BACHELOR THESIS & COLLOQUIUM – ME184834

PERFORMANCE ANALYSIS OF DIESEL ENGINE USING B30 FUEL IN COMPLIANCE WITH THE 2020 GLOBAL SULPHUR LIMIT – MARPOL ANNEX VI REGULATION 14

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DOUBLE DEGREE PROGRAM
DEPARTMENT OF MARINE ENGINEERING
FACULTY OF MARINE TECHNOLOGY
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SKRIPSI – ME 184834

ANALISA PERFORMA MESIN DIESEL MENGGUNAKAN BAHAN BAKAR B30 UNTUK MEMENUHI GLOBAL SULPHUR LIMIT 2020 - MARPOL ANNEX VI REGULASI 14

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2020

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APPROVAL SHEET

PERFORMANCE ANALYSIS OF DIESEL ENGINE USING B30 FUEL IN COMPLIANCE WITH THE 2020 GLOBAL SULPHUR LIMIT - MARPOL ANNEX VI REGULATION 14

BACHELOR THESIS

Submitted to Comply One of the Requirement to Obtain a Bachelor Engineering Degree
On
Laboratorium of Digital Marine Operation and Maintenace (DMOM)
Bachelor Program Department of Marine Engineering
Sepuluh Nopember Institute of Technology

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APPROVAL FORM

PERFORMANCE ANALYSIS OF DIESEL ENGINE USING B30 FUEL IN COMPLIANCE WITH THE 2020 GLOBAL SULPHUR LIMIT – MARPOL ANNEX VI REGULATION 14

BACHELOR THESIS

Submitted in fulfilment of requirement for the degree of Bachelor Engineering

at

Digital Marine Operation and Maintenance (DMOM)

Bachelor Program of Marine Engineering Faculty of Marine Technology

Sepuluh Nopember Institute of Technology

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SURABAYA

AGUSTUS, 2020

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DECLARATION OF HONOR

I hereby who signed below declare that :

This bachelor thesis has written and developed independently without any plagiarism act. All contents and idea drawn directly from internal and external sources are indicated such as cited sources, literatures, and other professional sources.

Name	:	Shafira Rosyada
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Department	:	Marine Engineering

Surabaya, August 2020

Shafira Rosyada

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PERFORMANCE ANALYSIS OF DIESEL ENGINE RUNNING USING B30 COMPLIANCE WITH THE 2020 GLOBAL SULPHUR LIMIT - MARPOL ANNEX VI REGULATION 14

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Abstract

Energy conversion is a topic being carried by the government as a step to find renewable energy amid the continuously decreasing number of fossil sources. The implementation of the policy on the use of fuel with a mixture of CPO or B30 is one of the government's efforts to reduce the use of fossil fuels and have good emissions. The use of a new type of B30 fuel, against engines that run on B30 will have different results. Changeover of the fuel type may have an impact on emissions and diesel engine performance. In this study, a comparative analysis was carried out between the two types of fuel use between B30 and HSD based on Ferry Ro-Ro onboard data. Based on the study results, it can be concluded that the use of B30 fuel affects the performance of the main engine, where the use of HSD fuel can produce higher power compared to the use of B30 fuel. However, B30 produces less sulfur emissions. Results B30 sulfur emissions are in the amount of 0.08 / ton while in the use of HSD in the range of 0.124 / ton..

***Keyword* : B30, performance, Sulphur emission.**

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ANALISA PERFORMA MESIN DIESEL MENGGUNAKAN BAHAN BAKAR B30 UNTUK MEMENUHI GLOBAL SULPHUR LIMIT 2020 - MARPOL ANNEX VI REGULASI 14

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Abstrak

Konversi energi menjadi topik yang sedang diusung pemerintah sebagai langkah untuk mencari energi yang terbaru di tengah jumlah sumber fosil yang berkurang secara terus-menerus. Diterapkannya kebijakan penggunaan bahan bakar dengan campuran CPO atau B30 sebagai salah satu upaya pemerintah untuk mengurangi penggunaan bahan bakar murni fosil dan memiliki emisi yang baik. Penggunaan jenis bahan bakar baru yaitu B30 terhadapa mesin yang berbahan bakar B30 akan memiliki hasil yang berbeda. Perubahan jenis bahan bakar mungkin berdampak pada emisi dan kinerja mesin diesel. Pada penelitian ini dilakukan analisa perbandingan antara dua jenis penggunaan bahan bakar antara B30 dengan HSD berdasarkan data onboard kapal Ferry Ro-Ro. Berdasarkan hasil analisa dapat disimpulkan bahwa penggunaan bahan bakar B30 mempengaruhi performa main engine , dimana pada penggunaan bahan bakar HSD dapat menghasilkan daya yang lebih besar jika dibandingkan dengan penggunaan bahan bakar B30. Akan tetapi B30 menghasilkan sedikit emisi gas buang sulfur. Hasil Emisi sulfur B30 berada di angka 0,08/ton sedangkan pada penggunaan HSD pada kisaran 0,124/ton.

***Kata Kunci* : B30, performance, Sulphur emission.**

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PREFACE

Praise and gratitude toward the Allah S.W.T for the guidance and blessings, so the author can finish the bachelor thesis discusses which about "Performance Analysis of Diesel Engine Using B30 Fuel In Compliance With The 2020 Global Sulphur Limit – Marpol Annex VI Regulation 14". This bachelor thesis submitted as a fulfillment to obtain for a Bachelor's Degree in marine engineering Institut Teknologi Sepuluh Nopember. Do not forget the blessings and greetings to our Prophet Muhammad S.A.W, who has brought us from the days of ignorance to a bright era, and hopefully, we get his intercession.

The author gives thanks to the following for encouragement, guidance, support, prayer, and valuable time dedicated to helping the author complete this bachelor thesis from gathering data, processing, and writing.

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2. Ir. Hari Prastowo, M.Sc., and Dr. Eng. Trika Pitana, S.T., M.Sc. as supervisors that help me to finish my study,
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The author hopes trough this writing; reader can get information and help. The author realized this bachelor thesis far from perfection, so constructive criticisms and suggestions are needed.

Surabaya, Juli 2020

Author

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CHAPTER I
INTRODUCTION

1.1 Background

Ship exhaust emissions are increasing in line with the growing level of ship use. This happened because of the combustion of ship engine fuel. Emissions produced by the combustion of ship engine fuel have an impact on climate change, which is characterized by the occurrence of acid rain, unfavourable air conditions and human health. Sulphur levels are reduced in the exhaust gas contained in the combustion engine of the ship carried out periodically. This has become one of the serious concerns due to minimizing the earth damage caused by ship activities.

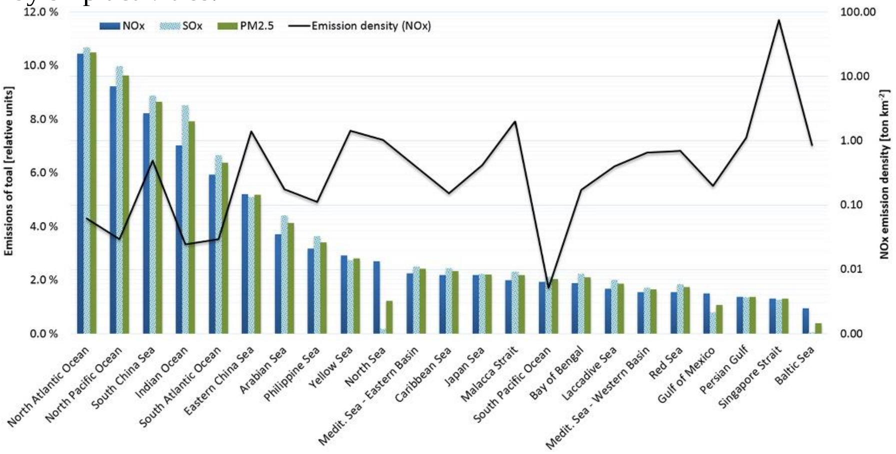

Figure 1. 1 *Relative emissions of NOx, SOx, and PM*

Source : *(Lasse Johansson, 2017)*

In the **Figure 1.1** above shows the total emissions from various places in the world. Based on the total emissions on the graph shows that 3 regions have high levels of Sulfur pollution namely North Atlantic Ocean, North Pacific Ocean, South China Sea. This causes high emission levels due to high ship traffic in the area so the resulting emissions also increase. The strait that has a density of ship traffic is the Singapore Strait. (Lasse Johansson, 2017)

The continued use of fossil fuels gives many negative impacts resulting from both air pollution and the depletion of fuel availability. Alternative fuel is needed that is used as a substitute for fossil fuels.

The government of Indonesia issued a new mandatory regulation that began in 2020, namely the use of 30% biodiesel or B30. The mandatory biodiesel program began in 2008 with a biodiesel mixture of 2.5%. Gradually the level of biodiesel increased to 7.5% in 2010. In the period 2011 to 2015, the percentage of biodiesel increased from 10% to 15%. Then on January 1, 2016, biodiesel levels were increased up to 20% (B20). Then, on 2019 testing on the B30 runs followed by testing on trains, heavy equipment, defence equipment, etc. The implementation of B30 aims to reduce fuel consumption, reduce imports of fuel oil (BBM), stabilize the price of crude palm oil (CPO), balance the trade. The application of the use of biofuels in Indonesia began in 2006. Other things that become the target of the government in addition to the utilization of CPO that has been available, it is hoped this can increase the contribution of new energy use.

The selection of biodiesel as a fuel made from crude palm oil is due to the diversification of energy. The government's concern in seeing the continued use of fossil fuels that cause dependence, so this is also a reason. Besides, the reliance on diesel fuel is also in line with a large number of oil and gas imports. With the diversification of energy, it is expected to reducing energy dependence on fossil fuels so that that fuel import reduces. So the government issued a regulation on biofuels. When energy diversification starts, the market demand for CPO increases, affecting oil palm farmers.

With this policy, many shipping companies use B30 fuel. B30 is categorized as biodiesel and this is an alternative fuels which has a low sulfur level. To find out the use of B30 as fuel on the main engine of the ship, the impact that may occur either from the main engine itself or the resulting gas emissions whether it meets the 2020 global sulphur cap.

1.2 Problem Analysis

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

1. How is the B30 affecting the engine performance?
2. How is the B30 affecting the sulphur emission?
3. What are the relations between fuel and emission?
4. How is the main engine performance using B30?

1.3 Scopes and Limitations

Scopes and limitations in this bachelor thesis are:

1. Characteristic of B30.
2. Use of B30 to meet 2020 global Sulphur (MARPOL Annex VI, Regulation 14).
3. Effects of using B30 on diesel engines.
4. All data is assumed to be correct.

1.4 Objectives

Purposes aimed from this research are:

1. To explain the effect of using B30.
2. To make the steps to analyze power vs speed of the diesel engine fueled with B30.
3. To make the steps to analyze fuel oil consumption vs rpm of the diesel engine fueled with B30.
4. To compare performance of engine using product oil vs B30.

1.5 Benefits

Benefits of this bachelor thesis are:

1. As a tool to evaluate $S0_x$ production.

2. As a suggestion for diesel engine fueled with B30.

1.6 Deliverable

This Bachelor thesis proposed to determine the impact of diesel engine fueled with B30 and suggestion about diesel engine fueled with B30.

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CHAPTER II
LITERATURE REVIEW

2.1 Problem Overview

In this era, the higher the pollution produced. The resulting impact on human health, environment. Because the increase in the use of ships is increasingly massive so this contributes to increasing pollution levels. The perceived impact is quite significant because one of the significant contributors to pollutants is the ship. Combustion on ship engines that use fossil fuels tends to produce high emissions. The shipping industry currently uses heavy fuel oil (HFO) and marine gas oil (MGO) as fuels; HFO has a maximum Sulphur of 3.5% (mass), while low Sulphur MGO contains 0.1% (mass) or less. (DNV-GL, 2019).

Worldwide, elemental sulfur is nowadays nearly exclusively an involuntary by-product of sour gas and crude oil processing to reduce sulfur dioxide emissions from the combustion of said fossil fuels. (Matthew J.King, 2013).

For ship operating outside designated Emission Control Areas IMO has set a limit for Sulphur in fuel oil used on board ships of 0.50% m/m(mass by mass) from 1 January 2020. This act will significantly reduce the number of Sulphur oxides emanating from ships. It should have significant health and environmental benefits for the world, particularly for populations living close to ports and coasts.[1]

Implementation of global sulphur limit not only for international voyages. Refer to IMO statement, all the ship whether they are on domestic voyages, between two or more countries, and international voyages.

In 2006 the Government of Indonesia began conducting research and development related to the use of biofuel derived fuels. The government is developing diesel fuel mixed with vegetable material. Starting from B-2,5, B-7,5, B-20 until in 2020 becoming B-30. The meaning of naming the fuel, for example, B-2.5 is 97.5% diesel fuel and 2.5% is CPO or Crude Palm Oil. The Indonesian government requires the use of these fuels in the industrial sector and commercial businesses. The biofuels intended to produce energy that is friendly to the environment. This biodiesel already used on diesel engines. Biodiesel used raises problems, because the nature and properties of biodiesel with diesel are different in research conducted by B-20.

2.2 IMO Regulation

IMO as the largest organization in the maritime sector has begun to think of ways to make the shipping industry more reduced in terms of emissions. The history of IMO's long time ago to reduce pollution began in 1960. Over time and research also followed, in 1997 a convention on pollution prevention caused by ships was created. Pollution originating from this ship has an impact on environmental problems, and human health. Air pollution prevention regulations pay attention to the content of sulfur oxides (SOx), nitrogen oxides (NOx), etc.

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[1] IMO, International Maritime Organisation (2016), " Frequently Asked Questions" (FAQ) (http://www.imo.org/en/MediaCentre/HotTopics/Pages/Sulphur-2020.aspx, Accessed on January 14, 2020)

Annex VI entered into force on 19 May 2005 and revise Annex with significantly strengthened requirements was adopted in October 2008. These regulations entered into force on July 2010. The regulations to reduce Sulphur oxide emissions introduced a global limit for Sulphur content of ships' fuel oil, with tighter restrictions in designated emission control areas.
Emission Control Areas (ECA) established to limit the emission of SO_x and particulate material applicable outside such areas and primarily achieved by limiting the maximum sulphur content of the fuel oils as loaded, bunkered, and subsequently used board. The ECAs established are, Baltic Sea area, North Sea area

2.3 MEMR Regulation

Ministry of Energy and Mineral Resources No.12 2015 has issued a regulation regarding an amendment to ministerial regulation No,32 2008 concerning the supply, utilization, and commerce system of biofuels as other fuels. The regulation includes a timeline for the estimated application of biodiesel for various industrial sectors. With also included the number of biodiesel presentations to be mixed.

Table 1. 1 *Utilization Stage of Biodiesel*
Source : *Ministry Energy and Mineral Resources*

Sector	April 2015	Januari 2016	Januari 2020	Januari 2025
Transportation, and Public Services (PSO)	15 %	20%	30%	30%

2.4 MARPOL

Marine Pollution or commonly abbreviated as MARPOL is a regulation with an international scope that has a focus on preventing pollution at sea. MARPOL contains several annexes covering various conditions and their respective specifications. There are six annexes in MARPOL. (Leo Campara, 2018). This Regulation 14 must be obeyed and implemented by all ships and followed by several conditions. IMO issued a new regulation that was implemented as of January 1, 2020. The regulation requires that the sulfur content allowed for ship fuel from 3.50% to 0.50%. This requirement is stated in Annex VI of the International Maritime Organization (IMO) International Convention for the Prevention of Pollution from Ships (MARPOL).

2.5 Biodiesel

Biodiesel is a esterified product from vegetable oil or terrestrial plant that already trough esterify process.. Biodiesel is the one of the alternative fuels that can be choose to replace the high sulphur fuels, marine diesel oil, or any fossil product because biodiesel is sustainable. The sustainability of fuels still in debate because its production needs land use and socio economic issues. There are some variety of biodiesel, such as FAME or fatty acid methyl ester, HVO or hydrogenated vegetable oil BTL or Biomass to liquids. Biodiesel has positive improvement from air pollutants because emissions are reduced. The use of B30 in Indonesia came into force in 2020..

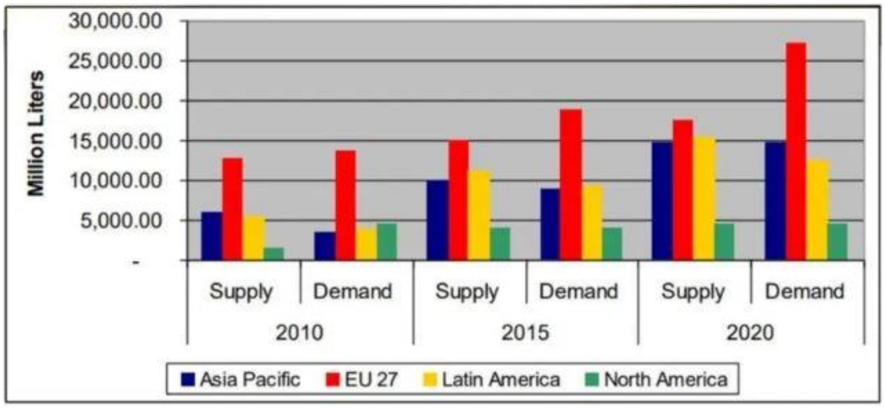

Figure 1. 2 *Supply and Demand of CPO*
Source : *(DNV-GL, 2019)*

Biofuel is a fuel derived from vegetable oil, both in the form of biodiesel, bioethanol, and bio-oil. Biodiesel in its chemical elements are alkyl esters (methyl, ethyl, isopropyl and the like) derived from fatty acids, usually, biodiesel is produced from palm oil, castor oil, and so on. Biodiesel is generally made through the reaction of metabolism or methanolysis of vegetable or animal fat oils with alcohol (methanol/ethanol). Because it has physical and chemical properties that are similar to alternative fuels that have great potential to meet most of the needs of diesel fuel. (DNV-GL, 2019).
Biodiesel is classified as one of the alternative energy which has rapidly gained interest and increased in commercial availability. Among the features and benefits of biodiesel are as follows : Renewable, versatile, easy to use, lower emission. (C.W. Mohd Noor M. N., 2018)

Table 1. 2 *B30 Fuel Properties*
Source : *ESDM 665.PERS/04/SII/2019*

Properties	Details
Density @40°C	850/890 Kg/m^3
Kinematic viscosity @40°C	2.3 – 6.0 mm^2/s (cSt)
Cetane Number	>51
Flash Point	>130
Copper strip corrosion	3 hours @50°C
Carbon residue in original sample	maximum 0.05%
	10% distilled residue 0.3% - mass
Distillation temperature	90% maximum 360°C

Sulfated ash	0.02% - mass
Sulfur maximum	10 mg/kg
Phosphorus maximum	4mg/kg
Acid number maximum	0.4 - KOH/g
Free glycerin maximum	0.02% - mass
Total glycerin maximum	0.24% - mass
Mtehyl ester minimum	96.5% - mass
Iodine value maximum	115% - mass (g-12/100g)
Oxidation stability	Rancimat method : 600 minutes
	PetroOXY method : 45 minutes
Monoglycerides maximum	0.55%-mass
Color maximum testing method ASTM D-1500	3
Water Content with testing method D-6304	350 ppm
Cold filter plugging point (CFPP) maximum	15℃
Metal I maximum with testing method EN 14108/14109, EN 14538	5 mg/kg
Metal maximum with testing EN 14538	5 mg/kg
Total contamination maximum with testing	20 mg/liter

The various fuel properties have different properties have different effects on performance of the engine and the storage and handling requirements of the system. (D.A. Tayor, 1983)

2.6 High Speed Diesel (HSD)

High-Speed Diesel is a fuel composed of complex Hydro Carbons. HSD has cetane number 45 and usually used at diesel engine. This fuel is used in an internal combustion engine with a type of engine that is medium speed and high speed. The works principle diesel engine, or an internal combustion engine is self-ignited by high compression..

Table 1. 3 *HSD Fuel Properties*
Source : *Pertamina Industrial Fuel*

Properties	Details
Density @40℃	815/860 Kg/m^3
Kinematic viscosity @40℃	2.0 – 4.5 mm^2/s (cSt)
Cetane Number	45
Flash Point	52
Carbon residue in original sample	0.1 % m/m

Distillation temperature	90% maximum 370℃
Sulfated ash	0.6 % - mass
Sulfur maximum	0.35 %m/m – 0,005 %m/m
Methyl ester minimum	-
Iodine value maximum	115% - mass (g-12/100g)
Monoglycerides maximum	0.55%-mass
Color maximum testing method ASTM D-1500	3
Water Content with testing method D-6304	500 ppm
Cold filter plugging point (CFPP) maximum	15℃
Metal I maximum with testing method EN 14108/14109, EN 14538	5 mg/kg
Metal maximum with testing EN 14538	5 mg/kg
Total contamination maximum with testing	-

2.7 Fuel Properties

Fuel properties are importance because give an impact to engine combustion

- Density
  Density is the mass of a specific volume at a given temperature. The quantity of the matter or mass compared with the volume of fuel. The temperature for each type of fuel is different. In the fuel system, when the fuel density high, the energy supplied to an engine increase.
- Viscosity
  Viscosity is the capability of flowable material to absorb stress while deforming. Fuel delivery characteristic depends on fuel viscosity. During the combustion process, viscosity influences the injection spray in the combustion chamber. When the temperature drops, viscosity decreases, and pressure increased.
- Cetane Number
  The cetane number represents the ignition quality. The cetane number is the ignition performance of diesel fuel measurement refer to engine test standard. The cetane number measure ability of the fuel will ignite the engine. Higher of cetane number, fuel more ignitable.
- Flash Point
  Flash point is the fuel's flash point or fuel temperature to start burning at normal pressure. When the fuel reaches a specific temperature, it changes into a vapor.
- Sulphur Content
  The sulfur content formate during combustion. The characteristics of sulfur are acidic, and it can affect the engine service’s life. The effect of

sulfur caused corrosive wear, above all, on the cylinder barrel and piston ring zone. Wear at component increased oil consumption and power losses.

- Heating Value

Heating value is a diesel fuel properties to measure the available energy and released when fuel is completely burning or combustion. Heating value expressed into low heating value and high heating value.

❖ Higher heating value (HHV): The total heat of combustion include water vapor formed ($H_2O_{(g)}$) during the combustion.

❖ Lower heating value (LHV): The net heat of combustion or the combustion without water vapor formed ($H_2O_{(g)}$) contamination.

2.8 Noon Report

Noon report is ship activities data were provides speed, ship's position, weather conditions and other data related to performances. Chief engineer were responsible to prepared noon report and recorded every four hours . In general, one can identify three ship operational modes; at sea, maneuvering, in port/berthing. (David Cooper IVL, 2004). Noon Report data is a low resolution dataset (sampling frequency of approximately 24 hours) from which it is possible to extract the principal variables required to define the performance terms of fuel consumption. (Lucy Aldous, 2013)

Table 1. 4 *Daily Noon Report*
Source : *Document Noon-Report*

Daily Noon Report	
Vessel Name	-
Destination	Place name
Date	Day
Time	Hour
Voyage Distance	Nauctical mile
Draft	Meter
Main Engine Fuel Consumption	Tons
Speed	Knot
Weather	Beaufort scale

2.9 Diesel Engine Performance

Engine performance is the engine's ability to produce power with rotation. Engine can produces power only when it is burning fuel. There are many parameters that can affect the biodiesel performace on marine engines. Among them are injection pressure, air fuel mixture quality, injector nozzle design, combustion chamber and ignition delay. Performance may also vary based on quality, biodiesel feedstock and engine operating parameters such as load, speed, torque, etc. The effect of biodiesel fuel on the engine performance features such as brake power exhaust gas temperature (EGT), brake specific fuel consumption and engine efficiency. (C.W. Mohd Noor M. N., 2018)

An important parameter for marine Diesel Engine is rating figure, stated as BHP or Kw per cylinder. (F.Molland, 2008)
The engine performance characteristics which are of interest when selecting an engine for particular application are torque, horsepower, fuel consumption, and speed. (Harrington, 1971)

2.10 Brake Horse Power

Brake Horse power is power developed by an engine at the output shaft. Power is the result of the combustion of fuel. Brake power is indicated power output. It is called brake because it is used to slow down the shaft inside a dynamometer. (Kamel Bencheikh, 2019). Brake Power is the power measured at the crankshaft coupling is the power measured at the crank shaft coupling by means of mechanical, hydraulic or electrical brake. It’s calculated by the formula : (V.Lewis, 1988)

$$P_B = 2\pi Q n$$

Where :
Q is brake torque, Kn-M
n is revolutions per sec

The necessary brake power or indicated power in the turbines, diesel or steam reciprocating engine as the case may be, can be estimated in a particular design from the proper values of gear efficiency mechanical efficiency and load factors. (V.Lewis, 1988)

The relationship between power, specific fuel oil consumption, and fuel flow describe by the following equation :

$$Brake\ Power = \frac{m_f \times 10^3}{SFOC}$$

P	: The average power output (kilo watt)
SFOC	: Specific Fuel Oil Consumption (g/kWh).
m_f	: Mass of fuel flow rate (kg/hour)

2.11 Specific Fuel Consumption

The specific fuel consumption is a measure of the fuel flow rate per unit power output. It measures how efficiently an engine uses the fuel supplied to produce work. (Sushant. S. Satputaley, 2018). Specific fuel consumption is to measure engine performance in combustion in 1 hour to produce power with unit kg/kWh.

2.12 Exhaust Gas Emission

Exhaust gas emissions are the result of combustion, both ship engines, automobile engines, jet engines and others. Not all combustion occurs completely when combustion occurs imperfectly it will produce residual results. Elemental particles in the fuel do not all react perfectly with oxygen and as a result, the unburned particles will be released through the exhaust system. Exhaust gas emission will consist of CO_x,SO_x, NO_x. In the previous research found that the reduction in exhaust emissions with biodiesel may be due to sufficient oxygen element in the fuel. High amount of oxygen in the engine chamber is believed to cause complete combustion and reduce emission. (C.W. Mohd Noor M. N., 2018)

Exhaust gas temperature is the temperature at the end of the combustion process that is released from the environment It provides qualitatives information about the progress of combustion in engine and thus it is an important parameter for pollutant formation during the exhaust process. (Kamel Bencheikh, 2019)

2.13 Sulphur Oxides

Sulphur Oxides (SO_x) are compounds of sulphur and oxygen molecules. Sulphur dioxide (SO_2) is the pre-dominant form foundin the lower atmoshphere. It is a colorless gas that can be detected by taste and smell. Sulphur dioxide is produced by burning fuels containing Sulphur or by sulfides ores.

$$S + O_2 \rightarrow SO_2$$

Health impacts cause by sulphur oxide emission can damage freshwater and stream ecosystems by lowering the Ph of the water. Lowered Ph could become completely devoid of fish life. Exposure to Sulphur dioxide in the ambient air has been associated with reduced lung function, increased incidence of respiratory symptoms and diseases,etc. Sulphur dioxide accelerates the corrosion of iron, steel, and zinc. (World Bank Group, 1998)

$$SO_x = 20 * S$$

Where :

SO_x : Sulphur Emission Factors for pollutants (kg/tonne fuel)
S : Percetage sulphur content in fuel % m/m

Source : (Lloyd's Register)

2.14 Calculation of Specific Fuel Oil Consumption

Approximation with calculating the specific fuel oil consumption with J. Moreno-Gutierrez et al.'s Method to get the delivered power. Power is energy use divided by interval of time. This equation for ME signifies the Maximum Continous Rating (MCR) for main engine when an energy and emission inventory is applied, for specific zone. The problem appears in knowing or calculating the LF value for specific fuel oil consumption. Although a ratio of 80% at sea is common.

Moreno-Guiterrez et.al's proposes general equation for calculating the Main Engine Load factor described in following below :

$$Load\ Factor = \frac{P_{transient}}{P1}$$

$$P_{transient} = P1(\frac{V_{transient}}{V_1})^n$$

$$Load\ Factor = \frac{P1(\frac{V_{transient}}{V_1})^n}{P1}$$

P_1	: Power respectively at 100% MCR from onboard test
V_1	: Speed respectively at 100% MCR from onboar test
$V_{transient}$	: Actual ship speed
$P_{transient}$	: Instantaneous power for calculation
n	: the constant ship speed coefficient and represents the raltionship between speed and power.

For medium-sized, medium-speed ships such as feeder container, reefers, Ro-Ro ships,etc: n =3,5. Because this study object was RoRo ships.

This equation below were applied in the calculation of specific fuel oil consumption.

$$SFOC_{Relative} = 0.455\ LF^2 - 0.71\ LF + 1.28$$

$$SFOC = SFOC_{relative} + SFOC_{base}$$

LF	: Load Factor, a value from 0 to 1
SFOC	: Specific Fuel Oil Consumption
$SFOC_{base}$	: From design guide

2.15 Calculation of Sulphur Emission

This Carlo Trozi.'s method calculate Emission over a complete trip based on the amount of Fuel Oil Consumption. This methodoly uses installed system and fuel oil consumption as alternative to estimates the emissions. (Trozzi, 2010)
This calculation followed by procedure below :

$$E_{Trip,i} = 10^{-3} \times \sum_{e}\sum_{j}\sum_{m}\sum_{p}(FC_{j,m,p} \times EF_{j,m,p})$$

Where :

E (Trip, i)	: Emission over a complete trip (tonnes)
FC	: Fuel Consumption
EF	:Fuel Consumption based on emission factor (kg/tonne)
i	: Pollutant.[2]
j	: Engine type (slow-, medium-, and high –speed diesel, gas turbine and steam turbine)
m	: Fuel type (bunker fuel oil, marine diesel oil /marine gas oil)
p	: the different phase of trip (cruise, hoteling, maneuvering).

[2] University of Calgary (Energy Education) https://energyeducation.ca/encyclopedia/Power#:~:text=Since%20power%20is%20a%20rate,kilowatt%2Dhours%20(kWh). Accessed on 12 April 2020

HAPTER III
METHODOLOGY

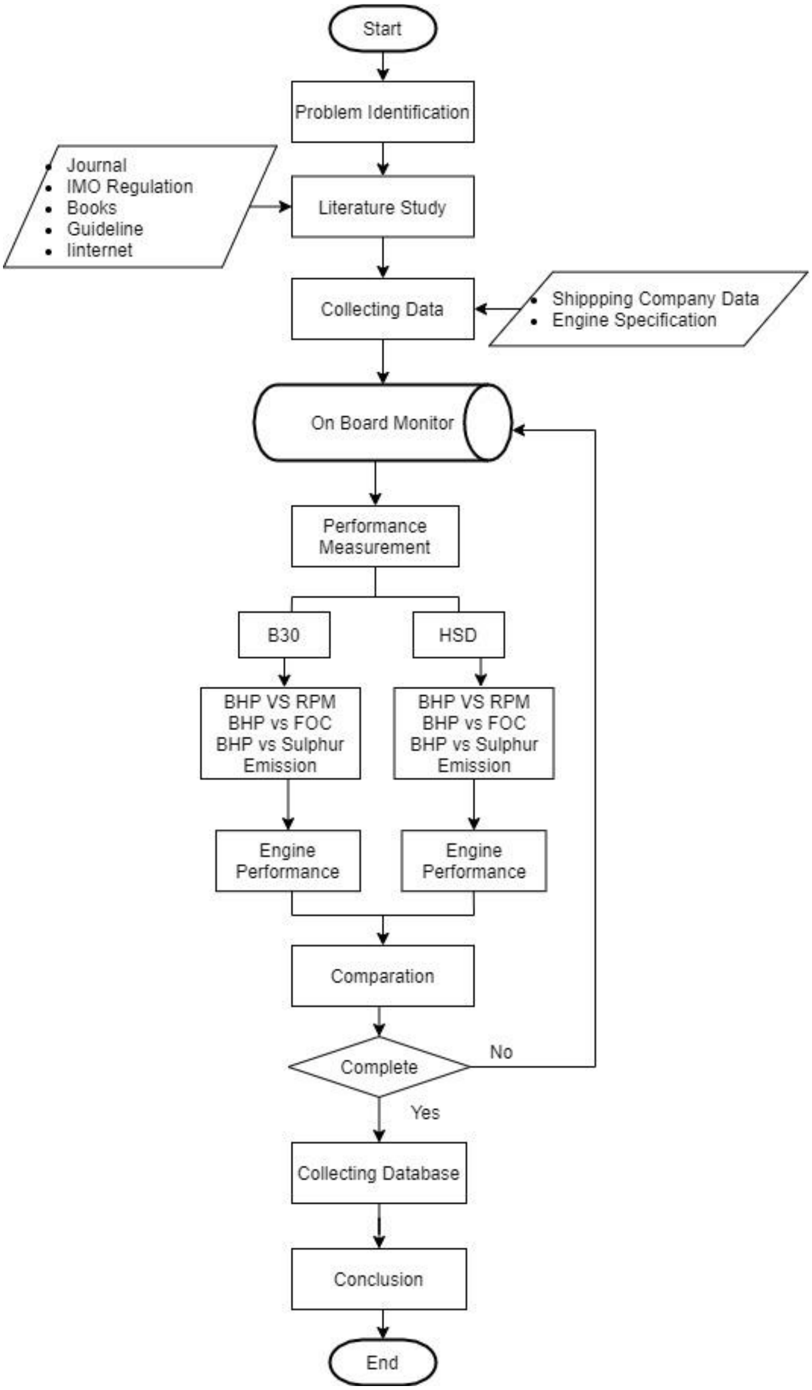

Figure 3. 1 *Flowchart*

3.1 Problem Identification

Problem identification is the first step in writing this thesis. Research questions are obtained through problem identification. The main problem comes from existing condition compared to required condition by regulation. In this stage, problems are specifically identified in order to determine the specific objectives of this thesis. Therefore, the purpose of this thesis could be acknowledged.

3.2 Literature Study

After problems identified, the study literature needs to done to get scientific information as a and to support the research analysis. The literature study refers to journals, IMO regulations, books, and websites. Analysis of engine performance through fuel oil consumption, power, and the resulting sulfur emissions.

3.3 Collecting Data

Data for this research needs to be collected. Data collection is done by gathering information from ship's operational data. Ship operational data to be collected is record data of the ship. Data to be needed consist of deck journal, machinery journal, engine condition report database,and engine manual guide.

3.4 Data Checking

After doing the literature study and collecting data during ship operational, then data be checked to ensure all data needed complete for calculation. Raw data from ship book record proceeds with sort required data that related to conduct in engine performance indicator.

3.5 Comparation Between Diesel Engine B30 Fueled and HSD

To determine the performance of the engine, then fulfil performance indicator. Parameters of performance parameters which available in this bachelor thesis are RPM or engine speed and fuel oil consumption per trip. The rest of the performance indicator got from the calculation of ship database. After finished calculating all the engine performance parameters for each fuel type, the calculation result will be compared. Compared to engine performance using B30 fuel and engine performance using HSD. Then interpret the condition of each engine performance

3.6 Collecting Database

After the calculation has done to meet the available parameters and compare the conditions between the performance when using B30 with HSD, then analyzed through the comparative graph provided.

3.7 Conclusion

After all the steps have implemented, it is closed by the conclusion of data analysis. Conclusions and suggestions are the last steps of this bachelor thesis research. The purpose of this research answered the statement in the conclusion chapter.

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CHAPTER IV
DATA ANALYSIS

4.1 Data Collection

Data collection needed to be calculated to support research, data collected from several sources, ship's journal, owner's documents, official websites, other literature studies, journals, and books.

4.2 Research Object and specification

This objective research based on Historical voyages of RoRo ship, and all the data was provided by the shipping company. The Detail of the research data object listed as follows are data as a basis for this research.

Table 4. 1 *Ship Principal Data KM. Dharma Kartika IX*
Source : *PT. Dharma Lautan Utama*

SHIP PRINCIPAL DIMENSION		
Ship Name	KM.Dharma Kartika IX	
IMO Number	9140023	
Ship Type	Ferry RORO	
Owner	PT. Dharma Lautan Utama	
Year of Build	1996	
LOA	155.04	Meter
LWL	145	Meter
Breadth Moulded	19	Meter
Depth Moulded	9.30	Meter
T	5.85	Meter
GT	6801	GT
Ship Speed	23.2	knot
Voyage	Surabaya - Banjarmasin	
Classification	BKI	

4.2.1 Machinery Data

The machinery system on the ship, the object of research, has two main engines. The engine system that uses B30 fuel on the RoRo ship is only on the main engine part, so the analysis is focused on the performance of the main engine. There is no modification at the main engine when the changeover fuel type. The origin fuel of the main engine is HSD. This ship was powered by two identic types of the medium speed engine.

Table 4. 2 *Main Engine Data*
Source : *PT. Dharma Lautan Utama*

MAIN ENGINE	
Number of Main Engine	2
Engine Work Type	4 Stroke
Brands	NKK-SEMP-PLELSTICK
Model	12PC-6V
Power at 100% MCR	9000 HP
	6600 kW
SFOC at 100% MCR	180,829 g/kwH
Fuel Type	HSD
RPM	520
Cyl Bore x Stroke	400 x 460
Cylinder Number	12

4.2.2 Fuel Oil Specification

The primary element in engine work is the source of fuel. Each fuel has different characteristics due to its particular properties. Fuel properties data attached to ensure suitability with engine specifications. The engine specification document obtained all result of standardized testing. For HSD fuel was implemented before 2019. And for B30 use since January 2020. There was not different procedure when changeover fuel type applied. As the ministry decree number 12 that oblige of B30 used, the changeover of the fuel immediately applies since the regulation was implemented.

Table 4. 3 *Specification Data B30*
Source : *Fuel Properties Document Pertamina*

Properties	Details
Density @15℃	851 kg/m^3
Kinematic viscosity @40℃	3.15 mm^2/s (cSt)
Calculated Cetane Number	53.1
Flash Point	70 ℃
FAME Content	30
Carbon residue in original sample	-
Distillation 90%	351 ℃
Ash content	-

Sulphur content	0.040 %m/m
Biological growth	-
Total Acid number	0.36 mg KOH/g
Water Content	230.7 mg/kg
Oxidation Stability	>48 hours

Table 4. 4 *Specification Data HSD*
Source : *Fuel Properties Document Pertamina*

Properties	Details
Density @15℃	834.4 Kg/m^3
Kinematic viscosity @40℃	2.66 mm^2/s (cSt)
Calculated Cetane Number	48.3
Flash Point	65 ℃
FAME Content	0
Distillation 90%	348.8
Ash content	-
Sulphur content	0.062 %m/m
Biological growth	-
Total Acid number	0.4 - KOH/g
Water Content	
Oxidation Stability	>48 hours

4.3 Collected Data

The ship has two main engines, the data obtained from both two ship's main engines. The Main Engine on the ship is a diesel engine categorize as a medium speed engine. Retrieval of data conducted in this study carried out using deck journals and journal machinery. The data to be processed is based on onboard data monitoring, in which data is collected at intervals every 4 hours. The object of research used is two main engines of the RoRo Ferries. Main Engines in 2018 still use HSD, then start to use B30 in 2020. Main engines fueled with B30 will be compared to main engines fueled with HSD. This comparison applied based on historical data records at sailing operations for the same route Surabaya - Makassar.

In this research, parameters obtained from onboard monitoring data. The onboard data processed through the formulas attached to determine the diesel engine's performance through the analysis supported by related data research. Performance analysis will show the relationship between Brake Horse Power, RPM, Fuel Oil Consumption, and the number of emissions produced by running with B30 compared to HSD.

4.3.1 Journal and Report

Several data sources are used as data sources in research.

- The engine condition report which contains a resume of fuel consumption in one trip in the report includes the duration of the trip, the speed of the ship, engine condition parameters (temperature and pressure), engine hours reported as a central data set.
- The Engine Journal or Log Book for Engines to be recapitulated by the Chief Engineer is updated every 4 hours. The engine journal displays the location data where the data was taken, the destination and origin of the ship, the trip date, recording the condition of the engine, rpm, temperature and pressure), the number of hours worked by the engine.

4.4 Brake Horse Power Calculation

The calculation was started based on Log Book for Engine. The available data was rotation per minute engine (RPM) and fuel oil consumption from this logbook. For RPM for each main engine in detail, the voyage and ship speed duration was available at Log Book for Deck.

After collecting data, then filtering data per voyage. So we can determine each voyage need many hours spend and much fuel oil consumed. Based on this data, we can approximate real-time power with the Moreno Guiterrez method.

At the Morreno Guiterrez method, there are several equations based on the available data. This study use equation for the main engine signifies the maximum continuous rating. The following steps below are an approximation to get an estimate of the amount of power produced by the main engine.

For **Main Engine I** calculated as below :

- **For High Speed Diesel (HSD)**

  Load Factor $= P_1 \, (V_{transient} : V_1)^n / P_1$

  $= 6600 \text{ kW } (15 \text{ knot} : 17.7 \text{ knot })^{3.5}$

  $= 0.56$

  After determining each Load factor of fuel used, then calculate specific fuel oil consumption.

  Specific Fuel Oil Calculation

  $SFOC_{relative} = 0.455\, LF^2 - 0.71\, LF + 1.28$

  $= 0.455(0.56)^2 - 0.71(0.56) + 1.28$

  $= 1.025$

  SFOC $= SFOC_{relatives} \times SFOC_{base}$

  $= 1.025 \times 180.8$

  $= 185.355$ g/kwh

Date	Running Hours (knot)	Actual Speed	RPM	FO Consumption (Ltr)	Load Factor	SFOC (g/kWh)
12/1/2018	20	15	339	6087	0.560	185.355

After knowing the value of SFOC, we can calculate the Brake Horse Power. To appears the number of Brake horsepower, value if the mass of fuel flow rate should be ensured. Fuel oil consumption data determined the mass of fuel flow rate.

m_f **= (Fuel oil consumption/running hours) x density**
= 6087 (liter)/20 (hours) x 834.4 (kg/m^3)
= 230.32 kg/hour

BHP **= m_f / SFOC**
= 230.32 (kg/hour) / 185.355 (g/kWh)
= 1243 kW

Date	Running Hours	FO Consumption (ton/day)	Mass Fuel flow (kg/hour)	SFOC (g/kWh)	Brake Horse Power (kW)
12/1/2018	20	6.09	230.32	185.355	1243

- **For B30**

Load Factor = P_1 ($V_{transient}$: V_1 $)^n$ / P_1
= 6600 kW (15 knot : 17.7 knot $)^{3.5}$ / 6600 kW
= 0.56

After determining each Load factor of fuel used, then calculate specific fuel oil consumption.

$SFOC_{relative}$ = 0.455 LF^2 – 0.71 LF + 1.28
= $0.455(0.56)^2 - 0.71(0.56) + 1.28$
= 1.025

SFOC = $SFOC_{relatives}$ x $SFOC_{base}$
= 1.025 x 180.8
= 185.355 g/kwh

Date	Running Hours (Hour)	Actual Speed (Knot)	RPM	FO Consumption (Ltr)	Load Factor	SFOC (g/kWh)
1/1/2020	17	15.0	335	8684	0.560	185.355

After knowing the value of SFOC, we can calculate the Brake Horse Power. To appears the number of Brake horsepower, value if the mass of fuel flow rate should be ensured. Fuel oil consumption data determined the mass of fuel flow rate.

m_f = (Fuel oil consumption/running hours) x density
= 8684 (liter)/17 (hours) x 851 (kg/m^3)
= 394.27 kg/hour

BHP = m_f / SFOC
= 394.27 (kg/hour) / 185.355 (g/kWh)
= 2127 kW

Date	Running Hours	FO Consumption (ton/day)	Mass Fuel flow (kg/hour)	SFOC (g/kWh)	Brake Horse Power (kW)
1/1/2020	17	10.43	394.27	185.355	2127

At calculation above between historical HSD used and B30, SFOC of each type of fuel have the same result, but they have different power output. It happens because of the mass of fuel flow rate influenced by amount of fuel oil consumption and density.

For **Main Engine II** calculated as below :

- **For High Speed Diesel (HSD)**

Load Factor = P_1 ($V_{transient}$: V_1 $)^n$ / P_1
= 6600 kW (15 knot : 17.7 knot $)^{3.5}$
= 0.56

After determining each Load factor of fuel used, then calculate specific fuel oil consumption.

Specific Fuel Oil Calculation

$SFOC_{relative}$ = 0.455 LF^2 – 0.71 LF + 1.28
= $0.455(0.56)^2 - 0.71(0.56) + 1.28$
= 1.025

SFOC = $SFOC_{relatives}$ x $SFOC_{base}$

$= 1.025 \times 180.8$
$= 185.350$ g/kwh

Date	Running Hours (Hour)	Actual Speed (knot)	RPM	FO Consumption (Ltr/day)	Load Factor	SFOC (g/kWh)
1/19/2019	19	15	355	10176	1	185.350

Same as the previous calculation, after knowing the value of SFOC we can calculate the Brake Horse Power. To appears the number of Brake horsepower, value if the mass of fuel flow rate should be ensured. Fuel oil consumption data determined the mass of fuel flow rate.

m_f = (Fuel oil consumption/running hours) x density
= 10176 (liter)/19 (hours) x 834.4 (kg/m^3)
= 385.95 kg/hour

BHP = m_f / SFOC
= 385.95 (kg/hour) / 185.355 (g/kWh)
= 2082 kW

Date	Running Hours (Hour)	FO Consumption (ton/day)	Mass Fuel flow (kg/hour)	SFOC (g/kWh)	Brake Horse Power (kW)
1/19/2019	19	10.21	385.951	185.350	2082

- **For B30 (B30)**

Load Factor $= P_1 (V_{transient} : V_1)^n / P_1$
$=$ 6600 kW (15.30 knot : 17.7 knot $)^{3.5}$
$= 0.60$

After determining each Load factor of fuel used, then calculate specific fuel oil consumption.

Specific Fuel Oil Calculation

$SFOC_{relative}$ $= 0.455\ LF^2 – 0.71\ LF + 1.28$
$= 0.455(0.60)^2 – 0.71(0.60) + 1.28$
$= 1.017$

SFOC $= SFOC_{relatives} \times SFOC_{base}$
$= 1.017 \times 180.8$
$= 184.033$ g/kwh

Date	Running Hours	Actual Speed (knot)	RPM	FO Consumption (Ltr)	Load Factor	SFOC (g/kWh)
9/1/2020	18	15.3	350	9325	0.601	184.033

after knowing the value of SFOC, we can calculate the Brake Horse Power. To appears the number of Brake horsepower, value if the mass of fuel flow rate should be ensured. Fuel oil consumption data determined the mass of fuel flow rate.

m_f **= (Fuel oil consumption/running hours) x density**
= 0325 (liter)/18 (hours) x 851 (kg/m^3)
= 390.53 kg/hour

BHP **= m_f / SFOC**
= 390.53 (kg/hour) / 187.532 (g/kWh)
= 2082 kW

Date	Running Hours (Hour)	FO Consumption (ton/day)	Mass Fuel flow (kg/hour)	SFOC (g/kWh)	Brake Horse Power (kW)
9/1/2020	18	10.33	390.440	187.532308	2082

The results of the Main Engine II brake horsepower calculation present the same power output that is 2082 kW. At HSD fuel used shows the amount of mass of fuel flow rate is 385.9 kg/hour, while B30 fuel used shows 390.4 kg/hour. Based on mf, b30 used tend to wasteful, if compared to HSD used.

4.5 Performance Analysis Main Engine I & II using B30 and HSD

The study was conducted based on the historical results of the use of HSD fuels in the period of December 2018 to February 2019. For the results of the history of the use of B30 in the period January 2020 to February 2020. These data are recorded at sea conditions. Data selection for the graph of performance based on the determined state. Data analysis was performed by taking several data samples between the use of HSD fuels with B30 fuels. So we get the analysis data on the same parameters (engine speed/rpm during at sea mode, fuel consumption, and brake horsepower).

4.5.1 Analysis of Relation Between BHP vs RPM Main Engine I

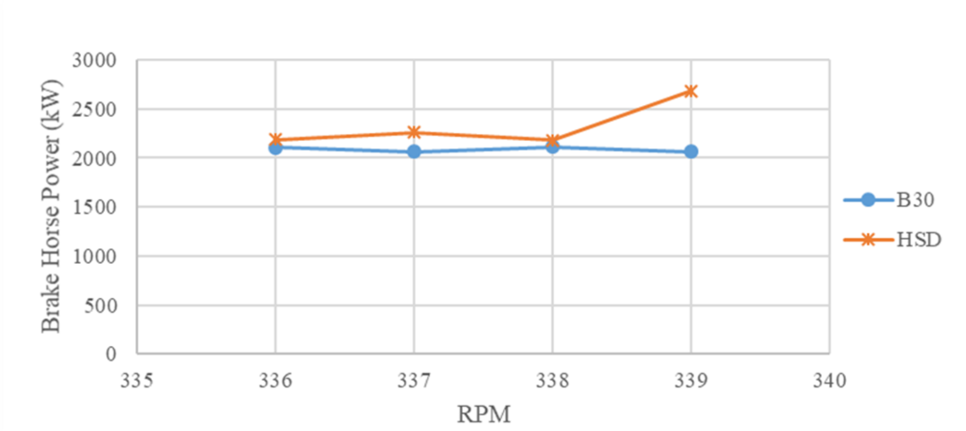

Figure 4. 1 *Graph of Brake Horse Power vs RPM between B30 and HSD Main Engine I*

As presented in figure 4.1, the graph of comparison between Brake Horse Power and engine speed (RPM) HSD fueled compared to B30 in Main Engine I shows the results that the highest power achieved at RPM 339. HSD fuel can produce power of 2687 kW. In comparison, the use of B30 can produce power of 2062 Kw. It means B30 have lower power than HSD at the same engine speed. The lowest power output is produced at RPM 338 with the amount of power that can be achieved for HSD used is 2180 kW, while for B30 used can produce power output 2113 kW. Based on the overall graph shows engine using HSD tend to produce higher Power rather than using B30. The maximum power that can be achieved at sea conditions is at RPM 339.

4.5.2 Analysis of Relation Between BHP vs RPM Main Engine II

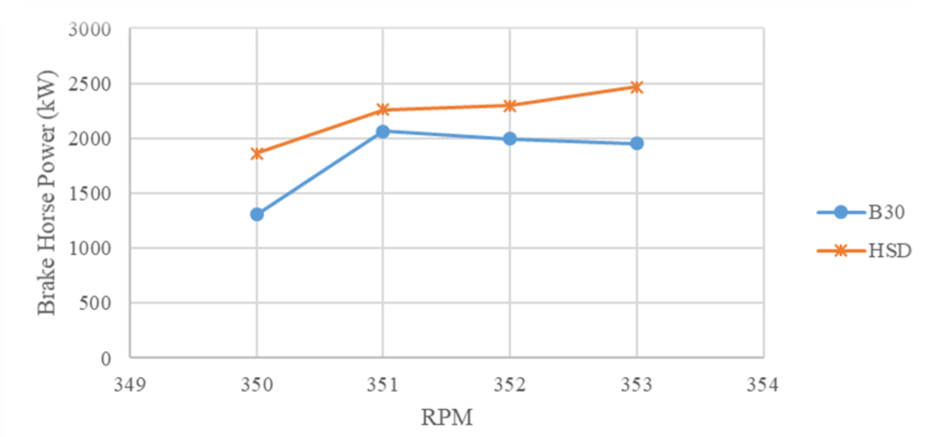

Figure 4. 2 *Graph of Brake Horse Power vs RPM between B30 and HSD Main Engine II*

Figure 4.2 comparison graph between power and RPM on Main Engine II when B30 fuelled and HSD fuelled. The graph in figure 4.2 shows that the highest power generated at RPM 353. When main engine using HSD fuel, power output can produced is 2468 kW, at the same RPM power can generate by using B30 fuel is 1955 kW, with a power difference is 513 kW. On both fuel Application, the smallest power is generated at RPM 350. At RPM 350 main engine II using HSD fuel can generate 1865 kW, while ME II B30 fueled can generate 1303 kW. Along with RPM increased, the result of power output increased also. When RPM increased it makes more high mechanical energy and power output goes by.

4.5.3 Analysis of Relation Between FOC vs RPM Main Engine I

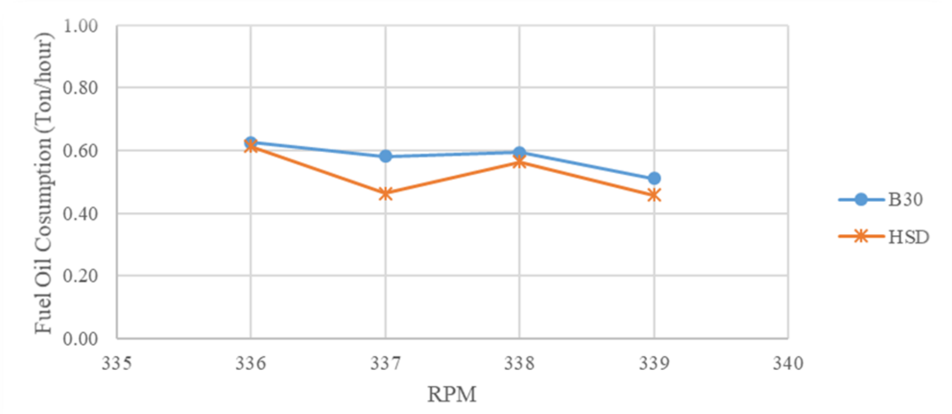

Figure 4. 3 *Graph of Fuel Oil Consumption vs RPM Main Engine I*

Figure 4.3 is a comparison graph between RPM and Fuel Oil Consumption tons/hour. The graph shows the highest fuel consumption achieved at RPM 336 with the amount of consumption of HSD fuelled is 0.61 tons/hour, for B30 fuelled can consume fuel 0.63 tons/day. On B30 utilization, the lowest fuel consumption is 0.51 tons/hour at engine speed 339 RPM. Whereas main engine HSD fulled has the lowest fuel consumption at the same RPM with B30 with amount of fuel oil consumption is 0.46 tons/hour.

4.5.4 Analysis of Relation Between FOC vs RPM Main Engine II

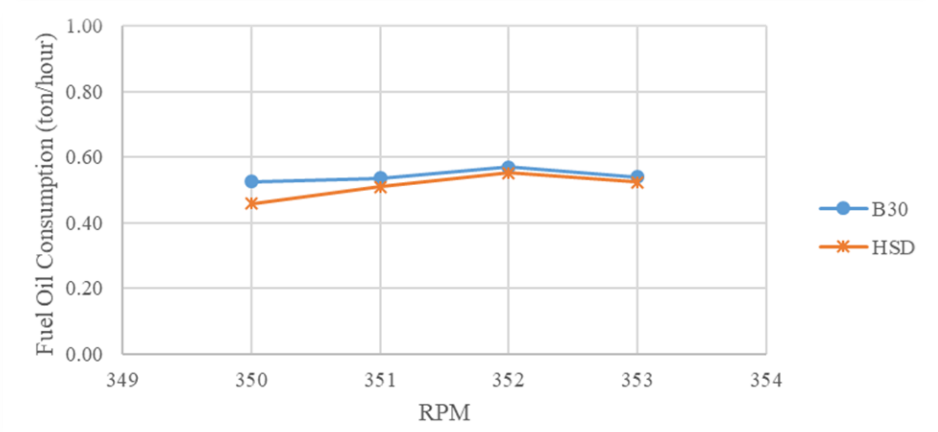

Figure 4. 4 *Graph of RPM vs Fuel Oil Consumption Main Engine II*

In figure 4.4 the comparison graph between fuel consumption and RPM on Main Engine II shows the result that the highest fuel consumption occurs at RPM 352 with 0.55 tons/hour of HSD fuel and when the main engine B30 fuelled can consume 0.57 tons/hour of fuel. Compared to HSD fuel, B30 at RPM 353, B30 used can consumed of fuel as much 0.54 tons/hour and for HSD 0.52. For fuel consumption, the smallest fuel consumed by using B30 fuel and HSD fuel occurs at RPM 353 with a fuel amount of B30 is 0.53 tons/hour. Whereas for HSD fuelled, the lowest consumption also occurred at RPM 353 with the amount of fuel 0.46 tons/hour.

4.5.5 Analysis of Relation Between BHP vs FOC Main Engine I

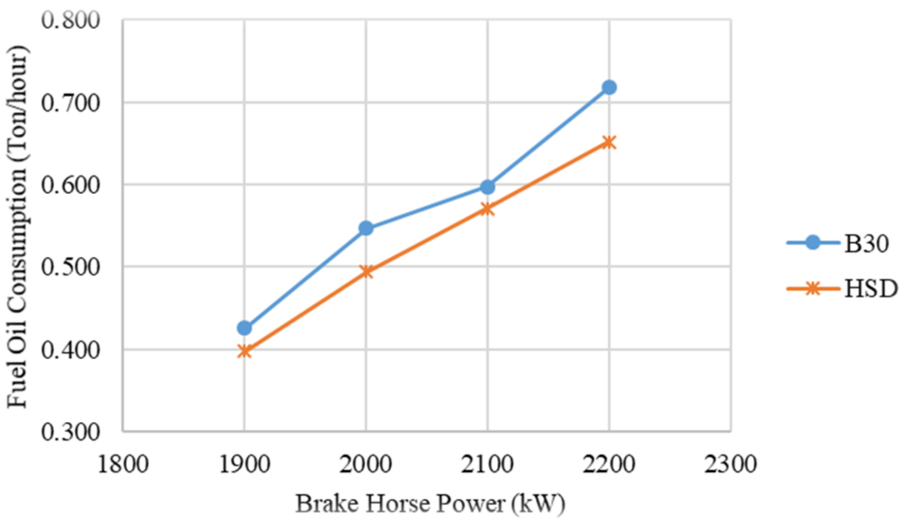

Figure 4. 5 *Graph of Brake Horse Power vs Fuel Oil Consumption Main Engine I*

Based on Figure 4.5 the comparison graph between brake horsepower and fuel oil consumption in the use of HSD with B30 shows the most high fuel consumption when 2200 kW power output generated. When using HSD to produce brake horsepower 2200 kW, fuel oil that can be consumed is 0.651 kg/hour. While using B30 to produce 2200 kW, the amount of fuel consumption is 0.718 tons/hour. The lowest fuel consumption when Main Engine II using B30 fuel and HSD at 1900 kW. To produce break hourse power 2600 kW for HSD fuel consumed 0.398 tons/hour, when using B30 requires 0.426 tons/hour. Overall, to produce the same power, the B30 tends to consume more fuel than HSD.

4.4.6 Analysis of Relation Between BHP vs FOC Main Engine II

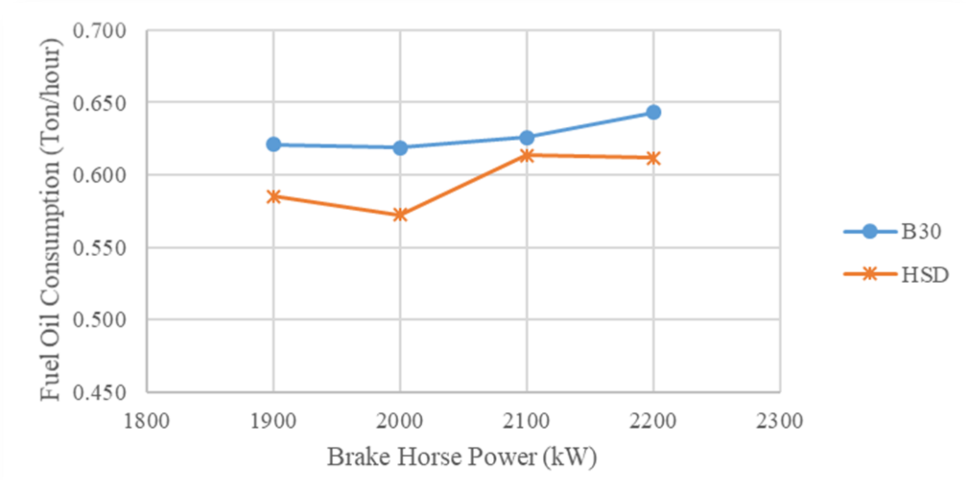

Figure 4. 6 *Graph of Brake Horse Power vs Fuel Oil Consumption Main Engine II*

Figure 4.6 present graph of brake horsepower and fuel oil consumption on main engine II. The graph shows that the highest fuel consumption for HSD used occurred at 2100 kW with total fuel consumption of fuel 0.614 tons/hour while at the same power condition B30 consumes more fuel with amount 0.626 tons/hour. In the use of B30 fuel, the largest fuel consumption is at 2200 kW with amount of consumption to 0.643 tons/hour, and for using HSD at the same power, it consumes 0.612 tons/hour. The graphs results is when main engine using B30 consumed more fuel than using HSD.

4.6 Total Sulphur Emission

For determining the amount of Sulphur emission remaining results of fuel combustion need data of fuel consumption in one voyage. Based on the ton of fuel oil consumption per day, Sulphur emission amount can be predicted.
Due to new regulation from IMO which MARPOL Annex VI Regulation 14, the maximum percentage Sulphur content in fuel oil for global use is 0.5%m/m. Indonesia included to global area, so the maximum allowance of Sulphur content in fuel oil is 0.5 %m/m. This regulation started at January 1st 2020. At the same time, Indonesia government via Ministry of Energy and Mineral Resources just released policy by Ministry of Energy and Mineral Resources Policy No.12 2015. This policy regulate the fuel utilization. This regulation explain about government movement about energy coversion. This policy establish utilization of diesel fuel mixed with crude palm oil (CPO) or Biodiesel. Refer to the new regulation, ship's owner changeover their type of fuel from HSD to B30.

Sulphur content at HSD is 0.062 %m/m. And for B30, the Sulphur content is 0.040 %m/m .

Trozi's method are used to determine the total Sulphur emission. To calculate the amount of Sulphur emission, the emission factor are needed. Approximation to get number of emission factor using Lloyd's Register table because there is no available information about emission factor of B30. To find the emission factor of B30 and HSD with this following calculation :

S = 20 * Sulphur content in fuel

Emission Factor For HSD,
S = 20 * 0.062 %m/m
= 1.24
Emission Factor For B30,
S = 20 * 0.040 %m/m
= 0.80

After determine the sulphur emission factor for each type of fuel, followed by calculate the total of Sulphur emission. Because the data provide is data at sailing mode or at sea mode, so this calculation determine the amount of Sulphur emission at sailing mode.

HSD used for one voyage or one trip
E_{trip} = 10^{-3} x (Fuel Consumption x Emission Factor)
= 10^{-3} x (9.1 ton x 1.24 kg/tonne fuel)
= 0.0113 Ton
Sulphur Percentage = SO_x emission /Fuel Oil Consumption x 100%
= 0.0113/9.1 x 100%
= 0.124 %

B30 used for one voyage or one trip

E_{trip} = 10^{-3} x (Fuel Consumption x Emission Factor)
= 10^{-3} x (9.1 ton x 0.8 kg/tonne fuel)
= 0.0073 Ton

Sulphur Percentage = SO_x emission /Fuel Oil Consumption x 100%
= 0.0073/9.1 x 100%
= 0.08 %

The amount of total sulphur emission depends on fuel oil consumption per trip. The calculation shows that percentage of Sulphur emission at B30 is 0.08% and for HSD is 0.124%

4.6.7 Analysis of Relation Between FOC per day vs Sulphur Emission

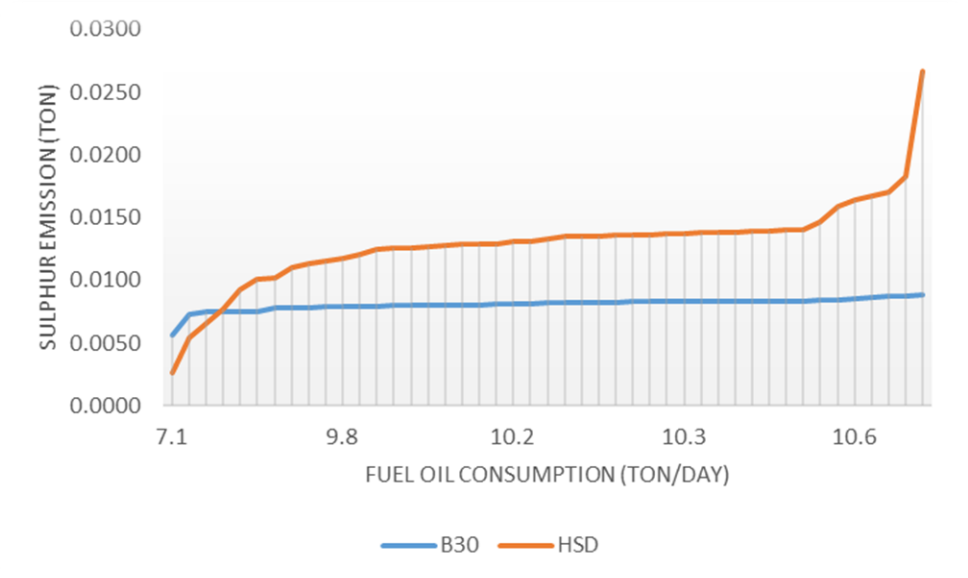

Figure 4. 7 *Fuel Consumption vs Total Sulphur Emission*

Sulfur emissions from combustion produce sulfur oxide (SOx). Figure 4.7 graph of total sulfur emissions produced by fuel consumption per tonne shows the difference in yields using of B30 fuel with HSD. From the calculation of sulfur content in each fuel showed results, the percentage of sulfur produced by B30 fuel was 0.08 while in using of HSD fuel the sulfur emissions contained were around 0.124. This value is below the safety limit stipulated in Marpol Annex VI Regulation 14, which is the maximum limit of sulfur emissions resulting from combustion from a maximum of 0.5. So that based on figure 4.7 can be concluded that the use of b30 fuel can reduce the number of sulfur gas emissions.

CHAPTER V
CONCLUSION

5.1 Conclusion

Based on the results of the performance analysis of B30 used and HSD used on the Main Engine I and Main Engine II can be known as follows:

- The graph relation between bhp and rpm between Main Engine I and Main Engine II shows that B30 fuel and HSD used RPM increased along with brake horsepower, because power generated influenced by engine rotation. HSD generates more power rather than B30.
- The graph relation between bhp and fuel oil consumption between Main Engine I and Main Engine II shows that Fuel consumption increases with the amount of power produced. To produce significant power, it needs a lot of engine speed or rpm so that when the engine speed increases, fuel consumption also increases. On the ME I and ME II graphics presented to generate same power output HSD fuel need less fuel oil rather than B30.
- From the analysis of sulfur emissions using B30 fuel shows a reduction in the number of sulfur emissions from combustion. Sulfur levels in the use of B30 are still far below regulatory limits, so it is proven that the use of B30 can reduce the number of sulfur emissions..

5.2 Suggestion

Along with energy conversion development to be environmentally friendly, it is necessary to further research on the type of fuel with a sustainable raw material content to the environment, a compatible engine with "new" fuel, complement with excellent performance and better exhaust emissions.

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APPENDIX

Appendix 1. 1 *Ship Particulars Data*

PT. DHARMA LAUTAN UTAMA
Armada pelayaran nasional

FM 4006 - 2006 Versi 1.3

DATA-DATA KAPAL
PARTICULARS OF SHIP

I.	PEMILIK	: PT. DHARMA LAUTAN UTAMA
II.	LINTAS PENYEBERANGAN	: Surabaya – Makasar, Surabaya - Balikpapan
III.	KAPAL PENYEBERANGAN	
	1. Nama Kapal	: KM. Dharma Kartika IX ex GL HAILONG
	2. Tempat Pembuatan	: Jepang
	3. Galangan Pembangunan	: MAR HAYASHIKANE DOCK YARD
	4. Tahun Pembuatan	: 1996
	5. Bahan	: BAJA
	6. Type Kapal	: Ferry RORO
	7. Klasifikasi	: BKI
	8. Surat Ukur No.	:
IV.	UKURAN UTAMA	
	1. Panjang Seluruhnya	: 155.04 ....METER
	2. Panjang Garis Air	: 145.00 ....METER
	3. Lebar	: 19.00 ....METER
	4. Dalam	: 9.30 ....METER
	5. Sarat Maximum	: 5.85 ....METER
	6. G T	: 6.801 ....GRT
	7. Kecepatan	: 23.2......................Knot
V.	KAPASITAS TANGKI	
	1. Tangki Bahan Bakar	: Ton
	2. Tangki Air Tawar	: Ton
VI.	MESIN UTAMA	
	1. Merk	: NKK-SEMP-PLELSTICK
	2. Type	: 12PC-6V
	3. Tenaga	: 9000 HP
	4. Putaran	: 520 Rpm
	6. Jumlah Mesin	: 2
	7. Jenis Bahan Bakar	: SOLAR
VII.	MESIN BANTU	
	1. Merk	: Yanmar
	2. Type	: M220 AL - SN
	3. Tenaga	: 1100 HP
	4. Putaran	: 900 Rpm
	5. Jumlah Mesin	: 2
VIII.	KAPASITAS MUAT	
	1. Jumlah penumpang	: 600 Orang
	2. Jumlah Kendaraan	: TB, TS
	3. Jumlah Crew	: - Orang
IX.	PINTU RAMPA	
	1. Pintu Rampa Haluan	= P : 4500 Mtr, L : 5300 Mtr
	2. Pintu Rampa Buritan	= P : 4500 Mtr, L : 5300 Mtr
	3. Pintu Rampa Kanan	= P : 4500 Mtr, L : 4500 Mtr (tanpa lidah –lidah)

Appendix 1. 2 *SFOC Calculation Main Engine I Using B30*

Date	Running Hours (Hour)	Actual Speed (Knot)	RPM	FO Consumption (Ltr)	Load Factor	SFOC (g/kWh)
1/1/2020	17	15.0	335	8684	0.560	185.355
3/1/2020	19	15.0	335	8684	0.560	185.355
4/1/2020	19	15.0	335	9277	0.560	185.355
5/1/2020	23	15.0	335	10951	0.560	185.355
6/1/2020	10	15.5	337	4873	0.628	183.271
7/1/2020	24	15.0	332	12765	0.560	185.355
9/1/2020	18	15.3	334	9325	0.601	184.033
10/1/2020	18	14.3	333	9374	0.470	189.287
11/1/2020	18	15.0	336	9545	0.560	185.355
12/1/2020	9	14.7	330	4624	0.516	187.126
13/1/2020	14	14.5	337	7105	0.492	188.228
14/1/2020	16	15.1	337	7882	0.578	184.743
15/1/2020	18	15.1	337	9560	0.577	184.780
16/1/2020	17	15.7	338	9185	0.654	182.694
17/1/2020	19	15.3	337	9295	0.596	184.170
18/2/2020	18	15.4	338	9055	0.619	183.514
19/1/2020	15	14.6	338	7588	0.507	187.532
21/1/2020	18	14.7	339	8712	0.525	186.728
22/1/2020	16	14.7	341	7836	0.525	186.728
24/1/2020	18	15.0	335	8226	0.560	185.355
25/1/2020	22	11.9	335	7595	0.251	204.418
28/1/2020	18	15.3	337	8726	0.601	184.033
29/1/2020	16	15.2	336	8111	0.591	184.309
30/1/2020	18	14.9	336	9060	0.549	185.777
31/1/2020	18	14.5	335	9125	0.502	187.739
1/2/2020	18	15.0	338	9125	0.557	185.474
2/2/2020	15	15.2	336	7117	0.590	184.344
4/2/2020	19	15.5	338	9571	0.628	183.271
5/2/2020	14	15.0	337	7148	0.557	185.474
6/2/2020	19	15.3	339	9611	0.605	183.899
7/2/2020	18	15.4	334	8844	0.619	183.514
8/2/2020	18	14.7	337	9105	0.522	186.860
9/2/2020	19	14.7	335	9480	0.525	186.728
10/2/2020	23	15.5	336	11706	0.626	183.322
11/2/2020	16	15.0	337	8073	0.564	185.221
12/2/2020	21	15.0	337	10541	0.564	185.221
13/2/2020	18	15.0	334	9105	0.560	185.355
14/2/2020	18	15.3	338	8950	0.605	183.899
15/2/2020	18	15.4	338	8950	0.614	183.639
16/2/2020	12	15.2	338	5781	0.582	184.596
18/2/2020	17	15.6	334	7800	0.638	183.041
19/2/2020	18	14.7	335	8671	0.526	186.685
20/2/2020	19	14.6	337	9027	0.506	187.578
21/2/2020	20	14.4	332	8916	0.489	188.370
22/2/2020	20	15.3	337	9113	0.601	184.033

Appendix 1. 3 *Power Calculation Main Engine I using B30*

Date	Running Hours	FO Consumption (ton/day)	Mass Fuel flow (kg/hour)	SFOC (g/kWh)	Brake Horse Power (kW)
1/1/2020	17	10.43	394.27	185.355	2127
1/2/2020	18	9.33	352.76	185.355	1903
2/2/2020	15	9.97	376.85	185.355	2033
3/1/2020	19	9.72	367.49	185.355	1983
4/1/2020	19	9.95	376.11	183.271	2052
4/2/2020	19	10.86	410.51	185.355	2215
5/1/2020	23	10.58	399.85	184.033	2173
5/2/2020	14	10.64	401.95	189.287	2123
6/1/2020	10	10.83	409.28	185.355	2208
6/2/2020	19	10.49	396.55	187.126	2119
7/1/2020	24	10.37	391.70	188.228	2081
7/2/2020	18	10.06	380.22	184.743	2058
8/2/2020	18	10.85	409.92	184.780	2218
9/1/2020	18	11.03	417.01	182.694	2283
9/2/2020	19	9.99	377.58	184.170	2050
10/1/2020	18	10.27	388.27	183.514	2116
10/2/2020	23	10.33	390.44	187.532	2082
11/1/2020	18	9.89	373.56	186.728	2001
11/2/2020	16	10.00	378.00	186.728	2024
12/1/2020	9	9.33	352.72	185.355	1903
12/2/2020	21	7.05	266.45	204.418	1303
13/1/2020	14	9.90	374.16	184.033	2033
13/2/2020	18	10.35	391.27	184.309	2123
14/1/2020	16	10.28	388.48	185.777	2091
14/2/2020	18	10.35	391.27	187.739	2084
15/1/2020	18	10.35	391.27	185.474	2110
15/2/2020	18	9.69	366.20	184.344	1987
16/1/2020	17	10.29	388.80	183.271	2121
16/2/2020	12	10.43	394.07	185.474	2125
17/1/2020	19	10.33	390.42	183.899	2123
18/2/2020	17	10.03	379.22	183.514	2066
18/2/2020	18	10.33	390.41	186.860	2089
19/1/2020	15	10.19	385.10	186.728	2062
19/2/2020	18	10.39	392.82	183.322	2143
20/2/2020	19	10.31	389.43	185.221	2103
21/1/2020	18	10.25	387.42	185.221	2092
21/2/2020	20	10.33	390.41	185.355	2106
22/1/2020	16	10.16	383.77	183.899	2087
22/2/2020	20	10.16	383.77	183.639	2090
24/1/2020	18	9.84	371.79	184.596	2014
25/1/2020	22	9.37	354.13	183.041	1935
28/1/2020	18	9.84	371.80	186.685	1992
29/1/2020	16	9.70	366.70	187.578	1955
30/1/2020	18	9.11	344.08	188.370	1827
31/1/2020	18	9.31	351.68	184.033	1911

Appendix 1. 4 *SFOC Calculation Main Engine I Using HSD*

Date	Running Hours (knot)	Actual Speed	RPM	FO Consumption (Ltr)	Load Factor	SFOC (g/kWh)
12/1/2018	20	15	339	6087	0.560	185.355
12/2/2018	21	15	343	10595	0.560	185.355
12/3/2018	12	15	343	5550	0.560	185.355
12/4/2018	21	15	339	9138	0.560	185.355
12/5/2018	11	15	339	7107	0.560	185.355
12/6/2018	18	15	340	10425	0.560	185.355
12/7/2018	14	15	340	8797.5	0.560	185.355
12/8/2018	20	15	340	9873	0.560	185.355
12/9/2018	17	15	340	6755	0.560	185.355
12/11/2018	19	15	339	12506	0.560	185.355
12/12/2018	13	15	339	9380	0.560	185.355
12/13/2018	24	15	338	11451	0.560	185.355
12/14/2018	18	15	338	4684	0.560	185.355
12/16/2018	22	15	341	9805	0.560	185.355
12/18/2018	19	15	338	10145	0.560	185.355
12/19/2018	20	15	339	8022.5	0.560	185.355
12/21/2018	16	15	339	8022.5	0.560	185.355
12/22/2018	16	15	339	10727	0.560	185.355
12/23/2018	20	15	339	10868	0.560	185.355
12/24/2018	20	15	339	9134	0.560	185.355
12/25/2018	18	15	339	6601	0.560	185.355
12/26/2018	13	15	339	12679	0.560	185.355
12/27/2018	23	15	338	4961	0.560	185.355
12/30/2018	24	15	339	2500	0.560	185.355
1/1/2019	21	15	340	11155	0.560	185.355
2/1/2019	19	15	334	10190	0.560	185.355
7/1/2019	24	15	341	13298	0.560	185.355
8/1/2019	20	15	339	10131	0.560	185.355
9/1/2019	12	15	339	6079	0.560	185.355
11/1/2019	24	15	340	12767	0.560	185.355
1/13/2019	18	15	338	9460	0.560	185.355
1/14/2019	20	15	339	10200	0.560	185.355
1/15/2019	21	15	339	11351	0.560	185.355
1/16/2019	10	15	339	5405	0.560	185.355
1/17/2019	20	15	340	10910	0.560	185.355
1/18/2019	11	15	340	6000.5	0.560	185.355
1/19/2019	19	15	336	10176	0.560	185.355
1/20/2019	13	15	336	6963	0.560	185.355
1/21/2019	21	15	338	10888	0.560	185.355
1/22/2019	19	15	337	10519	0.560	185.355
1/26/2019	12	15	340	5969	0.560	185.355
1/27/2019	18	15	340	8954	0.560	185.355
1/28/2019	17	15	342	9368	0.560	185.355
1/29/2019	15	15	342	8232	0.560	185.355
1/30/2019	24	15	339	12409	0.560	185.355

Appendix 1. 5 *Brake Horse Power Calculation Main Engine I Using HSD*

Date	Running Hours	FO Consumption (ton/day)	Mass Fuel flow (kg/hour)	SFOC (g/kWh)	Brake Horse Power (kW)
12/1/2018	20	6.09	230.32	185.355	1243
12/2/2018	21	10.10	381.81	185.355	2060
12/3/2018	12	9.26	350.00	185.355	1888
12/4/2018	21	8.71	329.30	185.355	1777
12/5/2018	11	12.94	488.94	185.355	2638
12/6/2018	18	11.60	438.29	185.355	2365
12/7/2018	14	12.58	475.55	185.355	2566
12/8/2018	20	9.89	373.58	185.355	2015
12/9/2018	17	7.96	300.70	185.355	1622
12/11/2018	19	13.18	498.11	185.355	2687
12/12/2018	13	14.45	546.04	185.355	2946
12/13/2018	24	9.55	361.07	185.355	1948
12/14/2018	18	5.21	196.93	185.355	1062
12/16/2018	22	8.93	337.28	185.355	1820
12/18/2018	19	10.69	404.07	185.355	2180
12/19/2018	20	8.03	303.56	185.355	1638
12/21/2018	16	10.04	379.45	185.355	2047
12/22/2018	16	13.43	507.37	185.355	2737
12/23/2018	20	10.88	411.23	185.355	2219
12/24/2018	20	9.15	345.62	185.355	1865
12/25/2018	18	7.34	277.52	185.355	1497
12/26/2018	13	19.53	738.08	185.355	3982
12/27/2018	23	4.32	163.23	185.355	881
12/30/2018	24	2.09	78.83	185.355	425
1/1/2019	21	10.64	401.99	185.355	2169
1/13/2019	18	10.74	405.87	185.355	2190
1/14/2019	20	11.10	419.31	185.355	2262
1/15/2019	21	10.14	383.34	185.355	2068
1/16/2019	10	10.14	383.37	185.355	2068
1/17/2019	20	10.65	402.57	185.355	2172
1/18/2019	11	10.52	397.72	185.355	2146
1/19/2019	19	10.21	385.95	185.355	2082
1/20/2019	13	10.82	409.05	185.355	2207
1/21/2019	21	10.82	409.03	185.355	2207
1/22/2019	19	10.92	412.82	185.355	2227
1/26/2019	12	10.92	412.82	185.355	2227
1/27/2019	18	10.73	405.31	185.355	2187
1/28/2019	17	10.73	405.34	185.355	2187
1/29/2019	15	10.38	392.37	185.355	2117
1/30/2019	24	11.09	418.97	185.355	2260
2/1/2019	19	9.96	376.43	185.355	2031
7/1/2019	24	9.96	376.45	185.355	2031
8/1/2019	20	11.04	417.02	185.355	2250
9/1/2019	12	10.99	415.31	185.355	2241
11/1/2019	24	10.35	391.28	185.355	2111

Appendix 1. 6 *SFOC Calculation Main Engine II Using B30*

Date	Running Hours	Actual Speed (knot)	RPM	FO Consumption (Ltr)	Load Factor	SFOC (g/kWh)
1/1/2020	17	15.0	345	8684	0.560	185.355
3/1/2020	19	15.0	345	8684	0.560	185.355
4/1/2020	19	15.0	350	9277	0.560	185.355
5/1/2020	23	15.0	345	10951	0.560	185.355
6/1/2020	10	15.5	350	4873	0.628	183.271
7/1/2020	24	15.0	345	12765	0.560	185.355
9/1/2020	18	15.3	350	9325	0.601	184.033
10/1/2020	18	14.3	350	9374	0.470	189.287
11/1/2020	18	15.0	350	9545	0.560	185.355
12/1/2020	9	14.7	350	4624	0.516	187.126
13/1/2020	14	14.5	350	7105	0.492	188.228
14/1/2020	16	15.1	350	7882	0.578	184.743
15/1/2020	18	15.1	350	9560	0.577	184.780
16/1/2020	17	15.7	350	9185	0.654	182.694
17/1/2020	19	15.3	350	9295	0.596	184.170
18/2/2020	18	15.4	350	9055	0.619	183.514
19/1/2020	15	14.6	350	7588	0.507	187.532
21/1/2020	18	14.7	350	8712	0.525	186.728
22/1/2020	16	14.7	350	7836	0.525	186.728
24/1/2020	18	15.0	350	8226	0.560	185.355
25/1/2020	22	11.9	350	7595	0.251	204.418
28/1/2020	18	15.3	345	8726	0.601	184.033
29/1/2020	16	15.2	345	8111	0.591	184.309
30/1/2020	18	14.9	345	9060	0.549	185.777
31/1/2020	18	14.5	345	9125	0.502	187.739
1/2/2020	18	15.0	345	9125	0.557	185.474
2/2/2020	15	15.2	345	7117	0.590	184.344
4/2/2020	19	15.5	345	9571	0.628	183.271
5/2/2020	14	15.0	350	7148	0.557	185.474
6/2/2020	19	15.3	350	9611	0.605	183.899
7/2/2020	18	15.4	350	8844	0.619	183.514
8/2/2020	18	14.7	350	9105	0.522	186.860
9/2/2020	19	14.7	351	9480	0.525	186.728
10/2/2020	23	15.5	345	11706	0.626	183.322
11/2/2020	16	15.0	345	8073	0.564	185.221
12/2/2020	21	15.0	350	10541	0.564	185.221
13/2/2020	18	15.0	352	9105	0.560	185.355
14/2/2020	18	15.3	352	8950	0.605	183.899
15/2/2020	18	15.4	345	8950	0.614	183.639
16/2/2020	12	15.2	352	5780.5	0.582	184.596
18/2/2020	17	15.6	352	7800	0.638	183.041
19/2/2020	18	14.7	352	8671	0.526	186.685
20/2/2020	19	14.6	353	9027	0.506	187.578
21/2/2020	20	14.4	352	8916	0.489	188.370
22/2/2020	20	15.3	350	9113	0.601	184.033

Appendix 1. 7 *Brake Horse Power Calculation Main Engine II Using B30*

Date	Running Hours (Hour)	FO Consumption (ton/day)	Mass Fuel flow (kg/hour)	SFOC (g/kWh)	Brake Horse Power (kW)
1/1/2020	17	10.43	394.265	185.355131	2127
3/1/2020	19	9.33	352.764	185.355131	1903
5/1/2020	23	9.97	376.853	185.355131	2033
7/1/2020	24	9.72	367.488	185.355131	1983
28/1/2020	18	9.95	376.109	183.271226	2052
29/1/2020	16	10.86	410.513	185.355131	2215
30/1/2020	18	10.58	399.847	184.032926	2173
31/1/2020	18	10.64	401.948	189.286637	2123
1/2/2020	18	10.83	409.281	185.355131	2208
2/2/2020	15	10.49	396.545	187.125834	2119
4/2/2020	19	10.37	391.700	188.228235	2081
10/2/2020	23	10.06	380.219	184.742808	2058
11/2/2020	16	10.85	409.924	184.779963	2218
15/2/2020	18	11.03	417.011	182.694327	2283
4/1/2020	19	9.99	377.584	184.16969	2050
6/1/2020	10	10.27	388.270	183.513542	2116
9/1/2020	18	10.33	390.440	187.532308	2082
10/1/2020	18	9.89	373.562	186.728274	2001
11/1/2020	18	10.00	378.000	186.728274	2024
12/1/2020	9	9.33	352.723	185.355131	1903
13/1/2020	14	7.05	266.454	204.417911	1303
14/1/2020	16	9.90	374.163	184.032926	2033
15/1/2020	18	10.35	391.266	184.309113	2123
16/1/2020	17	10.28	388.484	185.776723	2091
17/1/2020	19	10.35	391.271	187.738732	2084
18/2/2020	18	10.35	391.271	185.474043	2110
19/1/2020	15	9.69	366.204	184.344378	1987
21/1/2020	18	10.29	388.796	183.271226	2121
22/1/2020	16	10.43	394.071	185.474043	2125
24/1/2020	18	10.33	390.421	183.898874	2123
25/1/2020	22	10.03	379.222	183.513542	2066
5/2/2020	14	10.33	390.414	186.859772	2089
6/2/2020	19	10.19	385.099	186.728274	2062
7/2/2020	18	10.39	392.824	183.32214	2143
8/2/2020	18	10.31	389.433	185.220781	2103
12/2/2020	21	10.25	387.418	185.220781	2092
22/2/2020	20	10.33	390.414	185.355131	2106
9/2/2020	19	10.16	383.768	183.898874	2087
13/2/2020	18	10.16	383.768	183.639127	2090
14/2/2020	18	9.84	371.794	184.595724	2014
16/2/2020	12	9.37	354.131	183.041097	1935
18/2/2020	17	9.84	371.804	186.684672	1992
19/2/2020	18	9.70	366.697	187.578	1955
21/2/2020	20	9.11	344.079	188.370031	1827
20/2/2020	19	9.31	351.681	184.032926	1911

Appendix 1. 8 *SFOC Calculation Main Engine I Using HSD*

Date	Running Hours (Hour)	Actual Speed (knot)	RPM	FO Consumption (Ltr/day)	Load Factor	SFOC (g/kWh)
12/1/2018	20	15	354	6087	1	185.350
12/2/2018	21	15	357	10595	1	185.350
12/3/2018	12	15	357	5550	1	185.350
12/4/2018	21	15	354	9138	1	185.350
12/5/2018	11	15	354	7107	1	185.350
12/6/2018	18	15	352	10425	1	185.350
12/7/2018	14	15	352	8797.5	1	185.350
12/8/2018	20	15	352	9873	1	185.350
12/9/2018	17	15	354	6755	1	185.350
12/11/2018	19	15	353	12506	1	185.350
12/12/2018	13	15	353	9380	1	185.350
12/13/2018	24	15	354	11451	1	185.350
12/14/2018	18	15	354	4684	1	185.350
12/16/2018	22	15	359	9805	1	185.350
12/18/2018	19	15	355	10145	1	185.350
12/19/2018	20	15	351	8022.5	1	185.350
12/21/2018	16	15	351	8022.5	1	185.350
12/22/2018	16	15	351	10727	1	185.350
12/23/2018	20	15	351	10868	1	185.350
12/24/2018	20	15	350	9134	1	185.350
12/25/2018	18	15	352	6601	1	185.350
12/26/2018	13	15	352	13679	1	185.350
12/27/2018	23	15	355	4961	1	185.350
12/30/2018	24	15	351	2500	1	185.350
1/1/2019	21	15	352	11155	1	185.350
2/1/2019	19	15	352	10190	1	185.350
7/1/2019	24	15	351	13298	1	185.350
8/1/2019	20	15	352	10131	1	185.350
9/1/2019	12	15	352	6079	1	185.350
11/1/2019	24	15	357	12767	1	185.350
1/13/2019	18	15	357	9460	1	185.350
1/14/2019	20	15	352	10200	1	185.350
1/15/2019	21	15	353	11351	1	185.350
1/16/2019	10	15	354	5405	1	185.350
1/17/2019	20	15	354	10910	1	185.350
1/18/2019	11	15	355	6000.5	1	185.350
1/19/2019	19	15	355	10176	1	185.350
1/20/2019	13	15	354	6963	1	185.350
1/21/2019	21	15	354	10888	1	185.350
1/22/2019	19	15	355	10519	1	185.350
1/26/2019	12	15	353	5969	1	185.350
1/27/2019	18	15	352	8954	1	185.350
1/28/2019	17	15	352	9368	1	185.350
1/29/2019	15	15	352	8232	1	185.350
1/30/2019	24	15	354	12409	1	185.350

Appendix 1. 9 *Brake Horse Power Calculation Main Engine II Using HSD*

Date	Running Hours (Hour)	FO Consumption (ton/day)	Mass Fuel flow (kg/hour)	SFOC (g/kWh)	Brake Horse Power (kW)
12/1/2018	20	6.09	230.322	185.350	1243
12/2/2018	21	10.10	381.807	185.350	2060
12/3/2018	12	9.26	350.005	185.350	1888
12/4/2018	21	8.71	329.302	185.350	1777
12/5/2018	11	12.94	488.941	185.350	2638
12/6/2018	18	11.60	438.294	185.350	2365
12/7/2018	14	12.58	475.547	185.350	2566
12/8/2018	20	9.89	373.578	185.350	2016
12/9/2018	17	7.96	300.704	185.350	1622
12/11/2018	19	13.18	498.112	185.350	2687
12/12/2018	13	14.45	546.037	185.350	2946
12/13/2018	24	9.55	361.073	185.350	1948
12/14/2018	18	5.21	196.928	185.350	1062
12/16/2018	22	8.93	337.277	185.350	1820
12/18/2018	19	10.69	404.074	185.350	2180
12/19/2018	20	8.03	303.558	185.350	1638
12/21/2018	16	10.04	379.448	185.350	2047
12/22/2018	16	13.43	507.365	185.350	2737
12/23/2018	20	10.88	411.227	185.350	2219
12/24/2018	20	9.15	345.616	185.350	1865
12/25/2018	18	7.34	277.523	185.350	1497
12/26/2018	13	21.07	796.294	185.350	4296
12/27/2018	23	4.32	163.231	185.350	881
12/30/2018	24	2.09	78.830	185.350	425
1/1/2019	21	10.64	401.988	185.350	2169
1/13/2019	18	10.74	405.866	185.350	2190
1/14/2019	20	11.10	419.312	185.350	2262
1/15/2019	21	10.14	383.341	185.350	2068
1/16/2019	10	10.14	383.366	185.350	2068
1/17/2019	20	10.65	402.569	185.350	2172
1/18/2019	11	10.52	397.723	185.350	2146
1/19/2019	19	10.21	385.951	185.350	2082
1/20/2019	13	10.82	409.051	185.350	2207
1/21/2019	21	10.82	409.033	185.350	2207
1/22/2019	19	10.92	412.817	185.350	2227
1/26/2019	12	10.92	412.817	185.350	2227
1/27/2019	18	10.73	405.309	185.350	2187
1/28/2019	17	10.73	405.336	185.350	2187
1/29/2019	15	10.38	392.366	185.350	2117
1/30/2019	24	11.09	418.970	185.350	2260
2/1/2019	19	9.96	376.429	185.350	2031
7/1/2019	24	9.96	376.450	185.350	2031
8/1/2019	20	11.04	417.023	185.350	2250
9/1/2019	12	10.99	415.314	185.350	2241
11/1/2019	24	10.35	391.280	185.350	2111

Appendix 1. 10 *Total Sulphur Emission B30*

B30 FUEL

Date	Fuel Consumption (Ton)	Emission (Ton)	Sulphur Percentage (%)
1/1/2020	7.1	0.0056	0.08
3/1/2020	9.1	0.0073	0.08
4/1/2020	9.3	0.0074	0.08
5/1/2020	9.3	0.0075	0.08
6/1/2020	9.3	0.0075	0.08
7/1/2020	9.4	0.0075	0.08
9/1/2020	9.7	0.0078	0.08
10/1/2020	9.7	0.0078	0.08
11/1/2020	9.7	0.0078	0.08
12/1/2020	9.8	0.0079	0.08
13/1/2020	9.8	0.0079	0.08
14/1/2020	9.9	0.0079	0.08
15/1/2020	9.9	0.0079	0.08
16/1/2020	10.0	0.0080	0.08
17/1/2020	10.0	0.0080	0.08
18/2/2020	10.0	0.0080	0.08
19/1/2020	10.0	0.0080	0.08
21/1/2020	10.0	0.0080	0.08
22/1/2020	10.1	0.0080	0.08
24/1/2020	10.2	0.0081	0.08
25/1/2020	10.2	0.0081	0.08
28/1/2020	10.2	0.0082	0.08
29/1/2020	10.3	0.0082	0.08
30/1/2020	10.3	0.0082	0.08
31/1/2020	10.3	0.0082	0.08
1/2/2020	10.3	0.0082	0.08
2/2/2020	10.3	0.0082	0.08
4/2/2020	10.3	0.0083	0.08
5/2/2020	10.3	0.0083	0.08
6/2/2020	10.3	0.0083	0.08
7/2/2020	10.3	0.0083	0.08
8/2/2020	10.4	0.0083	0.08
9/2/2020	10.4	0.0083	0.08
10/2/2020	10.4	0.0083	0.08
11/2/2020	10.4	0.0083	0.08
12/2/2020	10.4	0.0083	0.08
13/2/2020	10.4	0.0083	0.08
147/2/2020	10.4	0.0083	0.08
15/2/2020	10.5	0.0084	0.08
16/2/2020	10.6	0.0085	0.08
18/2/2020	10.6	0.0085	0.08
19/2/2020	10.8	0.0087	0.08
20/2/2020	10.8	0.0087	0.08
21/2/2020	10.9	0.0087	0.08
22/2/2020	11.0	0.0088	0.08

Appendix 1. 11 *Total Sulphur Emission HSD*

HSD FUEL

Date	Fuel Consumption (Ton)	Emission (Ton)	Sulphur Percentage (%)
01/12/2018	2.1	0.0026	0.124
02/12/2018	4.3	0.0054	0.124
03/12/2018	5.2	0.0065	0.124
04/12/2018	6.1	0.0076	0.124
05/12/2018	7.3	0.0091	0.124
06/12/2018	8.0	0.0099	0.124
07/12/2018	8.0	0.0100	0.124
08/12/2018	8.7	0.0108	0.124
09/12/2018	8.9	0.0111	0.124
11/12/2018	9.1	0.0113	0.124
12/12/2018	9.3	0.0115	0.124
13/12/2018	9.6	0.0118	0.124
14/12/2018	9.9	0.0123	0.124
16/12/2018	10.0	0.0124	0.124
18/12/2018	10.0	0.0124	0.124
19/12/2018	10.0	0.0125	0.124
21/12/2018	10.1	0.0125	0.124
22/12/2018	10.1	0.0126	0.124
23/12/2018	10.1	0.0126	0.124
24/12/2018	10.2	0.0127	0.124
25/12/2018	10.4	0.0128	0.124
26/12/2018	10.4	0.0129	0.124
27/12/2018	10.5	0.0131	0.124
30/12/2018	10.6	0.0132	0.124
1/1/2019	10.7	0.0132	0.124
2/1/2019	10.7	0.0133	0.124
7/1/2019	10.7	0.0133	0.124
8/1/2019	10.7	0.0133	0.124
9/1/2019	10.7	0.0133	0.124
11/1/2019	10.8	0.0134	0.124
13/01/2019	10.8	0.0134	0.124
14/01/2019	10.9	0.0135	0.124
15/01/2019	10.9	0.0135	0.124
16/01/2019	10.9	0.0135	0.124
17/01/2019	11.0	0.0136	0.124
18/01/2019	11.0	0.0137	0.124
19/01/2019	11.1	0.0137	0.124
20/01/2019	11.1	0.0138	0.124
21/01/2019	11.6	0.0144	0.124
22/01/2019	12.6	0.0156	0.124
26/01/2019	12.9	0.0160	0.124
27/01/2019	13.2	0.0163	0.124
28/01/2019	13.4	0.0166	0.124
29/01/2019	14.4	0.0179	0.124
30/01/2019	19.5	0.0242	0.124

Appendix 1. 12 *Fuel Properties*

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Parameters	Unit	Limit		Test Result			Test Method
		Min	Max	B0	B20	B30	
Calculated Cetane Number		48	-	48.3	51.5	53.1	ASTM D 613
Density @15°C	kg/m³	815	870	834.4	847.6	851	D 4052/D 1298
Viscosity Kinematic @ 40°C	cSt	2.0	4.5	2.66	2.94	3.15	ASTM D 445
Sulphur content	% m/m	-	0.25	0.062	0.040	0.040	ASTM D 5453
Distillation 90%	°C	-	370	348.8	349.2	351.0	ASTM D 86
Flash Point	°C	52	-	65	70	70	ASTM D 93
Pour Point	°C	-	18	-3	0	0	ASTM D 2500
Carbon Residue	% m/m	-	0.1	Nihil	Nihil	Nihil	ASTM D 5430
Water Content	mg/kg	-	500	70.5	191.5	230.7	ASTM D 6304
Biological Growth	.	Nihil		Nihil	Nihil	Nihil	
FAME Content	% v/v	-	-	0	20	30	ASTM D 7806
Corrosion copper strip	Class		Class 1	1A	1A	1A	ASTM D 130
Ash Content	% m/m	-	0.01	Nihil	Nihil	Nihil	ASTM D 482
Sediment Content	% m/m	-	0.01	Nihil	Nihil	Nihil	ASTM D 473
Total Acid Number	mg KOH/gr	-	0.6	0.11	0.32	0.36	ASTM D 664
Strong Acid Number	mg KOH/gr	-	0	0	0	0	ASTM D 664
Appearance		Clear & Bright		Clear & Bright			
Colour ASTM		-	3.0	1.3	1.4	1.7	ASTM D 1500
Oxidation Stability	Hour	35	-	>48	>48	>48	EN 15751

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Appendix 1. 13 *Fuel Properties B30*

BUMN
Hadir untuk negeri

ENERGI UNGGUL INDONESIA MAJU

Spesifikasi

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Spesifikasi B30

Parameters	Unit	Limit		Test Method (ASTM)
		Min	Max	
Calculated Cetane Number		48	-	D613
Density @15°C	kg/m³	815	880	D4052/D1298
Viscosity Kinematic @ 40°C	cSt	2,0	5,0	D445
Sulphur content	% m/m	-	0,25	D4294/D5453
Distillation 90%	°C	-	370	D86
Flash Point	°C	52	-	D93
Cloud Point	°C	-	18	D2500
Pour Point	°C	-	18	D97
Carbon Residue	% m/m	-	0,1	D189
Water Content	mg/kg	-	425 and reportable	D6304/D1744
Biological Growth		Nihil		
FAME Content	% v/v	-	30	D7806/D 7371
Corrosion copper strip	Class		Class 1	D130
Ash Content	% m/m	-	0,01	D482
Sediment Content	% m/m	-	0,01	D473
Total Acid Number	mg KOH/gr	-	0,6	D664
Strong Acid Number	mg KOH/gr	-	0	D664
Appearance		Clear & Bright		
Colour ASTM		-	3,0	D1500
Lubricity (HFFR wear scar dia @ 60°C)	Micron	-	460	D6079
Oxidation Stability	Hour	35		EN15751

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Appendix 1. 14 *Main Engine Data*

PC エンジン概要
PC engine main data

PC2.6 (L,V)

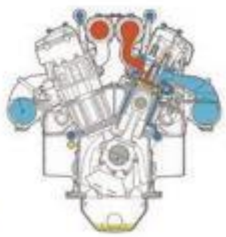
シリンダ数 Cylinder Number	L: 6cyl ~ 9cyl V: 12cyl ~ 18cyl
シリンダ径 Cylinder Diameter	400mm
ストローク Stroke	460mm
定格速度 Engine Speed	520min^{-1}
出力範囲 Power Range	3,300 ~ 9,900kW
単位出力 Unit Power	550 kW/cyl (750PS/cyl)

PC2.6BV

シリンダ数 Cylinder Number	12cyl ~ 20cyl
シリンダ径 Cylinder Diameter	400mm
ストローク Stroke	500mm
定格速度 Engine Speed	600min^{-1}
出力範囲 Power Range	9,000 ~ 15,000kW
単位出力 Unit Power	750 kW/cyl (1,000PS/cyl)

PC4.2BV

シリンダ数 Cylinder Number	12cyl ~ 18cyl	
シリンダ径 Cylinder Diameter	570mm	
ストローク Stroke	660mm	
定格速度 Engine Speed	428min^{-1}	
出力範囲 Power Range	Effeciency optimum	12 ~ 16cyl: 15,000 ~ 20,000kW
	Output optimum	12 ~ 18cyl: 15,900 ~ 23,850kW
単位出力 Unit Power	Effeciency optimum	1,250kW/cyl (1,700PS/cyl)
	Output optimum	1,325kW/cyl (1,800PS/cyl)



Appendix 1. 15 *Main Engine Particulars Data*

舶用向けエンジン要目
Engine particulars for marine propulsion

PC2.6 (L, V)

Engine type			4 stroke, single acting, air-less injection, direct reversibletrunk piston with turbo-charger and air cooler							
Cylinder arrangement			L				V			
Number of cylinder			6	7	8	9	12	14	16	18
Cyl. Bore × stroke		mm	400 × 460							
M.C.R.	Engine output	kW	3,300	3,850	4,400	4,950	6,600	7,700	8,800	9,900
		(PS)	(4,500)	(5,250)	(6,000)	(6,750)	(9,000)	(10,500)	(12,000)	(13,500)
	Engine speed	rpm	520							
	B.M.E.P.	MPa	2.19							
	Piston speed	m/s	7.97							
N.O.R.	Engine output	kW	2,970	3,465	3,960	4,455	5,940	6,930	7,920	8,910
		(PS)	(4,050)	(4,725)	(5,400)	(6,075)	(8,100)	(9,450)	(10,800)	(12,150)
	Engine speed	rpm	493							
	B.M.E.P.	MPa	1.97							
	Piston speed	m/s	7.56							

PC2.6BV

Engine type			4 stroke, single acting, air-less injection, trunk piston type with turbo-charger and air cooler				
Cylinder arrangement			V				
Number of cylinder			12	14	16	18	20
Cyl. Bore × stroke		mm	400 × 500				
M.C.R.	Engine output	kW	9,000	10,500	12,000	13,500	15,000
		(PS)	(12,000)	(14,000)	(16,000)	(18,000)	(20,000)
	Engine speed	rpm	600				
	B.M.E.P.	MPa	2.39				
	Piston speed	m/s	10				
N.O.R.	Engine output	kW	8,100	9,450	10,800	12,150	13,500
		(PS)	(10,800)	(12,600)	(14,400)	(16,200)	(18,000)
	Engine speed	rpm	568				
	B.M.E.P.	MPa	2.14				
	Piston speed	m/s	9.47				

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