BACHELOR THESIS – ME184834

ANALYSIS THE APPLICATION OF CLOSED LOOP SCRUBBER SYSTEM ON 816 TEUS CONTAINER SHIP TO COMPLY WITH 2020 GLOBAL SULPHUR LIMIT - MARPOL ANNEX VI REGULATION 14

RIFQI RIZQULLAH
NRP. 04211640000027

SUPERVISORS:
Ir. Hari Prastowo, M.Sc.
Taufik Fajar Nugroho, S.T., M.Sc.

**DEPARTMENT OF MARINE ENGINEERING
FACULTY OF MARINE TECHNOLOGY
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TUGAS AKHIR – ME 184834

ANALISIS PENERAPAN *CLOSED LOOP SCRUBBER SYSTEM* PADA KAPAL *CONTAINER 816 TEUS* UNTUK MEMENUHI *2020 GLOBAL SULPHUR LIMIT - MARPOL ANNEX VI REGULATION 14*

RIFQI RIZQULLAH
NRP. 04211640000027

DOSEN PEMBIMBING:
Ir. Hari Prastowo, M.Sc.
Taufik Fajar Nugroho, S.T., M.Sc.

DEPARTEMEN TEKNIK SISTEM PERKAPALAN
FAKULTAS TEKNOLOGI KELAUTAN
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
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ENDORESEMENT PAGE

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BACHELOR THESIS

Submitted as one of the Requirements to obtain a Bachelor Degree in Engineering

on

Digital Marine Operation And Maintenance (DMOM)

Bachelor Program in Marine Engineering

Faculty of Marine Technology

Institut Teknologi Sepuluh Nopember

Prepared by :

Rifqi Rizqullah

NRP. 04211640000027

Approved by Supervisors :

Ir. Hari Prastowo, M.Sc. ( )
NIP. 196510301991021001

Taufik Fajar Nugroho, S.T., M.Sc. ( )
NIP. 197603102000031001

SURABAYA, AUGUST 2020

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ENDORSEMENT PAGE

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Prepared by :

Rifqi Rizqullah

NRP. 04211640000027

Approved by,

Head of Department of Marine Engineering

Beny Cahyono, S.T., M.T., Ph.D

NIP. 197903192008011008

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NRP	: 04211640000027
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ANALYSIS THE APPLICATION OF CLOSED LOOP SCRUBBER SYSTEM ON 816 TEUS CONTAINER SHIP TO COMPLY WITH 2020 GLOBAL SULPHUR LIMIT - MARPOL ANNEX VI REGULATION 14

Name	**: Rifqi Rizqullah**
NRP	**: 04211640000027**
Department	**: Marine Engineering**
Supervisor 1	**: Ir. Hari Prastowo, M.Sc.**
Supervisor 2	**: Taufik Fajar Nugroho, S.T., M.Sc.**

Abstract

Sulphur oxide (SOx) emissions from the combustion of diesel engines can cause harm to human health and the environment. Starting in 2020, the International Maritime Organization imposes obligations every time it uses low sulfur fuels or better known as IMO 2020 Global Sulphur Limit. The Indonesian government itself confirms that every ship, both Indonesian-flagged vessels and foreign vessels operating in Indonesian waters, must use fuel with a sulfur content of a maximum value of 0.5% m / m, starting January 1, 2020. One method that can be used by shipowners in reducing sulfur content in the exhaust gas is to apply the exhaust gas cleaning system or scrubber. The scrubber is additional equipment to reduce levels of sulfur (SOx) in ship engine exhaust gases. The way it works is by spraying (in several stages) seawater or freshwater mixed with caustic chemicals into the exhaust gas stream so that pollutants (especially sulfur dioxide) react with alkaline water and form sulfuric acid. In a closed loop scrubber system, fresh water used as washing water is circulated for reuse after undergoing a treatment process in washwater treatment. In the research that has been done, in terms of technical feasibility, there are several components needed in the closed loop scrubber system. The components needed are SOx scrubber, NaOH pump, freshwater pump, seawater pump, washwater treatment unit, and heat exchanger. Economic calculations are then carried out in this study to determine the capital expenditure (CAPEX) and operational expenditure (OPEX) of the closed loop scrubber system. Capital expenditure itself includes component costs, taxes, shipping costs, and insurance costs. By estimating costs, the total capital expenditure of a closed loop scrubber system will cost around Rp 12,420,910,936. Then, for operational expenditure itself includes maintenance and repair costs as well as operational costs of the closed loop scrubber system. After calculating, the total operational expenditure required to operate the closed loop scrubber system is Rp. 3,843,120,022.

Key Words: closed loop scrubber, exhaust gas cleaning system, sulphur oxide.

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ANALISIS PENERAPAN *CLOSED LOOP SCRUBBER SYSTEM* PADA KAPAL *CONTAINER 816 TEUS* UNTUK MEMENUHI *2020 GLOBAL SULPHUR LIMIT - MARPOL ANNEX VI REGULATION 14*

Nama	**: Rifqi Rizqullah**
NRP	**: 04211640000027**
Departemen	**: Teknik Sistem Perkapalan**
Dosen Pembimbing I	**: Ir. Hari Prastowo, M.Sc.**
Dosen Pembimbing II	**: Taufik Fajar Nugroho, S.T., M.Sc.**

Abstrak

Emisi sulfur oksida (Sox) dari pembakaran mesin diesel dapat membahayakan kesehatan manusia dan lingkungan. Mulai tahun 2020, Organisasi Maritim Internasional memberlakukan kewajiban setiap kali menggunakan bahan bakar sulfur rendah atau lebih dikenal dengan IMO 2020 Global Sulphur Limit. Pemerintah Indonesia sendiri menegaskan bahwa setiap kapal, baik kapal berbendera Indonesia maupun kapal asing yang beroperasi di perairan Indonesia, harus menggunakan bahan bakar dengan kandungan sulfur dengan nilai maksimum 0,5% m / m, mulai 1 Januari 2020. Salah satu metode yang dapat digunakan oleh pemilik kapal dalam mengurangi kandungan sulfur dalam gas buang adalah dengan menerapkan sistem pembersihan gas buang atau scrubber. Scrubber adalah peralatan tambahan untuk mengurangi kadar sulfur (SOx) dalam gas buang engine kapal. Cara kerjanya adalah dengan menyemprotkan (dalam beberapa tahap) air laut atau air tawar yang dicampur dengan bahan kimia kaustik ke dalam aliran gas buang sehingga polutan (terutama sulfur dioksida) bereaksi dengan air alkali dan membentuk asam sulfat. Dalam sistem loop tertutup, air tawar yang digunakan sebagai air pencuci diedarkan untuk digunakan kembali setelah menjalani proses perawatan dalam pengolahan air pencuci. Dalam penelitian yang telah dilakukan, dalam hal kelayakan teknis, ada beberapa komponen yang dibutuhkan dalam sistem scrubber loop tertutup. Komponen yang dibutuhkan adalah SOx scrubber, pompa NaOH, pompa air tawar, pompa air laut, unit pengolahan air cuci dan penukar panas. Perhitungan ekonomi kemudian dilakukan dalam penelitian ini untuk menentukan pengeluaran modal (CAPEX) dan pengeluaran operasional (OPEX) dari sistem scrubber loop tertutup. Pengeluaran barang modal itu sendiri meliputi biaya komponen, pajak, biaya pengiriman dan biaya asuransi. Dengan memperkirakan biaya, total pengeluaran modal dari sistem scrubber loop tertutup akan menelan biaya sekitar Rp12.420.910936. Kemudian, untuk pengeluaran operasional itu sendiri termasuk biaya pemeliharaan dan perbaikan serta biaya operasional sistem scrubber loop tertutup. Setelah menghitung, total pengeluaran operasional yang diperlukan untuk mengoperasikan sistem loop tertutup adalah Rp. 3.843.120.022.

Kata Kunci: scrubber loop tertutup, sistem pembersihan gas buang, sulfur oksida.

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PREFACE

Praises to Allah SWT for his blessing and grace, so that this bachelor thesis titled "Analysis the Application of Closed Loop Scrubber System on 816 TEU's Container Ship to Comply with 2020 Global Sulphur Limit - MARPOL Annex VI Regulation 14" can be completed well. This thesis is submitted as one of the requirements to obtain a Bachelor Degree in Engineering in Marine Engineering Department, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember, Surabaya.

Many obstacles came during the completion of this thesis. Therefore, the author would like to extend gratitude to everyone who helped to finish this thesis by giving support, idea, and suggestion, as follow :

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Because this work also far from perfect work, the author will appreciated every advice, suggestion, and idea from all parties for this bachelor thesis correction and improvement in the future. By the completion of this bachelor thesis, the author hopes this thesis will be helpful and beneficial for other parties who are going to conduct similar research.

Surabaya, August 2020

Author

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CHAPTER I
INTRODUCTION

1.1. Background

According to the International Chamber of Shipping, the shipping industry is the backbone of global trade, transporting around 90% of the total volume of commodities traded. Based on statistics provided by UNCTAD in 2016, it is estimated that global cross-sea trade is expected to have an amount exceeding 10 billion tons in 2015. The rapid growth of the international cross-sea business is in line with the increasing number of global ships and high energy demand.

Over the past 150 years, energy sources for ship fuel have changed significantly from sails (renewable energy) to steam (coal) and then to utilize heavy fuel oil (HFO) and marine diesel oil (MDO), the last two types of fuel with high emissions are the dominant fuel source used in the maritime sector today.

Nitrogen oxide, sulphur oxide, and particulate matter (NO_x, SO and PM) are the result of the combustion of internal combustion engines. The combustion results can affect the health of human breathing, environmental safety, and can cause acid rain.

International Maritime Organization, through MARPOL Annex VI Regulation 14, requires every ship to use fuel that has a low sulfur content of a maximum value of 0.5% m / m. This is, of course, a particular concern for shipowners because they have to adjust these rules so that the ships they have can still sail.

Therefore, the Indonesian government, through the *Direktorat Jenderal Perhubungan Laut*, issued a circular letter of the *Direktorat Jenderal Perhubungan Laut* number 35 in 2019 which in point 2.a reads "Indonesian-flagged vessels and foreign-flagged vessels operating in Indonesian waters must use fuel with sulfur content with a maximum value of 0.5%. Then in point 2.c reads "Indonesian-flagged vessels which still use fuel with a sulfur content of 0.5%, to be completed with an exhaust gas cleaning system or scrubber of the type approved by the *Direktorat Jendral Perhubungan Laut*.

Sulphur legislation issued by IMO is goal-oriented and allows the use of alternative methods to achieve emission targets. One alternative to reduce sulfur content is to reduce the sulphur content from exhaust gases. This option is known as exhaust gas scrubber that is defined in MARPOL Annex VI Regulation 14. The primary motivation for installing an exhaust gas cleaning system onboard is the value of economical, where the use of scrubber technology allows ship operators to burn fuel with high sulphur content, which is cheap (Jari, 2016).

Referring to DNV GL, more than 3,000 installations scrubber for the vessel system using the open loop even though there are concerns about the wash water produced because some countries ban the use of the open loop type in their waters.

Although there is controversy regarding the wash water from the open loop system, the majority of the type of scrubber that was ordered by the owner of the vessel using a type of open loop, according to DNV GL, 2,625 of 3,266 scrubber systems are being installed, or 80.3%, using a system of open loop. 540 hybrid scrubber installation units, and 65 units using a closed loop.

According to (Fridell & Salo, 2014) study, scrubbers on ships using HFO remove more than 98 percent of the sulfur oxides from the exhaust, resulting in emissions lower in sulfur oxides than those of marine gas oil (MGO), which is considered the benchmark for the IMO's 0.5 percent sulfur cap scheduled to be implemented on January 1, 2020. As a result, scrubbers are an approved method of compliance with the sulfur regulation by the IMO, European Union, and US Environmental Protection Agency.

1.2. Problem Analysis

The formulation of the problems that will be discussed in this study are as follows:

1. How to analyze the technical feasibility of sulphur scrubber on 816 TEUS container ship, particularly using a closed loop scrubber system to comply with MARPOL Annex VI Regulation 14?
2. How to design the key plan of the closed loop scrubber system on 816 TEU's container ship?
3. How to determine the bill of quantity (BoQ) and engineering cost estimation of this closed loop scrubber system?
4. How to analyze the economic calculation of applying a closed loop scrubber system on 816 TEU's container ship?

1.3. Objective

1. To analyze the technical feasibility of applying sulphur scrubber on 816 TEU's container ship, particularly using a closed loop scrubber system to comply with MARPOL Annex VI Regulation 14.
2. To generate a key plan of closed loop scrubber system on 816 TEU's container ship.
3. To determine the bill of quantity (BoQ) and engineering cost estimation of this close loop scrubber system.
4. To analyze the economic calculation of applying sulphur scrubber on 816 TEU's container ship, particularly using closed loop scrubber system to comply with MARPOL Annex VI Regulation 14.

1.4. Scope and Limitation

1. This research is only done on 816 TEU's container ship sailing in the Indonesian domestic water area.
2. Only designing Key plan and arrangement drawing, not until detail drawing and construction drawing.
3. This study is limited to the layout drawing of the closed loop scrubber system and does not discuss the stability of the ship after the installation of the closed loop scrubber system.
4. The economic calculation conducted an only analysis of capital expenditure and operational expenditure.

1.5. Benefit

1. Provide a description to the shipowner about the installation of a closed loop scrubber system on the ship to comply with MARPOL Annex VI Regulation 14.
2. Provide a description to the shipowner about what components are needed in installing a closed loop scrubber system and the specifications of those components and find out the installation and operational costs of the system.

CHAPTER II
LITERATURE STUDY

2.1. 2020 Global Sulphur Limit – MARPOL ANNEX VI Regulation 14

At present, the majority of all ships in the world use petroleum as the primary fuel. The fuel used by ships has various types, such as heavy fuel oil (HFO), marine diesel oil (MDO), and marine gas oil (MGO). Because it comes from petroleum, of course, every type of fuel used by ships contains sulphur, which is harmful to health. The sulphur content in the fuel itself varies depending on the type of fuel. Heavy Fuel Oil (HFO) is the most widely used marine fuel. Based on the sulfur monitoring program carried out by the IMO, the average content of sulfur in HFO for three years (2015 -2017) of 2.54%.

When fuel is used, the sulfur contained in the fuel will produce sulfur oxides in the exhaust emissions of ships. Sulfur oxides contribute to the formation of acid rain as well as the formation of secondary aerosol particles, which are of concern from a health perspective. Therefore, SO_x emissions are regulated by IMO with gradual reductions implemented since 2008. Emission Control Areas for SO_x and PM (SO_x ECA's) have been established in the most sensitive areas (Baltic Sea, Sea, and North Channel, US, and Canadian coastal zones). In this ECA, the maximum sulfur level has been reduced from 1.5% initially, to 1% in 2010 and 0.10% in 2015. Outside this area, the maximum sulfur level has been reduced from 4.5% initially to 3, 50% in 2012, and will be reduced to 0.50% in January 2020, as decided in October 2016.

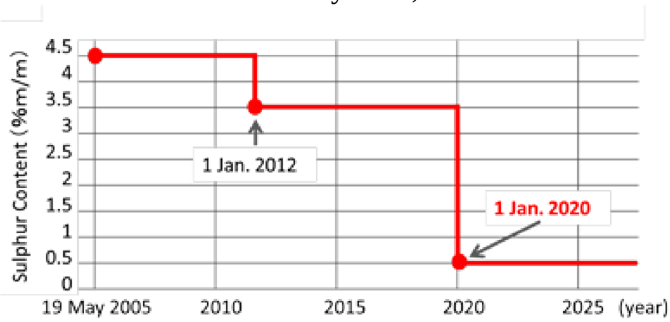

Figure 2. 1 Global fuel oil sulphur limit
Source: classnk.or.jp

Regulations that the sulfur fuel limit containment for ships are specified in Regulation 14 Sulfur Oxide (SO_x) and Particulate Matter (PM) of MARPOL 73/78 Annex VI, where the sulfur content limit of ship fuels has been limited. The global sulfur content limit, which was initially from 3.5%, has been reduced to 0.5% on January 1, 2020.

In this case, the shipping company and the shipyard will be taking account of the methods that they can use to comply with regulations, such as making use of fuel with a sulfur content compliant with the regulations, installing SO_x scrubber, or converting to alternative fuels such as LNG.

Starting March 1, 2020, ships using fuel with a sulfur content higher than 0.5% (excluding vessels operating scrubbers) will be banned. In addition, the sulfur content limit has been gradually tightened in the Emission Control Area (ECA) area, as shown in Figure 2.2. below this.

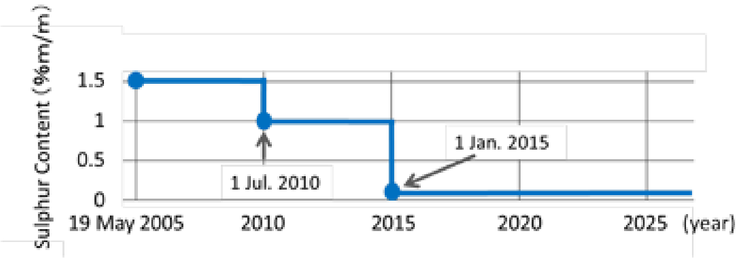

Figure 2. 2 Fuel oil sulphur limits on ECA's area
Source: classnk.or.jp

2.2. Ship Exhaust Gas Emission

In general, the operation of ships produces exhaust gas, sanitation waste, garbage, oil waste, and ballast water. All products produced can cause problems if not processed. In this case, the International Maritime Organization (IMO) has made regulations on the International Convention of Marine Pollutants from Ships of 1973 Annex I - VI. The regulations issued by IMO apply internationally, and the mandate of implementing these regulations is given to several national and international authorities such as classification society, port countries, flag states, and trade associations.

IMO states that exhaust emissions are any substances which, if put into the sea or the atmosphere, can pose a danger to human health, ecosystems, or marine life, damage facilities, or interfere with other legitimate marine uses (MARPOL 73/78, 2005). Focusing on air pollutants, there are many substances produced by ships that affect air conditions.

At present, the heavy fuel oil (HFO) used by most ships contains 3.5% sulfur. In a study conducted by (Ibrahim, 2016) on fuels that have a 3.5% sulphur content will produce 900 ppmv SO_2 in the exhaust gas produced by the ship's engine. Here is the percentage of exhaust gas content produced by fuels with 3.5% sulfur content.

Table 2. 1 Exhaust gas composition on 3.5% sulphur content on HFO

Exhaust Gas Composition	Mass Basis
N_2	75.8%
O_2	12.97%
H_2O	5.94%
CO_2	5.1%
SO_2	900 ppmv
NO_2	73 ppmv
NO	658 ppmv

The following are components of the exhaust gas produced by the ship exhaust gas.

a. Carbon Dioxide (CO_2)

Carbon dioxide is produced by a diesel engine with a perfect combustion process. Carbon dioxide is formed from fuels containing the elements carbon and hydrogen and reacts with oxygen. The release of energy from the chemical reaction between fuel and oxygen (and heat as energy) consequently produces carbon dioxide (CO_2) and water vapor (H_2O). The exhaust gas from this combustion which then becomes a greenhouse gas for the atmosphere.

b. Carbon Monoxide (CO)

Carbon monoxide is known as a product of incomplete combustion. CO substances are produced by combustion, which lacks air. This happened because there was a problem in the combustion chamber. Lack of oxygen forces the amount of fuel (C_xH_y) burning with insufficient oxygen (O_2).

c. Sulphur Oxide (SO_x)

Sulfur oxides are the most common pollutants, especially those caused by burning fossil fuels, which contain high sulfur in the form of organic and inorganic sulfur. Burning fossil fuels will produce about 30 parts of sulfur dioxide for each part of sulfur trioxide. Oxides - sulfur oxides usually consist of sulfur dioxide, sulfur trioxide, sulfuric acid, sulphurous acid. Sulfur dioxide is the most dominant part, so sulfur oxides are usually measured as sulfur dioxide (Soedomo, 2001).

SO_2 gas can also form sulfate salts if they meet with metal oxides, through the following chemical process:

$$4MgO + 4SO_2 \rightarrow 3MgSO_2 + MgS \quad (2.1)$$

Air that contains water vapor will react with SO_2 gas to form sulfuric acid:

$$SO_2 + H_2O \rightarrow H_2SO_3 \text{ (sulfite acid)} \quad (2.2)$$

Air that contains water vapor will react with SO_3 gas to form sulfuric acid:

$$SO_3 + H_2O \rightarrow H_2SO4 \text{ (sulfate acid)} \quad (2.3)$$

d. Nitrogen Oxide (NO_x)

The source of nitrogen in the exhaust gas comes from the intake air. The air in the atmosphere contains 78% nitrogen, 20% oxygen, and 2% are other substances. This nitrogen oxidation produces nitrogen oxides. The oxidation process is supported by high temperatures. In the combustion chamber, the formation of nitrogen oxides depends on local temperature, local oxygen partial pressure, and the time available (Ackerman, 2009).

e. Hydrocarbon

The hydrocarbon content in the exhaust gas is formed due to incomplete burning of fuel. Some hydrocarbons can be dissolved in lubricating oil, but most of them flow out of the combustion chamber by exhaust gases.

Hydrocarbons contain unburned fuel components and contain partially oxidized compounds, for example, formaldehyde and acetaldehyde. At high concentrations, these by products endanger human health. White smoke can indicate that the exhaust contains hydrocarbons.

f. Particle

Other emissions by exhaust gases are particles. Common particles that come out of the exhaust gas are carbon, mineral elements, ash, and metals. Most particles are micron in size, and because of their lightweight, they can be transported through the air to several distances. The size and substance depend on the composition of the fuel used by the engine and the quality of combustion.

2.3. Ship Engine

Every ship currently uses the principle of energy conversion for operations. Early in the shipping industry, engineers designed steam turbines as the main engine for ships. In the latest technology, they installed a diesel engine instead of a steam engine. In other exceptional cases, gas turbines are installed on ships to meet ship specifications, especially for speed and reliability.

At present, the diesel engine is one of the prime movers mounted on ships. The main principle of a diesel engine uses fuel ignition in the combustion chamber to produce energy. With a mixture of oxygen, fuel can be ignited and produce energy through chemical reactions. Every perfect combustion will produce the following chemical reaction :

$$C_xH_y + O_2 \rightarrow CO_2 + H_2O + Energy \quad (2.4)$$

In the internal combustion process, fuel will be injected and ignited in the combustion chamber through the work process. In a four-stroke diesel engine, there are four steps (strokes) that are passed to do one cycle of engine energy conversion. The piston, as the recipient of energy from the combustion process, moves in four steps: suction, compression, expansion, and exhaust. Therefore, it takes two crankshaft turns to make one four-stroke engine speed.

2.4. Sulphur Abatement Technology

Currently, there are three ways to reduce the sulfur content in ship exhaust gases, the first way is to continue to use high fuel sulfur but using the sulphur scrubber to reduce the sulfur content in the exhaust gas, the second way is to replace the fuel using low Sulfur fuel, and the third way is to use alternative fuel materials such as LNG or methanol (Mollenbach, Schack, Eefsen, & Kat, 2012).

2.4.1. Exhaust Gas Cleaning System (EGCS) or Scrubber

Exhaust gas cleaning systems (EGCS) or scrubbers are additional equipment to reduce sulfur (SO_x) levels in ship engine exhaust gases. Water is utilized to wash off the sulphur content of exhaust gas in the use of wet scrubbers. Depending on the type of scrubber, either seawater with natural alkalinity of freshwater dosed with sodium hydroxide (NaOH) is brought into close contact with the exhaust gas and treated adequately before discharging back to the ocean or circulating back to the system. Wet scrubbers are usually installed in the engine casing or funnel in a vertical direction since it is not possible to install the scrubbers horizontally as the efficient needs the counter current interaction between the exhaust gas and the scrubbing water.

Wet scrubbing technology is a proven technology that has been utilized on many land based industrial applications for years. Many experts and vendors believe that wet scrubbing is a simple and efficient way to remove SO_x and particulate matter from marine engine exhausts. Figure 2.3. will explain how the working principle of the scrubber.

According to (Smith, 1985), the analysis based on the volume of the condition of the gas elements after entering the scrubber is as follows:

Table 2. 2 Exhaust gas composition after the scrubber

Gas Type	Content
Carbon dioxide, CO_2	12 %
Oxygen, O_2	4.5 %
Sulphur dioxide, SO_2	0.02 %
Nitrogen, N_2	77 %

In Table 2.1 can be seen the gas content that is found after the cleaning process is done through a scrubber. Among these contents are CO_2 at 12%, SO_2 at 0.02%, N_2 at 77%, and O_2 at 4.5%.

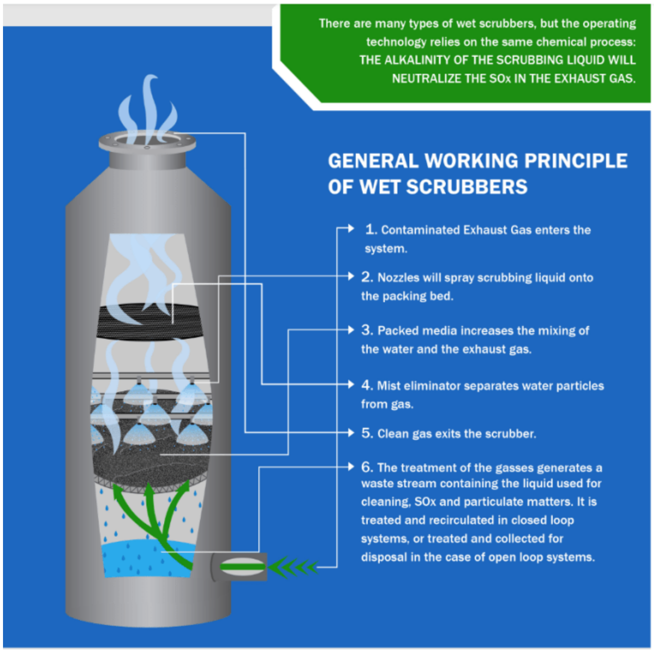

Figure 2. 3 General working principles of wet scrubbers
Source: worldmaritimeaffairs.com

There are several types of scrubbers. What distinguishes from this type is the media used to clean exhaust gas, be it exhaust gas produced from an engine or from a boiler. The types of scrubbers are open type scrubber and closed type scrubber.

Open loop type scrubber is a scrubber that uses water ocean where ships sail as a medium that clean the exhaust gases, seawater is pumped from the sea into the scrubber unit, mixed with exhaust gas, filtered and cleaned in the water treatment system before discharged back into the open sea. Closed loop type scrubber is a scrubber system that uses freshwater as exhaust gas cleaning media where fresh water is pumped from the freshwater tank into the scrubber unit, mixed with exhaust gas, filtered and cleaned in the water treatment system before circulating back to the system. Unlike the open loop system, wash water is reused in the system. Sludge filtered from the wash water is stored in the sludge tank, which also needs to be disposed of at port facilities and cannot be incinerated onboard. In table 2.2 and table 2.3 (Rosyadi, 2019) explains the comparison of seawater and freshwater scrubber systems have advantages and disadvantages as follows:

a. Open Loop Scrubber System

Table 2. 3 Open loop scrubber system analysis

Advantage	**Disadvantage**
Easy to get	Corrosive
Amount of seawater is unlimited	The system uses more expensive materials
Seawater has natural alkalinity	Maintenance of components must be more frequent
The installation system is more simple	The ability to clean exhaust gas depends on water conditions

b. Closes Loop Scrubber System

Table 2. 4 Close loop scrubber system analysis

Advantage	**Disadvantage**
Freshwater has a low corrosive level	The system carries additional freshwater and additional NaOH
Absence of water and waste disposal into the sea	The installation of the system is more complicated
The system can use cheaper materials	The new system need additional components
Maintenance of components are less frequent	Maintenance must be done for more components
The ability to clean the exhaust gas does not depend on the condition of the water	

2.4.1.1. Open Loop Scrubber

In seawater scrubbers or "open loop type" scrubbers, seawater is used as washing water for scrubbing, and the resulting wastewater will be cleaned then discharged back into the sea. Natural alkalinity from seawater is used to neutralize acidity resulting from the removal of sulfur oxide (SO_x) content. Figure 2. 3 can be seen as the process that occurs in seawater scrubbers. The following chemical equation from mixing SO_2 gas with seawater according to (Shu, 2013) :

The basic chemistry for open loop seawater system can be described along with the following principles:

$$SO_2 + H_2 \rightarrow H_2SO_3 \text{ (sulphurous acid)} \rightarrow H^+ + HSO_3^- \text{ (bisulphite)} \quad (2.5)$$

$$SO_2 + H_2 \rightarrow H_2SO_3 \text{ (sulphurous acid)} \rightarrow H^+ + HSO_3^- \text{ (bisulphite)} \quad (2.6)$$

$$SO_3^{2-} \text{(sulphite)} + {}^1/_2\, O_2 \rightarrow SO_4^{2-} \text{(sulphate)} \quad (2.7)$$

Sulphur dioxide (SO2) will be dissolved and ionized in seawater, creating sulphurous acid. The sulphurous acid is then ionized in water with normal acidity creating bisulphite and sulphite ions. Sulphite ions will then be oxidized into sulphate since oxygen is in the seawater.

$$SO_3 + H_2O \rightarrow H_2SO_4 (sulphuric\ acid) \quad (2.8)$$

$$H_2SO_4 + H_2O \rightarrow HSO_4^- (hydrogen\ sulphate) + H_3O^+ \quad (2.9)$$

$$HSO_4^- (hydrogen\ sulphate) + H_2O \rightarrow SO_4^{2-} (sulphate) + H_3O^+ \quad (2.10)$$

Similarly for the sulphuric acid formed from SO_3, it will undergo reactions that turn hydrogen sulphate into sulphate ions. The acidity resulting from the chemical reactions in SWS systems is neutralized by the alkalinity in the seawater by pumping sufficient seawater into the scrubber unit. Therefore, the amount of seawater needed depends significantly on the natural buffering capacity of seawater.

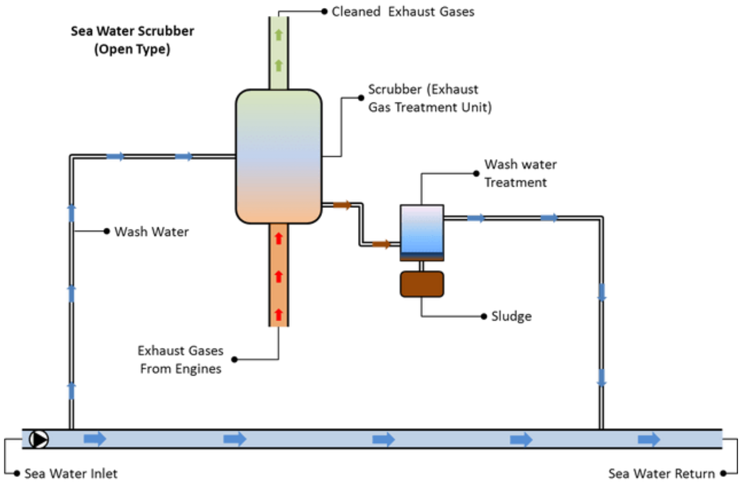

Figure 2. 4 Open loop scrubber
Source: worldmaritimeaffairs.com

In cleaning the exhaust gas, the volume of seawater needed to clean the exhaust gas is proportional to the alkalinity and temperature of the water used (DNV, 2009). In an open loop scrubber system, scrubbing water pumps are installed to transport seawater from the sea chest into the scrubber. In the open loop scrubber, the water flow is 45 m3/MWh (for a SO_x reduction corresponding to 3,5% S down to 0,1%S) (Wartsila, 2017). Energy consumption from the use of a seawater scrubber system is 2 to 3 percent of the output power of a cleaning machine (Filancia, 2009).

Seawater scrubber processes require exhaust gases to dissolve with seawater to dissolve Sulfur Oxide (SO_x). The content of Sulfur Oxides produced by machines usually consists of 95% Sulfur Dioxide (SO_2) and 5% Sulfur Trioxide (SO_3) (EGCSA, 2010). When dissolved, a reaction occurs where sulfur dioxide is ionized to bisulfite and sulfite, which then easily oxidizes to sulfate in seawater containing oxygens (Hasselov & Turner, 2007).

2.4.1.2. Closed Loop Scrubber

In a freshwater scrubber system or closed type scrubber, freshwater is added to chemical alkalis such as caustic soda, which is then used as a neutralizer when scrubbing. Freshwater that has been used in circulation again and any loss due to evaporation will be replaced with additional freshwater. In figure 2.4 can be seen as the process that occurs in a freshwater scrubber system. The freshwater that has been used is treated and then reused, while the dung will be disposed of (Maulana, Kristanto, & Dahlan, 2018).

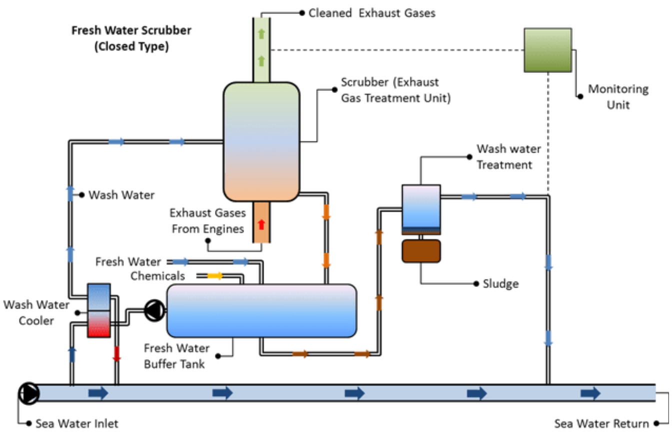

Figure 2. 5 Closed loop scrubber
Source: worldmaritimeaffairs.com

Freshwater scrubber systems can be periodically operated in a "zero discharge mode," which is a method of cleaning up the exhaust gas without dumping the cleaning water into the sea (SSG, 2007). Freshwater scrubber systems are used when high-efficiency cleaning is needed or when the alkalinity of seawater is not sufficient to clean exhaust gases. The ability to operate EGCS with a closed system will be advantageous when sailing in waters with low alkalinity. The removal efficiency of Sulfur Oxide (SO_x) exhaust gas from freshwater scrubbers are usually more than 90 percent, and cleaning ability of up to 97 percent can be obtained for disposal from generator engines. According to (Lloyd's Register, 2012) freshwater consumption in closed loop sulphur scrubber system approximately 20 m3/MWh.

To minimize sulphur oxide (SO_x) in exhaust gas sodium hydroxide (NaOH) is dosed to the wash water to buffer the acidity resulting from the chemical reactions instead of the alkalinity in the seawater. The following chemical equation from mixing SO_2 gas with sodium hydroxide (NaOH) according to (Issa, Beaulac, Ibrahim, & Ilinca, 2019).

$$2NaOH + SO_2 \rightarrow Na_2SO_3 \tag{2.11}$$

$$Na_2SO_3 + SO_2 + H_2O \rightarrow 2NaHSO_3 \tag{2.12}$$

$$SO_2(gas) + H_2SO_4 \rightarrow NaHSO_4 + H_2O \tag{2.14}$$

$$2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O \tag{2.15}$$

In closed loop scrubber system sodium hydroxide (NaOH) consumption depends on the concentration of the sodium hydroxide (NaOH) solution, operating power, the sulphur content in the fuel oils used, and designated SOx reduction efficiency. The dosing module will control the amount of NaOH automatically depend on the parameters mentioned above (Shu, 2013). The size of the NaOH storage tank depends on the amount of NaOH needed and can be estimated from the consumption rate and the continuous operation days between bunkering.

Closed loop scrubber systems typically consume sodium hydroxide (NaOH) in a 50 % aqueous solution. The dosage rate is approximately 15 liters/MWh of scrubbed engine power if a 2.70 % sulphur fuel is scrubbed to equivalent to 0.10 % (Mariko, 2014). In theory, the use of 50% sodium hydroxide (NaOH) solution can be seen in figure 2.5.

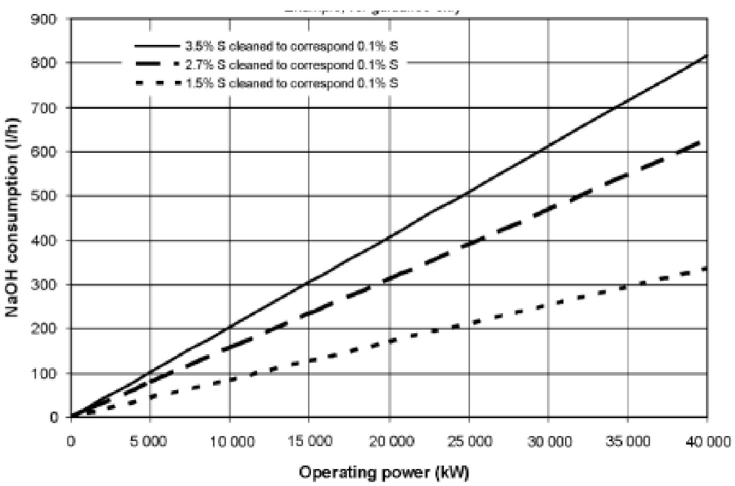

Figure 2. 6 Sodium hydroxide (NaOH) consumption rate

Source: classnk.or.jp

The closed loop scrubber system usually discharges 250 times less water than an open loop scrubber system. The bleed off significantly smaller for closed loop scrubber system (0.1-0.3 m3/MWh), and as a result, the concentration of pollutants is higher, making wash water cleaning easier. (den Boer & 't Hoen, 2015)

2.4.1.3. Scrubber Main Component

To produce clean exhaust gas, there are several processes that the gas passes through the scrubber system. From Figure 2.7. can be seen as the processes that are passed. There is a process of cleaning the exhaust gas by using water media. Then there is the process of treatment of water that is used to clean the exhaust gas to produce sludge. Therefore, each scrubber will be equipped with at least three main components (Office of Wastewater Management, 2011):

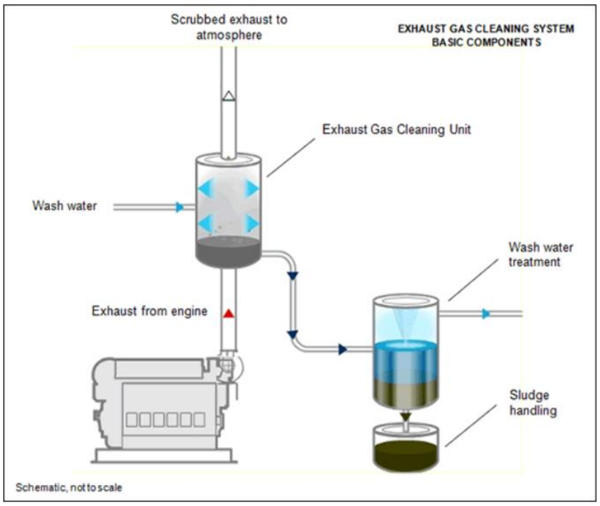

Figure 2. 7 Scrubber main component
Source: Gas scrubber washwater fluent

1. Exhaust Gas Cleaning Unit

   It is a chamber that is useful as a meeting place for boiler and engine exhaust gases with water, both in the form of seawater and freshwater. The process of meeting water with exhaust gas is also a process of cleaning up exhaust gases from dust and dirt resulting from combustion. In this system, where the exhaust gas meets with the cleaning media is the scrubber tank. The exhaust gas can flow into the scrubber tank by utilizing a blower installed in the system. At the same time, water as a cleaning medium can flow into the scrubber tank by using a pump.

Figure 2. 8 Exhaust gas cleaning unit
Source: wartsila.com

2. Wash Water Treatment Unit

It is a device used to remove dissolved pollutants in water, such as Sulfur Oxides (SO_x) and Nitrogen Oxides (NO_x). The contents have changed form into sulfates and nitrates, which are dissolved in water after the scrubbing process. Scrubbing water also contains suspended solids, heavy metals, hydrocarbons, and polycyclic aromatic hydrocarbons (PAHs). Before scrubbing water is discarded, it must be treated to remove solids.

Figure 2. 9 Washwater treatment
Source: wartsila.com

Regulations related to washwater quality are regulated in the Marine Environment Protection Committee (MEPC) .184 (59) Annex 9 Section 10. The aspects considered in the regulation include:

Table 2. 5 Washwater quality

Parameter	**Value**
pH	> 6,5
PAH	1,226 µg/l
Turbidity	25 FNU
Nitrate	60 g/l

3. Sludge Handling
   Sludge Handling is the process of removing sludge or dirt contained in a Sludge tank or settling tank. The sludge that is accommodated after the scrubbing process can be combined with the sludge produced by the oily water bilge system.

2.4.1.4. Exhaust Gas Scrubber Piping Arrangement

Most scrubbers installed on ships clean exhaust gases from a single combustion system, which can be the main engine, auxiliary engine or auxiliary boiler. According to (Jari, 2016) several mainstream scrubbers may be installed onboard a vessel. A mainstream installation is interesting primarily in vessels where a single heavy fuel oil main engine consumes most of the fuel by producing propulsion energy for the ship. If the same engine is connected with an exhaust gas boiler and shaft generator, even heat and electricity are produced by heavy fuel oil. In port and during maneuvering, distillate fuel is typically burnt in auxiliary engines and in auxiliary boilers without high additional expenses depending on the electricity and heat needs. These types of merchant vessels are common, excluding the smallest ships which typically use distillate fuel oil in all combustion units and the large size vessels which consume HFO in all combustion units.

If the exhaust gas scrubber is not in use, two different running modes are possible. In the exhaust gas piping system, the scrubber unit can be by-passed by an exhaust gas diverter (3-way valve), or the cleaning process in the scrubber can be stopped. The first option is shown in Figure 2.10. The latter option, the so called scrubber hot running option, sets high standards for wet scrubber construction and materials because of heat and temperature stresses and the risk of metal corrosion. Especially the transitions between the scrubber run and stop modes may be challenging to operate.

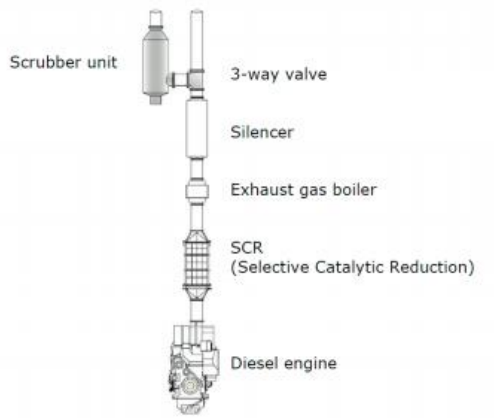

Figure 2. 10 Typical mainstream scrubber exhaust gas piping arrangement
Source: classnk.or.jp

Large vessels usually have several combustion units. If mainstream scrubbers are used, a multi-scrubber installation onboard is needed. In such an arrangement, the increased weight, price, volume, and complexity may result in an uninteresting exhaust gas cleaning concept, and to avoid these challenges, an integrated scrubber system may be attractive. The principle of the system is shown in Figure 2.11. All the exhaust gas produced by combustion units is fed into one scrubber unit only, capable of cleaning all gases.

Depending on the actual combustion unit load, the exhaust gas flow into the scrubber may alternate rapidly. An exhaust gas fan may be installed into the system to create a suitable atmospheric pressure level inside the exhaust gas manifold. The pressure level in the manifold can be controlled by the exhaust gas fan. In the case of scrubber malfunction, by-pass valves are opened into the atmosphere, and the exhaust gas system operates in the traditional way without scrubbing. An exhaust gas fan may also be located upstream of the scrubber unit to operate in dry but at the same time hotter conditions.

Merchant ship closed loop scrubbers are typically designed for conditions where the maximum fuel sulphur content may be as high as 3.5% m/m, the sulphur removal capacity is equal to 0.10% m/m sulphur fuel, maximum continuous combustion unit power is allowed (no power limits), and global operation is possible (no sea water temperature, atmosphere temperature or humidity limits).

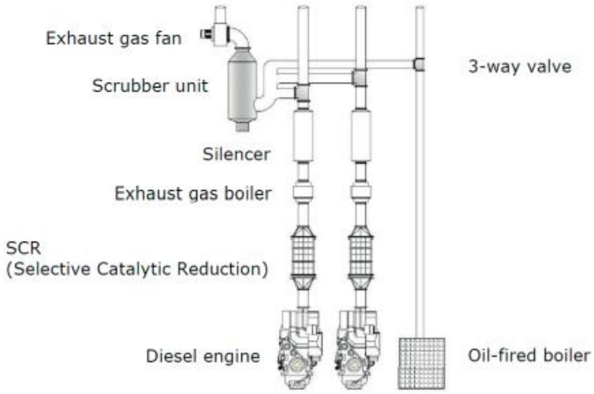

Figure 2. 11 Typical integrated scrubber exhaust gas piping arrangement
Source: classnk.or.jp

2.4.2. Low Sulphur Fuel

Changes to low sulfur fuel can already comply with Global Sulphur Cap 2020 regulations at this time without adding additional equipment on the ship, even though fuel costs incurred tend to be higher. Most vessels designed to use HFO fuel have provisions on the use of MDO under certain conditions, for example, when the ship is maneuvered (FCBI Energy, 2015).

Several fuels are available, such as low sulfur marine diesel oil (MDO) or marine gas oil (MGO). There are also hybrid fuels that have low sulfur HFO quality and are produced by combining the product in an oil refinery. This fuel can comply with sulfur content restriction regulations. The process of mixing the fuel must be done carefully because mixing hybrid fuels of different bunkering facilities can produce wax precipitation in the fuel, which can cause operational problems.

The most discussed fuels to meet SECA demand are low sulfur marine diesel, LNG, and methanol. LNG and methanol produce low NO_xemissions and can meet Tier III requirements.

2.4.3. Liquefied Natural Gas

To meet IMO regulations, the use of Liquefied Natural Gas (LNG) is one method that can be used by ships. LNG is stored in a vacuum insulated tank at -163 ° C and a pressure of 1.7 bar. After the liquefaction process, the volume is reduced by about 600 times the original condition, which is the main advantage of LNG for shipping and storage. LNG must be evaporated and given pressure according to the pressure by engine specifications. The resulting boil-off must be controlled to avoid the occasional release of gas into the atmosphere.

Also, CH_4 emissions sometimes referred to as "methane slips," are one of the weaknesses of the application of LNG on marine engines, which mostly work in accordance with the Diesel or Otto cycle. Diesel engines produce lower levels of methane slips compared to Otto cycle engines.

LNG was initially used as fuel on an LNG Carrier vessel where the gases produced in the LNG tank were used as fuel in boilers or steam turbine systems than in the later stages of use continued on dual fuel diesel engines.

The LNG propulsion system seems to be an economically attractive solution for types of ships that spend a long time sailing on such practical, handy size tankers and medium-size RO-RO vessels (Leo et al., 2010).

2.5. CCS Guidelines

Detailed guidelines regarding the exhaust gas cleaning system are also regulated in class, as CCS regulates the use of the exhaust gas cleaning system in the Guidelines for Exhaust Gas Cleaning System Ready 2016 Chapter 2 EGC Ready Requirements. CCS regulates related technical guidelines for the use of exhaust gas cleaning systems such as :

- The pressure resistance of scrubber is to be analyzed in accordance with the connection methods and operating conditions of the EGC system and fuel oil combustion units to assess whether the exhaust backpressure of all connected fuel oil combustion units, after installation of the EGC system, can remain within limits stated by the manufacturer.
- Sufficient space is to be reserved for the installation and arrangement of the scrubber. In addition to satisfying the needs of the geometric structure of the scrubber, consideration is also to be given to the needs of installation of bypass and isolation devices (if any), exhaust gas collection devices (if applicable), and necessary maintenance space.
- Where the EGC system is connected to a common seawater/freshwater system onboard, the capacity of the seawater/freshwater pump is to be sufficient to provide the desulfurization system with the required seawater/freshwater at the system’s maximum working load without affecting the normal operation of other essential auxiliary systems.
- Sufficient space is to be reserved for the arrangement of residue tanks, facilities for discharging residue to shore, and relevant pipes.
- The capacity of washwater treatment units is to satisfy the needs of washwater treatment of EGC system in the design condition.

2.6. Closed Loop Scrubber System Design

2.6.1. General Operational Requirements

Before doing the closed loop scrubber system installation process. We must know about some operational requirements (Jari, 2016). Outflowing scrubber exhaust gas typically has 100% relative humidity, which generates a plume in the atmosphere as a function of several parameters :

- Exhaust gas temperature
- Atmospheric temperature
- Atmospheric humidity
- Exhaust gas outflow speed
- The mixing ratio of exhaust gas and outdoor air

2.6.2. Fuel Oil Consumption

Fuel Oil Consumption is the amount of fuel used by the engine. To find out the fuel oil requirements needed by an engine can use the following equation :

$$FOC = SFOC \times BHP_{engine} \times t \qquad (2.16)$$

Where :

SFOC = Specific fuel oil consumption (gr/kWh)

BHP_{engine} = Engine power (kW)

t = Time (hour)

2.6.3. Chemical Reaction on Scrubber

In the process of reducing sulfur content in the ship exhaust gas, there is a chemical reaction that occurs between the exhaust gas with water so that the high sulfur content in the exhaust gas becomes low and can meet the regulations. In this close loop scrubber system utilizes the alkalinity of sodium hydroxide (NaOH) (Chang, 2008).

In this process, there are three reaction equations that occur when using sodium hydroxide in the exhaust gas removal process :

$$NaOH + SO_2 \qquad (2.17)$$

$$NaOH + NO \qquad (2.18)$$

$$NaOH + NO_2 \qquad (2.19)$$

By knowing the equation of the reaction that occurs in the scrubber, it can be calculated the need for NaOH to clean the exhaust gas produced by the ship.

2.6.4. Pump and Pipe Needs

In the close loop scrubber system, the media used to clean exhaust gas is freshwater. Freshwater that has been mixed with sodium hydroxide will be channeled into the scrubber by using a pump. The pump itself is a device used to move a liquid or fluid from one place to another through a media pipe. The principle of the pump itself is to convert mechanical energy into kinetic energy. In determining the pump requirements, several variables need to be known, including the head and pump capacity (Sularso & Tahara, 2000).

Head is the energy per unit weight that must be provided to drain the amount of liquid that is planned in accordance with the conditions of the pump installation, or the pressure to flow a certain amount of liquid, which is generally expressed in units of length. According to the Bernoulli equation, there are three types of the fluid head (energy) from a flow installation system, namely, pressure energy, kinetic energy, and potential energy. This can be stated by the following formula:

$$Ht = \left[\frac{(p_1 - p_2)}{\rho g} + \frac{(v_1^2 - v_2^2)}{2g} + (z_1 - z_2) \right] \tag{2.20}$$

Where :
Ht = Head Total (m)
p = Fluid pressure (atm)
v = Fluid flow rate (m/s)

Flow capacity is the amount of fluid flowing in the system in units of time. Fluid flow capacity is determined by the flow velocity and cross-sectional area of the piping system. The formula of flow capacity is as follows :

$$Q = v\ x\ A \tag{2.21}$$

Where :
Q = Flow capacity (m^3/h)
A = Cross-sectional area (m^2)
v = Fluid flow rate (m/s)

After knowing the flow capacity and head requirements that must be overcome by the pump, the pump specifications for this system can be determined. Then the process of calculating the diameter of the pipe will be used to order the fluid. The formula for calculating the diameter of the pipe to be used is as follows :

$$dh = \sqrt{\frac{4Q}{\pi x v}} \tag{2.22}$$

Where :
dH = Inside diameter of pump
Q = Capacity of pump
v = Fluid velocity

2.6.5. Heat Transfer on Close Loop Scrubber System

In the close loop scrubber system, in addition to the process of cleaning up the exhaust gas with water media, there is also a heat transfer process. One of the reasons for the use of freshwater media to clean exhaust gases is to remove impurities and sulfur content in exhaust gases, but seawater is also needed to cool the freshwater that has been used in the scrubbing process to be recirculated into the holding tank.

In determining heat transfer that occurs in the scrubber system can use the following heat transfer equation (Kern, 1983):

$$Q = m\ x\ cp\ x\ \Delta T \qquad (2.23)$$

Where :

Q = The amount of heat received or released by an object (J)
m = The mass of objects that receive or release heat (kg)
cp = Heat type of substance (J/kgK)
ΔT = Change in Temperature (K)

Besides being used to determine the heat transfer that occurs in the scrubber tank, it is also necessary to know the heat transfer that occurs in the scrubber system, especially in the freshwater scrubber system. That is because of government regulations related to dumping waste into the sea as the Republic of Indonesia government regulation in the Minister of Environment Regulation No. 8 of 2009, where waste permitted to be discharged into the sea must not exceed 40 ° C.

2.6.6. Back Pressure on Close Loop Scrubber System

Engine manufacturers include a permitted range of exhaust backpressures within the technical specifications of their engines operating outside this range may lead to accelerated wear, significantly reduced maintenance intervals, reduced power, and increased fuel consumption. Installation exhaust gas treatment system (EGTS) increases backpressure, and system designers need to understand the impact of this on the engine.

The exhaust gas backpressure after the turbocharger depends on the total pressure drop in the exhaust gas piping system. The components, exhaust gas boiler, silencer, and spark arrester, if fitted, usually contribute with a major part of the dynamic pressure drop through the entire exhaust gas piping system. The pressure loss calculations have to be based on the actual exhaust gas amount and temperature valid for specified MCR. According to (MAN, 2014) some general formulas and definitions are given in the following.

2.6.6.1. Exhaust Gas Data

M = exhaust gas amount at specified MCR in kg/sec.

T = exhaust gas temperature at specified MCR in °C

2.6.6.2. Mass Density of Exhaust Gas (ρ)

The pressure loss calculations have to be based on the actual exhaust gas amount and temperature valid for specified MCR. After knowing the amount of exhaust gas at a particular MCR, it is necessary to calculate the mass density of exhaust gas (ρ).

$$(\rho) = 1.293\ x\ \frac{273}{273 + T}\ x\ 1.015 \qquad (2.24)$$

Where :

ρ	= Mass density of exhaust gas (kg/m^3)
T	= Exhaust gas temperature at specified MCR (°C)

The factor 1.015 refers to the average backpressure of 150 mm WC (0.015 bar) in the exhaust gas system.

2.6.6.3. Exhaust Gas Velocity

In calculating backpressure in the exhaust gas, it is necessary to know the speed of the exhaust gas. In a pipe with a diameter D, the exhaust gas velocity is:

$$v = \frac{M}{\rho}\ x\ \frac{4}{\pi \text{ x } D^2} \qquad (2.25)$$

Where :

v	= Exhaust gas velocity (m/s)
M	= Exhaust gas amount at specified MCR (kg/sec)
T	= Exhaust gas temperature (°C)
ρ	= Mass density of exhaust gas (kg/m^3)
D	= Pipe diameter (m)

2.6.6.4. Pressure Losses in Pipe (Δp)

For a pipe element, like a bend, etc., with the resistance coefficient ζ, the corresponding pressure loss is:

$$\Delta p = \zeta, \text{x } {}^{1}/_{2}\, \rho\, v^2 \text{ x } \frac{1}{9.81} \qquad (2.26)$$

Where :

Δp	= Pressure loss in the pipe (mm WC)
ζ,	= Resistance coefficient
ρ	= Mass density of exhaust gas (kg/m^3)
v	= Exhaust gas velocity (m/s)

Where the expression after ζ is the dynamic pressure of the flow in the pipe, the friction losses in the straight pipes may, as guidance, be estimated as 1 mm WC per 1 diameter length whereas the positive influence of the updraught in the vertical pipe usually is negligible.

2.6.6.5. Pressure Losses Across Components (Δp)

The pressure loss Δp across silencer, exhaust gas boiler, spark arrester, rainwater trap, et cetera, to be measured/ stated (at specified MCR) usually is given by the relevant manufacturer.

2.6.6.6. Total Backpressure (Δp_M)

The total backpressure, measured/stated as the static pressure in the pipe after the turbocharger, is then:

$$\Delta p_M = \sum \Delta p \quad (2.27)$$

Where :
Δp = Pressure loss in pipe elements and components (mm WC)

2.7. Feasibility Study

The feasibility study is an analysis conducted to determine the feasibility of a project to be done. The feasibility study aims to find the strengths and weaknesses of the proposed project, the opportunities, and resources needed to implement it, which then leads to the prospect of success. There are various types of feasibility studies, such as technical, economic, legal, operational, and scheduling (Jawaid, 2013). In the technical feasibility study, the study reviews the technical operation of a project. In the modifications made in this research, a technical feasibility study discusses the related aspects to see if modifications to the scrubber system can be made.

In the economic feasibility study, this study looks at the cost of doing a project. There are two types of costs reviewed in the economic feasibility study. First is the initial investment cost or what is called Capital Expenditure. Initial investment costs of an important investment capital expenditure activity in a company. The initial investment cost is defined as the cost of the new asset + the cost of installation along with the calculation of taxes that come from adding assets. The second is operational costs or what is called Operational Expenditure. Operational costs are costs incurred in operating the project when it is operational. This calculation covers all operational needs, including equipment operating costs, maintenance costs, and labor costs.

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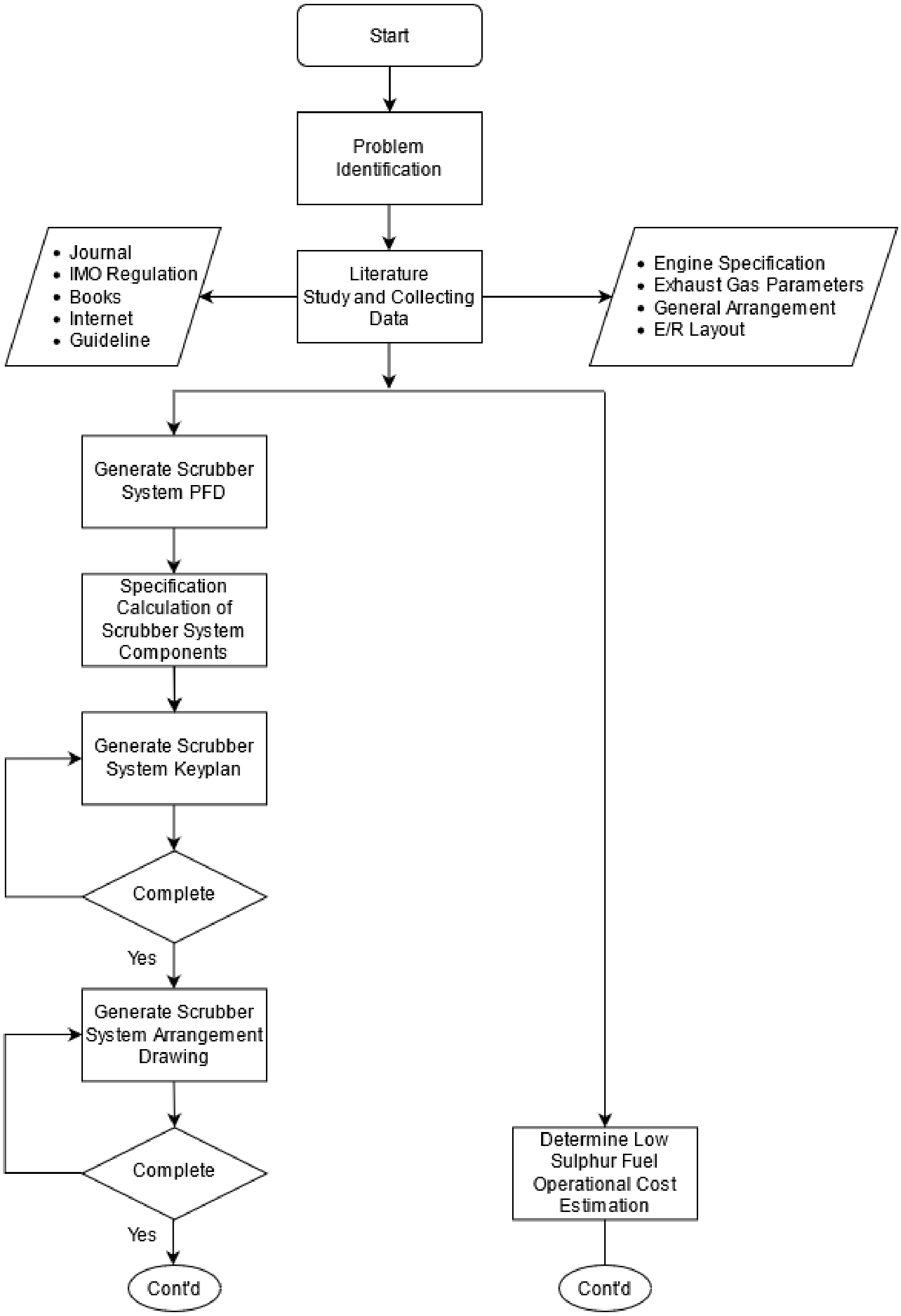
CHAPTER III
METHODOLOGY

3.1. Flowchart



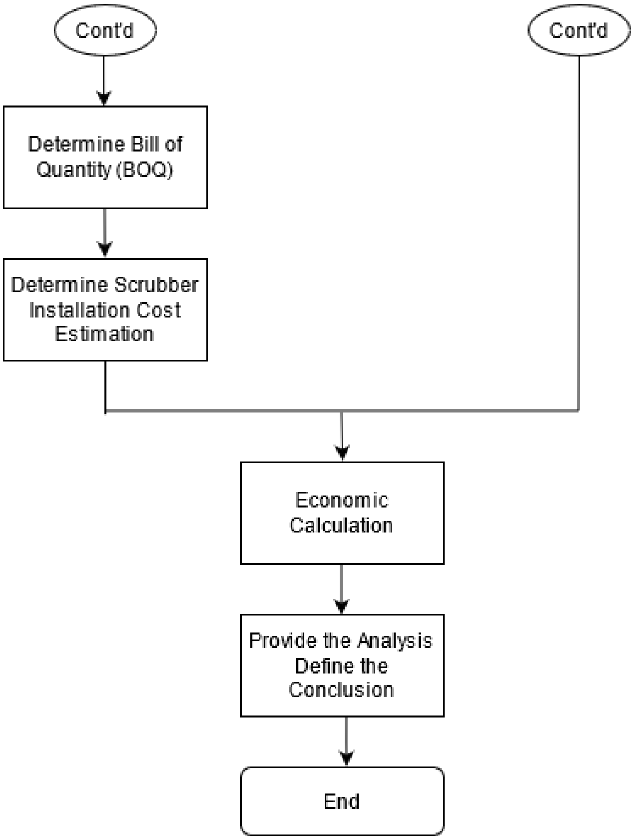


Figure 3. 1 Flowchart

3.2. Problem Identification

In this thesis, the first step carried out is the identification and formulation of the problem. The International Maritime Organization, through IMO 2020 regulations, requires each vessel to use fuel that has a low sulfur content of a maximum value of 0.5% m / m. This is, of course, a special concern for ship managers because they have to adjust these rules so that the ships they have can still sail. Therefore, this research aims to obtain the results of technical and economic calculation of the application of closed loop scrubbers on 816 TEUS Container Ship in Indonesia.

3.3. Literature Study and Collecting Data

A literature study is the next step to get information that supports the completion of this thesis. The information is in the form of theories, work methods, regulations, and standards. A literature study can be obtained by reading books, journals, papers, regulations, and standards related to the discussion in this thesis.

In addition to literature studies, ship data collection is also carried out to support data processing as initial input. The following are the data needed in this final project, including:

1. Engine Specification
2. Exhaust Gas Parameter

3. General Arrangement
4. Engine Room Layout

3.4. Generate Scrubber System PFD

At this stage, the PFD or Process Flow Diagram is designed on the scrubber system. PFD is conducted to determine the processes that are passed on the scrubber system.

3.5. Specification Calculation of Scrubber System Components

At this stage, the calculation is performed to determine the component requirements on the scrubber system. So from the calculation of component requirements, components with specifications suitable for scrubber systems can be determined.

3.6. Generate Scrubber System Key plan

After calculating the component specifications based on needs that have been determined in the previous stage. So that the appropriate P&ID depictions can be done.

3.7. Generate Scrubber System Arrangement Drawing

At this stage, after generating the scrubber system key plan, the layout drawing arrangement of the scrubber system will be made.

3.8. Determine Bill of Quantity

After having arrangement drawing, the bill of quantity can be provided according to the construction materials, machinery, and other equipment needed to be installed onboard. The Bill of quantity consists of technical specifications and the number of materials and equipment.

3.9. Provide Engineering Cost Estimation

Engineering cost estimation is a calculation of the costs of modifications made. Engineering cost estimation carried out in this study is limited to the investment costs of assets required for a modified system. The value taken as a benchmark in determining equipment prices is based on domestic shipyard data and online platforms for ship equipment.

3.10. Economic Calculation

In an economic calculation, this study looks at the cost of doing a project. There are two types of costs reviewed in the economic calculation. First is the initial investment cost or what is called Capital Expenditure. Initial investment costs of an important investment capital expenditure activity in a company. The initial investment cost is defined as the cost of the new asset + the cost of installation - along with the calculation of taxes that come from adding assets. The second is operational costs or what is called Operational Expenditure. Operational costs are costs incurred in operating the project when it is operational.

3.11. Conclusion

The final step in this study is the conclusions and suggestions obtained by completing all the steps of the flow diagram in Figure 3.1 and must answer all the problems that have been previously formulated. So that advice can be given, and this research can be used as a basis for further research related to the application of closed loop scrubber systems or other research.

CHAPTER IV
DATA ANALYSIS

4.1. Ship Particular

In this study, the ship that will be applied to the close loop scrubber system is a container carrier that has a capacity of 816 TEU's. The ship used as the object of study this time has Indonesian domestic shipping routes. Ship specific data from these vessels can be seen in Table 4.1.

Table 4. 1 Ship particular

Ship Type	Container Ship
LOA :	146 m
LPP :	142.2 m
Breadth (Mld) :	23.25 m
Depth (Mld) :	10.50 m
Draft Max :	7 m
Gross Tonnage :	11,512 Ton
Deadweight :	12,798 Ton
Sevice Speed :	13 knot
Engine Power	3,990 kW

4.2. Fuel Oil Consumption Cost

One option to reduce sulfur content in fuels is to use low-sulfur fuels that are already available on the market, such as low sulfur fuel oil (LSFO). In the market, low sulfur fuel oil itself has a price that is more expensive than heavy fuel oil (HFO). To find out the operational costs of using low sulfur fuel oil needs to be calculated. The following is the calculation of the fuel cost needed by the ship when using low sulphur fuel oil (LSFO).

Before installing a closed loop scrubber system on a ship, it is necessary to calculate the fuel consumption required by the ship, both using heavy fuel oil (HFO) and low sulfur fuel oil (LSFO). The route and service speed of the ship that will be the object of research can be seen in the following table.

Table 4. 2 Ship voyage data

Ship Route	Jakarta – Surabaya – Bitung – Gorontalo – Jakarta
Service Speed	13 knot
Voyage Duration	10 days at sea
Trip per Year	29 Trip

After knowing the route of the ship to calculate fuel consumption, the next step is to calculate the fuel consumption of the ship. To calculate the fuel consumption needed by the ship, the data output power needed by the main engine of the ship and the specific fuel oil consumption of the main engine is needed. In table 4.3 can be seen the specifications of the main engine of the ship to be examined.

Table 4. 3 Engine specification

Maker	Mitsubishi
Type	6 UEC 33 LSE-C2
Output Power at 100% MCR	3,990 kW
Output Power at 90% MCR	3,590 kW
Output Power at 85% MCR	3,390 kW
SFOC at 100% MCR	170 g/kWh
SFOC at 90% MCR	168.2 g/kWh
SFOC at 85% MCR	167.6 g/kWh

In table 4.4, it can be seen the specifications along with the price of the fuel to be calculated so that later it can be known the fuel oil consumption cost of the ship to be studied.

Table 4. 4 Fuel oil specification

ρ HFO	1.01 ton/m^3
ρ LSFO	0.91 ton/m^3
HFO Price	$ 280 /mt (per August 5th, 2020)
LSFO Price	$ 350 /mt (per August 5th, 2020)
Rupiah Conversion	14,596/USD (per August 5th 2020)

4.2.1. Heavy Fuel Oil (HFO) Consumption Cost

After knowing how much output power is generated by the ship's main engine and specific fuel oil consumption (SFOC), fuel oil consumption is calculated when using heavy fuel oil (HFO).

Fuel Oil Consumption = BHPmcr × SFOC × 24 hours / ρ HFO
= 3,390 kW × 167.6 g/kWh × 24 hours / 1.01 ton/m3
= 13.50 m^3
= 13.37 ton/day

Cost of HFO per day = 13.37 ton/day × 280 USD
= $3,742.8 per day
= Rp54,630,363 per day

Cost per Trip = Rp54,630,363 ×10 Days

	= Rp546,303,638
Cost per Year	= Rp546,303,638 × 29 Trip
	= Rp15,842,805,504

4.2.2. Low Sulphur Fuel Oil (LSFO) Consumption Cost

After knowing how much output power is generated by the ship's main engine, as well as the specific fuel oil consumption (SFOC), the fuel oil consumption is calculated when using low sulfur fuel oil (LSFO).

Fuel Oil Consumption	= BHPmcr × SFOC × 24 hours / ρ LSFO
	= 3,390 kW × 167.6 g/kWh x 24 hours / 0.91 ton/m3
	= 14.98 m^3
	= 16.47 ton/day
Cost of LSFO per day	= 16.47 ton/day × 350 USD
	= $5,763.3 per day
	= Rp84,120,930
Cost per Trip	= Rp84,120,930 ×10 Days
	= Rp841,209,306
Cost per Year	= Rp841,209,306 × 29 Trip
	= Rp24,395,069,880

4.3. Closed Loop Scrubber System Arrangement

4.3.1. Process Flow Diagram Drawing

In designing the scrubber system, the first thing to do is to describe the Process Flow Diagram (PFD). PFD is done to find out the processes that are passed in a system, wherein this system is a closed loop scrubber system. In a freshwater scrubber system, freshwater is carried by the ship when it will sail. The freshwater will be stored in the piping system, and then using a pump will give a boost to the scrubber top side. When freshwater is channeled into the scrubber, freshwater is injected with a strong base solution to neutralize the acid content carried in the exhaust gas. The basic solution used is sodium hydroxide (NaOH). Because freshwater does not have natural alkalinity, the addition of a basic solution is necessary to prevent the content of dissolved acids and pollute the environment. Like the seawater scrubber system, the freshwater scrubber system cleans ship exhaust gases by spraying through the nozzle from the top side of the scrubber, by having a "pool" or so-called seal on the underside of the scrubber where the exhaust gases come out. Freshwater that has been used to clean exhaust gases is then cleaned using wash water treatment to be separated between water and sludge. The sludge is then flowed into the sludge tank for disposal, while the water will be recirculated to clean the exhaust gas. The schematic of a freshwater system can be seen in Figure 4.1.

In the freshwater scrubber system has several additional components that are not owned by the seawater scrubber system. Some of these components include Chemical Addition, Expansion Tank, Wash Water Treatment, and Heat Exchanger.

• Chemical Addition is the process of adding a strong base solution that is used to neutralize the acid content in the exhaust gas.

• Expansion Tank, which is used as an additional tank for water to expand, and also as a supply of freshwater when the amount of water in the system decreases. Due to the temperature of the heat that comes from the exhaust gas during the cleaning process in the scrubber, causing some water to change into gas and some water to expand.

• Wash Water Treatment, which is used to treat water resulting from exhaust gas scrubbing. The results of wash water treatment in the form of freshwater that is ready to be used again, as well as sludge containing impurities. Freshwater is then re-circulated to clean the exhaust gas, and the sludge is channeled into the sludge tank for later disposal.

• Heat Exchanger is the process of re-cooling water that has been cleaned through wash water treatment before entering the scrubber tank. The purpose of the freshwater cooling process is that the freshwater is ready to be used again or to be safe when disposed of at sea. As the government regulation of the Republic of Indonesia in the Minister of Environment Regulation No. 8 of 2009, where waste permitted to be discharged into the sea must not exceed 40 ° C. The cooling process utilizes heat exchange with seawater media. After freshwater is added, the freshwater is pumped back into the scrubber tank, and the freshwater scrubber system cycle repeats itself.

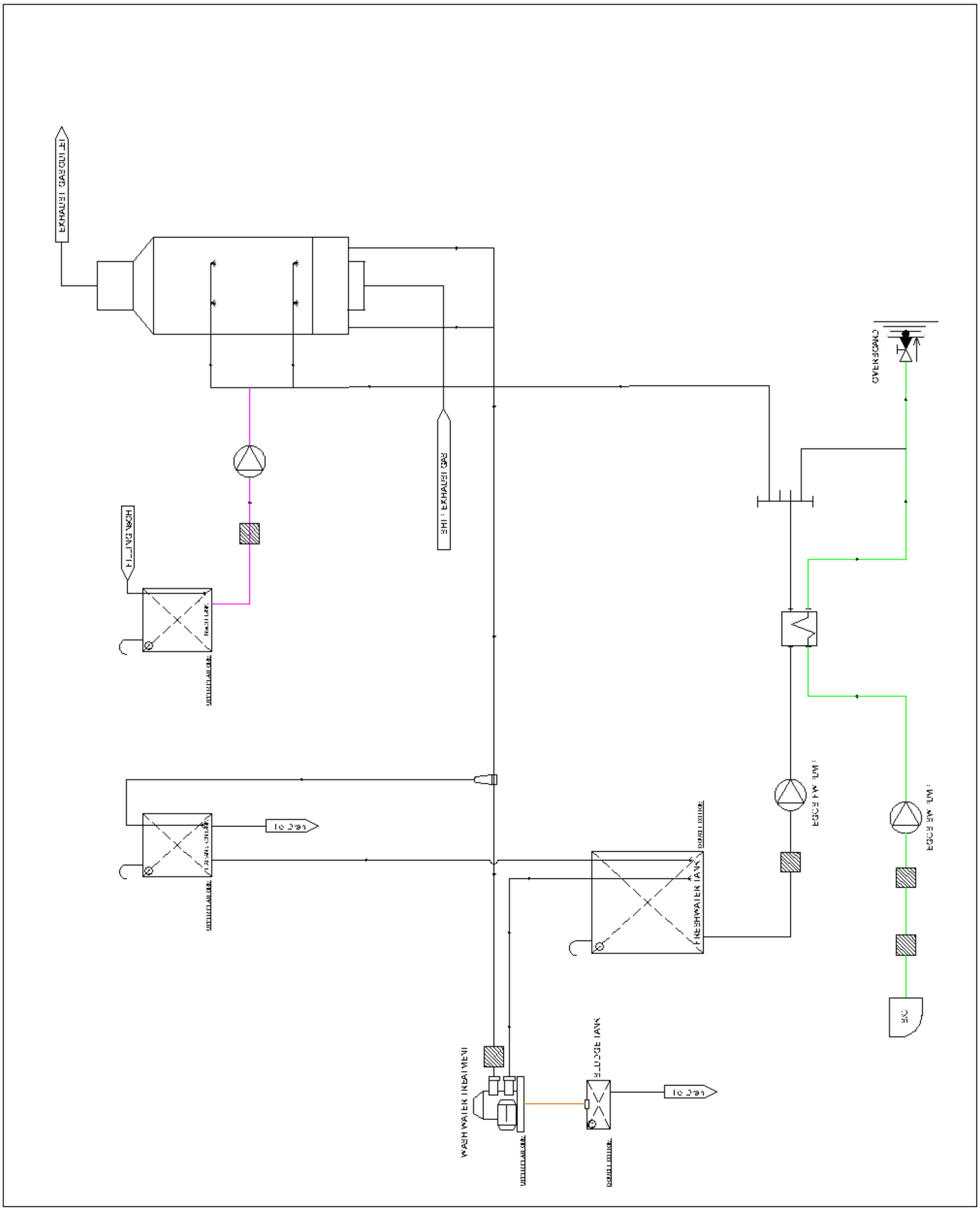


Figure 4. 1 Closed loop scrubber PFD

4.3.2. Closed Loop Scrubber System Calculation

In designing a closed loop scrubber system, it is necessary to know the components that will be used and their specifications. To find out the specifications of the components needed in a closed loop scrubber system, a calculation is needed.

4.3.2.1. Fresh Water Pump Calculation

In closed loop scrubber system, which becomes the cleaning media from the exhaust gas is freshwater. In the process of cleaning up the vessel's exhaust gas, later freshwater will be mixed with Sodium Hydroxide to reduce the sulfur content in the exhaust gas. To drain freshwater from a freshwater tank to the scrubber, a freshwater pump is needed. The capacity of the freshwater pump required is around 20 m^3/ MWh.

Freshwater Pump Capacity = 20 m^3/MWh × 4 MW
= 80 m^3 /h

4.3.2.2. Cooling Process and Sea Water Pump Calculation

Next is to calculate the heat transfer that occurs during the scrubbing process. There is two times the heat transfer process that occurs. The first process is the process when cleaning the exhaust gas in the scrubber. Where the media that experiences heat transfer is the exhaust gas and freshwater. The second process is heat transfer that occurs when you want to cool the temperature of freshwater by using seawater media.

Process 1. Fresh Water and Exhaust Gas Heat Exchanger

Calculation in process 1. What we want to know is the output temperature of freshwater after going through a scrubbing process. As illustrated in Figure 4.1 about the process that occurs in the scrubber, it can be seen that the scrubber output water or called wash water will experience an increase in temperature. So the heat transfer calculation is then performed as follows :

Known :

- Exhaust gas flowrate = 20,893 m^3/h
- Inlet gas temperature = 331°C = 604.15 °K
- Outlet gas temperature = 50°C = 323.15 °K
- Inlet water temperature = 35°C = 308.15 °K
- Freshwater flow rate = 80 m^3/h

Table 4. 5 Exhaust gas specific heat

Substance	Total Vol. (m3/h)	Content (%)	Content (m3/h)	Density (kg/m3)	Mass Flow (kg/h)	Specific Heat, Cp (kJ/kgK)	m x Cp
N_2	20893	75.8%	15836.89	1.0564	16730.09	1.042	17432.76
CO_2		5.1%	1065.54	1.6597	1768.48	0.8666	1532.566
H_2O		5.9%	1241.04	0.6794	843.17	1.874	1580.092
O_2		13.0%	2709.82	1.2068	3270.21	0.9217	3014.156
SO_2		0.1%	18.80	2.927	55.04	0.64	35.2246
NO		0.07%	13.75	1.34	18.42	0.995	18.32967
NO_2		0.0%	1.53	1450	2211.52	4.69	10372.05
Total							**33985.2**

Where :

- ρ fresh water = 997 kg/m^3
- m fresh water = 80,000 kg/h
- cp fresh water = 4.18 kJ/kgK
- m x cp Gas = 33,985.2 kg/h

Calculation :

$$Q1 = Q2$$

$$m \times cp \times \Delta T = m \times cp \times \Delta T$$

$$80{,}000 \times 4.18 \times (T2 - 308.15) = 33{,}985.2 \times (604.15 - 323.15)$$

$$T2 - 308.15 = \frac{9549{,}841.2}{80{,}000 \times 4.18}$$

$$T2 - 308.15 = 28.6 \text{ K}$$

$$T2 = 336.75 \text{ K}$$

$$\mathbf{T2 = 63.6}°\text{C}$$

Proses 2. Wash water and Sea Water Heat Exchanger

The calculation in process 2 is to find out the amount of heat released by wash water so that the water is ready to be used again in the next cycle. After knowing the amount of heat released, then further determine the need for seawater as a cooling medium.

Known :

- T Water inlet = 63.6°C = 336.75 K
- T Water outlet = 40°C = 308.15 K
- m fresh water = 80,000 kg/h
- cp fresh water = 4.18 kJ/kgK

Then, the amount of heat released is :

$$Q = m \times cp \times \Delta T$$
$$Q = 80{,}000 \times 4.18 \times (336.75 - 308.15)$$
$$Q = 9{,}563{,}840 \text{ kJ/hour}$$
$$Q = 2{,}656.62 \text{ kW} = 3{,}552.6 \text{ HP}$$

Seawater Cooling Needs

Known :

- T Water inlet = 25°C = 298.15 K
- T Water outlet = 40°C = 313.15 K
- Heat (Q) = 9,563,840 kJ/hour
- cp of Sea Water = 4.012 kJ/kgK

So,

$$m = \frac{Q}{cp \times \Delta T}$$

$$m = \frac{9,563,840}{4.012 \times (313.15 - 303.15)}$$

$$m = 158,920 \text{ kg/hour}$$

P of Sea Water = 1025 kg/m^3

Sea Water Flow Rate = 155 m^3/hour

4.3.2.3. Exhaust Gas Composition

In the scrubbing process in the closed loop scrubber system, utilizing the alkalinity of sodium hydroxide. To find out the amount of sodium hydroxide needed in the scrubbing process, it is necessary to know the content of sulphur oxide (SO_2), nitrogen dioxide (NO_2), and nitrogen oxide (NO) in the exhaust gas of the ship. The levels of substances in the ship exhaust gas are shown in Table 4.6.

Table 4. 6 Exhaust gas composition

Exhaust Gas Composition	Mass Basis
N_2	75.8%
O_2	12.97%
H_2O	5.94%
CO_2	5.1%
SO_2	900 ppmv
NO_2	73 ppmv
NO	658 ppmv

From Table 4.6. can be seen as the levels of substances carried in the ship exhaust gas. In ship exhaust gas, there are 900 ppmv of sulphur oxide (SO_2), which must be reduced. The content of these substances is still in percent units. Furthermore, calculate these levels into actual measurements. The reference used to calculate the levels of substances in the overall exhaust gas rate.

Known :

Exhaust gas flowrate = 20893 m^3/h

Item to be removed :

- SO_2 = 0.09%
- NO = 0.0658%
- NO_2 = 0.0073%

Sulphur Dioxide (SO_2)

V SO_2 = 20,893 × 0.09%

= 18.83 m^3/h

ρ SO_2 = 2.63 kg/m3

m SO_2 = 18.83 × 2.63
= **49.45 kg/h**

Nitrogen Oxide (NO)

V NO = 20,893 × 0.0658%
= 13.74 m^3/h

ρ NO = 1.34 kg/m^3

m NO = 13.74 × 1.34
= **18.42 kg/h**

Nitrogen Dioxide (NO_2)

V SO_2 = 20,893 × 0.0073%
= 1.52 m^3/h

ρ SO_2 = 3.4 kg/m^3

m SO_2 = 1.52 × 3.4
= **5.17 kg/h**

4.3.2.4. Addition of NaOH Bases

After knowing the levels of substances to be cleaned by the scrubber system, then calculate the amount of additional sodium hydroxide (NaOH) bases needed. The process of adding bases is done due to differences in the properties of freshwater and seawater. In seawater has natural alkalinity, so as to neutralize the acid content carried by the exhaust gas. While the alkalinity is not possessed by freshwater, it is necessary to add a base to neutralize the acid carried in the exhaust gas.

The first step in determining the addition of a hydroxide (NaOH) base is to calculate the reaction that occurs with the acid compound to be cleaned. Where in this process acids that react with bases are sulphur oxide (SO_2), nitrogen dioxide (NO_2) and nitrogen oxide (NO).

Reaction 1. NaOH + SO_2

Mass Number

Na	= 23	H	= 1
S	= 32	O	= 16

Reaction	**2NaOH**	+	**SO_2**	↔	**Na_2SO_3**	+	**H_2O**
Weight	61.47 kg/h		49.45 kg/h		97.29 kg/h		13.9 kg/h
Molar Mass	40		64		126		18
Moles	1.54 mol/h		0.77 mol/h		0.77 mol/h		0.77 mol/h

Reaction Result :

- Na_2SO_3 = 97.29 kg/h
- H_2O = 13.9 kg/h

Reaction 2. NaOH + NO

Mass Number	Na	= 23	H	= 1
	O	= 16	N	= 14

Reaction	$2NaOH$	+	$4NO$	↔	$2NaNO_2$	+	N_2O	+	H_2O
Weight	12.27 kg/h		18.42 kg/h		21.17 kg/h		6.75 kg/h		2.76 kg/h
Molar Mass	40		30		69		44		18
Moles	0.3 mol/h		0.6 mol/h		0.3 mol/h		0.15 mol/h		0.15 mol/h

Reaction Result :

- $NaNO_2$ = 21.17 kg/h
- N_2O = 6.75 kg/h
- H_2O = 2.76 kg/h

Reaction 3. NaOH + NO_2

Mass Number	Na	= 23	H	= 1
	O	= 16	N	= 14

Reaction	$2NaOH$	+	$2NO_2$	↔	$NaNO_2$	+	$NaNO_3$	+	H_2O
Weight	4.49 kg/h		5.17 kg/h		3.87 kg/h		4.77 kg/h		1.01 kg/h
Molar Mass	40		46		69		85		18
Moles	0.11 mol/h		0.11 mol/h		0.05 mol/h		0.05 mol/h		0.05 mol/h

Reaction Result :

- $NaNO_2$ = 3.87 kg/h
- $NaNO_3$ = 4.77 kg/h
- H_2O = 1.01 kg/h

Total NaOH Base Addition :

Reaction 1. NaOH + SO_2

NaOH Amount = 61.74 kg/h

Reaction 2. NaOH + NO

NaOH Amount = 12.27 kg/h

Reaction 3. NaOH + NO_2

NaOH Amount = 4.49 kg/h

Total NaOH addition for one scrubbing process

= 61.74 kg/h + 12.27 kg/h + 4.49 kg/h

= 78.25 kg/h

Density of NaOH 50% Solution = 1525 kg/m^3
NaOH flow rate = **0.0515 m^3/hour**

4.3.2.5. Tank Calculation

In closed loop scrubber system, there are at least four tanks that need to be calculated to determine the volume requirements of the tank. The tanks that need to know the volume are freshwater tank, expansion tank, NaOH tank, and sludge tank.

Freshwater Tank

Freshwater flowrate	= 80 m^3/h
Freshwater tank volume	= 80 m^3 located at F.W. tank Starboard side

Freshwater Expansion Tank Calculation

The volume of Freshwater tank	= 80 m^3
Tank size estimation	= 3 %
Expansion tank volume	= 80 m^3 × 3 %
	= 2.4 m^3

NaOH Tank Calculation

Flow rate	= 0.0515 m^3/h
Tank size estimation	= NaOH Consumption/day × 10 day
	= 1.236 m^3 × 10 day
NaOH volume	= **12.36 m^3**

Sludge Tank

Sludge Estimation	= 0.1 – 0.3 m^3 / MWh of Scrubbed engine
Main Engine Power Output	= 4 MW
Aux. Engine Power Output	= 1.3 MW
Number of sludge	= 0.3 m^3 × 5.3 MWh × 24 hour
	= 1.59 m^3
Sludge Tank Volume	= **2 m^3**

4.3.2.6. Pipe Calculation

Pipeline calculations are performed to determine the size and dimensions of the pipes that are in the scrubber system after modification. There are at least three types of pipes that need to be calculated, including sodium hydroxide (NaOH) pipes, freshwater pipes, and seawater cooling pipes.

NaOH Pipe Calculation

Flow rate	= 0.0515 m^3/h
	= 0.00000143 m^3/s
dH	= $\sqrt{(4Q/\pi x v)}$
dH	= Inside diameter of NaOH Pipe
Q	= Capacity of NaOH Pump

v = Fluid velocity = 1 m/s

dH = $\sqrt{(4 \text{ x } 0.00000143 / 3.14 \text{ x } 1)}$

= 0.0043 m

= 4.3 mm

Table 4. 7 NaOH pipe size

NaOH Pipe				
Type	JIS G3459	Thickness	2.8	mm
Nominal	15 A	Outside Diameter	21.7	mm
Schedule	Sch 40	Inside Diameter	16.1	mm

The minimum pipe thickness, according to CCS Rules Part Three Chapter 2 Section 2, for stainless steel material with a diameter of 21.7 mm is 2.0 mm.

Calculation of Freshwater Scrubber Pipes

Flow rate = 80 m^3/h

= 0.022 m^3/s

dH = $\sqrt{(4Q/\pi x v)}$

dH = Inside diameter of Freshwater Scrubber Pipe

Q = Capacity of Freshwater Pump

v = Water velocity = 2 m/s

dH = $\sqrt{(4 \text{ x } 0.022 / 3.14 \text{ x } 1)}$

= 0.119 m

= 119 mm

Table 4. 8 Freshwater pipe size

Freshwater Pipe				
Type	JIS G3452	Thickness	4.5	mm
Nominal	125 A	Outside Diameter	139.8	mm
Schedule	Sch 40	Inside Diameter	130.8	mm

The minimum pipe thickness, according to CCS Rules Part Three Chapter 2 Section 2, for carbon steel material with a diameter of 139.8 mm is 4.5 mm.

Expansion Tank Pipe Calculation

Flow rate = 3 m^3/h

= 0.00083 m^3/s

dH = $\sqrt{(4Q/\pi x v)}$

dH = Inside diameter of Expansion Tank Pipe

Q = Capacity of Expansion Tank

v = Water velocity = 2 m/s

dH = $\sqrt{(4 \times 0.00083143 / 3.14 \times 1)}$

= 0.023 m

= 23 mm

Table 4. 9 Expansion tank pipe

Expansion Tank Pipe				
Merk	JIS G3452	Thickness	3.2	mm
Nominal	25 A	Outside Diameter	34	mm
Schedule	Sch 40	Inside Diameter	27.6	mm

The minimum pipe thickness, according to CCS Rules Part Three Chapter 2 Section 2, for carbon steel material with a diameter of 34 mm is 3.2 mm.

Sea Water Cooling Pipe Calculation

Flow rate = 155 m^3/h

= 0.043 m^3/s

dH = $\sqrt{(4Q/\pi x v)}$

dH = Inside diameter of Sea Water Pipe

Q = Capacity of Sea Water Pump

v = Water velocity = 2 m/s

dH = $\sqrt{(4 \times 0.043 / 3.14 \times 1)}$

= 0.1656 m

= 165.6 mm

Table 4. 10 Seawater pipe size

Sea Water Pipe				
Merk	JIS G3459	Thickness	8.2	mm
Nominal	200 A	Outside Diameter	216.3	mm
Schedule	Sch 40	Inside Diameter	199.99	mm

The minimum pipe thickness, according to CCS Rules Part Three Chapter 2 Section 2, for carbon steel material with a diameter of 216.3 mm is 5.4 mm.

4.3.2.7. Head Calculation

Head calculations are performed to determine the pump needs to drain the fluid inside the freshwater scrubber system. There are three types of fluids, namely

NaOH, freshwater, and seawater. The three types of fluid must be known to the needs of the head and flow capacity so that the appropriate pump can then be selected.

NaOH Pump Calculation

Pump Head

H = Hz + Hp + Hv + total Head loss.

Where,

a) Static Head (Hz)

Height Difference between Tank and Side Discharge

- Height at Z=0 towards discharge line = 5 meter
- Height at Z=0 towards suction line = -2.5 meter

Hz = Zd – Zs
= 5 – (-2.5)
= 7.5 m

b) Head Pressure (Hp)

Pressure Difference between Suction Side and Pipe Discharge Side

- Pressure at suction = Atmospheric Pressure + Hydrostatic Pressure
  = 101,325 N/m^2 + (2.5 ρ g)
  = 150,208.5 N/m^2
- Pressure at discharge = Atmospheric Pressure
  = 101,325 N/m^2

Hp = (Pd – Ps) / ρ × g

Where,

ρ = 2,130 kg/m^3

g = 9.81 m/s^2

Hp = (101.325 – 150,208.5) / (2,130 x 9.81)
= -2.5 m

c) Head Velocity (Hv)

The difference in Flow Speed on the Suction and Discharge Side

- Flow speed at suction side = 1 m/s
- Flow speed at discharge side= 1 m/s

Hv = (V^2d – V^2s) / 2 g

Where

g = 9.81 m/s^2

Hv = (1-1) / 2 × 9.81
= 0 m

d) Head Loss (Hl)

Losses experienced by flow along pipes and fittings. Head Loss is divided into 2, namely Head Loss Major and Head Loss Minor. Head Loss Major is a loss experienced due to friction that occurs along the pipeline between the fluid and the pipe wall. Minor Head Loss is a loss suffered due to fittings and other piping accessories.

a. Suction Line

Head Loss Major

Reynold Number

$Re = (v \times D) / \upsilon$

Where,

d = Pipe Diameter
= 0.0042 m

v = Fluid Flow Speed
= 1 m/s

υ = Fluid Kinematic Viscosity (at 30°C)
= $3 \times 10^{-6}\ m^2/s$

$Re = (0.0042 \times 1) / (3 \times 10^{-6})$
$= 1{,}400$

If the value of Re < 2,300, fluid flow is said to be a “Laminar” flow
If the value of Re > 2,300, fluid flow is said to be a “Turbulent” flow

Because the flow is Laminar, the friction factor calculation uses :

$f = 64 / Re$
$= 64 / 1{,}400$
$= 0.0457$

By using the Forged Stainless Steel material as a NaOH pipe, the value of the friction factor is 0.0457. Then, the value of the Head Loss Major can be calculated using the following equation :

$Hlm = f \times L \times v^2 / (D \times 2g)$
$= 0.044 \times 3 \times 1^2 / (0.0042 \times 2 \times 9.81)$
$= 1.66$ m

Head Loss Minor

Table 4. 11 NaOH suction fittings

No	**Type**	**N**	**k**	**N x k**
1	Butterfly Valve	1	2	2
2	Elbow 90°	1	1.1	1.1
3	Filter	1	2.5	2.5
			Total	5.6

Then, the value of Minor Head Loss can be calculated using the following equation :

$$Hl = k\ Total \times v^2 / 2\ g$$
$$= 5.6 \times 1^2 / (2 \times 9{,}81)$$
$$= 0.291\ m$$

b. Discharge Line
Head Loss Major

Reynold Number
$Re = (v \times D) / \upsilon$

Where,
d = Pipe Diameter
= 0.0042 m
v = Flid Flow Speed
= 1 m/s
υ = Fluid Kinematic Viscosity (at 30°C)
= $3 \times 10^{-6}\ m^2/s$

$$Re = (0.0042 \times 1) / (3 \times 10^{-6})$$
$$= 1{,}400$$

If the value of Re < 2,300, fluid flow is said to be a "Laminar" flow
If the value of Re > 2,300, fluid flow is said to be a "Turbulent" flow

Because of the flow, including Turbulent, by using the method on Head Loss Major, a friction factor value of 0.0457 is obtained. Then, the value of the Head Loss Major can be calculated using the following equation :

$$Hlm = f \times L \times v^2 / (D \times 2g)$$
$$= 0.0457 \times 2 \times 1^2 / (0.0042 \times 2 \times 9{,}81)$$
$$= 1.1\ m$$

Head Loss Minor

Table 4. 12 NaOH discharge fittings

No	**Type**	**N**	**k**	**N x k**
1	NRV	1	2,0	2,0
2	T Joint	1	1,1	1,1
			Total	3,1

Then, the value of Minor Head Loss can be calculated using the following equation :

$$Hl = k\ Total \times v^2 / 2\ g$$

$= 3.1 \times 1^2 / (2 \times 9{,}81)$
$= 0.158$ m

e) Total Head
The total pump head can be determined by adding up all the head parameters.

Total Head = Hz + Hp + Hv + Hl (Major + Minor)
= 7.5 – 2.5 + 0 + 1.66 + 0.291 + 1.1 + 0.158
= 8.2 m

Pump Capacity
The pump capacity for NaOH fluid in this system requires a flow rate of 0.0515 m3 / h.

Pump Needs
Head = 8.2 m
Q = 0.0515 m^3/h

Table 4. 13 NaOH pump selection

NaOH Pump	
Pump Type	Centrifugal
Maker	Forte
Type	S-PC 4012H
Capacity	14.4 m3/h
Head	13 m
Power	0.75 kW
Frequency	50 Hz

Sea Water Pump Calculation
Pump Head

H = Hz + Hp + Hv + total Head loss.
Where,

a) Head Statis (Hz)
Height Difference between Tank and Side Discharge
- Height at Z=0 towards discharge line = 20 meter
- Height at Z=0 towards suction line = -2 meter

Hz = Zd – Zs
= 20 – (-2)
= 22 m

b) Head Pressure (Hp)
Pressure Difference between Suction Side and Pipe Discharge Side
- Pressure at suction = Atmospheric Pressure + Hydrostatic Pressure

= 101,325 N/m^2 + (2 ρ g)
= 121,435 N/m^2

- Pressure at discharge = Atmospheric Pressure
= 101,325 N/m^2

Hp = (Pd – Ps) / ρ × g
Where,
ρ = 1,025 kg/m^3
g = 9.81 m/s^2

Hp = (101,325 – 121,435) / (1,025 × 9.81)
= -2 m

c) Head Velocity (Hv)
The difference in Flow Speed on the Suction and Discharge Side

- Flow speed at suction side = 2 m/s
- Flow speed at discharge side= 2 m/s

Hv = (V^2d – V^2s) / 2 g
Where,
g = 9,81 m/s^2

Hv = (2-2) / 2 × 9,81
= 0 m

d) Head Loss (Hl)
Losses experienced by flow along pipes and fittings. Head Loss is divided into 2, namely Head Loss Major and Head Loss Minor. Head Loss Major is a loss experienced due to friction that occurs along the pipeline between the fluid and the pipe wall. Minor Head Loss is a loss suffered due to fittings and other piping accessories.

a. Suction Line
Head Loss Major
Reynold Number
Re = (v × D) / υ
Where,
d = Pipe Diameter
= 0.165 m
v = Fluid Flow Speed
= 2 m/s
υ = Fluid Kinematic Viscosity (at 30°C)
= 0.802 × 10^{-6} m^2/s

Re = (0.165 × 2) / (0.802 × 10^{-6})
= 411,471

If the value of Re < 2,300, fluid flow is said to be a "Laminar" flow
If the value of Re > 2,300, fluid flow is said to be a "Turbulent" flow

Because the flow is Turbulent, the friction factor calculation uses Moody's diagram :

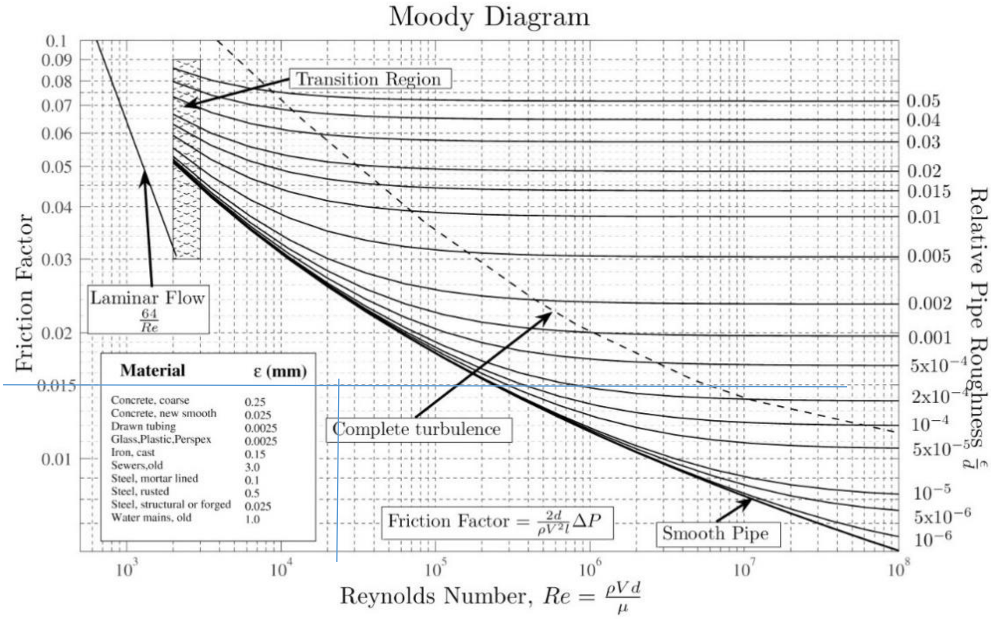


Figure 4. 2 Seawater moody diagram

By using the Forged Stainless Steel material as Sea Water pipe, the value of the friction factor is 0.015. Then, the value of the Head Loss Major can be calculated using the following equation :

Hlm $= f \times L \times v^2 / (D \times 2g)$

$= 0.015 \times 6 \times 2^2 / (0.165 \times 2 \times 9.81)$

$= 0.11$ m

Head Loss Minor

Table 4. 14 Seawater suction fittings

No	Type	N	k	N x k
1	Gate Valve	1	0.11	0.11
2	Butterfly Valve	1	2	2
3	Elbow 90°	1	1.1	1.1
4	Filter	2	2.5	5
			Total	8.21

Then, the value of Minor Head Loss can be calculated using the following equation :

Hl $= k\ Total \times v^2 / 2\ g$

$= 8.21 \times 2^2 / (2 \times 9{,}81)$

$= 1.67$ m

b. Discharge Line

Head Loss Major

Reynold Number

$Re = (v \times D) / \upsilon$

Where,

d = Pipe Diameter
= 0.165 m

v = Fluid Flow Speed
= 2 m/s

υ = Fluid Kinematic Viscosity (at 30°C)
$= 0.802 \times 10^{-6}\ m^2/s$

$Re = (0.165 \times 2) / (0.802 \times 10^{-6})$
$= 411{,}471$

If the value of Re < 2,300, fluid flow is said to be a "Laminar" flow
If the value of Re > 2,300, fluid flow is said to be a "Turbulent" flow

Because of the flow, including Turbulent, by using the method on Head Loss Major, a friction factor value of 0.015 is obtained. Then, the value of the Head Loss Major can be calculated using the following equation :

$$Hlm = f \times L \times v^2 / (D \times 2g)$$
$$= 0.015 \times 45 \times 2^2 / (0.165 \times 2 \times 9.81)$$
$$= 0.83 \text{ m}$$

Head Loss Minor

Table 4. 15 Seawater discharge fittings

No	**Type**	**N**	**k**	**N x k**
1	NRV	1	2.0	2.0
2	Elbow 90°	4	1.1	4.4
3	Pipe Reduction	1	0.3	0.3
4	Pipe Enlargement	1	0.33	0.33
			Total	7.03

Then, the value of Minor Head Loss can be calculated using the following equation:

$$Hl = k\ Total \times v2 / 2\ g$$
$$= 7.03 \times 2^2 / (2 \times 9{,}81)$$
$$= 1.43 \text{ m}$$

Heat Exchanger

On the discharge side, seawater will be used to cool freshwater with a heat exchanger. Based on references from the Heat Exchanger Project Guide from Hisaka Works Ltd., the pressure loss caused by HE is 0.6 MPa or equivalent to 6.12 meter head.

e) Total Head

The total pump head can be determined by adding up all the head parameters.

Total Head = Hz + Hp + Hv + Hl (Major + Minor)
= 22 – 2 + 0 + 0.11 + 1.67 + 0.83 + 1.43 + 6.12
= 30.16 m

Pump Capacity

The pump capacity for Seawater in this system requires a flow rate of 155 m3/h

Pump Needs

Head = 30.16 m

Q = 155 m^3/h

Table 4. 16 Seawater pump selection

Seawater Pump	
Pump Type	Centrifugal
Maker	Taiko
Type	ESC-250D
Capacity	190 m3/h
Head	60 m
Power	55 kW
Frequency	50 Hz

Fresh Water Pump Calculation

Pump Head

H = Hz + Hp + Hv + total Head loss.
Where,

a) Head Static (Hz)

Height Difference between Tank and Side Discharge

- Height at Z=0 towards discharge line = 20 meter
- Height at Z=0 towards suction line = 2 meter

Hz = Zd – Zs
= 20 – 2
= 18 m

b) Head Pressure (Hp)

Pressure Difference between Suction Side and Pipe Discharge Side

- Pressure at suction = Atmospheric Pressure + Hydrostatic Pressure
  = 101,325 N/m^2 + (2 ρ g)
  = 120,886 N/m^2
- Pressure at discharge = Atmospheric Pressure
  = 101,325 N/m^2

$$Hp = (Pd - Ps) / \rho \times g$$

Where,

ρ = 997 kg/m3

g = 9.81 m/s^2

$$Hp = (101{,}325 - 120{,}886) / (997 \times 9.81)$$
$$= -2 \text{ m}$$

c) Head Velocity (Hv)

The difference in Flow Speed on the Suction and Discharge Side

- Flow speed at suction side = 2 m/s
- Flow speed at discharge side = 2 m/s

$$Hv = (V^2d - V^2s) / 2\ g$$

Where,

g = 9.81 m/s^2

$$Hv = (2 - 2) / 2 \times 9.81$$
$$= 0 \text{ m}$$

d) Head Loss (Hl)

Losses experienced by flow along pipes and fittings. Head Loss is divided into 2, namely Head Loss Major and Head Loss Minor. Head Loss Major is a loss experienced due to friction that occurs along the pipeline between the fluid and the pipe wall. Minor Head Loss is a loss suffered due to fittings and other piping accessories.

a. Suction Line

Head Loss Major

Reynold Number

$Re = (v \times D) / \upsilon$

Where,

D = Pipe Diameter
= 0.118 m

v = Fluid Flow Speed
= 2 m/s

υ = Fluid Kinematic Viscosity (at 30°C)
= 0.802×10^{-6} m^2/s

Re = $(0.118 \times 2) / (0.802 \times 10^{-6})$
= 294,264

If the value of Re < 2,300, fluid flow is said to be a "Laminar" flow
If the value of Re > 2,300, fluid flow is said to be a "Turbulent" flow

Because the flow is Turbulent, the friction factor calculation uses Moody's diagram :

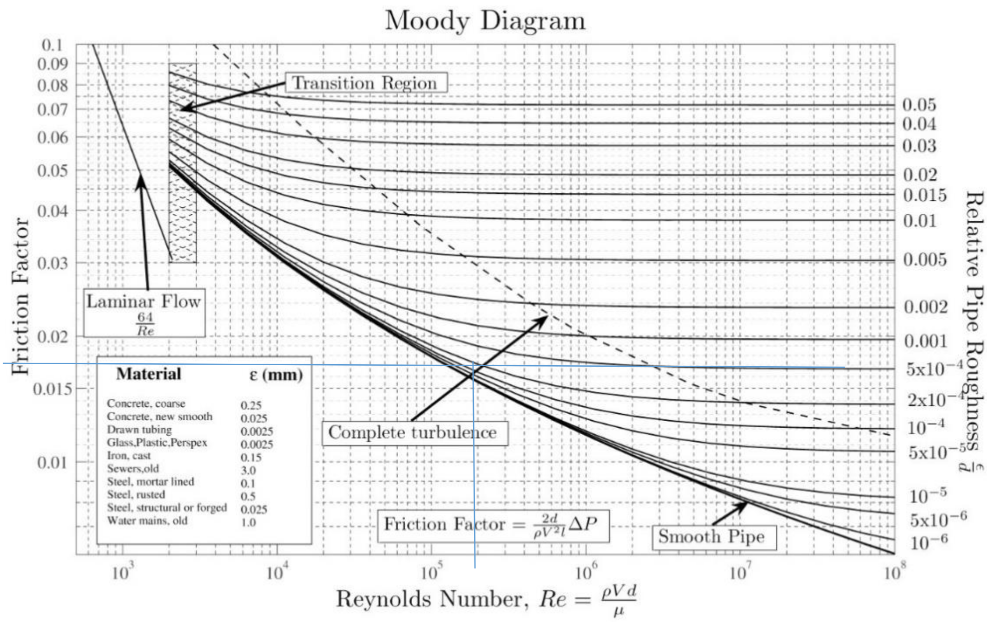


Figure 4. 3 Moody diagram of freshwater suction

By using the Carbon Steel material as a Freshwater pipe, the value of the friction factor is 0.018. Then, the value of the Head Loss Major can be calculated using the following equation :

Hlm = $f \times L \times v^2 / (D \times 2g)$
= $0.018 \times 8 \times 2^2 / (0.118 \times 2 \times 9.81)$
= 0.248 m

Head Loss Minor

Table 4. 17 Freshwater suction fittings

No	Type	N	k	N x k
1	Butterfly Valve	3	2	6
2	Elbow 90°	3	1,1	3
3	Filter	2	2.5	5
4	T Joint	3	1.1	3.3

5	Pipe Reduction	1	0.4	0.4
			Total	17.7

Then, the value of Minor Head Loss can be calculated using the following equation :

Hl = k Total × v2 / 2 g
= $17.7 \times 2^2 / (2 \text{ x } 9.81)$
= 3.6 m

b. Discharge Line
Head Loss Major

Reynold Number
Re = (v × D) / υ

Where,
d = Pipe Diameter
= 0.118 m
v = Fluid Flow Speed
= 2 m/s
υ = Fluid Kinematic Viscosity (at 30°C)
= 0.802×10^{-6} m^2/s

Re = $(0.118 \times 2) / (0.802 \times 10^{-6})$
= 294,264

If the value of Re < 2,300, fluid flow is said to be a “Laminar” flow
If the value of Re > 2,300, fluid flow is said to be a “Turbulent” flow

Because the flow is Turbulent, the friction factor calculation uses Moody's diagram:

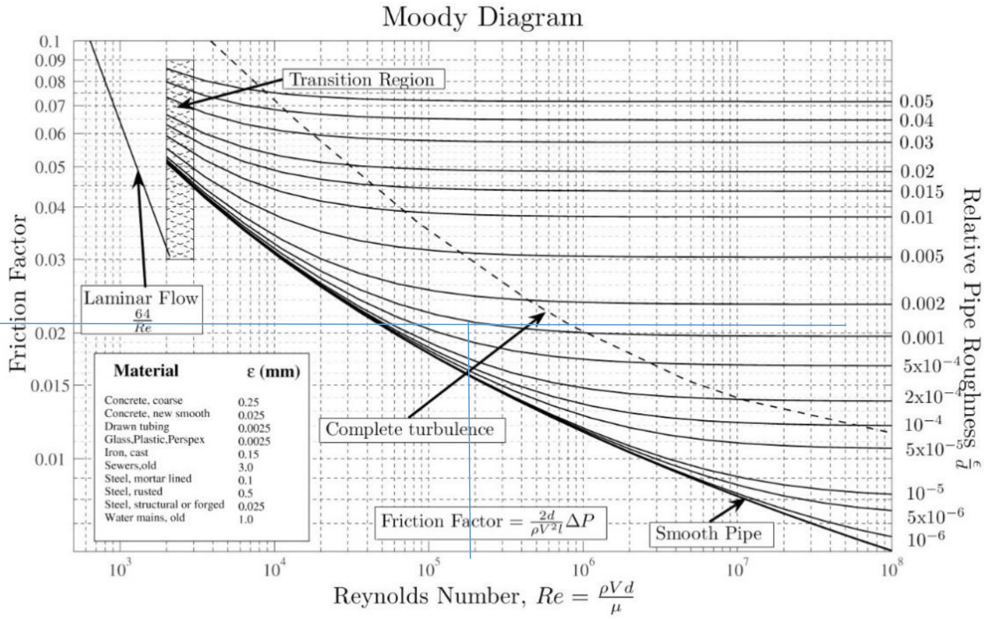


Figure 4. 4 Moody diagram of freshwater discharge

By using the Carbon Steel material as a Freshwater pipe, the value of the friction factor is 0.018. Then, the value of the Head Loss Major can be calculated using the following equation :

Hlm $= f \times L \times v^2 / (D \times 2g)$
$= 0.018 \times 10 \times 2^2 / (0.118 \times 2 \times 9.81)$
$= 0.31$ m

Head Loss Minor

Table 4. 18 Freshwater discharge fittings

No	Type	N	k	N x k
1	NRV	1	2.0	2.0
2	T Joint	2	0.75	1.5
3	Elbow 90	2	1	2.0
4	Nozzle	5	0.755	3.775
			Total	9.275

Then, the value of Minor Head Loss can be calculated using the following equation :

Hl $= k$ Total $\times$ v2 / 2 g
$= 9.275 \times 2^2 / (2 \times 9.81)$
$= 1.89$ m

Heat Exchanger

On the discharge side, freshwater will be cooled by seawater with a heat exchanger before entering the scrubber. Based on references from the

Heat Exchanger Project Guide from Hisaka Works Ltd., the pressure loss caused by HE is 0.6 MPa or equivalent to 6.12 meter head.

e) Total Head
The total pump head can be determined by adding up all the head parameters.

Total Head = Hz + Hp + Hv + Hl (Major + Minor)
= 18 - 2 + 0 + 0.248 + 3.6 + 0.31 + 1.89 + 6.12
= 28.168 m

Pump Capacity
The pump capacity for Fresh Water this system requires a flow rate of 80 m^3/h

Pump Needs
Head = 28.168 m
Q = 80 m^3/h

Table 4. 19 Freshwater pump selection

Freshwater Pump	
Pump Type	Centrifugal
Maker	Taiko
Type	ESC-150D
Capacity	100 m3/h
Head	50 m
Power	26 kW
Frequency	50 Hz

4.4. Component Selection

After the calculation is related to the installation process in the freshwater scrubber system, then the available components can be selected according to the calculation requirements. The selected components include pipes, pumps, heat exchangers, and wash water treatment.

Pipe Specification

Table 4. 20 Pipe specification

Pipe	**NaOH**	**Expansion Tk.**	**Fresh Water**	**Sea Water**
Nominal	15A	25A	125A	200A
Inside Diameter	16.1 mm	27.6 mm	130.8 mm	199.99 mm
Thickness	2.8 mm	3.2 mm	4.5 mm	8.2 mm
Outside Diameter	21.7 mm	34 mm	139.8 mm	216.3 mm
Material	Stainless Steel	Carbon Steel	Carbon Steel	Stainless Steel

Pump Specification

Table 4. 21 Pump specification

	NaOH Pump	Fresh Water Pump	Sea Water Pump
Pump Type	Centrifugal	Centrifugal	Centrifugal
Maker	Forte	Taiko	Taiko
Type	S-PC 4012H	ESC-150D	ESC-250D
Capacity	14.4 m3/h	100 m3/h	190 m3/h
Head	13 m	50 m	60 m
Power	0.75 kW	26 kW	55 kW
Frequency	50 Hz	50 Hz	50 Hz

Heat Exchanger Specification

Table 4. 22 Heat exchanger specification

Heat Exchanger	
Maker	Hisaka
Type	UX-20
Max. Flow Rate	197 m3/h
Max. Working Temp.	180°C
Max. Working Pressure	20 Bar

Washwater Treatment Specification

Table 4. 23 Washwater treatment specification

Washwater Treatment	
Maker	Wartsila
Type	SWT 500
Capacity	5 m3/h
Power	6 kW

4.5. Piping and Instrumentation Diagram

After making a Process Flow Diagram of the closed loop scrubber system, and find out the specifications of each component in the closed loop scrubber system, a Piping and Instrumentation Diagram will be made. The Piping and Instrumentation Diagram will display the specifications of each component and the flow of the desulfurization process. The depiction of PID can be seen in Figure 4.5.

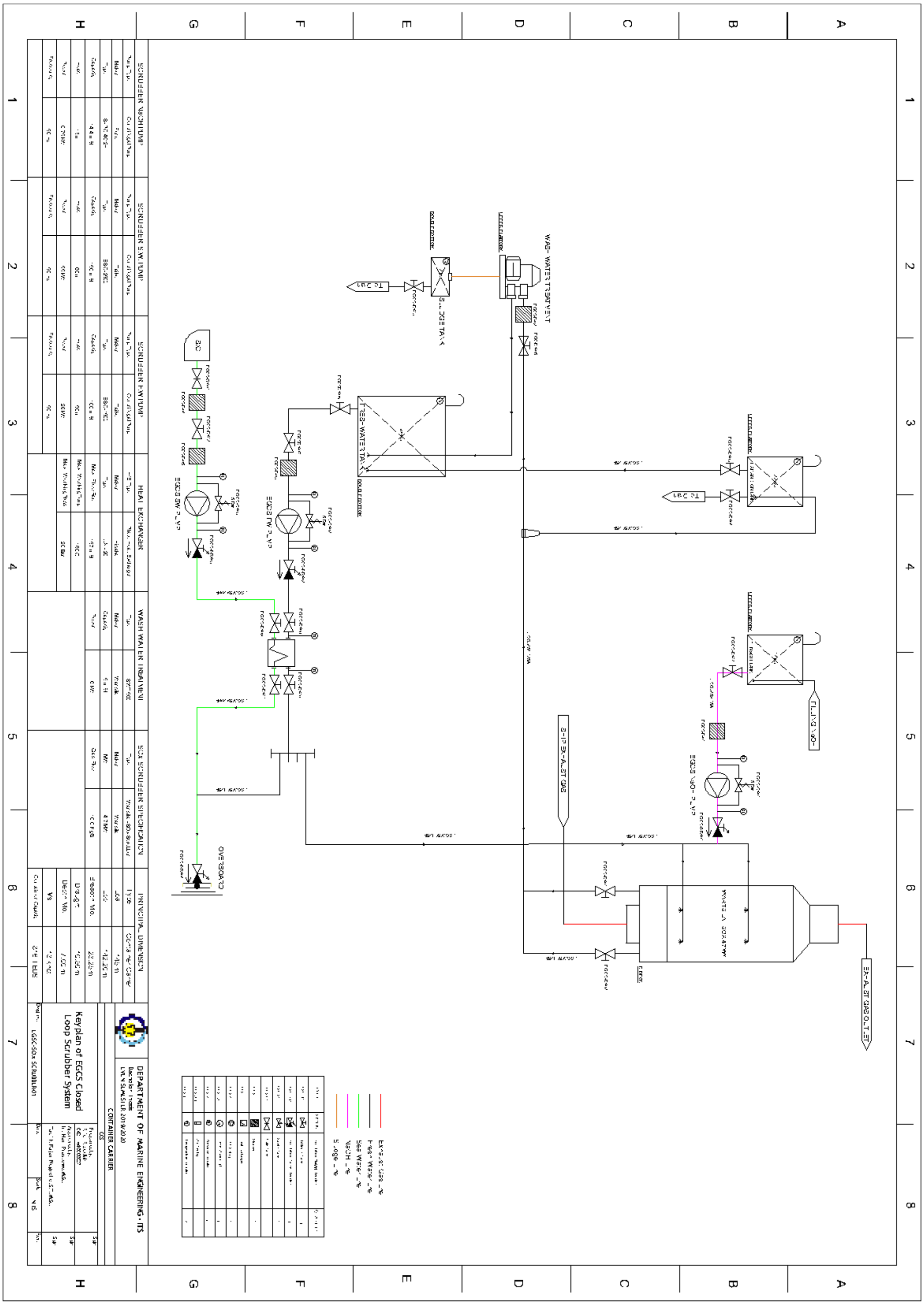


Figure 4. 5 Closed Loop Scrubber System PID

4.6. Closed Loop Scrubber System Drawing Arrangement

The depiction of Sulfur Scrubber System Drawing Arrangement is done to determine the placement of each component in the system. The sulfur scrubber unit on the ship is placed on Deck C to the tank top. The depiction of the closed loop scrubber system side view can be seen in figure 4.6.

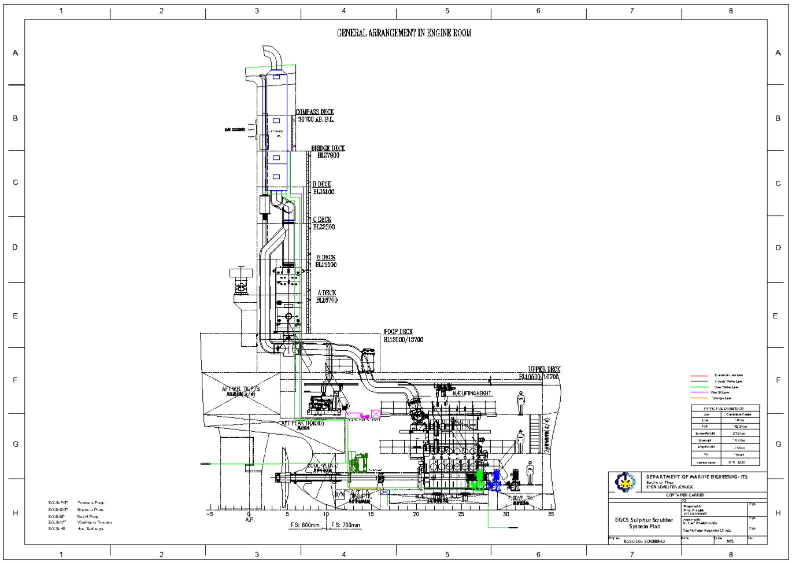


Figure 4. 6 Side view of closed loop scrubber system

In the double bottom of the ship, freshwater pumps, seawater cooling pumps and heat exchangers are placed. The purpose of laying the pump on the double bottom of the ship is because the freshwater tank on the ship is located at the bottom of the ship, then for the seawater cooling pump is placed at the bottom because the sea chest which is the entry point of seawater to the ship is at the bottom of the ship. The depiction of the closed loop scrubber system side view can be seen in figure 4.7.

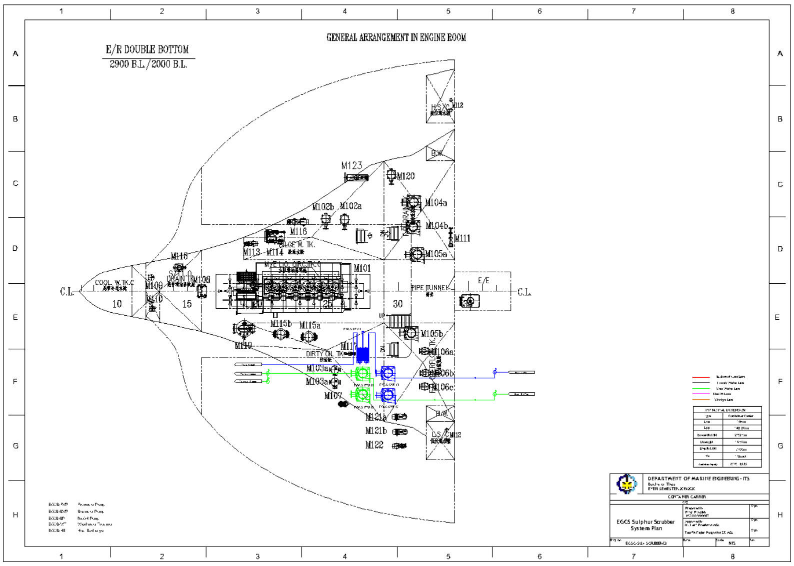


Figure 4. 7 Closed loop scrubber system view from the double bottom

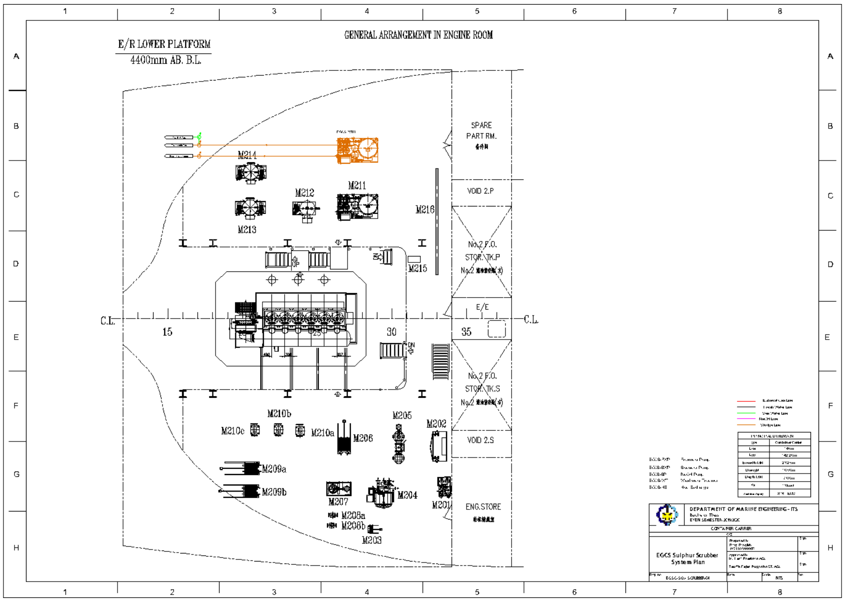


Figure 4. 8 Closed loop scrubber system view from E/R lower platform

In Figure 4.8. It can be seen that the wash water treatment unit that functions to clean freshwater that has been used to clean the sulfur oxide (SO_2) content is placed in the lower platform engine room.

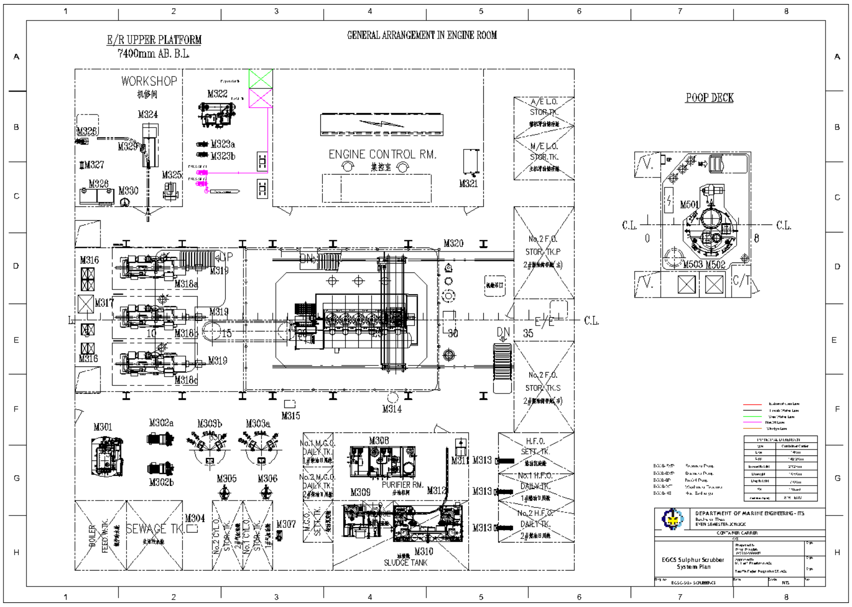


Figure 4. 9 Closed loop scrubber system view from E/R upper platform

In Figure 4.9, it can be seen that the sodium hydroxide (NaOH) tank, sodium hydroxide (NaOH) pump, and expansion tank are placed in the engine platform upper platform.

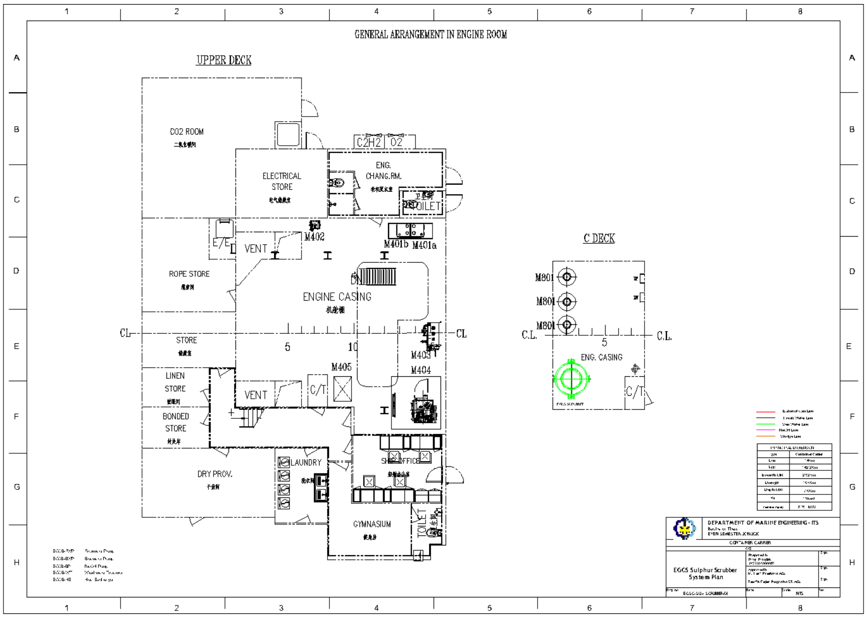


Figure 4. 10 Closed loop scrubber system view from the upper deck

In figure 4.10 shows a cross-section of the sulfur scrubber unit located on deck C of the ship, where on deck C, it is part of the ship's funnel.

4.7. Back Pressure Calculation

Engine exhaust backpressure is defined as the exhaust gas pressure that is produced by the engine to overcome the hydraulic resistance of the exhaust system in order to discharge the gases into the atmosphere. For this discussion, the exhaust backpressure is the gauge pressure in the exhaust system at the outlet of the exhaust turbine in turbocharged engines or the pressure at the outlet of the exhaust manifold in naturally aspirated engines.

The exhaust gas backpressure after the turbocharger depends on the total pressure drop in the exhaust gas piping system. The components, exhaust gas boiler, exhaust gas scrubber, silencer, and spark arrester, if fitted, usually contribute with a major part of the dynamic pressure drop through the entire exhaust gas piping system. The pressure loss calculations have to be based on the actual exhaust gas amount and temperature valid for specified MCR. Some general formulas and definitions are given in the following.

According to Mitsubishi 6UEC33LSE-C2 technical data, maximum exhaust gas at the engine exhaust outlet is expected to exceed the maximum value, i.e. 300 mm WC.

Exhaust gas data

M = 25,100 kg/h
= 6,972 kg/sec
T = 273 ºC

Mass density of exhaust (ρ)

ρ = 1.293 × (273/273+T) × 1.015
= 1.293 × (273/273+273) × 1.015
= 359.6 kg/m3

The factor 1.015 refers to the average back presssure of 150 mm WC (0.015 bar) in the exhaust gas system

Exhaust gas velocity (v)

v = (M/ρ) × (4/π × D2)
v = (6,972/359.6) × (3/3.14 × 0.8)
v = 0.015808 m/s

Pressure losses in pipes (Δp)

For a pipe element, like a bend etc., with the resist-ance coefficient ζ, the corresponding pressure loss is:

(Δp) $= \zeta \, x \, ^1/_2 \, x \, \rho \, x \, v^2 \, x \, ^1/_{9.81}$

where the expression after ζ is the dynamic pressure of the flow in the pipe.

(Δp) for 60 bendings in exhaust pipe $= \zeta \, x \, ^1/_2 \, x \, \rho \, x \, v^2 \, x \, ^1/_{9.81}$
$= 0.16 \, x \, ^1/_2 \, x \, 359.6 \, x \, (0.0158)^2 \, x \, ^1/_{9.81}$
$= 0.00073 \, mmWc$

(Δp) for 45 bendings in exhaust pipe $= \zeta \, x \, ^1/_2 \, x \, \rho \, x \, v^2 \, x \, ^1/_{9.81}$
$= 0.14 \, x \, ^1/_2 \, x \, 359.6 \, x \, (0.0158)^2 \, x \, ^1/_{9.81}$
$= 0.00064 \, mmWc$

(Δp) for 30 bendings in exhaust pipe $= \zeta \, x \, ^1/_2 \, x \, \rho \, x \, v^2 \, x \, ^1/_{9.81}$
$= 0.05 \, x \, ^1/_2 \, x \, 359.6 \, x \, (0.0158)^2 \, x \, ^1/_{9.81}$
$= 0.00023 \, mmWc$

(Δp) for 30 change over valve 90 $= \zeta \, x \, ^1/_2 \, x \, \rho \, x \, v^2 \, x \, ^1/_{9.81}$
$= 1.2 \, x \, ^1/_2 \, x \, 359.6 \, x \, (0.0158)^2 \, x \, ^1/_{9.81}$
$= 0.00687 \, mmWc$

(Δp) for 30 change over valve 60 $= \zeta \, x \, ^1/_2 \, x \, \rho \, x \, v^2 \, x \, ^1/_{9.81}$
$= 1.5 \, x \, ^1/_2 \, x \, 359.6 \, x \, (0.0158)^2 \, x \, ^1/_{9.81}$
$= 0.0055 \, mmWc$

(Δp) for 30 change over valve 120 $= \zeta \, x \, ^1/_2 \, x \, \rho \, x \, v^2 \, x \, ^1/_{9.81}$

$= 2 \, x \, {}^{1}/_{2} \, x \, 359.6 \, x \, (0.0158)^2 \, x \, {}^{1}/_{9.81}$
$= 0.00916 \, mmWC$

Pressure losses across components (Δp)

(Δp) for exhaust gas boiler.

Engine plants are usually designed for utilization of the heat energy of the exhaust gas for steam production or for heating the thermal oil system. The exhaust gas passes an exhaust gas boiler, which is usually placed near the engine top or in the funnel. It should be noted that the exhaust gas temperature and flow rate are influenced by the ambient conditions, for which reason this should be considered when the exhaust gas boiler is planned. At specified MCR, the maximum recommended pressure loss across the exhaust gas boiler is normally 150 mm WC.

(Δp) for exhaust gas scrubber.

According to Wartsila I-line exhaust gas scrubber, the maximum pressure loss of the I-Sox scrubber is 150 mm WC.

Total back-pressure (ΔpM)
(ΔpM) = Σ Δp
= 300.02 mm WC

4.8. Electrical Calculation

The power source on the ship comes from a generator. The generator functions to meet all the electricity needs on the ship in various conditions. By making modifications that require the addition of components will cause electricity demand on the ship to increase. The increase in electricity demand will affect the generator load on the ship. Therefore, the calculation of electricity needs to be done again to find out whether the generator that has been installed on the ship is able to meet the electricity needs of the ship after adding components to the scrubber system.

To find out the load of the generator after being given the addition of components requires data in the form of Electrical Load or the electrical load that is owned on the ship. The load generator on the ship is divided into four conditions, namely when sailing (sea going), when maneuvering (maneuvering), loading and unloading (cargo operation), and port (harbor).

Table 4. 24 Ship electrical load

Item		Sea going	Manoeuvring	Cargo Operation	Harbour
Intermittent load (kW)	Total	316.2	167.8	149.6	121.2
	Diversity factor	0.7	0.7	0.7	0.7
	Demand power	221.3	117.46	104.72	84.84

Continous load (kW)	**Demand power**	360.1	253.4	627.6	291.4
Total continous & intermitten load		581.4	370.8	762.2	400.5
Design margin (2%) (kW)		11.62	7.41	15.24	8.01
Total demand power with provision for design margin (kw)		**593**	**378.2**	**777.4**	**408.5**

(Advanced Table 4.24 Ship electrical load)

The electricity needs recalculation in the closed loop scrubber system installation is carried out under sea going, maneuvering, cargo operations, and harbor conditions. This is done because the closed loop scrubber system operates continuously on the ship. So, making adjustments to electricity needs will provide an additional load on a continuous load in every ship's operation. The calculations related to additional generator loads due to modification of the inert gas system are as follows:

New Sea Going CL = Initial CL + (LF × New component power)
= 360.1 + (0.85 × 169.5)
= 504.17 kW

Total demand power = Total IL & CL × (1 + design margin)
= 221.3 + 504.17 × (1 + 2%)
= 739.98 kW

New Maneuvering CL = Initial CL + (LF × New component power)
= 253.4 + (0.85 × 169.5)
= 397.47 kW

Total demand power = Total IL & CL × (1 + design margin)
= 117.46 + 397.45 × (1 + 2%)
= 525.23 kW

New Cargo Oper. CL = Initial CL + (LF × New component power)
= 627.6 + (0.85 × 169.5)
= 771.67 kW

Total demand power = Total IL & CL × (1 + design margin)
= 104.72 + 771.67 × (1 + 2%)
= 893.92 kW

New Harbour CL = Initial CL + (LF × New componen power)
= 291.4 + (0.85 × 169.5)
= 435.475 kW

Total demand power = Total IL & CL × (1 + design margin)

= 84.84 + 435.475 × (1 + 2%)
= 530.72 kW

Table 4. 25 Ship electrical load for after adding new component power

Item		Sea going	Maneuvering	Cargo Operation	Harbour
Intermittent load (kW)	**Total**	316.2	167.8	149.6	121.2
	Diversity factor	0.7	0.7	0.7	0.7
	Demand power	221.3	117.46	104.72	84.84
Continous load (kW)	**Demand power**	504.17	397.47	771.67	435.75
Total continous & intermitten load		725.47	514.93	876.39	520.31
Design margin (2%) (kW)		14.5	10.29	17.52	10.4
Total demand power with provision for design margin (kw)		**739.98**	**525.23**	**893.92**	**530.72**

After knowing the total demand power, the next step is to calculate the shipload factor, especially in the condition of sea going, maneuvering cargo operation, and harbor. The load factor calculation using three generators contained in the ship can be determined using the following formula:

Load Factor Sea Going = Total power needed / Total power generated by the generator
= 739.9 / (450 × 3)
= 55 %

Load Factor Maneuvering = Total power needed / Total power generated by the generator
= 525.2 / (450 × 3)
= 39 %

Load Factor Cargo Operation = Total power needed / Total power generated by the generator
= 893.92 / (450 × 3)
= 66 %

Load Factor Harbour = Total power needed / Total power generated by the generator
= 530.72 / (450 × 3)
= 39 %

After calculating the load factor of each operation on the ship, it was concluded that the capacity of the generator that was available on the ship was still sufficient to do the installation of the closed loop scrubber system.

The next step is the calculation of the starting current with load conditions after adding components. This calculation requires the highest value of power consumption among all components that are on the ship. On this ship, the most significant power consumption is used for cargo cranes that are worth 345 kW. Because the scrubber system component is not a component with the highest power consumption value, there is no significant change in the calculation of load analysis at the starting current. The following is the calculation of load analysis at start condition:

Starting Power = Cargo operation total power (without cargo crane) / Cargo crane power
= 393.92 / (250 × 3)
= 1,143.92 kW

After calculating the starting current, the generator efficiency is then calculated using the following formula:

Generator Efficiency = Starting power / Generator total power
= 1,143.92 / (450 × 3)
= 84.7 %

This value is still permitted, meaning that the ship's generator is still sufficient for electricity after adding the closed loop scrubber system.

4.9. Bill of Quantity and Equipment Cost Estimation

According to previous calculation and design from the closed loop scrubber system, there are several types of equipment installed consists of pumps, pipes, fittings, and other equipment. The following is a list of equipment that will be installed closed loop scrubber system.

Table 4. 26 Equipment bill of quantity

No	Item	Specification	Qty	Unit
Equipment List				
1	Sox Scrubber	Brand: Wartsila Type: Wartsila I-Sox Closed Loop Scrubber 4.7 MW	1	Pcs
2	Sea Water Pump	Brand: Taiko ESC-200 D Flow Rate: 190 m3/h Head: 60 m Power : 55 kW	2	Pcs

3	Fresh Water Pump	Brand: Taiko ESC-150D Capacity: 100 m3/h Head: 50 m Power : 26 kW	2	Pcs
4	NaOH Pump	Brand: Forte S-PC 4012H Capacity : 14.4 m3/h Head: 13 m Power : 0.75 kW	2	Pcs
5	Heat Exchanger	Brand: Hisaka UX-20 Max. Flow Rate: 197 m3/h Max. Working Temperature: 180°C Max. Working Pressure: 20 Bar	1	Pcs
6	Wash Water Treatment	Brand: Wartsila OWS 5000 Capacity: 5 m3/h Power : 6 kW	1	Pcs

(Advanced Table 4.26 Equipment bill of quantity)

Table 4. 27 Pipe and fittings bill of quantity

No	Item	Specification	Qty	Unit
1	Stainless Steel Pipe	Stainless Steel, Sch 40, 8"	20	m
2	Stainless Steel Pipe	Stainless Steel, Sch 40, 1/2"	27	m
3	Carbon Steel Pipe	Carbon Steel, Sch 40, 5"	78	m
4	Carbon Steel Pipe	Carbon Steel, Sch 40, 1"	10	m
5	Gate Valve	8 inch	1	pcs
6	Butterfly Valve	8 inch	3	pcs
7	Butterfly Valve	5 inch	7	pcs
8	Butterfly Valve	1 inch	3	pcs
9	Butterfly Valve	0.5 inch	1	pcs
10	NRV	8 inch	2	pcs
11	NRV	5 inch	1	pcs
12	NRV	0.5 inch	1	pcs
13	Safety Valve	5 Bar 3/8 inch	3	pcs
14	Elbow 90	Carbon Steel 5 inch	5	pcs
15	Elbow 90	Stainless Steel 8 inch	4	pcs
16	Elbow 90	Carbon Steel 1 inch	1	pcs
17	Elbow 90	Stainless Steel 0.5 inch	1	pcs
18	Filter	8 inch	2	pcs
19	Filter	5 inch	2	pcs
20	Filter	0.5 inch	1	pcs
21	T Joint	Carbon Steel 5 inch	3	pcs

22	T Joint	Carbon Steel 1 inch	1	pcs
23	T Joint	Stainless Steel 0.5 inch	4	pcs
24	Pressure Indicator		8	pcs
25	Level Alarm		4	pcs

(Advanced Table 4.27 Pipe and fittings bill of quantity)

After knowing the list of required components along with the number and size, then the estimated cost of equipment is then based on the size and specifications of the equipment. Equipment costs estimation is needed to determine then the installation costs of the closed loop scrubber system. It will be used to determine capital expenditure (CAPEX) to install this system. The price of each unit can be from approximation and online shop for marine machinery. For price information that is not in Rupiah (IDR) will be converted by xe.com as a currency converter website. The Rupiah exchange rate used in this research was taken on August 5, 2020, with an exchange rate of 1 USD to rupiah of IDR 14,596.

Table 4. 28 Closed loop scrubber component cost

No.	Item	Qty	Units Cost	Total Cost
1	Sulphur Scrubber	1	Rp7,298,000,000	Rp7,298,000,000
2	Sea Water Pump	2	Rp233,536,000	Rp467,072,000
3	Fresh Water Pump	2	Rp160,556,000	Rp321,112,000
4	NaOH Pump	2	Rp37,500,000	Rp75,000,000
5	Heat Exchanger	1	Rp291,920,000	Rp291,920,000
6	Wash Water Treatment	1	Rp291,920,000	Rp291,920,000
Total				Rp8,745,024,000

Table 4. 29 Closed loop scrubber pipe and fittings cost

No.	Item	Qty	Unit	Units Cost	Total Cost
1	Stainless Steel Pipe, Sch 40, 8"	20	m	Rp3,575,100.00	Rp71,502,000
2	Stainless Steel Pipe, Sch 40, 1/2"	27	m	Rp354,450.00	Rp9,570,150
3	Carbon Steel Pipe, Sch 40, 5"	78	m	Rp1,487,500.00	Rp116,025,000
4	Carbon Steel Pipe, Sch 40, 1"	10	m	Rp309,400.00	Rp3,094,000
5	Gate Valve 8"	1	pcs	Rp3,062,000.00	Rp3,062,000
6	Butterfly Valve 8"	3	pcs	Rp5,250,000.00	Rp15,750,000
7	Butterfly Valve 5"	7	pcs	Rp4,378,000.00	Rp30,646,000
8	Butterfly Valve 1/2"	3	pcs	Rp770,000.00	Rp2,310,000
9	Butterfly Valve 1"	1	pcs	Rp770,000.00	Rp770,000
10	NRV 8"	2	pcs	Rp6,187,920.00	Rp12,375,840

11	NRV 5"	1	pcs	Rp2,672,928.00	Rp2,672,928
12	NRV 1/2"	1	pcs	Rp651,360.00	Rp651,360
13	Safety Valve 3/8"	3	pcs	Rp1,740,972.00	Rp5,222,916
14	Elbow 90 Carbon Steel 5"	5	pcs	Rp377,000.00	Rp1,885,000
15	Elbow 90 Stainless Steel 8"	4	pcs	Rp746,000.00	Rp2,984,000
16	Elbow 90 Carbon Steel 1"	1	pcs	Rp95,000.00	Rp95,000
17	Elbow 90 Stainless Steel 1/2"	1	pcs	Rp139,000.00	Rp139,000
18	Filter 8"	2	pcs	Rp1,132,800.00	Rp2,265,600
19	Filter 1"	2	pcs	Rp620,237.00	Rp1,240,474
20	Filter 1/2"	1	pcs	Rp594,720.00	Rp594,720
21	T Joint Carbon Steel 5"	3	pcs	Rp377,000.00	Rp1,131,000
22	T Joint Carbon Steel 1"	1	pcs	Rp95,000.00	Rp95,000
23	T Joint Stainless Steel 5"	4	pcs	Rp139,000.00	Rp556,000
24	Pressure Indicator	8	pcs	Rp283,200.00	Rp2,265,600
25	Level Alarm	4	pcs	Rp708,000.00	Rp2,832,000
Total					Rp289,735,588

(Advanced Table 4.29 Closed loop scrubber pipe and fittings cost)

4.10. Economic Calculation

4.10.1. Capital Expenditure

After knowing the costs of each component, pipe and fitting costs can be calculated procurement cost of closed loop scrubber system, which can be seen in table 4.30.

a. Procurement Cost

Table 4. 30 Closed loop scrubber procurement cost

Procurement Cost			
No	**Item**	**Estimation**	**Total Cost**
1	Equipment Cost	Component + Pipe & Fittings	Rp9,107,110,788
2	Shipping Cost	5% of Equipment Cost	Rp455,355,539
3	Component Spare Parts	5% of Component Cost	Rp440,868,760
4	Insurance	0.5% of Shipping + Equipment Cost	Rp47,812,331
5	Import Duty	7.5% of Equipment + Shipping + Insurance	Rp720,770,899
6	PPN	10% of Equipment Cost	Rp910,711,078
Total			Rp11,682,629,397

b. Installation Cost

Table 4. 31 Closed loop scrubber installation cost

Installation Cost			
No	**Item**	**Estimation**	**Total Cost**
1	Component & Fittings Installation Cost	5% of Equipment Cost	Rp455,355,539
2	Dry Dock	18 Days x Rp11,143,000	Rp200,574,000
3	Docking & Undocking	Rp74,279,000	Rp74,279,000
4	Docking Report	Rp8,073,000	Rp8,073,000
Total			Rp738,281,539

c. Total Capital Expenditure

After knowing the costs of each component, pipe and fitting costs can be calculated procurement cost of closed loop scrubber system, which can be seen in table 4.30.

Table 4. 32 Closed loop scrubber total capital expenditure

Total Capital Expenditure		
No	**Item**	**Total Cost**
1	Procurement Cost	Rp11,682,629,397
2	Installation Cost	Rp738,281,539
Total		Rp12,420,910,936

4.10.2. Operational Expenditure

a. Fuel Oil Consumption Cost

Table 4. 33 Closed loop scrubber fuel consumption cost

No	Formula/Data	Information	Value	Unit
1	Equipment's Power Consumption	Sea Water Pump: 55 kW × 2 Fresh Water Pump: 26 kW × 2 NaOH Pump : 0.75 kW × 2 Wash Water Treatment: 6 kW	169.5	kW
2	Exhaust Gas Duration		24.00	hour
3	Equipment's Energy Consumption kWh = P x t	kWh = 169.5 × 24	4,068	kWh
4	SFOC	Generator Specification	206	g/kWh

5	Fuel Consumption (ton)/day Fuel Consumption = Energy Consumption x SFOC x 10^{-6}	FOC = 4,068 × 206 × 10^{-6}	0.84	ton
6	Fuel Consumption/trip	FOC = 0.84 ton × 10 Day	8.38	ton
6	MGO Fuel Price	shipandbunker.com	388	USD/MT
7	Fuel Consumption Cost Cost = Fuel Consumption x MGO Fuel Price x Rupiah Conversion	Cost = 8.38 × 388 × 14,596	47,458,471	Rupiah

(Advanced Table 4.33 Closed loop scrubber fuel consumption cost)

b. Sodium Hydroxide (NaOH) Consumption Cost

Table 4. 34 Sodium hydroxide (NaOH) consumption cost

No	Formula/Data	Information	Value	Unit
1	NaOH Consumption/day	0.0515 m3 × 24 hour	1.24	m3
2	NaOH Consumption/trip	1.24 m3 × 10 days	12.36	m3
3	NaOH Price		350.00	USD/MT
4	NaOH Consumption Cost/trip	12.36 × 350 × 14,596	63,142,296	Rupiah

c. Operational Cost

Table 4. 35 Closed loop scrubber total operational expenditure

No	Cost Type	Quantity	Unit	Price/Unit	Total Cost
1	Fuel	29	Voyage	Rp47,458,471	Rp1,376,295,667
2	NaOH	29	Voyage	Rp63,142,296	Rp1,831,126,548
3	Freshwater	29	Voyage	Rp2,400,000	Rp69,600,000
Total					Rp3,277,022,251

d. Total Operational Expenditure

Table 4. 36 Total operational expenditure for closed loop scrubber

No	Item	Estimation	Total Cost
1	Maintenance & Repair Cost	15% of Installation Cost	Rp109,048,390
2	Maintenance of Equipment	5% of Equipment Cost	Rp444,063,268
3	Operational Cost	From table 4.28	Rp3,277,022,251
Total			Rp3,843,120,022

4.10.3. Comparison of Operational Cost between Closed Loop Scrubber System and LSFO

From the calculation of operational costs from the application of closed loop scrubber system and the use of low sulfur fuel oil without scrubbers can be seen in Table 4.35 below.

Table 4. 37 Operational costs of closed loop scrubber system vs. LSFO

No	Operational Cost (HFO + Scrubber)	Operational Cost LSFO	Item
1	Rp656,904,405	Rp841,209,306	Per Trip
2	Rp19,119,827,756	Rp24,395,069,881	Per Year

CHAPTER V
CONCLUSION

5.1. Conclusion

In this bachelor thesis, "Analysis the Application of Closed Loop Scrubber System on 816 TEUS Container Ship to Comply with 2020 Global Sulphur Limit - MARPOL Annex VI Regulation 14" has the following results. :

1. According to technical feasibility, that has been done. In installing the closed loop scrubber system, the following components are required:

Table 5. 1 Scrubber Specification

SOx Scrubber	
Maker	Wartsila
Type	I-SOx
MW	4.7
Gas Flow	10.0 kg/S

Table 5. 2 Pump specification

	NaOH Pump	**Fresh Water Pump**	**Sea Water Pump**
Pump Type	Centrifugal	Centrifugal	Centrifugal
Maker	Forte	Taiko	Taiko
Type	S-PC 4012H	ESC-150D	ESC-250D
Capacity	14.4 m3/h	100 m3/h	190 m3/h
Head	13 m	50 m	60 m
Power	0.75 kW	26 kW	55 kW
Frequency	50 Hz	50 Hz	50 Hz

Table 5. 3 Heat exchanger specification

Heat Exchanger	
Maker	Hisaka
Type	UX-20
Max. Flow Rate	197 m3/h
Max. Working Temp.	180°C
Max. Working Pressure	20 Bar

Table 5. 4 Washwater treatment specification

Washwater Treatment	
Maker	Wartsila
Type	SWT 500
Capacity	5 m3/h
Power	6 kW

2. Key plan of the closed loop scrubber system on 816 TEU's container ship can be seen in sub-chapter 4.5.
3. Based on the results of economic calculations carried out in sub-chapter 4.10.1, it shows that the capital expenditure (CAPEX) cost of the closed loop scrubber system is Rp12,420,910,936
4. Based on the results of economic calculations carried out in sub-chapter 4.10.2 shows that the operational expenditure (OPEX) costs of the closed loop scrubber system are Rp3,843,120,022
5. Based on calculation, comparison of operational cost between closed loop scrubber system and LSFO, the following result is obtained :

Tabel 5. 1 Operational cost of closed loop scrubber system vs. LSFO

No	**Operational Cost (HFO + Scrubber)**	**Operational Cost LSFO**	**Item**
1	Rp656,904,405	Rp841,209,306	Per Trip
2	Rp19,119,827,756	Rp24,395,069,881	Per Year

5.2. Suggestion

There are many aspects to be improved in the next research regarding:

1. The cost for each equipment in engineering cost estimation shall be based on the real cost from sellers, not an approximation, so the total capital expenditure (CAPEX) can be obtained optimally.

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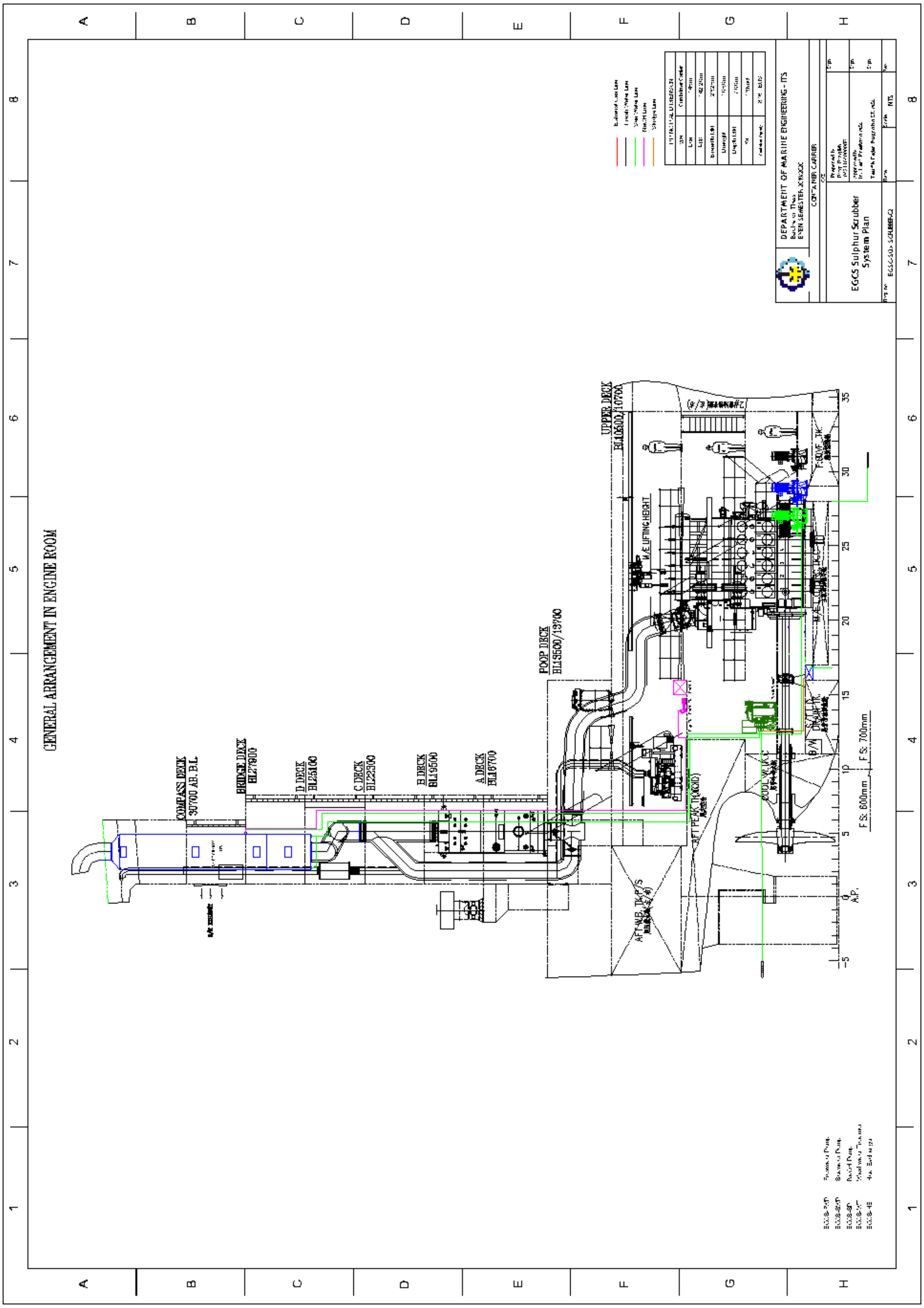
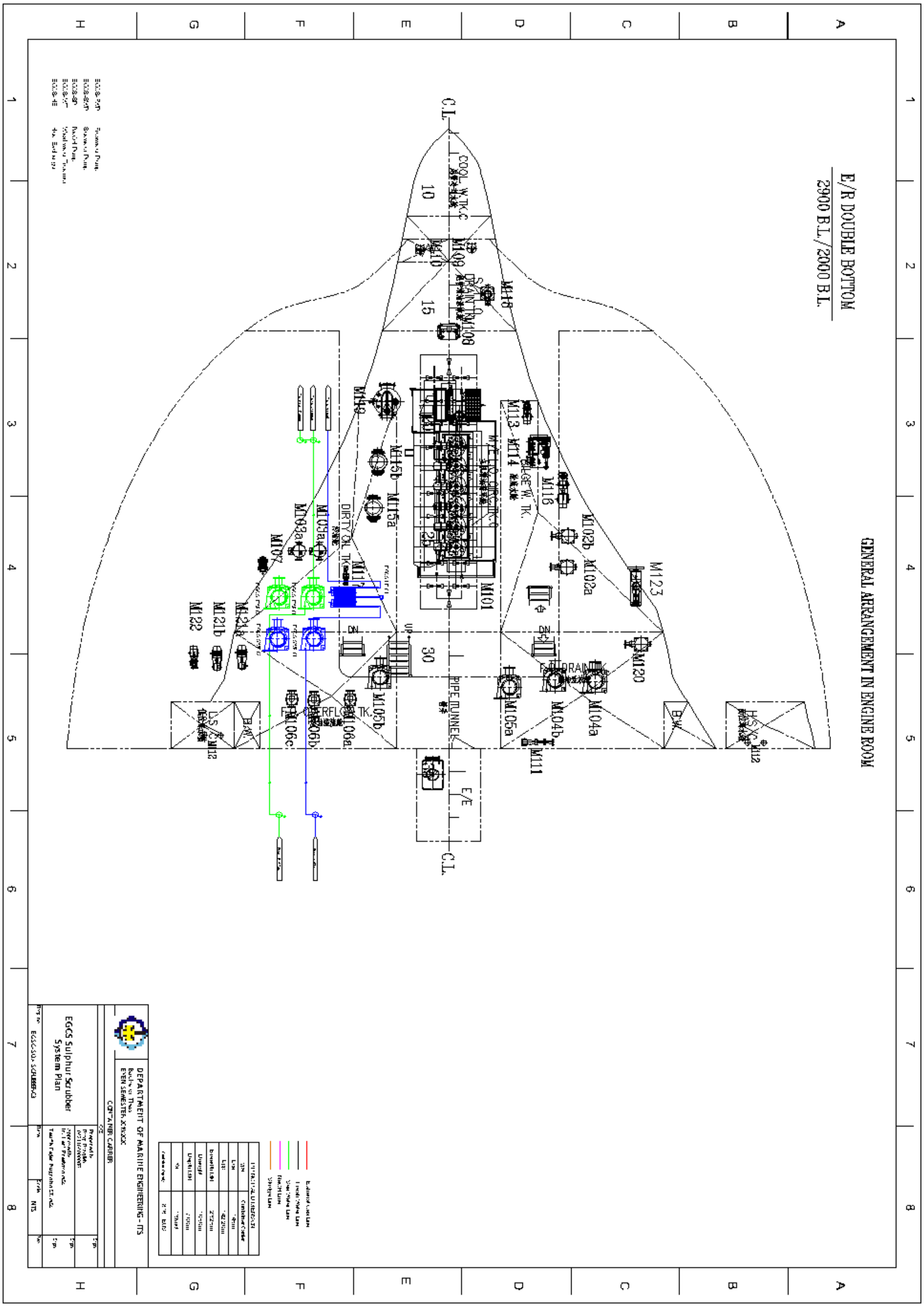
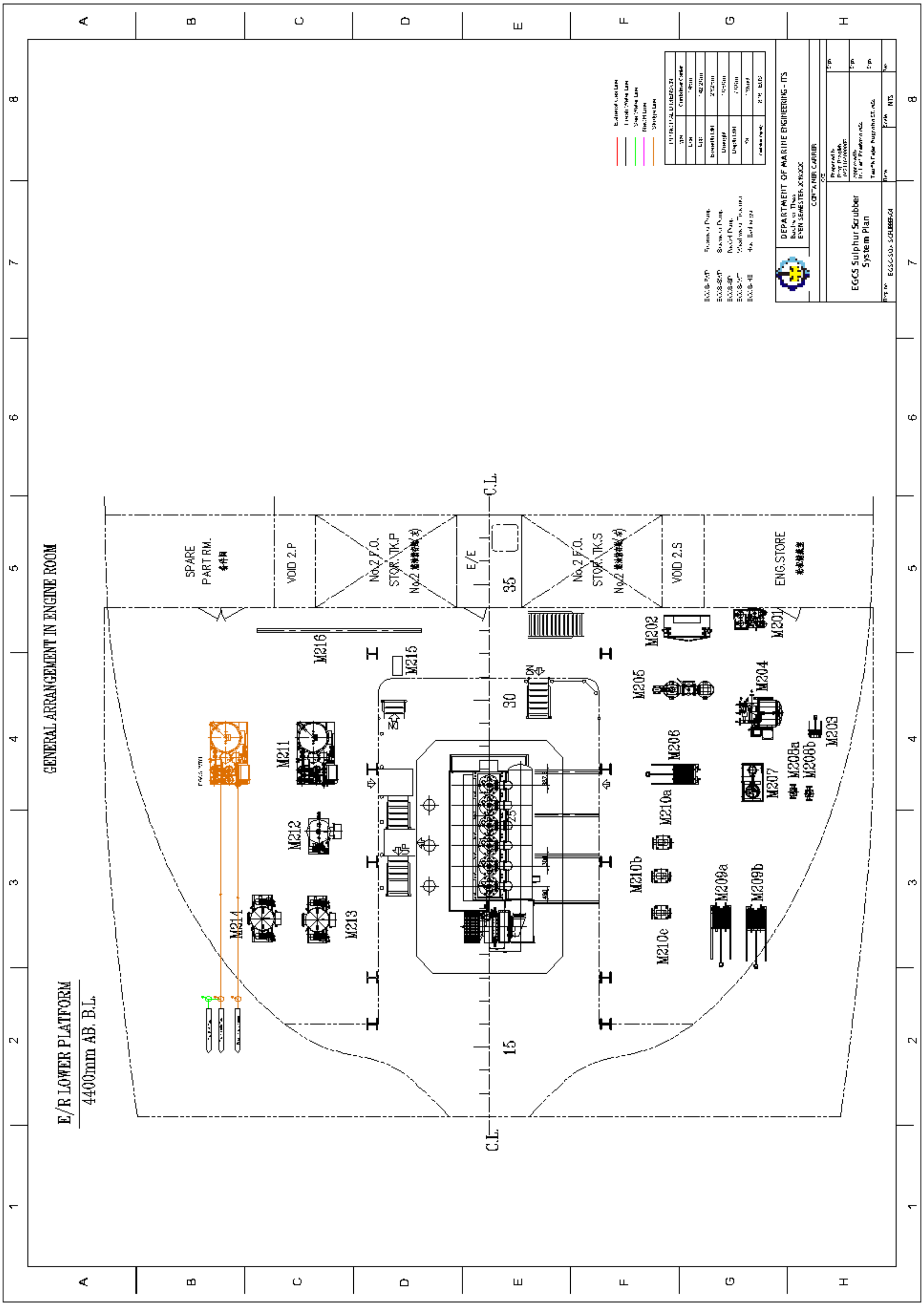
Appendix 1. 1 Side view of closed loop scrubber system



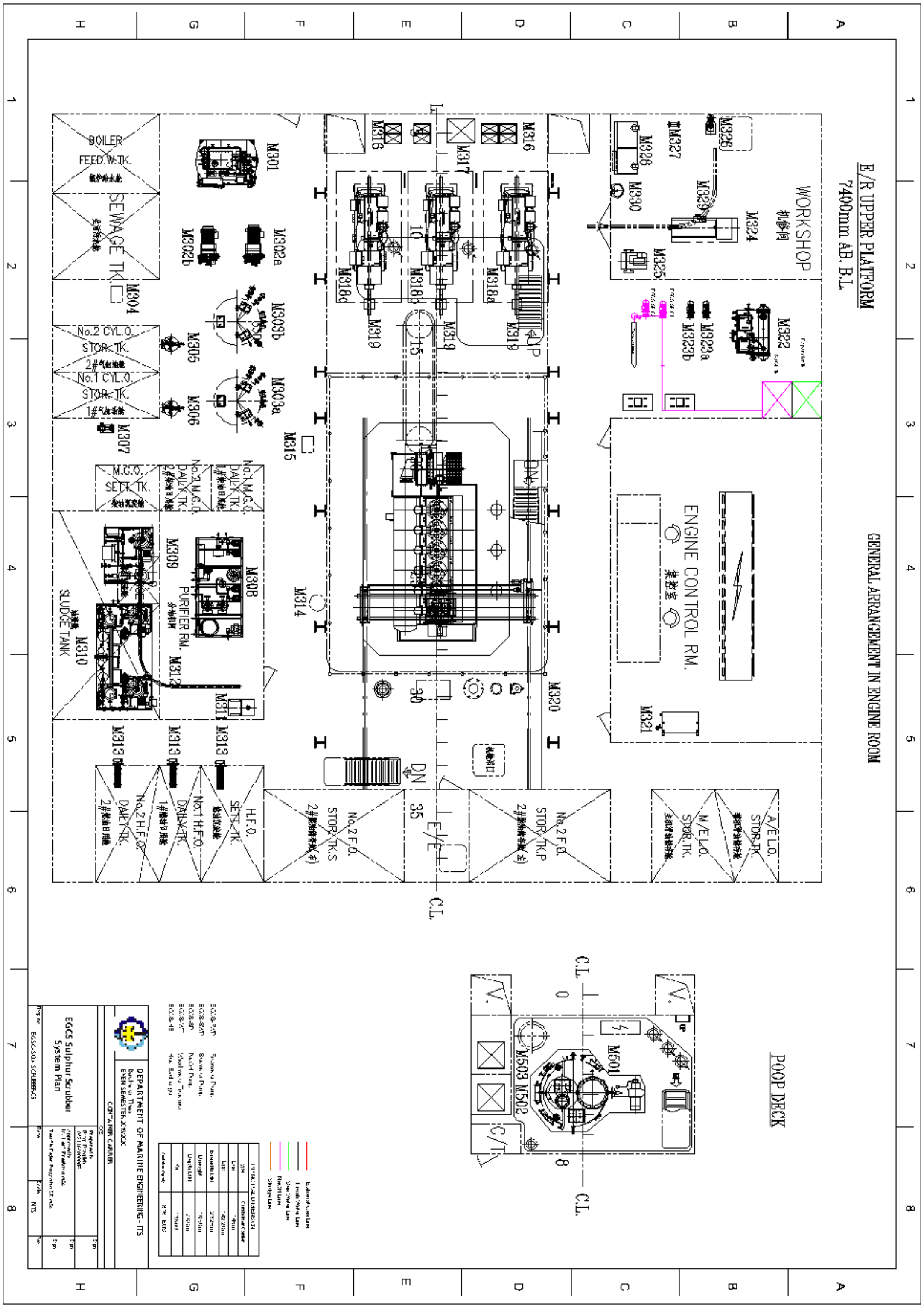
Appendix 1. 2 Closed loop scrubber system view from the double bottom



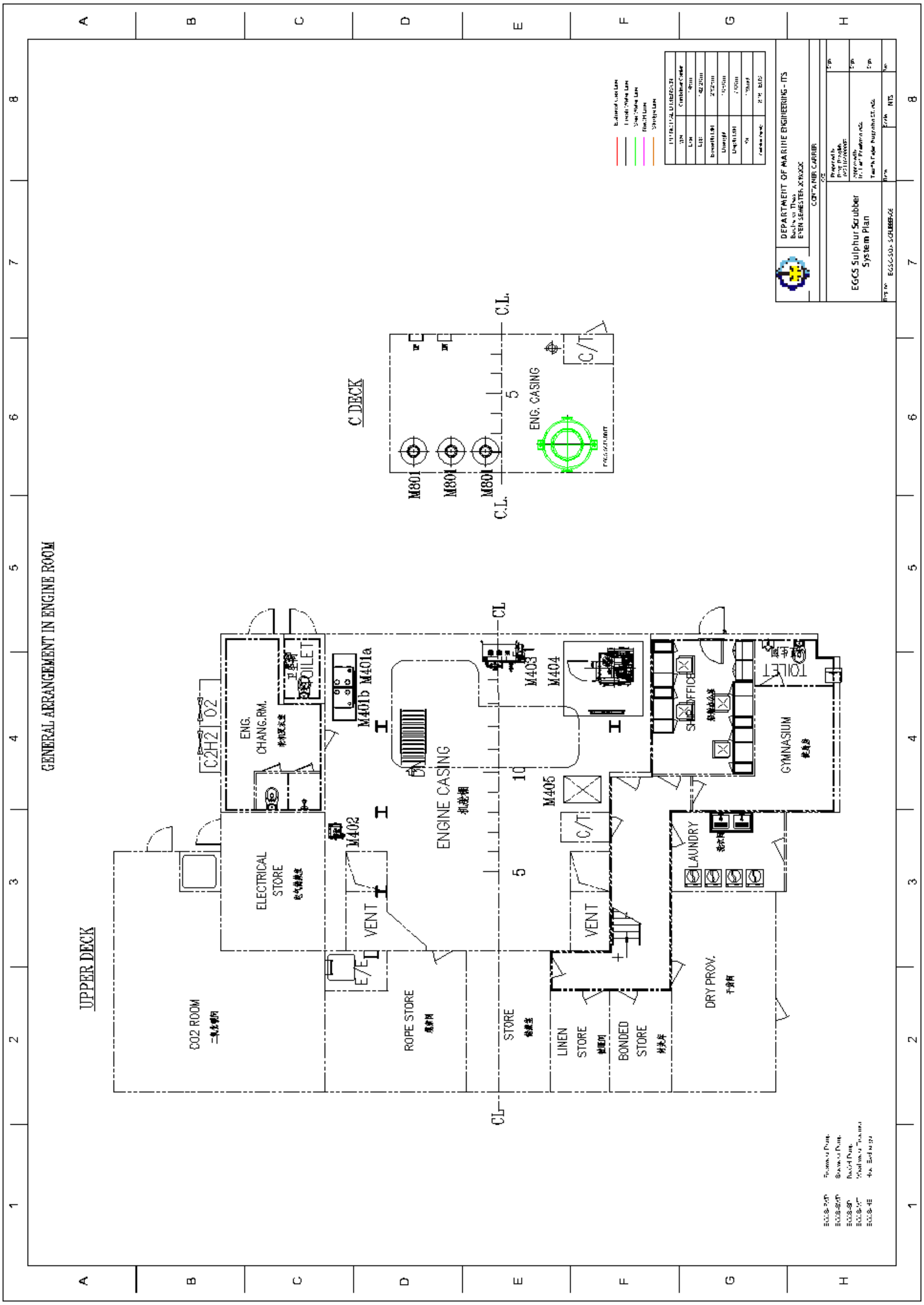
Appendix 1. 3 Closed loop scrubber system view from E/R lower platform



Appendix 1. 4 Closed loop scrubber system view from E/R upper platform



Appendix 1. 5 Closed loop scrubber system view from the upper deck



Appendix 1. 6 SOx scrubber specification

WÄRTSILÄ

WÄRTSILÄ Exhaust Gas Cleaning

Wärtsilä I-SOx scrubber system

PRODUCT LEAFLET

Wärtsilä exhaust gas cleaning technology is an economical and environmentally friendly solution that meets the highest standards of emission compliance. Wärtsilä's SOx scrubber system solutions are suitable for both newbuildings and retrofitting of existing vessels having either 2-stroke or 4-stroke engines and are designed to provide flexibility and reliable operations wherever you operate.

Where there are space restrictions that prove a challenge for scrubber system operations, Wärtsilä's innovative I-SOx scrubber system overcomes these issues and eases the installation process.

Wärtsilä's I-SOx scrubber system operates as a conventional Wärtsilä V-SOx scrubber with the exception that the exhaust gas flow enters directly from the bottom.

The Wärtsilä I-SOx system is designed to provide operational flexibility and save space. The fact that the system has a reduced footprint and no external venturi means that installation is made easier, which consequently reduces the time the vessel is out of service.

Wärtsilä has an unrivalled reference list, and data from operational exhaust gas cleaning units confirm sulphur oxide gas removal in excess of 98%. This means that with a Wärtsilä SOx scrubber system installed, vessels are ECA compliant and the systems provide unparalleled reductions in harmful ship emissions.

ENVIRONMENTAL COMPLIANCE

04 / 2017

I-SOx scrubber system design

The I-SOx scrubber system unit is longer and slimmer than the traditional design. The reduced size is enabled by having a open spray solution. Scrubbing water is divided into six spray layers to ensure a good mix between gas and water. A water trap in the scrubber inlet prevents scrubbing water from entering the engine. Due to the hot running possibility there is no need for a bypass system and hence, the footprint of the system is considerably smaller than when using the traditional design. From the scrubber materials point of view it is beneficial to have an exhaust gas boiler in the exhaust gas line before the scrubber.

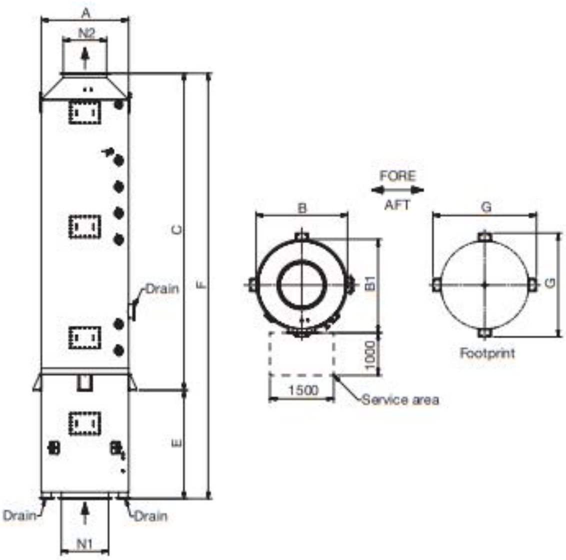
Due to its design an I-SOx scrubber requires higher water flow than a conventional scrubber.

Pressure drop of the I-SOx scrubber is similar to that of the traditional V-SOx design, i.e., maximum 150 mm H_2O (ca. 15 mbar). Current product size range is for engines between ca. 6 and 20 MW.

WEIGHTS & DIMENSIONS - STANDARD I-SOx SCRUBBER SIZES

Dim.	Description (Diameter A)	Ø850	Ø1050	Ø1250	Ø1450	Ø1650	Ø1850	Ø2050	Ø2250	Ø2450	Ø2650	Ø2850	Ø3050	Ø3250
	MW	1.2	1.9	2.7	3.6	4.7	5.9	7.2	8.7	10.3	12.0	13.9	15.9	18.1
	Gas flow (kg/S)	2.7	4.1	5.8	7.7	10.0	12.6	15.5	18.6	22.1	25.9	29.9	34.3	38.9
F	Total height (mm)	8,100	8,300	8,500	8,800	9,200	10,000	10,000	10,500	11,000	11,500	11,500	12,500	13,500
B	Overall length (mm)	950	1,150	1,350	1,550	1,750	1,950	2,150	2,350	2,550	2,750	2,950	3,150	3,350
B1	Overall width (mm)	1,000	1,200	1,400	1,600	1,800	2,000	2,200	2,400	2,600	2,800	3,000	3,200	3,400
C	Outlet height (mm)	6,100	6,300	6,500	6,800	7,200	7,450	7,450	7,950	8,450	8,950	8,950	9,450	9,450
G	Footprint (mm)	1,240	1,440	1,640	1,840	2,040	2,240	2,440	2,660	2,900	3,120	3,380	3,600	3,850
E	Drain below base (mm)	2,000	2,000	2,000	2,000	2,000	2,550	2,550	2,550	2,550	2,550	2,550	2,550	2,250
N1	Inlet nominal bore	DN400	DN500	DN600	DN700	DN800	DN900	DN1000	DN1100	DN1200	DN1300	DN1400	DN1500	DN1500
N2	outlet nominal bore	DN400	DN500	DN600	DN700	DN800	DN900	DN900	DN1000	DN1100	DN1200	DN1300	DN1400	DN1400
W1	Approx. dry weight (kg)	1,600	1,900	2,200	2,600	3,000	4,200	4,600	5,000	5,900	7,500	8,100	9,000	10,800
W2	Approx. operational weight (kg)	1,800	2,100	2,500	2,900	3,600	5,100	5,600	6,200	7,900	9,700	10,600	11,700	13,800

Above 20 MW requires customized solution.



Appendix 1. 7 Freshwater and seawater pump specification

TAIKO

CENTRIFUGAL PUMP
ESC−D

2 - 1

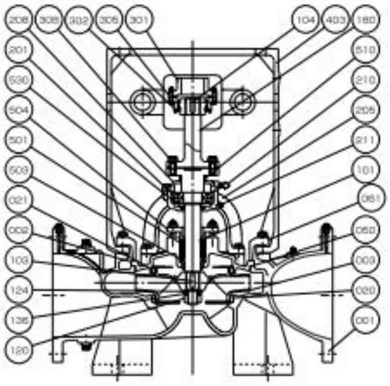
Application

Fire & G.S. Pump
Bilge & Ballast Pump

Feature

Vertical Single-stage Single-suction
Spacer Coupling Type

Structure & Material



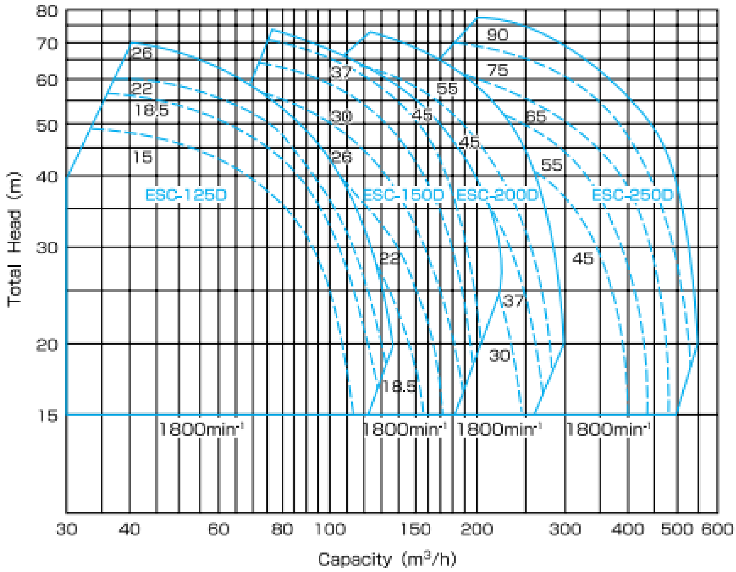
Part No.	Name	Req. No.	Sea Water Material	Sea Water JIS	Fresh Water Material	Fresh Water JIS
001	CASING	1	BRONZE	CAC402	CAST IRON	FC200
002	CASING COVER	1	BRONZE	CAC402	CAST IRON	FC200
003	IMPELLER	1	PHOSPHOR BRONZE	CAC502A	PHOSPHOR BRONZE	CAC502A
020	CASING RING	1	BRONZE	CAC402	BRONZE	CAC402
021	CASING RING	1	BRONZE	CAC402	BRONZE	CAC402
050	O-RING	1	RUBBER	NBR	RUBBER	NBR
051	FIXING PLATE	8	MILD STEEL	SS400	MILD STEEL	SS400
101	SHAFT	1	STAINLESS STEEL	SUS304	STAINLESS STEEL	SUS304
103	KEY	1	STAINLESS STEEL	SUS304	STAINLESS STEEL	SUS304
104	KEY	1	CARBON STEEL	S45C	CARBON STEEL	S45C
120	IMPELLER NUT	1	STAINLESS STEEL	SUS304	STAINLESS STEEL	SUS304
124	IMPELLER WASHER	1	STAINLESS STEEL	SUS304	STAINLESS STEEL	SUS304
136	SPRING WASHER	1	STAINLESS STEEL	SUS304	STAINLESS STEEL	SUS304
180	COUPLING SPACER	1	CARBON STEEL	S45C	CARBON STEEL	S45C
201	BALL BEARING	1	BEARING STEEL	SUJ2	BEARING STEEL	SUJ2

Part No.	Name	Req. No.	Sea Water Material	Sea Water JIS	Fresh Water Material	Fresh Water JIS
205	BEARING HOUSING	1	CAST IRON	FC200	CAST IRON	FC200
206	BEARING COVER	1	CAST IRON	FC200	CAST IRON	FC200
210	GREASE NIPPLE	1	BRASS	C3602	BRASS	C3602
211	GREASE FITTING	1	BRASS	C3602	BRASS	C3602
301	COUPLING	1	CARBON STEEL	S45C	CARBON STEEL	S45C
302	COUPLING	1	CARBON STEEL	S45C	CARBON STEEL	S45C
305	COUPLING BOLT & NUT	6	Cr-Mo STEEL	SCM435	Cr-Mo STEEL	SCM435
308	BOLT	8	Cr-Mo STEEL	SCM435	Cr-Mo STEEL	SCM435
403	FRAME	1	CAST IRON	FC200	CAST IRON	FC200
501	GLAND PACKING	4	CARBONIZED FIBER	−	CARBONIZED FIBER	−
503	LANTERN RING	1	BRONZE	CAC402	BRONZE	CAC402
504	GLAND	1	BRONZE	CAC402	BRONZE	CAC402
510	V-RING	1	RUBBER	NBR	RUBBER	NBR
530	OIL SEAL	1	RUBBER	NBR	RUBBER	NBR

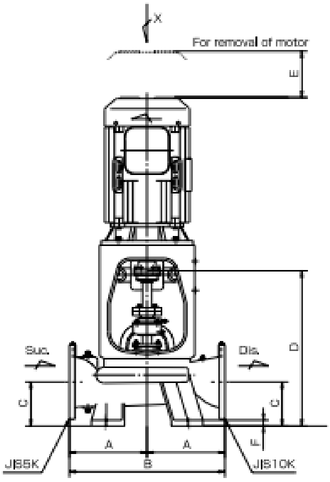
CENTRIFUGAL PUMP

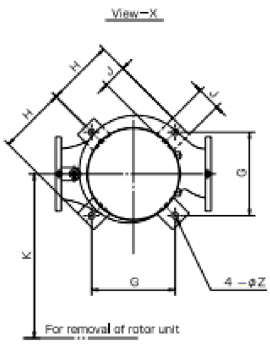
ESC−D

Performance



Dimension





Model No.	Bore		Dimension (mm)										
	Suc.	Dis.	A	B	C	D	E	F	G	H	J	K	Z
ESC-125D	125	100	345	690	180	727	200	25	360	290	100	800	28
ESC-150D	150	125	345	690	180	740	250	25	360	290	100	800	28
ESC-200D	200	150	385	730	190	750	250	25	360	290	100	800	28
ESC-250D	250	200	460	920	230	831	250	25	460	380	100	800	28

Appendix 1. 8 Washwater treatment specification

ADVANTAGES

- 5 years of scrubber water treatment experience.
- Extensive knowledge about scrubber water quality.
- > 10,000 operating hours over a wide range of operational settings.
- Tested the system to the highest capacity and extreme pollutant concentrations.
- Suitable for various operational conditions.
- Continuous work to optimize operations and minimize operational costs.

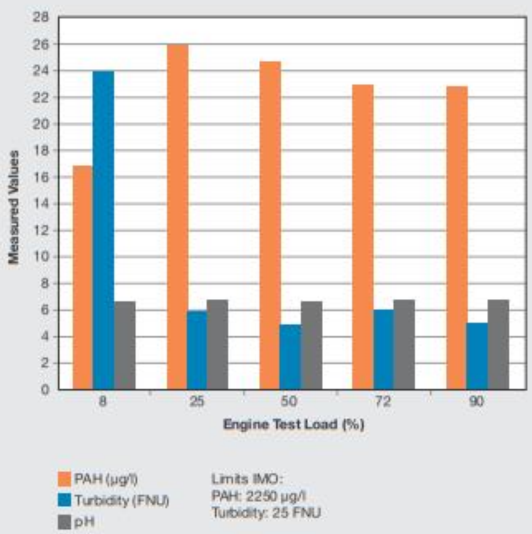
FOOTPRINT SWT 500

Model	Capacity m^3/h	Capacity gal/h	Size (mm)			Size (inches)		
			Length (L)	Width (W)	Height (H)	Length (L)	Width (W)	Height (H)
SWT	5.0	31700	2760	1100	2565	108.7	43.3	101.0

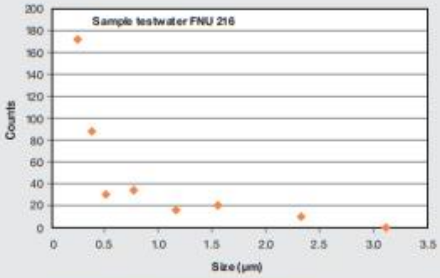
CAPACITY AND PERFORMANCE

- Capacity $5 m^3/h$
- Effluent characteristics (in accordance to IMO requirements)
  - < 25 FNU
  - < 2250 µg/l PAH
  - > 6.5 pH
  - < 1350 nitrates mg/l
- Chemical consumption
  - Coagulant 0.05 - 0.2 l/MWh
  - Flocculant 0.005 - 0.015 l/MWh

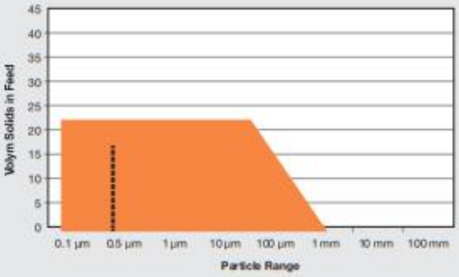
pH, PAH AND TURBIDITY VALUES AFTER THE BLEED-OFF TREATMENT UNIT WITH HIGH SULPHUR FUEL (2,83% M/M)



ANALYSIS OF PARTICLES IN SCRUBBER WATER



Source: Swedish Environmental Institue, www.ivl.se, Dr Fredrik Norin
Method: Leica Laborlux LM @100x, n.a.=1.3 optical resolution 0.23 µm



Scrubber water composition is a very complex mixture of soot, sulfite, sulfate and heavy metals. Analysis of water shows that the major particles are very small. Considering the small size of the particles, technologies such as centrifugal separation is not suitable for this application.

The Wärtsilä Scrubber Water Treatment system is designed to handle the specific high amount of small particles of soot and other purifications in the scrubber water composition.

AFTERSALES, SERVICE & SUPPORT

Wärtsilä supports its customers throughout the lifecycle of their installations by optimizing efficiency and performance. We offer expertise, proximity and responsiveness for all our customers in the most environmentally sound way.

Our services and support solutions range from basic support, installation and commissioning, performance optimization, upgrades and conversions to service projects and agreements focusing on overall equipment performance and asset management.

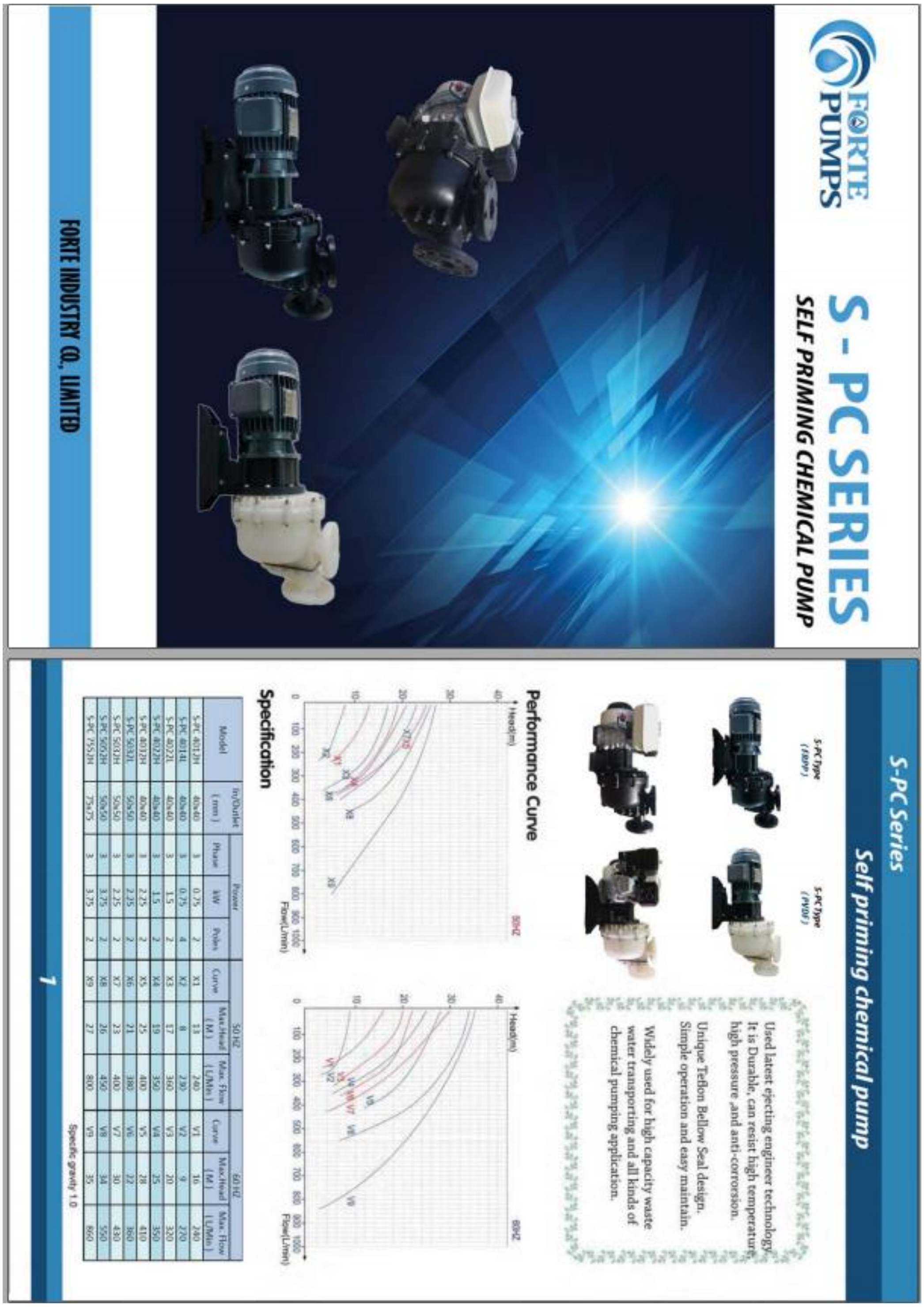
We deliver aftersales support through our network of service centres in over 70 countries worldwide.

egc-sales@wartsila.com

WÄRTSILÄ

Printed 06/2015 CA

Appendix 1. 9 NaOH pump specification



FORTE PUMPS

S - PC SERIES

SELF PRIMING CHEMICAL PUMP

FORTE INDUSTRY CO., LIMITED

S-PC Series

Self priming chemical pump

S-PC Type (FRPP)

S-PC Type (PVDF)

Used latest ejecting engineer technology. It is Durable, can resist high temperature, high pressure ,and anti-corrorsion.

Unique Teflon Bellow Seal design. Simple operation and easy maintain.

Widely used for high capacity waste water transporting and all kinds of chemical pumping application.

Performance Curve

Specification

Model	In/Outlet (mm)	Power			50 HZ			60 HZ		
		Phase	kW	Poles	Curve	Max.Head (M)	Max. Flow (L/Min)	Curve	Max.Head (M)	Max. Flow (L/Min)
S-PC 4012H	40x40	3	0.75	2	X1	13	240	V1	16	240
S-PC 4014L	40x40	3	0.75	4	X2	8	230	V2	9	270
S-PC 4022L	40x40	3	1.5	2	X3	17	360	V3	20	320
S-PC 4022H	40x40	3	1.5	2	X4	19	350	V4	25	350
S-PC 4032H	40x40	3	2.25	2	X5	25	400	V5	28	410
S-PC 5032L	50x50	3	2.25	2	X6	21	380	V6	22	360
S-PC 5032H	50x50	3	2.25	2	X7	23	400	V7	30	430
S-PC 5052H	50x50	3	3.75	2	X8	26	450	V8	34	550
S-PC 7552H	75x75	3	3.75	2	X9	27	800	V9	35	860

Specific gravity 1.0

1

Appendix 1. 10 Heat exchanger specification

Plate Heat Exchanger

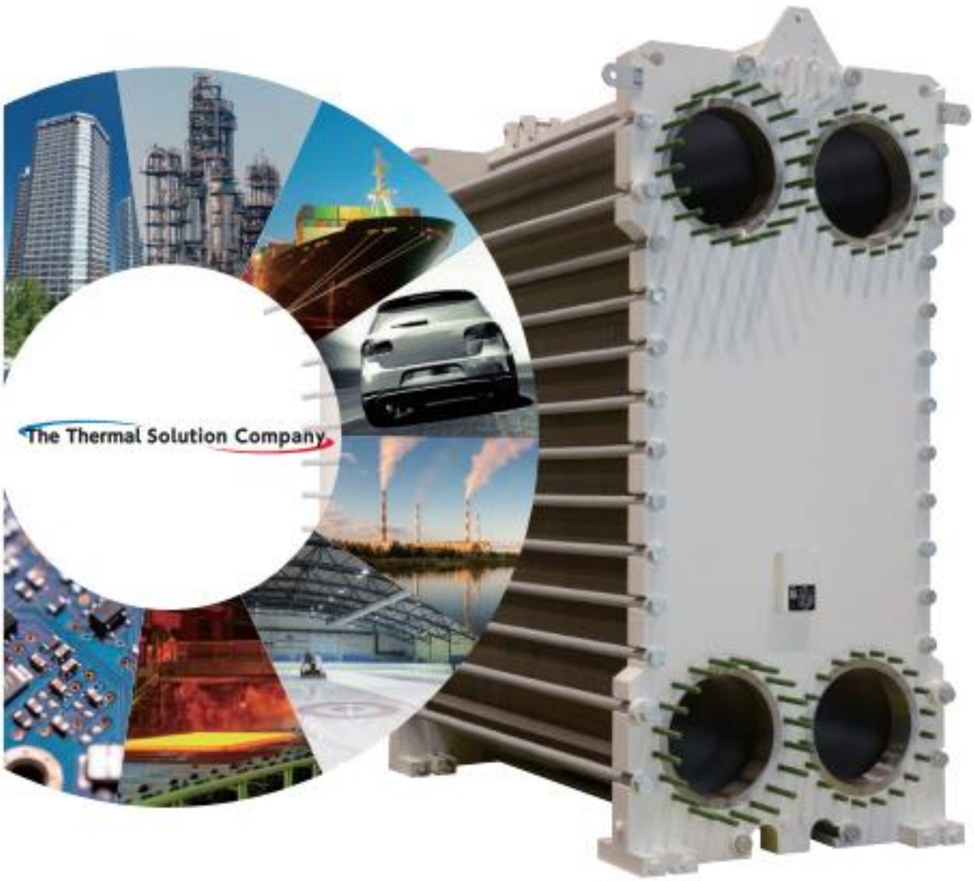
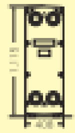
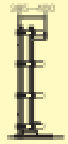
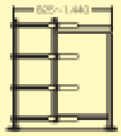
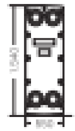
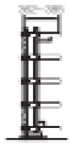
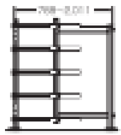
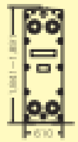
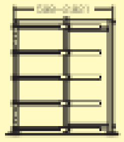
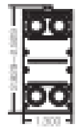
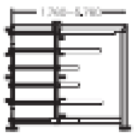
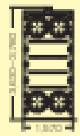
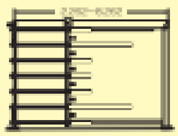
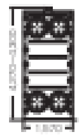
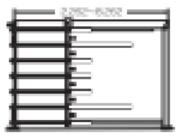
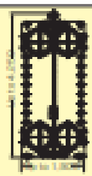
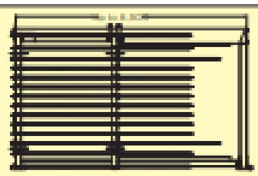


Plate Types and Dimensions

Type	Main specifications		Frame standard type		
			Width and Height	NJ type	NP type
UX-10	Max. flow rate / unit	97m^3/h			
	Max. working pressure	2.5MPaG			
	Max. working temperature	150℃			
	Max. heat transfer area / unit	30m^2			
	Porthole Dia.	70mm			
	Connection Dia.	50A			
UX-20	Max. flow rate / unit	197m^3/h			
	Max. working pressure	2.0MPaG			
	Max. working temperature	180℃			
	Max. heat transfer area / unit	60m^2			
	Porthole Dia.	100mm			
	Connection Dia.	100A			
UX-30	Max. flow rate / unit	285m^3/h			
	Max. working pressure	2.2MPaG			
	Max. working temperature	180℃			
	Max. heat transfer area / unit	200m^2			
	Porthole Dia.	120mm			
	Connection Dia.	100A			
UX-90	Max. flow rate / unit	2,314m^3/h			
	Max. working pressure	1.7MPaG			
	Max. working temperature	150℃			
	Max. heat transfer area / unit	800m^2			
	Porthole Dia.	342mm			
	Connection Dia.	350A			
UX-100	Max. flow rate / unit	4,948m^3/h			
	Max. working pressure	1.3MPaG			
	Max. working temperature	100℃			
	Max. heat transfer area / unit	1,600m^2			
	Porthole Dia.	500mm			
	Connection Dia.	500A			
UX-130	Max. flow rate / unit	4,948m^3/h			
	Max. working pressure	1.3MPaG			
	Max. working temperature	100℃			
	Max. heat transfer area / unit	1,600m^2			
	Porthole Dia.	500mm			
	Connection Dia.	500A			
UX-160	Max. flow rate / unit	7,300m^3/h			
	Max. working pressure	2.3MPaG			
	Max. working temperature	100℃			
	Max. heat transfer area / unit	4,300m^2			
	Porthole Dia.	600mm			
	Connection Dia.	600A			

Note : The above data are subject to change without notice.

Appendix 1. 11 Docking, pipe and fitting price list

IKATAN PERUSAHAAN INDUSTRI KAPAL DAN SARANA LEPAS PANTAI INDONESIA
(INDONESIA SHIPBUILDING AND OFFSHORE INDUSTRIES ASSOCIATION)

PEDOMAN STANDARD TARIP

PEMELIHARAAN DAN PERBAIKAN KAPAL

TAHUN 2019

IPERINDO

DPP IPERINDO
Komplek Griya Inti Sentosa, Jalan Griya Agung No. 77
Sunter - Jakarta Utara 14350
Tel. 021 - 640 4253, 641 1513
Fax. 021 - 640 4253
E-mail : iperindo@indo.net.id

B TARIP PENGEDOKAN

1 TARIP PENGEDOKAN

GT	Assistensi Naik & Turun Dock (Rp.	Docking & Undocking (Rp.)	Docking Per Hari (Rp.)	Docking Report (Rp.)
s/d - 500	6,501,000	11,304,000	1,719,000	4,847,000
501 - 1500	7,267,000	14,534,000	2,202,000	4,847,000
1501 - 2500	8,882,000	17,764,000	2,686,000	4,847,000
2501 - 3500	10,497,000	22,607,000	3,389,000	8,073,000
3501 - 5000	12,112,000	29,067,000	4,360,000	8,073,000
5001 - 7000	13,723,000	38,754,000	5,815,000	8,073,000
7001 - 9000	15,340,000	48,442,000	7,267,000	8,073,000
9001 - 11000	17,764,000	61,361,000	9,204,000	8,073,000
11001 - 13000	20,184,000	74,279,000	11,143,000	8,073,000
13001 - 15000	22,607,000	90,428,000	13,564,000	8,073,000
15001 - 17000	25,031,000	106,575,000	15,986,000	11,304,000
17001 - 19000	27,380,000	125,952,000	18,892,000	16,149,000

Catatan :

a. Tarip ini berlaku naik / turun dock di dalam jam kerja normal pada hari kerja, di luar jam kerja normal akan dikenakan tarip sesuai butir 8

b. Pengedokan kurang dari 2 hari, dihitung dua hari.

c. Apabila selama docking perlu dilakukan penggeseran balok lunas, akan dikenakan biaya tambahan sebesar 100% dari tarip docking / undocking.

d. Apabila diperlukan pengaturan khusus balok lunas atau fasilitas darat lainnya akan dikenakan biaya tambahan.

e. Emergency docking dikenakan biaya ekstra.

f. Kapal type khusus (KRI, Ferry Roro, TD, Yacht, Barge, Kapal Kerja) dihitung tersendiri

g. Untuk kapal type khusus dikenakan index / dihitung tersendiri berdasarkan :

   a. KRI, Ferry Roro, Yacht = index tambahan min. 150% tarip

   b. Kapal dengan draft 4 Meter s/d 5 Meter, = index tambahan min. 200% tarip

   c. Kapal dengan draft 5 Meter s/d 6 Meter, = index tambahan min. 500% tarip

h. Bongkar & pasang kembali Dock block dikenakan biaya :

   a. Keel Block Rp. 650.000,-/buah

   b. Side Block Rp. 520.000,-/buah

   c. Bottom Share Rp. 650.000,-/buah

   Catatan : Dock block khusus dikenakan tarip tersendiri

i Docking Report diberikan maksimal 6 rangkap.

j Air Bag dihitung tersendiri

k Biaya sandar 50 % dari docking perhari

F SISTIM MINYAK

F1 GANTI BARU PIPA LURUS PER METER

DIAMETER		PIPA SCH 40 (Rp.)	PIPA SCH 80 (Rp.)
s/d	1/2"	236,300	347,500
s/d	1"	309,400	455,000
s/d	2"	601,800	885,000
s/d	3"	858,500	1,262,500
s/d	4"	1,179,800	1,735,000
s/d	5"	1,487,500	2,187,500
s/d	6"	1,774,800	2,610,000
s/d	8"	2,383,400	3,505,000
s/d	10"	3,051,500	4,487,500
s/d	12"	3,692,400	5,430,000

Catatan :

a. Bongkar / pasang pipa sebagai penghalang 40% harga per meter.
b. Bongkar / pasang pipa dan perbaikan 60% harga per meter.
c. Panjang pipa kurang dari 1 meter dihitung jadi 1 meter.
d. Pekerjaan pipa di dalam DBT 150% harga per meter.
Pekerjaan pipa di dalam tangki 125% harga per meter.
e. Pipa aluminium dihitung 1½ kali pipa putih.
g. Pipa tembaga dihitung 3½ kali pipa putih.
h. Pipa Cuni dihitung 4½ kali pipa putih.
i. Proses galvanish dihitung tersendiri.
j. Untuk pipa diameter lebih dari 12", minimum dihitung 6 meter.
k. Untuk pipa di engine room dan funnel menjadi 120%

Karena berlaku dibawah Jawa Timur (Font Merah)

F4 Penggantian Elbow, Potongan-T

DIAMETER (INCH)	HARGA Per BUAH	
	Elbow Galvanish (Rp.)	Elbow Steel (Rp.)
s/d 1/2"	86,000	139,000
1"	95,000	155,000
2"	152,000	202,000
3"	212,000	286,000
4"	324,000	467,000
5"	377,000	545,000
6"	429,000	621,000
8"	515,000	746,000
10"	647,000	939,000
12"	857,000	1,240,000
diatas 12"	dihitung tersendiri	dihitung tersendiri

Catatan :

1 Untuk bahan Sch 40 ditambah 100%

F5 Bengkokan (Bending) per Bengkokan
(Untuk Pekerjaan Pipa Putih)

DIAMETER (Inch)	Per BUAH (Rp.)
s/d 1/2"	83,000
0.55 s/d 1"	126,000
1.1 s/d 2"	179,000
2.1 s/d 3"	306,000
3.1 s/d 4"	380,000
4.1 s/d 5"	436,000
5.1 s/d 6"	494,000
6.1 s/d 8"	722,000
8.1 s/d 10"	1,520,000
10.1 s/d 12"	1,777,000
diatas 12"	dihitung tersendiri

G. SISTIM AIR LAUT

Penggantian pipa, flendes, Elbow dan sebagainya lihat item F1 - F5

G1. Katup-katup air laut

a. Kran-kran laut

DIAMETER (INCH)	GLOBE VALVE (BUAH) (Rp.)	GATE VALVE (BUAH) (Rp.)
s/d 1"	385,000	876,000
1.1 s/d 2"	701,000	1,107,000
2.1 s/d 3"	876,000	1,313,000
3.1 s/d 4"	1,107,000	1,749,000
4.1 s/d 5"	1,547,000	2,189,000
5.1 s/d 6"	2,189,000	2,625,000
6.1 s/d 8"	2,625,000	3,062,000
8.1 s/d 10"	3,296,000	3,732,000
10.1 s/d 12"	3,938,000	4,374,000
12.1 s/d 14"	5,045,000	5,481,000
14.1 s/d 16"	6,123,000	6,560,000

Catatan :

1 Buka pasang, dibersihkan, diperiksa dikonserver untuk pemeriksaan dicat meni, untuk pemeriksaan class dan dicoba sampai baik.
2 Pekerjaan dan test di bengkel biaya menjadi 200%.
3 Belum termasuk biaya bongkar pasang penghalang.
4 Lokasi pekerjaan di tangki, DBT menjadi 120%.
5 Pekerjaan Butterfly Valve menjadi 200% dari type Globe Valve.
6 Pekerjaan Angle Valve menjadi 300% dari type Globe Valve.
7 Penggantian material packing dan baut mur dihitung tersendiri.
8 Stop Valve dan jenis katup lainnya dihitung tersendiri.

Appendix 1. 12 Ship electrical load data

a. Before scrubber installation

Item		**Sea going**	**Manuvering**	**Cargo Operation**	**Harbour**
Intermitten load (kW)	Total	316.2	167.8	149.6	121.2
	Diversity factor	0,7	0,7	0,7	0,7
	Demand power	221.3	117.46	104.72	84.84
Continous load (kW)	Demand power	360.1	253.4	627.6	291.4
Total continous & intermitten load		581.4	370.8	762.2	400.5
Design margin (2%) (kW)		11.628	7.416	15.244	8.01
Total demand power with provision for design margin (kw)		593.028	378.216	777.444	408.51

b. After scrubber installation

Item		**Sea Going**	**Manuvering**	**Cargo Operation**	**Harbour**
Intermitten load (kW)	Total	316.2	167.8	149.6	121.2
	Diversity factor	0,7	0,7	0,7	0,7
	Demand power	221.3	117.46	104.72	84.84
Continous load (kW)	Demand power	504.175	397.475	771.675	435.475
Total continous & intermitten load		725.475	514.935	876.395	520.315
Design margin (2%) (kW)		14.5095	10.2987	17.5279	10.4063
Total demand power with provision for design margin (kw)		739.9845	525.2337	893.9229	530.7213

Appendix 1. 13 Capital expenditure

a. Procurement cost

Procurement Cost			
No	**Item**	**Estimation**	**Total Cost**
1	Equipment Cost	Component + Pipe & Fittings Cost	Rp8,881,265,363
2	Shipping Cost	5% of Equipment Cost	Rp444,063,268
3	Component Spare Parts	5% of Component Cost	Rp429,576,488.75
4	Insurance	0,5% of Shipping + Equipment Cost	Rp46,626,643.16
5	Import Duty	7.5% of Equipment + Freight + Insurance	Rp702,896,645.57
6	PPN	10% of Equipment Cost	Rp888,126,536.30
		Total	**Rp11,392,554,944.93**

b. Installation cost

Installation Cost			
No	**Item**	**Estimation**	**Total Cost**
1	Component & Fittings Installation Cost	5% of Equipment Cost	Rp444,063,268.15
2	Dry Dock	18 Days x Rp11.143.000	Rp200,574,000.00
3	Docking & Undocking	Rp74.279.000	Rp74,279,000.00
4	Docking Report	Rp8.073.000	Rp8,073,000.00
		Total	**Rp726,989,268.15**

c. Total capital expenditure

Total Capital Expenditure		
No	**Item**	**Total Cost**
1	Procurement Cost	Rp11,392,554,944.93
2	Installation Cost	Rp726,989,268.15
	Total	**Rp12,119,544,213.08**

Appendix 1. 14 Operational expenditure

a. Fuel consumption cost

Fuel Consumption Cost Calculation				
No	**Formula/Data**	**Information**	**Value**	**Unit**
1	Equipment's Power Consumption	Sea Water Pump : 55 kW x 2 Fresh Water Pump : 26 kW x 2 NaOH Pump : 0.75 kW x 2 Wash Water Treatment : 6 kW	169.5	kW
2	Exhaust Gas Duration		24.00	hour
3	Equipment's Energy Consumption kWh = P x t	kWh = 169.2 x 24	4068.00	kWh
4	SFOC	Generator Specification	206	g/kWh
5	Fuel Consumption (ton)/day Fuel Consumption = Energy Consumption x SFOC x 10^{-6}	FOC = 4068 x 206 x 10^{-6}	0.84	ton
6	Fuel Consumption/trip	FOC = 0.84 ton x 10 Day	8.38	ton
6	MGO Fuel Price	shipandbunker.com	332	USD/MT
7	Fuel Consumption Cost Cost = Fuel Consumption x MGO Fuel Price x Rupiah Conversion	Cost = 8.38 x 332 x Rp14.305,96	Rp39,801,850	Rupiah

b. NaOH consumption cost

NaOH Consumption Cost Calculation				
No	**Formula/Data**	**Information**	**Value**	**Unit**
1	NaOH Consumption/day	0.0515 m3 x 24 hour	1.24	m3
2	NaOH Consumption/trip	1.24 m3 x 10 days	12.36	m3
3	NaOH Price		350.00	USD/MT
4	NaOH Consumption Cost/trip	12.36 x 350 x 14.305.96	Rp61,887,583	Rupiah

c. Total operational cost

Operational Cost						
No.	**Price Type**	**Specification**	**Quantity**	**Unit**	**Price/Unit**	**Total Price**
1	Fuel Consumption	8.38 ton x 332 x Rp14.305,96	29	Voyage	Rp39,801,850	Rp1,154,253,639.56
2	NaOH	12.36 m3 x 350 x Rp14.305,96	29	Voyage	Rp61,887,583	Rp1,794,739,905.84
3	Freshwater	80 m3 x Rp30.000,00	29	Voyage	Rp2,400,000	Rp69,600,000.00
					Total	**Rp3,018,593,545.40**

d. Total operational expenditure

Operation Cost per Year			
No.	**Item**	**Estimation**	**Total Cost**
1	Maintenance & Repair Cost	15% of Installation Cost	Rp109,048,390
2	Maintenance of Equipment	5% of Equipment Cost	Rp444,063,268
3	Operational Cost	Rp3,018,593,545	Rp3,018,593,545
		Total	**Rp3,571,705,203.77**

AUTHOR'S BIOGRAPHY

Rifqi Rizqullah was born in Padang, May 24th 1998, the firstborn of two siblings. He grew up in Padang, Sumatera Barat, studying at SMA Negeri 2 Padang. Author then continue his education in Marine Engineering Department, Faculty of Marine Technology, *Institut Teknologi Sepuluh Nopember Surabaya*. During his study, author had been actively involved in some organization and activities. He was active in *Himasiskal FTK ITS* as staff of Marine Technology and Innovation Club (METIC) (2018-2019), Head of Marine Technology and Innovation Club (METIC) (2019-2020). He was also active in *Unit Kegiatan Mahasiswa* Tennis as the Vice Chairman of ITS OPEN Tennis 2018. Author has done his internship two times; 1) *PT Yasa Wahasa Tirta Samudera* (Samudera Shipyard) in Semarang, 2) *Balai Teknologi Hidrodinamika* BPPT in Surabaya. During the research for the bachelor thesis, author was a member of Digital Marine Operation and Maintenance (DMOM) Laboratory. For futher discussion and suggestion regarding to this bachelor thesis, the author can be reached through his email: rifqirr@outlook.com