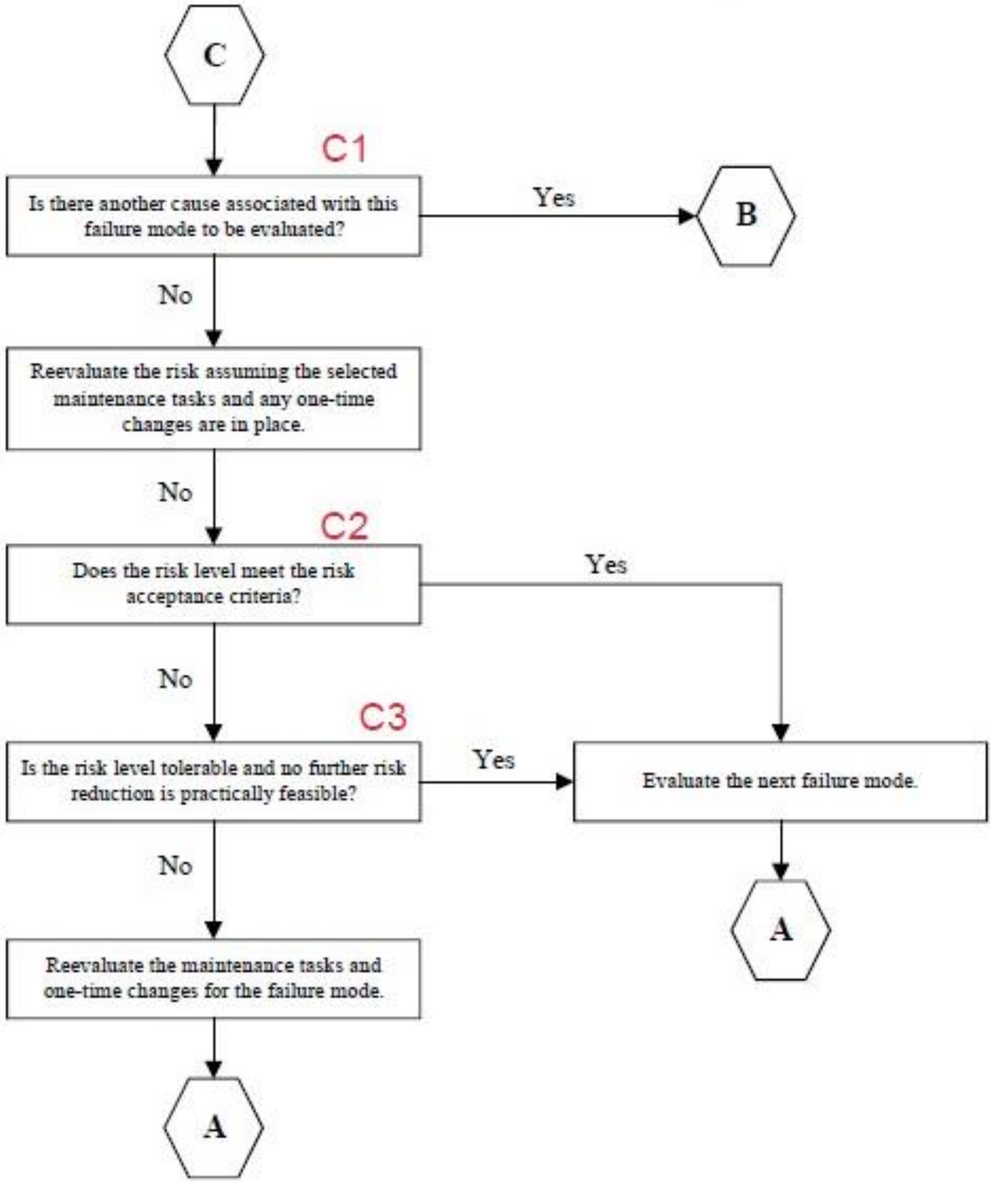
SUMMARY OF MAINTENANCE TASK

Maintenance Category	**: Category B**						
Fuctional Group	**: Cargo handling**						
System	**: Cargo system**						
Sub-System	**: Inert gas system**						
Equipment of System	**: Inert Gas Fan**						
Task	**Task Type**	**Item No.**	**Risk**		**Frequency**	**Procedure No. or Class References**	**Comments**
			Unmitigated	**Mitigated**			
Open the stuffing box for inspection	PM	1.1	High	High	Once a year		undertaken alongside by equipment vendors or with use of dockside facilities
Open the inspection hole of fan casing and check the coating of inner surface on fan	PM	1.1	High	High	Every 6 months		
Check the wear and soiled condition	PM	1.1	High	High	Every 6 months		
Open the stuffing box for inspection	OTC	1.2	High	High	Once a year		
Open the inspection hole of fan casing and check the coating of inner surface on fan	OTC	1.2	High	High	Every 6 months		
Check the wear and soiled condition	OTC	1.2	High	High	Every 6 months		

APPENDIX 11

RCM TASK SELECTION FLOW DIAGRAM

Rcm Task Selection Flow Diagram



Rcm Task Selection Flow Diagram