BACHELOR THESIS & COLLOQUIUM – ME 184841

ANALYSIS OF LUBRICANT OIL PROPERTIES FILTERED BY MODIFIED OIL FILTER PRODUCED FROM SAWDUST AND ITS EFFECT ON 4-STROKES DIESEL ENGINE PERFORMANCE AND ENGINE EMISSIONS

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DOUBLE DEGREE PROGRAM OF
DEPARTEMENT OF MARINE ENGINEERING
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SKRIPSI– ME 184841

ANALISA SIFAT MINYAK PELUMAS YANG DISARING OLEH FILTER MINYAK PELUMAS MODIFIKASI TERBUAT DARI SERBUK KAYU DAN PENGARUHNYA TERHADAP KINERJA MESIN DIESEL 4 LANGKAH DAN EMISI MESIN

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APPROVAL FORM

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Submitted to Comply One of the Requirements to Obtain a Bachelor Engineering Degree
on
Laboratory of Marine Power Plant (MPP)
Bachelor Program Departement of Marine Engineering
Faculty of Marine Technology
Sepuluh Nopember Institute of Technology

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DECLARATION OF HONOR

I hereby who signed below declare that:

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

Name	:	Ardi Pangestu Wuryantoro
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Final Project Title	:	Analysis of Lubricant Oil Properties Filtered by Modified Oil Filter Produced from Sawdust and Its Effect on 4-Strokes Diesel Engine Performance and Engine Emissions
Departement	:	Marine Engineering

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

Surabaya, July 2019

Ardi Pangestu Wuryantoro

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ABSTRACT

The impact of oil filter on lubricating oil stability and engine performance has been of interest to researchers for a long time. In early years, some additives were added into the oil filter element to extend the useful life of lubricating oil in an internal combustion engine. The most widely used materials for oil filter are the synthetic fiber paper or metal mesh on the market which can effectively remove particulate impurities but show deficiency in the removal of insoluble colloids from lubricant. Renewable and easy available biomass materials, such as plant residues, straw, and sawdust possess rich pore structure and natural texture which show large adsorption capacity to dyes, oil, toxic salts, and heavy metals. In this study, a modified-sawdust oil filter (MSF) was developed and its effect on emission characteristic and performance of diesel engine was studied compared with conventional metal mesh oil filter (CMF). The test was performed using a one-cylinder, light-duty direct injection diesel engine. In steady state, the specific fuel oil consumption (SFOC), engine output power was measured at four different typical engine speeds. Exhaust emissions of nitrogen oxides (NO_x), particulate matter (PM), carbon monoxide (CO) and hydrocarbons (HC) were analysed according to IMO emission test procedure. Besides, lubricant oil sample were extracted from the crankcase in the equipment of MSF and CMF individually. Then the kinematic viscosity, viscosity index, flash point, pour point, total base number (TBN) and metal content of oil samples were determined. The results showed that MSF effectively reduced wear metal accumulation and degradation in lubricating oil. Compared to CPF, an increase of 0,02 kW in maximum output power and decrease of 2 g/kWh in SFOC were observed for MSF. In addition, the using of MSF significantly reduced HC and PM emission while increased CO and NOx emission slightly. The results proved that MSF is a suitable choice for diesel engine to improve engine performance and reduce exhaust emissions.

Keywords: Engine Oil Filter, Engine Exhaust Emissions, Engine Performance, Diesel Engine, Impurity Adsorption

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STUDI LANJUTAN PENGGUNAAN DATA AUTOMATIC IDENTIFICATION SYSTEM (AIS) UNTUK ESTIMASI KONSUMSI BAHAN BAKAR PADA KAPAL TUNDA

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ABSTRAK

Dampak filter oli pada stabilitas oli pelumas dan kinerja mesin telah lama menjadi perhatian para peneliti. Pada tahun-tahun awal, beberapa aditif ditambahkan ke dalam elemen filter oli untuk memperpanjang masa manfaat oli pelumas dalam mesin pembakaran internal. Bahan yang paling banyak digunakan untuk filter oli adalah kertas serat sintetis atau jaring logam di pasaran yang secara efektif dapat menghilangkan kotoran partikel tetapi menunjukkan kekurangan dalam menghilangkan koloid yang tidak dapat larut dari pelumas. Bahan biomassa yang terbarukan dan mudah tersedia, seperti residu tanaman, jerami, dan serbuk gergaji memiliki struktur pori yang kaya dan tekstur alami yang menunjukkan kapasitas adsorpsi besar untuk pewarna, minyak, garam beracun, dan logam berat. Dalam penelitian ini, filter oli serbuk gergaji modifikasi (MSF) dikembangkan dan pengaruhnya terhadap karakteristik emisi dan kinerja mesin diesel dipelajari dibandingkan dengan filter oli mesh logam (CMF) konvensional. Pengujian dilakukan dengan menggunakan mesin diesel direct injection satu silinder, ringan. Dalam kondisi mantap, konsumsi bahan bakar minyak spesifik (SFOC), daya output engine diukur pada empat kecepatan engine yang berbeda. Emisi gas buang nitrogen oksida (NOx), partikel debu (PM), karbon monoksida (CO) dan hidrokarbon (HC) dianalisis menurut IMO. Selain itu, sampel minyak pelumas diekstraksi dari bak mesin di peralatan MSF dan CPF secara individual. Kemudian ditentukan viskositas kinematik, indeks viskositas, titik nyala, titik tuang, jumlah basa total (TBN) dan kandungan logam sampel minyak. Hasil menunjukkan bahwa MSF secara efektif mengurangi akumulasi dan degradasi logam aus dalam minyak pelumas. Dibandingkan dengan CMF, peningkatan 0,02 kW dalam keluaran daya maksimum dan penurunan 2 g/kWh di SFOC diamati untuk MSF. Selain itu, penggunaan MSF secara signifikan mengurangi emisi HC dan PM sementara sedikit meningkatkan emisi CO dan NOx. Hasilnya membuktikan bahwa MSF adalah pilihan yang cocok untuk mesin diesel untuk meningkatkan kinerja mesin dan mengurangi emisi gas buang.

Keywords: Adsorpsi Kotoran, Emisi Gas Buang Mesin, Filter Oli Mesin, Mesin Diesel, Performa Mesin

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PREFACE

All the gratitude towards Almighty Allah for all the blessings and gifts so that the author can complete final project with title of “Analysis of Lubricant Oil Properties Filtered by Modified Oil Filter Produced from Sawdust and Its Effect on 4-Strokes Diesel Engine Performance and Engine Emissions" in order to fulfill the requirements to obtaining the bachelor degree program at Marine Engineering Department, Faculty of Marine Technologym Institut Teknologi Sepuluh Nopember Surabaya.

During the accomplishment of this final project, author want to thank every parties who helped, assisted, and supported the author so that the author is able to complete this very well. All thanks are delivered to:

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Because this work is also far from a perfect work, author will really apreciated for 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, author hopes this thesis will be helpful and beneficial for other parties who are going to conduct the similar research.

Surabaya, July 2019

Author

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CHAPTER 1

INTRODUCTION

1.1 Backgrounds

Nowadays, the depletion of non-renewable fossil resources and the deterioration of global air condition that has caused irreversible human health problems are two challenges faced any countries and citizen. With the development of internal combustion engine, these two issues have been increasingly serious. It would be very urgent to save fossil resources and to reduce harmful exhaust emissions produced by internal combustion engine vehicles in the coming decades (Gligorijevic, Jevtic, & Borak, 2006). It has been reported that transportation engine emissions account for 23,5% of air pollution and many countries have drawn up stringent environment engine for its high fuel-energy conversion efficiency, as a consequence diesel exhaust emission becomes an important source of atmospheric pollution (Storey, et al., 2015).A lot of technologies have been developed to meet the strict environmental regulations and reduce consumption of petroleum-based fuel.

Currently, many researchers have focused on the development of alternative biofuel or fuel additives to improve fuel economy and to reduce exhaust gas emissions. (Asokan, Prabu, Kamesh, & Khan, 2018) found that diesel engine fueled by bio-diesel/diesel blend produced lower CO and HC emission as well as lower diesel consumption rate. (Wei, Cheng, Mao, & Geng, 2018) reported lower NOx emission in diesel engine fueled with waste cooking oil biodiesel blends. However, it still has a long way to go for its widespread because of low calorific value. At the same time, many researchers have proposed improvement method that based on the optimization of stroke structure design of the fuel injection system injector to make exhaust gas lean and rich conditions for controlling LNT system to reduce NOx emissions. (Gumus, Sayin, & Canakci, 2012) found that the increasing of injection pressure could decrease SFOC, CO, and HC emissions. Although the above auxiliary operation and technology can promote fuel efficiency and reduce emissions to a certain degree, is still suffer from high cost and may not practical for the existing internal combustion engines and on-road vehicles.

The lubrication system in internal combustion engine plays an important role in maintaining its normal running. Industry and transport sector are mainly dependent on the petroleum-based lubricant that can clean the mechanical parts, seal piston and cylinder wall as well as prevent corrosion. The lubricant can also reduce friction loss thus directly save fossil resource (Holmberg, Andersson, Nylund, Mäkelä, & Erdemir, 2014). However, lubricating oil is easy to be contaminated by various impurities such as wear metal particulate and fuel residue especially for engine that has run for a long time. At high temperature, lubricant oil is prone to be oxidized by air and generate colloids which are detrimental to lubrication property (Hasannudin, et al., 2016). Recent research indicates that the quality and composition of lubricant oil have a direct impact on the engine emissions (Manni, Florio, & Gommellini, 1997) and performance (Dowling, 2019). Once replaced by a new lubricant, the used oil will also pollute environment if not properly handed. Furthermore, the disposal would require a complex technology and large cost (Yang, Chen, Xiang, & Li, 2013). Therefore, to prevent environmental pollution and save petroleum sources, the properties of lubricants need to be maintained to promote engine performance, extend drain intervals and reduce emissions in the long-term running. The impact of oil filter on lubricating oil stability and engine performance has been of interest to researchers for a long time (Cai, Guo, Zhou, & Liu, 2013). In early years, some additives were added into the oil filter element to extend the useful life of lubricating oil in an internal combustion engine. Afterward, (Watson, Wong, Brownawell, & Lockledge, 2009) developed an innovative oil filter with chemical modification which performed well in controlling of engine oil acidity. In recent years, (Gulzar, Masjuki, Kalam, Varman, & Fattah, 2015) modified the oil filter element with sodium hydroxide which showed great prospect in improvement of lubricant sustainability and reduction of exhaust emissions.

The most widely used materials for oil filter are the synthetic fiber paper or metal mesh on the market which can effectively remove particulate impurities but show deficiency in the removal of insoluble colloids from lubricant. Renewable and easy available biomass materials, such as plant residues, straw, and sawdust possess rich pore structure and natural texture which show large adsorption capacity to dyes, oil, toxic salts, and heavy metals (Shukla, Zhang, Dubey, Margrave, & Sukhla, The Role of Sawdust in the Removal of Unwanted Materials from Water, 2002). These materials have aroused great interest of researchers as an economic adsorption material for the remove of heavy metals in sewage and grease in industrial drainage (Kathiresan & Mas, 2010). However, it is rarely reported for the filtration of oily substances. (Chen, et al., 2018), a chemical modification method has been developed for raw sawdust and the modified sawdust showed good adsorption ability for impurities from used lubricant.

In this research, the modified sawdust was processed as a lubricant oil filter, which was defined as MSF. Its effect on engine performance and exhaust emissions were investigated on diesel engine durability test compared with

CMF. Besides, the effect of this novel oil filter on lubricant property changes and impurity content was also investigated in the actually running engine. In this research, light-duty diesel engine was used as an example of all kinds of diesel internal combustion engine to illustrate the impact of MSF on engine performance and emissions.

1.2 Problem Statement

Based on the background of this bachelor thesis, the author can state some problems as below:

1. How is the comparison of lubricating oil properties filtered by Conventional Metal-Mesh Oil Filter (CMF) and Modified-Sawdust Oil Filter (MSF)?
2. How is the engine performance comparison of a diesel engine equipped by Conventional Metal-Mesh Oil Filter (CMF) and Modified-Sawdust Oil Filter (MSF)?
3. How is the comparison of NOx, HC, CO, and PM emissions of a diesel engine equipped by Conventional Metal-Mesh Oil Filter (CMF) and Modified-Sawdust Oil Filter (MSF)?

1.3 Research Limitation

To define the clear limit of the research, the author has set the limitation of the research to be:

1. Variables of lubricating oil filter that will be compared are Conventional Metal-Mesh Oil Filter (CMF) and Modified-Sawdust Oil Filter (MSF).
2. Variable of lubricating oil that will be used is PERTAMINA MESRAN B SAE 40.
3. Variable of fuel oil that will be used is PERTAMINA DEXLITE.
4. Analyzed parameters for diesel engine emissions includes NOx, HC, CO, and PM.
5. Analyzed parameters for lubricating oil properties includes Kinematic Viscosity, Viscosity Index, Total Base Number, Flash Point, Pour Point and Wear Metals (Fe, Al, and Cr).
6. Engine performance test will be conducted with Engine Manufacturers Association (EMA) engine durability test procedure for 200 hours.
7. Analyzed parameters for diesel engine performance includes Maximum Output Power and Specific Fuel Oil Consumption (SFOC).
8. Engine performance test will be conducted using DONGFENG R180 diesel engine which belongs to Marine Power Plant Laboratory of Marine Engineering Department of ITS.

1.4 Research Objective

From the problems that have been stated in this bachelor thesis, the objectives of this research are:

1. To analyze the comparison of lubricant oil properties filtered by Conventional Metal Mesh Oil Filter (CMF) and Modified Sawdust Oil Filter (MSF).
2. To analyze the comparison of engine performance of a diesel engine equipped by Conventional Metal Mesh Oil Filter (CMF) and Modified Sawdust Oil Filter (MSF).
3. To analyze the comparison of engine emissions of diesel engine equipped by Conventional Metal Mesh Oil Filter (CMF) and Modified Sawdust Oil Filter (MSF).

1.5 Research Benefit

The benefits that can be obtained from this bachelor thesis are:

1. To improve the knowledge about the utilization of waste resources (sawdust) as an alternative improvement way on engine performance and emissions.
2. To improve the knowledge about correlations between lubricating oil, lubricating oil filter, engine performance, and engine emissions.
3. To enhance the understanding about lubricating oil filter effects on engine performance and emissions of an engine equipped with Modified Sawdust Oil Filter (MSF) and its comparison with the Conventional Metal-Mesh Oil Filter (CMF).

CHAPTER 2

LITERATURE REVIEW

2.1 Adsorption of Unwanted Materials by Sawdust

Numerous studies on adsorption properties of naturally occurring and low cost adsorbents, such as agricultural by products or natural fibers, have been documented. Namely barley straw, tree bark, peanut skins, human hair, waste tire rubber, and moss peat, etc. have been reported in recent years. Studies have shown that sawdust, among the low cost adsorbents mentioned, is the most promising adsorbent for removing heavy metals, acid and basic dyes, and some other unwanted materials from waste water. Not only is sawdust abundant, but also it is actually an efficient adsorbent that is effective to many types of pollutants, such as, dyes, oil, salts, heavy metals, etc. many agricultural byproducts are little or no economic value, and some such as sawdust which are available in large quantities in lumber mills, are often present a disposal problem. The use of sawdust for removing pollutants would benefit both the environment and wood agriculture (Chen, et al., 2018).

2.1.1 Sawdust Adsorption in the Removal of Heavy Metals

The adsorption phenomenon has still been found economically appealing for the removal of toxic metals from water by choosing some adsorbents under optimum operation condition. Sawdust both treated and untreated is effective in removal of heavy metals from water. (Yu, Zhang, Shukla, Shukla, & Dorris, 2001) reported a study on the adsorption behavior of maple sawdust for the removal of heavy metals, such as copper and lead, presented some guidelines for the application of sawdust adsorption. (M. Ajmal, 1998) reported a study on the role of sawdust in the removal of copper from industrial waste. The effects of contact time, pH, concentration, temperature, dose, particle size of the sawdust and salinity on the removal of copper were studied and valuable information presented in the report. It was reported that the efficiency for the removal of copper from real river water using sawdust was 63%, and it was thus concluded that the sawdust is an excellent adsorbent for copper removal from aqueous solution. (Bryant, Petersen, Lee, & Brouns, 1992) showed that divalent copper and hexavalent chromium could be removed from solution with untreated red fir sawdust. Under an optimized condition, an adsorption of 100% could be achieved. To enhance the capability and efficiency of sawdust adsorption, pre-treatment of sawdust may be needed. Untreated sawdust does not necessarily mean that the sawdust is used directly without any cleaning, size reduction or mechanical preparation. What treated sawdust means is that the sawdust has been treated or mixed with some other chemicals or materials before use. Research data has shown that sawdust treated with a special materials or chemical can be significantly effective to the removal of a particular element and that treated sawdust had a higher capacity for ion removal.

2.2 Influence of Adsorption Condition on the Removal of Dyes and Heavy Metals by Sawdust

Factors such as pH, temperature, ionic strength, etc., have various degrees of influence on the pollutant uptake by the sawdust material. This section is intended to give a brief discussion on these parameters.

2.2.1 Influence of pH

The initial pH of solution can significantly influence adsorption of dyes and metals. It determines the surface charge of the adsorbent and the degree of ionization and speciation of the adsorbent. So, it is very important to consider the ionic states of the functional groups of the adsorbent as well as the metal solution chemistry at different pH values. The influence of metal speciation in solutions certainly requires attention. Metal ions are precipitated out in alkaline pH range and, the chemical speciation of metal is decided by solution pH. The pH is a significant factor for determining existing form of the metallic species in aqueous solution. In general, as solution pH increases, most cationic dye sorption or cationic metal sorption is enhanced with pH, increasing to a certain value followed by a reduction on further pH increase. The opposite trend happens for anionic dye and anionic metal sorption. At low pH, competition occurs between protons and metal cations, leading to less metal uptake. At higher pH values, the metal sorption stops and the hydroxide precipitation start (Shukla, Zhang, Dubey, Margrave, & Shukla, The Role of Sawdust in the Removal of Unwanted Materials from Water, 2002).

2.2.2 Effect of Initial Concentration

(Naima Ouazene, 2010) reported that astrazon yellow uptake by Aleppo pine-tree sawdust increased from 13.24 to 28.51 mg/g as the initial concentration of astrazon yellow increased from 15 to 50 mg/l. with increased in the initial dye concentration, the number of collisions between dye cations and sorbent increases, which enhances the sorption process.

2.2.3 Effect of Adsorbent Dose

In principle, with more adsorbent present, the available adsorption sites or functional groups also increase. In turn, the amount of adsorbed dye ions or heavy metal ions is increased, which brought about improved adsorption efficiency. (Naima Ouazene, 2010) revealed that the removal efficiency of Astrazon Yellow by Aleppo pipe tree sawdust increased from 30 to 91% with increasing dosage from 0.33 to 4 g/l and then remained almost constant.

2.2.4 Effect of Particle Size of the Sawdust

Intraparticle diffusion study shows that particle size of the sawdust used greatly influences the adsorption rate. Decrease in particle size would lead to increase in surface area and then increase in the adsorption opportunity at the outer surface of the sawdust materials. Besides adsorption at the outer surface of the sawdust there is also possibility of intraparticle diffusion from the outer surface into the pores the material. The diffusional resistance to mass transfer is greater for large particles. Due to various factors, such as diffusional path length or mass transfer resistance, contacting time, and blockage of some diffusional path most of the internal surface of the particle may not be utilized for adsorption consequently the adsorption efficiency may be low.

2.3 Lubrication Oil Filter

The lubrication system of an engine provides a supply of lubricating oil to the various moving parts in the engine. Its main function is to enable the formation of a film of oil between the moving parts, which reduces friction and wear. The lubricating oil is also used as a cleaner and in some engines as a coolant.

The lubricating oil filter is the final barrier preventing particulate matter (solid impurities) from reaching the engine bearings. If the particulate size is greater than the hydrodynamic film thickness, i.e. (0.002 to 0.007 mm) then mechanical damage will occur to the bearing shell wearing surfaces and the journal and crankpin surfaces of the crankshaft. It is a fact that failure to maintain an adequate flow of clean lubricating oil will lead to bearing failure and possible severe damage to the crankshaft.

Filtering of lubricating oil is becoming more and more important. These strainers must intercept all the fine foreign matter that would cause wear of the fine clearances of the bearings, to name only one of the parts. These fine fits must be preserved if good running is going to be retained. By removing this foreign matter, wear is reduced and the life of all the various parts prolonged. The strainer must at all times pass sufficient oil to lubricate the engine. It must be so arranged that the supply is continuous at all times while the engine is working. The pressure drop between inlet and outlet must be low. This allows the unwanted particles to lie on the filtering media. If the pressure drop is considerable, some of the particles may be forced through the media. If the drop increases to any extent, then this is a sure indication that the strainer is dirty and is offering to great a resistance to the passage of the oil. This may mean a reduction of the supply to some important part. (Bowden, 1978)

2.3.1 Functions of Lubricating Oil Filter

Oil filters play such an important role in ensuring that all oil that is being transferred through the engine is of goof quality. If any abrasive particles get into the oil, the engine's parts can become excessively worn. If particles reach the sump, that will form a grinding paste that can damage bearings and precision parts in the engine. The main function of an oil filter is to sift out foreign particles in the oil to maintain the quality of the oil circulating in the lubrication system and in other vital components, such as the turbocharger.

Oil filters also contribute to the efficiency of the engine. When an engine stops running, the oil typically drains to the bottom part of the engine. The filter however makes sure that a small amount of the oil stays in place instead of draining down like the rest of the liquid. When the engine is started again, the remaining oil kept by the filter automatically starts lubrication without waiting for the others to rise up. This allows the engine to start quickly and efficiently without any chance of damage.

2.3.2 Types of Lubricating Oil Filter

There are three main types of oil filters that are currently available. The oil filter that will be most suitable depend on what engine it will be used on as each different type of oil filter has slightly different functionality. The three main types of oil filters are:

1. Mechanical Oil Filter

   This type of oil filter traps the contaminants and keeps them in a separate cubicle from the oil. Over time, these contaminants will be too much, making it necessary to change the filter. (Diederichs, 2009, pp. 340-345)

2. Centrifugal Oil Filter
   This type utilizes centrifugal force to separate the contaminant from the oil. A spinning motion induced and the energy created is what attracts the larger particles away from the liquid. Centrifugal types are typically two sided – one part is fiber to filter the particles and another to keep them separated within a small terminal. The fiber can also accumulate dirt overtime. (Diederichs, 2009, pp. 340-345)

3. Magnetic Oil Filter
   An electromagnet is used in here to obtain the particles from the oil. The problem with this design is that if not cleaned on a periodic basis, some of the contaminants might actually pass through. Replacement of the filter is not necessary. (Diederichs, 2009, pp. 340-345)

2.3.3 Types of Lubricating Oil Filter Media

In the September-October 2012 issue of Machinery Lubrication, Wes Cash explained how the porosity of the filter media plays a role in how well the filter can retain captured particles. This is known as the dirt holding capacity. As pore size goes down, to maintain a low differential pressure across the media, the pores density must go up to account for the oil volume in contact with the surface. The filter depth and size also influence the dirt-holding capacity. Another factor is the filter media material. Oil filter have different media inside them that filter out and clear the contaminants of the lubricating oil as it circulates.

1. Micro Glass
   the Rexroth micro glass filter medium achieves a high degree of pureness for hydraulic fluids, lubricants as well as for chemical and industrial fluids. Due to its defined retention capacity (ISO 16889), it offers a highly effective protection for machines and system components which are sensitive to contamination. (Rexroth Bosch Group, 2014).

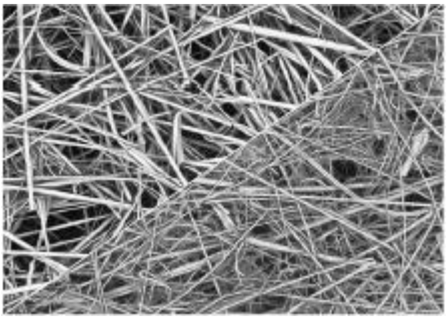

Figure 2.1 Micro Glass Filter Media
source: Rexroth Bosch Group Data Sheet

2. Stainless Steel Wire Mesh
   There is a comprehensive field of applications for wire mesh filter media. Not only pre-filtration is possible, but also the filtration of lubricating oils, hydraulic oils, coolants and water like fluids. As surface filters, these materials are generally cleanable. Due to their fine mesh, however, cleaning is more difficult than with coarser filter mesh. (Rexroth Bosch Group, 2014)

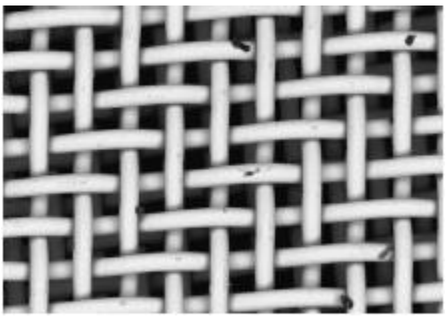

Figure 2.2 Stainless Steel Wire Mesh Filter Media
source: Rexroth Bosch Group Data Sheet

3. Metal Fiber Fleece

Metal fiber fleece can attain high cleanliness for special fluids or at high operating temperatures. Due to its absolute filtration according to ISO 16889, metal fiber fleece also offers effective protection for machinery parts which are sensitive to contamination. As metal fiber fleece consists of firmly meshed and bound stainless steel fibers, it is also classified as depth filter medium and is thus not cleanable. (Rexroth Bosch Group, 2014)

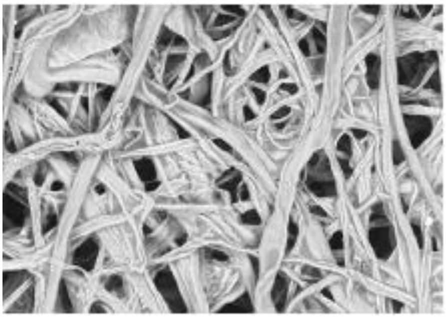

Figure 2.3 Metal Fiber Fleece Filter Media
source: Rexroth Bosch Group Data Sheet

4. Filter Paper

Filter paper is used for the filtration of lubricating oil and for pre-filtration. Filter paper has depth filter made of cellulose fibers and specially impregnated against swelling caused by moisture. (Rexroth Bosch Group, 2014)

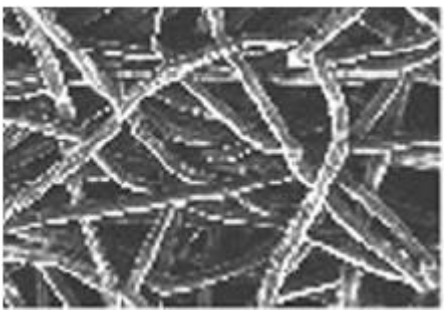

Figure 2.4 Filter Paper Filter Media
source: Rexroth Bosch Group Data Sheet

5. Fleece Material
   fleece material allows for the filtration of cooling lubricants as well as of water and water media. Moreover, this filter medium can be used for the filtration of emulsions or in general for pre-filtration. (Rexroth Bosch Group Filter Element Data Sheet)

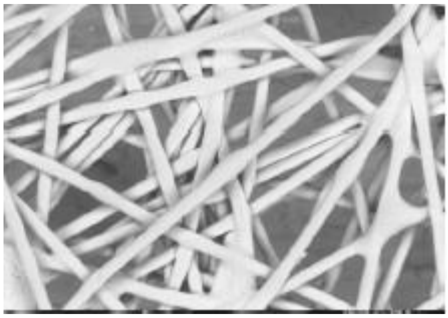

Figure 2.5 Fleece Material Filter Media
source: Rexroth Bosch Group Data Sheet

2.3.4 Filtration Mechanisms of Lubricating Oil Filter

A filter's primary function is to remove and retain contaminants as oil flows through the porous component called the media. The media operate under several types of filtration mechanisms, including:

1. Direct Interception and Depth Entrapment
   Particle blockage on the media due to the particles being larger that the taken passage within the media. (Bennett Fitch, 2013)

2. Adsorption
   The electrostatic or molecular attraction of particles between the particles and the media. (Bennett Fitch, 2013)

3. Inertial Impaction
   Particles are impacted onto the filter media by inertia and held there by adsorption as the oil flows around. (Bennett Fitch, 2013)

4. Brownian Movement
   This causes particles smaller than 1 micron to move irrespectively of the fluid flow and results in the particles being adsorbed by media in close proximity. It is much less prevalent, especially in viscous fluids. (Bennett Fitch, 2013)

5. Gravitation Effects
   These allow much larger particles to settle away from fluid flow regions when there is low flow. (Bennett Fitch, 2013)

In addition, filter media can be designed to capture particles through two distinct methods:

1. Surface Retention
   Contaminants are held at the surface of the media. This provides an opportunity for the contaminant to become trapped as it comes in contact with the media surface. (Bennett Fitch, 2013)

2. Depth Retention
   Contaminants are held either at the surface of the media or within the labyrinth of passages within the “depth” of the filter media. This creates several opportunities of contaminants to become trapped. (Bennett Fitch, 2013)

2.4 Lubricating Oil

A lubricant is a substance that mainly a liquid that is using between two moving surface to reduce the friction between them, thus reducing wear and improving efficiency. It also has function to dissolving foreign particles and distributing heat.

Lubricating oil are basically made of two components-lube base oil which comes out from refineries after refining the crude oil for having some inherent lubricating properties like any other liquid and the performance enhancing chemical additives which are added to improve different characteristics of the resultant mixture. Lubricants in general contain 90 percent base oil (mostly petroleum fraction) and less than 10% additives. Lubricating oil are basically made of two components-lube base oil which comes out from refineries after refining the crude oil for having some inherent lubricating properties like any other liquid and the performance enhancing chemical additives which are added to improve different characteristics of the resultant mixture. (Ayub, Lube Oil Additives, 2010)

The mixture of lubricant oil also determined its effects, the differences in mixture can produce different on performance. The additive contains is reducing the friction and wear, increased viscosity, improved viscosity index, resistance to corrosion, oxidation and contamination.

There are two basic categories of lubricating oil: mineral and synthetic. Mineral oils are lubricating oils refined from naturally occurring crude oil. Synthetic oils are lubricating oils that are manufactured. Mineral lubricating oils are currently the most commonly used type because of the low cost of extracting the oils from crude oil. Additionally, mineral oils can be manufactured to have a varying viscosity, therefore making them useful in a wide range of applications. Lubricating oils of different viscosities can be blended together, and it is this ability to blend them that makes some oils so useful. (Stachowiak, 2006)

2.4.1 Functions of Lubricating Oil

The purpose of lubrications is to maintain the engine to function optimally and can be used for a period of time.

1. Reduced Friction
   Lubricant forms an oil film on the surface of metals, converting solid friction into liquid friction to reduce friction, which is the most common and essential function of lubricants. Reduced friction prevents heating and abrasion of the friction surface. (Michael Rachow, 2009, pp. 684-689)

2. Cooling
   Friction certainly causes heating on the area and more heat is produced if metals rub against each other. Therefore, the heat needs to be absorbed or released; otherwise the system is destroyed or deformed. To prevent it, lubricants are applied. (Michael Rachow, 2009, pp. 684-689)

3. Cleaning
   Long-term use of systems may lead to corrosion or aging producing foreign substances. In case of using hydraulic oil and gear oil, sediments accumulate such as sludge from deterioration. Especially an internal combustion engine generates too much soot, so that it is likely to shorten the life of systems and make them fail to work properly. Therefore, lubricant itself cleans out foreign substances like soap. (Michael Rachow, 2009, pp. 684-689)

4. Sealing
   Sealing is to close the macro-gap between systems. Sealing the space between pistons and cylinders in the internal combustion engines or air compressors blocks the leakage of combustion gas and the inflow of external foreign substances to maintain the defined internal pressure and protect the system. Especially in the hydraulic system, lubricants itself serve to prevent the leakage by creating a hydraulic film. (Michael Rachow, 2009, pp. 684-689)

5. Rust Prevention
   Metals produce rust when contacting water and oxygen. However, rust formation can be controlled and the system lifetime is extended if the surface of metals is coated with lubricating film. (Michael Rachow, 2009, pp. 684-689)

2.4.2 Characteristics of Lubricating Oil

This material can be obtained from book with title A Glossary of Petroleum Terms, the characteristics of lubrication oil is stated on the paragraph below, which are:

1. Viscosity
   Viscosity is a measurement of a fluid's thickness, or resistance to flow. The higher a lubricant's viscosity, the thicker it will be and the more energy it will take to move an object through the oil. One common scale used to describe viscosity in lubricating oils is the numerical grading given by The Society of Automotive Engineers, or SAE. (Eni, 2012)

2. Viscosity Index
   The viscosity index, or VI, of a lubricant describes how the oil's viscosity changes as its temperature changes. As temperatures increase, viscosities decrease, and vice versa. For example, a piece of machinery that operates over a wide range of temperatures will require a lubricant with a high VI, meaning that the oil will retain its lubricating characteristics whether it is starting up cold or running at full speed and peak temperature. (Eni, 2012)

3. Pour Point
   The pour point of a lubricant is the lowest temperature at which the oil will flow from its container. At low temperatures, the viscosity of the oil

will be very high, causing the oil to resist flow. This is important in equipment that operates in a cold environment or handles cold fluids. (Eni, 2012)

4. Flash Point
   When lubricating oil is heated to a high enough temperature; it will begin to boil off as a vapor. Eventually, a temperature will be reached where the vaporized oil can be ignited by an external source. This temperature is called the flash point. When the source of ignition is removed, the vapor will cease to burn. The fire point will be slightly higher than the flash point, and is where the vapor will continue to burn for at least five seconds after the ignition source has been removed. (Eni, 2012)

5. Total Base Number
   Total base number is a property generally associated with engine oils. It is the oils' ability to neutralize acid. The higher the TBN, the higher acid it is able to neutralize. This quality is also referred to as alkaline reserve and is directly proportional to the amount of active detergent contained in the oil. (Eni, 2012)

2.4.3 Classifications of Lubricating Oil

There are several widely used oil viscosity classifications. The most commonly used are SAE (Society of Automotive Engineers), ISO (International Organization for Standardization) and military specifications that can be obtained from research by Stachowiak, 2006, which are:

1. SAE Viscosity Classification

   The problem associated with the use of multi-grade oils is that they usually shear thin, i.e., their viscosity drops significantly with increased shear rates, due to the polymeric additives. This has to be taken into account when designing machine components lubricated by these oils. The drop in viscosity can be significant, and with some viscosity improvers even a permanent viscosity loss at high shear rates may occur due to the breaking up of molecules into smaller units. The viscosity loss affects the thickness of the lubricating film and subsequently affects the performance of the machine.

Table 2.1 SAE Viscosity Classification

SAE Viscosity Grade	Viscosity (cP) at temp (°C) max		Kinematic Viscosity (cSt) at 100°C	
	Cranking	Pumping	Min.	Max.
0W	3.250 at -30	30.000 at -35	3,8	-
5W	3.500 at -25	30.000 at -30	3,8	-
10W	3.500 at -20	30.000 at -25	4,1	-
15W	3.500 at -15	30.000 at -20	5,6	-
20W	4.500 at -10	30.000 at -15	5,6	-
25W	6.000 at -5	30.000 at -10	9,3	-
20	-	-	5,6	< 9,3
30	-	-	9,3	< 12,5
40	-	-	12,5	< 16,3
50	-	-	16,3	< 21,9
60	-	-	21,9	< 26,1

2. ISO Viscosity Classification
   The ISO (International Standards Organization) viscosity classification system was developed in the USA by the American Society of Lubrication Engineers (ASLE) and in the United Kingdom by The British Standards Institution (BSI) for all industrial lubrication fluids. It is now commonly used throughout industry.

Table 2.2 ISO Viscosity Classification

ISO Viscosity Grade	Kinematic Viscosity Limits (cSt) at 40°C		
	Min.	midpoint	Max.
ISO VG 2	1,98	2,2	2,42
ISO VG 3	2,88	3,2	3,52
ISO VG 5	4,14	4,6	5,06
ISO VG 7	6,12	6,8	7,48
ISO VG 10	9,00	10	11,0
ISO VG 15	13,5	15	16,5
ISO VG 22	19,8	22	24,2
ISO VG 32	28,8	32	35,2
ISO VG 46	41,4	46	50,6
ISO VG 68	61,2	68	74,8
ISO VG 100	90,0	100	110
ISO VG 150	135	150	165
ISO VG 220	198	220	242
ISO VG 320	288	320	352
ISO VG 460	414	460	506
ISO VG 680	612	680	748
ISO VG 1000	900	1000	1100
ISO VG 1500	1350	1500	1650

2.4.4 General Element and Contamination of Lubricating Oil

There are several general element and contamination in lubricating oil that can be obtained from Technical Bulletin (John S. Evans, 2010), which are:

1. Iron (Fe)

   In engines, the cylinder liners and the crankshaft are the major wearing components along with timing gears, shafts and valves. In gearboxes and drive train components, iron is the major constituent of the gears, shafts and antifriction (rolling element) bearings. Finally, iron can also be a contaminant. When iron reacts with water (which contains oxygen) and atmospheric oxygen, rust can form, which may indicate contamination or component degradation. Rust, containing iron, can be formed in cooling systems. If an internal coolant leak occurs whereby the coolant comes into contact with the lubricating oil, then the coolant may evaporate at working temperature and pressure whilst leaving coolant additives and contaminants behind in the oil.

2. Aluminum (Al)

   The most common source of aluminum in engines is from the piston. Almost without exception, all pistons are made from aluminum or one of its alloys. In transmissions, torque convertors are made of aluminum. Hydraulic pump housings and housings in general are often made of aluminum. Thrust washers, plain bearings and bushes can also be made of the metal. Aluminum can also be a contaminant. It is an additive component of some greases so if grease is transferring into an oil wetted component then aluminum may be present. Common dirt (dust and grit) is highly abrasive and can be very dangerous to any lubricated piece of machinery. Traditionally dirt is detected by the presence of silicon.

3. Chromium (Cr)

   In engines, the rings are normally made of chromium or are coated with the metal. On rare occasions, the liners can be chromed and the rings are then made of cast iron. Shafts, gears and anti-friction bearings can contain trace amounts of chromium as an alloying metal with iron to form certain steels, which can occur in most types of components. Chromium can also be used as a surface hardening coating on gears. Chromium can be a contaminant too. In areas where the metal is being mined it can show up in the oil as an indication of dirt entry. Finally, chromium can sometimes be seen as an indication of an internal coolant leak.

4. Nickel (Ni)
   Nickel is most commonly seen as an alloy of anti-friction bearings (and sometimes gears) along with iron. Valves and valve guides may contain nickel and some turbine components may also contain the metal. Coatings, similar to chromium, can contain nickel. Nickel is also a component of most heavy and medium furnace oils so this shows up in the oil as a combustion by-product making it a contaminant as well as a wear metal.

5. Manganese (Mn)
   This metal is found as an alloying element with iron in some steels and may occur in shafts, valves, gears and anti-friction bearings. It is quite a common contaminant in equipment working in manganese mines where it indicates dirt entry. Some lead replacement fuels contain manganese as an anti-knock additive so it can show up as a combustion by-product in the oils of petrol engines using these types of fuel. In very rare cases manganese exists as an additive.

2.5 Engine Performance

Rowen (1971), states that engine performance is an indication of the degree of success with which it is doing assigned job, i.e. the conversion of chemical energy contained in the fuel into the useful mechanical work.

2.5.1 Specific Fuel Oil Consumption

Specific fuel oil consumption (SFOC) is the ratio between the fuel mass flow rate and engine power (Rakopoulos, 2008). It is a parameter that shows the efficiency of a combustion engine which consume fuel and produces rotational power. SFOC can be used as indicator to evaluate the efficiency of the internal combustion. The brake is due to the utilize of dynamometer to measure the engine parameters (fuel mass flow rate, torque, etc.). The formula is the formula to calculate SFOC in kg/kWh:

$$SFOC = \frac{\dot{m}_f}{p_b} \qquad (2\text{-}1)$$

Where,

$\dot{m}_f$	: Fuel mass flow rate (kg/s)
p_b	: Engine power in (kW)
SFOC	: Specific fuel oil consumption (kg/kWh)

2.5.2 Maximum Output Power

The power (P) delivered by the engine is the product of torque and angular speed, that can be defined by equation:

$$P = 2 \times \mathrm{N} \times \mathrm{T} \quad (2\text{-}2)$$

Where,

N	: The crankshaft rotational speed (rev/min)
T	: Torque to measure an engine's ability to do work (Nm)

2.6 Engine Emissions

Diesel engine exhaust consists of non-toxic substances, such as nitrogen (N_2), carbon dioxide (CO_2), and water vapour (H_2O), and toxic substances such as carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), sulfur oxide (SOx), lead dust (Pb), and particulates. Nitrogen oxide gas (NOx) is divided into two types, namely nitrogen monoxide and nitrogen dioxide gas. Both types of gas have very different properties and both are harmful to health (Prasutiyon, 2017).

2.6.1 Test Cycle and Weight Factor

Emission test and load factor must be carried out to verify the adjustments of diesel engines with limit restriction based on regulation 13 of Annex VI (IMO, 2016). Because in this research, the diesel engine used is a diesel electric drive, the test cycle and weight factor used are E2 type test cycles.

Table 2.3 IMO Emission Test

Test Cycle Type E2	Speed	100%	100%	100%	100%
	Power	100%	75%	50%	25%
	Weighting Factor	0,2	0,5	0,15	0,15

2.6.2 Nitrogen Oxide (NOx) Emission

The NOx emission (g/kWh) shall be calculated in the following way:

$$\overline{NO_x} = \frac{\sum NO_{x,mass} \times WF_i}{\sum P_i \, x \, WF_i} \quad (2\text{-}3)$$

$$NO_{x,mass} = U_{gas} \times C_{gas} \times G_{mew} \times K_{hd} \text{.........................} \quad (2\text{-}4)$$

Where,

$NO_{x,\ mass}$	:	NOx emissions mass flow rate (g/h)
WF_i	:	Weighting factor
P_i	:	Measured power at each mode (kW)
U_{gas}	:	Ratio between density of exhaust component and density of exhaust gas
C_{gas}	:	Concentration of the respective component in the raw exhaust gas (ppm)
G_{mew}	:	Exhaust mass flow (kg/h)
K_{hd}	:	NO_x humidity correction factor

2.6.3 Hydrocarbon (HC) Emission

The HC emission (g/kWh) shall be calculated in the following way:

$$\overline{HC} = \frac{\sum HC_{mass} \times WF_i}{\sum P_i \ x \ WF_i} \text{..} \quad (2\text{-}5)$$

$$HC_{mass} = U_{gas} \times C_{gas} \times G_{mew} \text{...} \quad (2\text{-}6)$$

Where,

HC_{mass}	:	HC emissions mass flow rate (g/h)
WF_i	:	Weighting factor
P_i	:	Measured power at each mode (kW)
U_{gas}	:	Ratio between density of exhaust component and density of exhaust gas
C_{gas}	:	Concentration of the respective component in the raw exhaust gas (ppm)
G_{mew}	:	Exhaust mass flow (kg/h)

2.6.4 Carbon Monoxide (CO) Emission

The CO emission (g/kWh) shall be calculated in the following way:

$$\overline{CO} = \frac{\sum CO_{mass} \times WF_i}{\sum P_i \ x \ WF_i} \text{..} \quad (2\text{-}7)$$

$$CO_{mass} = U_{gas} \times C_{gas} \times G_{mew} \text{...} \quad (2\text{-}8)$$

Where,

CO_{mass}	:	HC emissions mass flow rate (g/h)
WF_i	:	Weighting factor

P_i	:	Measured power at each mode (kW)
U_{gas}	:	Ratio between density of exhaust component and density of exhaust gas
C_{gas}	:	Concentration of the respective component in the raw exhaust gas (ppm)
G_{mew}	:	Exhaust mass flow (kg/h)

2.6.5 Particulate Matter (PM) Emission

The PM emission (g/kWh) shall be calculated in the following way:

$$\overline{PM} = \frac{PM_{mass}}{\sum P_i \ x \ WF_i} \quad (2\text{-}9)$$

Where,

PM_{mass}	:	PM emissions mass flow rate (g/test)
WF_i	:	Weighting factor
P_i	:	Measured power at each mode (kW)

2.6.6 NO_x Humidity Correction Factor

The NO_x humidity correction factor shall be calculated in the following way:

$$K_{hd} = \frac{1}{1-0{,}0182\times(H_a-10{,}71)} \quad (2\text{-}10)$$

$$H_a = \frac{6{,}220\times R_a\times P_a}{P_B-P_a\times R_a\times 10^{-2}} \quad (2\text{-}11)$$

Where,

H_a	:	Humidity of the intake air water per kg dry air
R_a	:	Relative humidity of the intake air (%)
P_a	:	Saturation vapor pressure of the intake air (kPa)
P_B	:	Total barometric pressure (kPa)

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CHAPTER 3
METHODOLOGY

3.1 Flowchart of Research Methodology

In order to solve and answer the problems that have been stated on the first chapter, the author will use experimental method to collect the data. There will be three experiments that will be taken in this research such as: lubricant oil properties, engine performance, and engine emissions. The flow chart of this methodology is as in Figure 3.1:

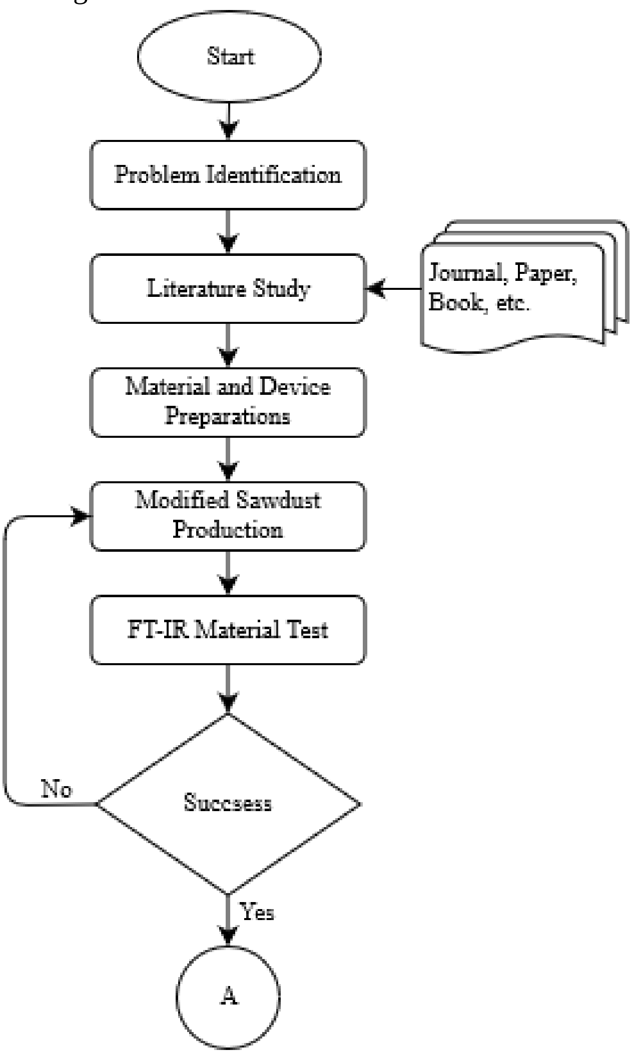

Figure 3.1 Flowchart of Research Methodology (Part I)

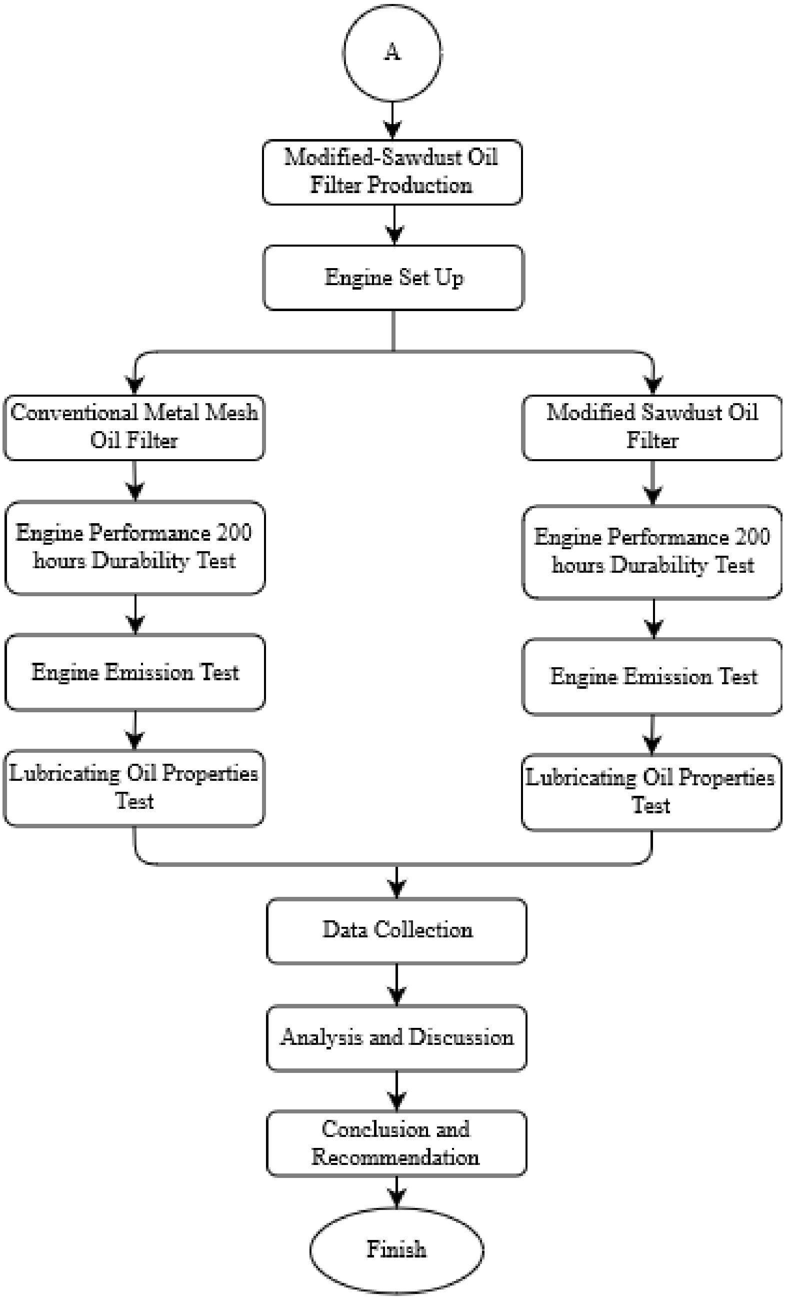

Figure 3.2 Flowchart of Research Methodology (Part II)

3.2 Methodology Explanation

3.2.1 Problem Identification

The research will begin with problem statement and identification to the related topics. The identified problems for this research are how to produce a modified oil filter from sawdust and the comparison of oil properties, engine performance, and engine emissions of a diesel engine equipped by conventional oil filter and modified-sawdust oil filter.

3.2.2 Literature Study

Literature study will support the author to do the research by learning and studying the supporting theories in finding the best solution to solve the existing problems that have been stated in Chapter 1. The study literature sources vary from different types such as: books, established journals, paper, completed bachelor thesis, and academic online platforms.

3.2.3 Materials and Device Preparation for *Casuarinaceae* Sawdust Modification

On this stage, materials and devices required for the experiment will be prepared. The preparations include the process of modified sawdust. The devices prepared for the sawdust modification are in a laboratory scale to support the chemical modification process of the sawdust. To summarize, the device and material which are required for the modified oil filter production are:

1. *Casuarinaceae* Sawdust
2. Tetraethyl Ammonium Bromide (TEAB)
3. Triethanolamine (TEOA)
4. Lithium Bromide
5. Sodium Carbonate
6. Distilled Water
7. Measuring Glass
8. Pipette
9. Electric Stove
10. Desiccator

3.2.4 *Casuarinaceae* Sawdust Modification

To be able to modify the casuarinaceae raw sawdust, there are several steps, which are:

1. Alkaline Solvent Making Process

   To modify the raw sawdust, the sawdust material mixture with a size between 20 and 30 mesh screens is selected. Then the solvent which consist of tetraethyl ammonium bromide (TEAB), triethanolamine (TEOA), lithium bromide, sodium carbonate, and distilled water at mass ratio of 0,2:0,3:2,5:12:70 are mixed. Then the raw sawdust mixture is immersed in the solvent and stirred at 50°C for 48 hours. After the mixing process, the modified sawdust is washed with distilled water until the filtrate was mainly clear with the pH around 7.

Figure 3.3 Chemical Materials for Raw Sawdust Modifying Process

2. Modified Sawdust Drying Process
   The water content in oil leads to severe corrosion inside the engine. The modified sawdust dried in a dry oven at 80°C for 100 hours to dehydrate it. The dry oven will remove the modified sawdust water content.

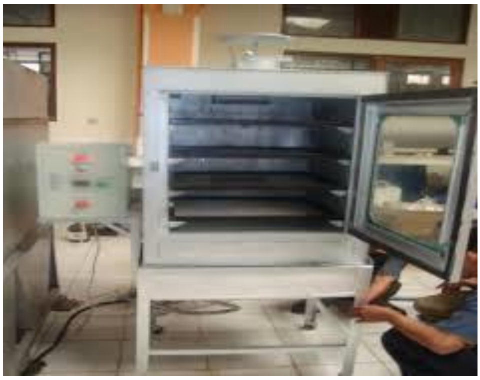

Figure 3.4 Dry Oven for Modified Sawdust Drying Process

3. Modified Sawdust Cooling Process
   On this stage, the desiccator is used to store dried modified sawdust in a dry atmosphere, thus the dried modified sawdust will not go hydrated in normal atmospheric condition. The desiccator is not used to dry the modified sawdust, but to maintain its dry condition.

Figure 3.5 Desiccator for Modified Sawdust Cooling Process

3.2.5 FT-IR Material Test

In this research, Fourier-Transform Infrared Spectroscopy (FT-IR) is used to know and compare the difference between raw *casuarinaceae* sawdust and modified *casuarinaceae sawdust.* After the raw sawdust modification phase, the raw sawdust and the modified sawdust will be compared in FT-IR material test.

3.2.6 Modified Sawdust Oil Filter Production

On this stage, after the *casuarinaceae* sawdust modification and material test. The modified sawdust is processed into a tube with the same dimension as conventional metal mesh oil filter's filter media and replaced the conventional metal mesh oil filter's filter media from its filter head and end cap into the modified sawdust tube as the new filter media.

Figure 3.6 Modified Sawdust Oil Filter Final Product

3.2.7 Engine Setup

Engine set up is one of the vital activity for this research. In this phase, it well be taken an engine running test and engine cleaning to ensure a valid initial condition of the engine. This test will check the basic performance of the engine, capability of the engine in handling full load. The other purpose of this engine set up is to ensure a valid initial condition for lubricant oil testing properties. DONGFENG Diesel Engine type R180 will be the engine where the test will take place.

Therefore, to support the data collecting for the analysis of the lubricant oil properties test, the filters and materials which are required are such as below:

1. DONGFENG R180 Diesel Engine.

2. Conventional Metal Mesh Oil Filter and Modified Sawdust Oil Filter as filter comparison.
3. PERTAMINA MESRAN B 40 lubricating oil.

Table 3.1 Engine Specification

Brand	:	DONGFENG
Model	:	R180
Type	:	In-line, Single Cylinder, 4-Stroke, Water Cooling, Direct Injection
Bore x Stroke	:	85 x 87 mm
Piston Displacement	:	493 cc
Rated Power / Rated Speed	:	5,5 kW / 2200 RPM

The scheme of engine set up will be as figured in Figure 3.7:

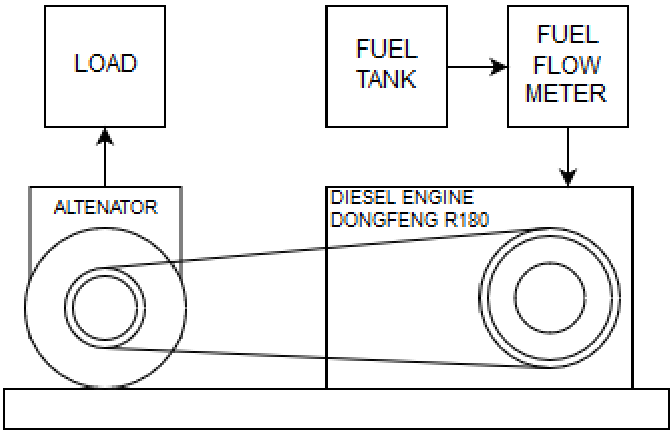

Figure 3.7 Engine Set Up

There are some variables to be used in the experiment and analysis of engine performance and its emissions process, such as:

A. Independent Variables
   1) Lubricant Oil Variables
      - PERTAMINA MESRAN B 40
   2) Lubricant Oil Filter Variables
      - Conventional Metal-Mesh Oil Filter

- Modified-Sawdust Oil Filter

3) Engine Manufactures Association (EMA) Durability Test
    - Low Idle, 30 minutes
    - High Idle, 30 minutes
    - Rated Power, 60 minutes
    - Peak Torque, 60 minutes

B. Controlled Variables
1) Analog Set Up
2) Engine Set Up
3) Fuel Oil (PERTAMINA DEXLITE)

C. Dependent Variables
1) Lubricant Oil Properties
    - Kinematic Viscosity (40^{o}C and 100^{o}C)
    - Viscosity Index
    - Flash Point
    - Pour Point
    - Total Base Number (TBN)
2) Lubricating Oil Wear Metals
    - Iron (Fe)
    - Aluminum (Al)
    - Chromium (Cr)
3) Specific Fuel Oil Consumption (SFOC)
4) Maximum Output Power
5) Engine Emissions
    - Nitrogen Oxide (NOx)
    - Carbon Monoxide (CO)
    - Hydrocarbon (HC)
    - Particulate Matter (PM)

3.2.8 Engine Performance Durability Test

After the production of modified sawdust oil filter and engine set up are already done, the test will be ready to be started. The test will vary in four different engine conditions according to Engine Manufacture Association (EMA) durability test. The test will take place in Marine Power Plant Workshop of Institut Teknologi Sepuluh Nopember.

The engine conditions that will be used are:

- Low idle is when a diesel engine runs without a load and the engine RPM is set at the minimum engine RPM. This condition is carried for 30 minutes.
- High Idle is when a diesel engine runs with 25% load of total maximum torque and engine RPM is set at 90% of the rated power speed. This condition is carried out for 30 minutes.
- Rated power speed is when the diesel engine RPM is set at maximum RPM in accordance with the specification of the engine with maximum load. This condition is carried out for 60 minutes.
- Peak torque speed is when the diesel engine RPM and load experiencing maximum torque. This condition is carried out for 60 minutes.

3.2.9 Engine Emission Test

In this phase, engine emission test conducted to know the effect of lubricating oil and lubricating oil filter to engine emissions. Engine emission test conducted using regulation 13 of Annex VI (IMO, 2016). Because in this research, the diesel engine used is a diesel electric drive, the test cycle and weight factor used are E2 type test cycles.

3.2.10 Lubricant Oil Properties Test

Lubricant oil properties test will be conducted in a laboratory to compare the adsorption ability of modified sawdust oil filter and conventional metal mesh oil filter. The research will use one type lubricating oil (PERTAMINA MESRAN SAE 40) and will be filtered with two different filter.

3.2.11 Data Collection

The tests will result data of filtered lubricant oil properties, engine performance, and engine emissions. The result will be achieved from the experiment of using two types of oil filter, such as: conventional oil filter and modified-sawdust oil filter. The data will be collected to support the analysis and discussion phase will be:

1. Properties of the filtered lubricating oil which includes: kinematic viscosity, viscosity index, flash point, pour point, TBN, and wear metals at the end of engine performance durability test.

2. Data of engine performance which includes: Specific Fuel Oil Consumption and Maximum Power Output of the diesel engine with EMA durability test procedure for 200 hours.
3. Data of engine emissions which includes: NOx, HC, CO, and PM.
4. Documentations of the modified sawdust filter oil production and whole experiment period.

3.2.12 Data Analysis and Discussion

On the data analysis and discussion stage, the collected data (filtered lubricating oil properties, engine performance, and engine emissions) will be analyzed. The properties of the filtered lubricating oil will be analyzed to compare the adsorption ability of two different oil filter. Also, there will be a comparison of engine performance and engine emissions between each experiments using two different types of oil filter.

3.2.13 Conclusion and Recommendation

After every stage has been carried out completely, the author will be able to find the final conclusion from the experiments and analysis that have been done before. The author highly hopes that this experiment will answer and give the best solution for the stated problems and reaching the goals of this bachelor thesis. The author also would likely give recommendations based on the evaluation of the process in the making of this bachelor thesis and advices to achieve the perfection of this bachelor thesis.

CHAPTER 4
DATA ANALYSIS AND DISCUSSION

4.1 Test and Measurement Results

4.1.1 FT-IR Spectra of Raw Sawdust and Modified Sawdust Samples

Fourier Transform Infrared Spectroscopy, also known as FT-IR Analysis or FT-IR Spectroscopy, is an analytical technique used to identify organic, polymeric, and, in some cases, inorganic materials. In this research, FT-IR analysis method used infrared to scan test samples and observe chemical properties.

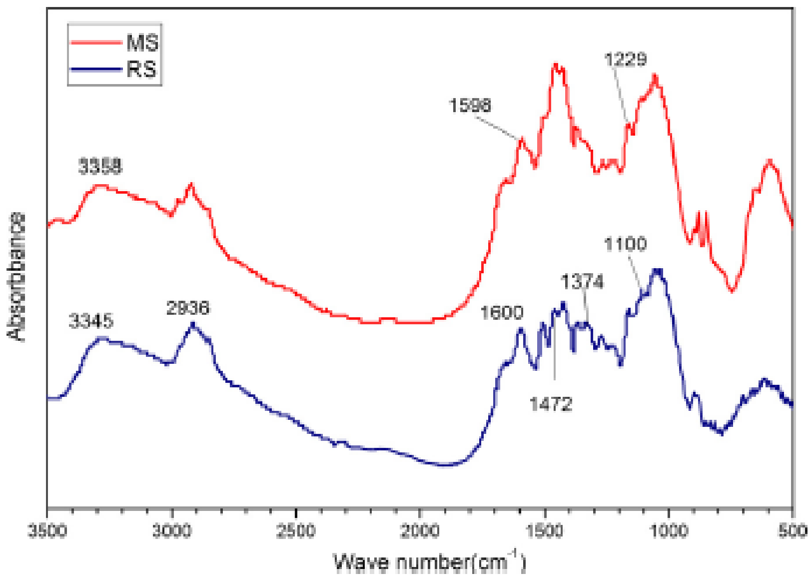

Figure 4.1 FT-IR Spectra of Raw Sawdust and Modified Sawdust Comparison

In this research, the FT-IR spectra of raw sawdust and modified sawdust were used to determine the vibrational frequency changes of the functional groups. Sawdust is used as a novel adsorbent because of its rich hydroxyl and carbonyl groups, while the crystalline structure such as lignin and hemicellulose occupy part of the pore and decrease the active component in sawdust. Therefore, mixed solvent of alkaline and organic amine was used to modify sawdust to improve its adsorption capacity. To elucidate the change of sawdust and reveal the mechanism of modification, FT-IR characterization analysis of raw sawdust and modified sawdust is used and the result is shown in Figure 4.1. The spectra of adsorbents were measured within the range of 500-4000 cm^{-1} wave number.

In the spectra of the untreated sawdust, the broad absorption peak around 3342,27 cm^{-1} indicates the existence of intermolecular bonded hydroxyl groups and carbon hydrogen (Chen, et al., 2018). The absorption peak of carbon hydrogen bond was observed at 2936 cm^{-1}. The peak around 1600 cm^{-1} correspond to the C=C stretching that may attribute to the lignin aromatic groups (Chen, et al., 2018). some small vibration peaks were observed in the range from 1200 cm^{-1} to 1500 cm^{-1}, which correspond to the C—O stretching vibration and C=C bond vibration respectively. The peak at 1374 cm^{-1} can be considered the symbol of the hemicellulose. The $–OCH_3$ group was found at 1100 cm^{-1}, which can confirm the presence of the cellulose in wood structure.

Those peaks become broader for the treated sawdust which are beneficial for the adsorption metal ions. In the modified sawdust spectra, it was found that the absorption peaks of 3358 cm^{-1}, which indicated the presence of hydroxyl groups, become broader and stronger. It was advantageous to the adsorption of metal ions. Compared with the raw sawdust, the peaks located at 1288 cm^{-1} were disappeared, which indicated the break of the C=O bond. There is a clear absorption peak of C—O stretching vibrational absorption at 1507 cm^{-1}, which was attributed to resins. But the characteristic absorption peak of the carboxyl group disappeared after modification, indicating that the resins of the sawdust were dissolved. The N—H vibration absorption peak is at 1598 cm^{-1} and the C—N vibration absorption peak is at 1229 cm^{-1}, which gave indirect evidence to the success of grafting more azyl. The peak around 1742 cm^{-1} corresponding to aromatic in the lignin was disappeared, which indicated that the lignin was also modified. The symbol peak of the hemicellulose at 1374 cm^{-1} was disappeared because the hemicellulose dissolved after modification.

The spectrum analysis of sawdust before and after modification showed that characteristic absorption peaks have a significant change: the peak around 3351 cm^{-1} and 1598 cm^{-1} were obviously weaker than those of the raw sawdust, while the C—H stretching vibration at 2920 cm^{-1} and 2848 cm^{-1} were significantly stronger.

4.1.2 Lubricating Oil Properties

In this study, lubricating oil was tested as a result of 200 h engine durability experiment equipped with conventional metal mesh oil filter and modified sawdust oil filter. Lubricating oil test was carried out in the laboratory to determine the lubricating properties as a result of 200 h engine durability experiment to analyze the degradation of lubricating oil after experiment with conventional metal mesh oil filter and modified sawdust oil filter.

Table 4.1 Lubricating Oil Properties Before and After Experiment

No.	Lubricant Oil Properties	PERTAMINA MESRAN B SAE 40 Lubricating Oil Initial Value	PERTAMINA MERAN B SAE 40 Lubricating Oil after 200 Hours Experiment with Conventional Metal Mesh Oil Filter	PERTAMINA MERAN B SAE 40 Lubricating Oil after 200 Hours Experiment with Modified Sawdust Oil Filter	Units
1.	Kinematic Viscosity 40^{o}C	145,80	80	46,01	cSt
2.	Kinematic Viscosity 100^{o}C	14,90	14	7,247	
3.	Viscosity Index	102	99	119	-
4.	Flash Point	>230	230	189	^{o}C
5.	Pour Point	-12	-3	3	
6.	Total Base Number (TBN)	11,70	11,38	9,89	mg/g
7.	Wear Metals Content				
Iron (Fe)		-	1,35	0,87	ppm
Aluminum (Al)		-	7,5	2,33	
Chromium (Cr)		-	< 0,006	< 0,006	

4.2 Lubricating Oil Degradation Analysis

4.2.1 Viscosity Kinematic

The viscosity of the lubricant determines the thickness of the oil layer on the metal surface of the engine component and also an important physical parameter to evaluate the lubricant degradation over time. The most widely used viscosity measurement unit is centistoke (cSt) (Eni, 2012). In diesel engines, acidic environment and related contaminations results in thickening and gelling of the engine lubricating oil. The change in lubricating oil viscosity was measured for both experiment with two kinds of filter to determine the degradation of lubricating oil that had been used in the test. The maximum degradation allowed in lubricating oil viscosity for high speed diesel is 25% reduction or an increase of 30%. The lubricating oil viscosity in this research was measured at 40°C and 100°C using ASTM D 445 standard.

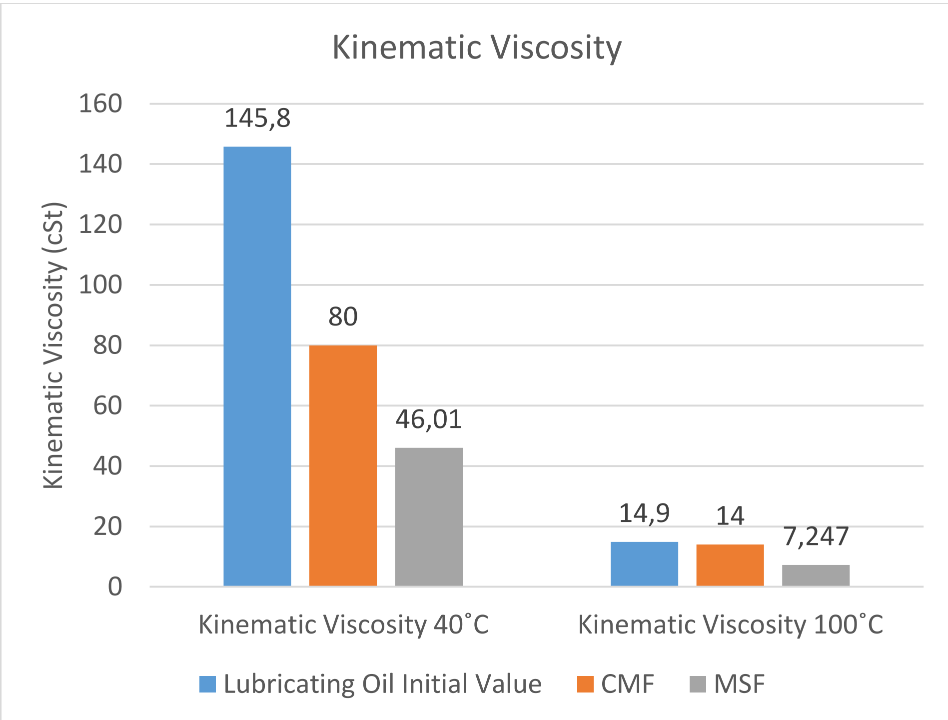

Figure 4.2 Lubricating Oil Viscosity Comparison of Engine Equipped with Conventional Metal Mesh Oil Filter and Modified Sawdust Oil Filter

From figure 4.2 shows the change of engine lubricating oil kinematic viscosity at 40°C and 100°C after 200 h engine durability test equipped with two kinds of filter. The figure depicts that lubricating oil's kinematic viscosity decreases after 200 h engine test. By using modified sawdust oil filter, kinematic viscosity at 40°C decrease from 145,8 to 46,01 cSt and 14,9 to 7,247 cSt for kinematic viscosity at 100°C. In the other hand, conventional metal mesh oil filter experiment decrease lubricating oil viscosity kinematic at 40°C from 145,8 to 80 cSt and 14,9 to 14 cSt, for viscosity kinematic at 100°C. This is attributed to the reduction of wear metal content in the lubricating oil. (Chen, Wang, Pan, & Pan, 2018) investigated the reduction in lubricating oil viscosity is caused by the mixing of lubricating oil with wear metals. In this research, the decrease in lubricating oil viscosity possibly caused by wear metals with the increase wear that occurs in the piston ring so that the gap between the piston ring and the cylinder liner increases.

Table 4.2 Piston Ring Gap - Conventional Metal Mesh Oil Filter

No.	Top Dead Center (T. D. C.)			Bottom Dead Center (B. D. C.)		
	Piston Ring	Gap before Experiment	Gap after Experiment	Piston Ring	Gap before Experiment	Gap after Experiment
1.	1	0,5 mm	0,7 mm	1	0,5 mm	0,6 mm
2.	2	0,5 mm	0,6 mm	2	0,4 mm	0,5 mm
3.	3	0,5 mm	0,55 mm	3	0,3 mm	0,45 mm

From table 4.2 shows piston rings from engine test equipped with Conventional Metal Mesh Oil Filter increase with the amount of 0,2 mm; 0,1 mm; and 0,05 mm for compression piston ring 1, compression piston ring 2, and compression piston ring 3 at top dead center condition (T. D. C.) while at bottom dead center condition (B. D. C.), piston rings gap increase with the amount of 0,1 mm, 0,1 mm, and 0,15 mm for compression piston ring 1, compression piston ring 2, and compression piston ring 3.

Table 4.3 Piston Ring Gap - Modified Sawdust Oil Filter

No.	Top Dead Center (T. D. C.)			Bottom Dead Center (B. D. C.)		
	Piston Ring	Gap before Experiment	Gap after Experiment	Piston Ring	Gap before Experiment	Gap after Experiment
1.	1	0,5 mm	0,65 mm	1	0,5 mm	0,6 mm
2.	2	0,5 mm	0,55 mm	2	0,4 mm	0,45 mm
3.	3	0,5 mm	0,5 mm	3	0,3 mm	0,4 mm

Table 4.3 shows piston rings gap from engine test equipped with Modified Sawdust Oil Filter increase with the amount of 0,65 mm; 0,55 mm; and 0,5 mm for compression piston ring 1, compression piston ring 2, and compression piston ring 3 at top dead center condition (T. D. C.) and 0,6 mm; 0,45 mm; and 0,4 mm for compression piston ring 1, compression piston ring 2, and compression piston ring 3 at bottom dead condition (B. D. C.). From piston rings gap measurement

from Table 4.2 and 4.3 indicated parts wear from 200 h engine durability test which caused a decrease in viscosity. Most likely the piston rings are damaged or dirty, so they contaminate the lubricating oil. Too high viscosity would result in a high friction coefficient and energy is wasted in shearing the thick lubricant film. Besides, it may lead to local temperature increase and so acceleration of lubricant decomposition reactions and mechanical wear and tear, and eventually reduced lifetime of both the lubricant and the engine.

4.2.2 Viscosity Index

Viscosity Index (VI) is an arbitrary, dimensionless number which expresses the resistance of a lubricant to viscosity change with temperature. A lubricating oil with high VI display only small changes in viscosity with temperature, which denotes stable viscosity. The higher its VI value, the greater the resistance of a lubricant to thicken at low temperatures and thin out at high temperatures. Lubricants with VI > 100 are often considered useful in many applications.

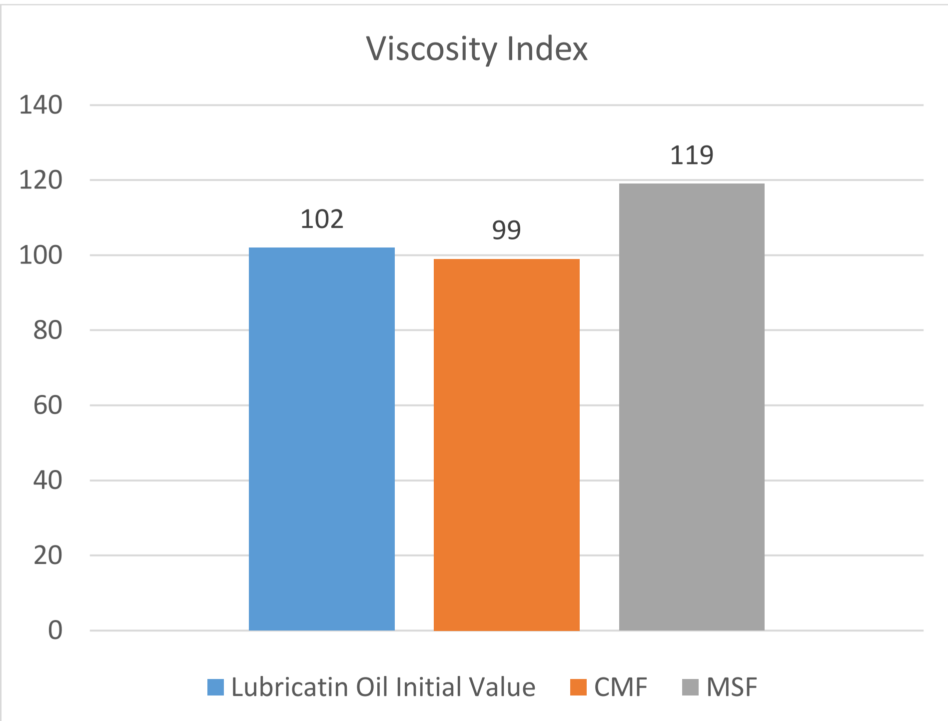

Figure 4.3 Lubricating Oil Viscosity Index Comparison of Engine Equipped with Conventional Metal Mesh Oil Filter and Modified Sawdust Oil Filter

Figure 4.3 shows the comparison of viscosity index for engine test with different oil filter. It depicts that lubricating oil viscosity index from conventional metal mesh oil filter experiment decrease by 3 from its initial value. On the contrary, lubricating oil viscosity index from modified sawdust oil filter increase by 20 from its initial value. Lubricating oil from modified sawdust oil filter experiment has higher VI compared to conventional metal mesh oil filter experiment. This shows lubricating oil from modified sawdust oil filter experiment has less viscosity change when temperature increases, indicating better resistance to thinning. With lower viscosity index, engine equipped with modified sawdust oil filter has a better temperature stability and performance.

4.2.3 Flash Point

The flash point is the lowest temperature at which vapors of a volatile material will ignite, when given an ignition source. When lubricating oil is heated to a high enough temperature, it will begin to boil off as a vapor.

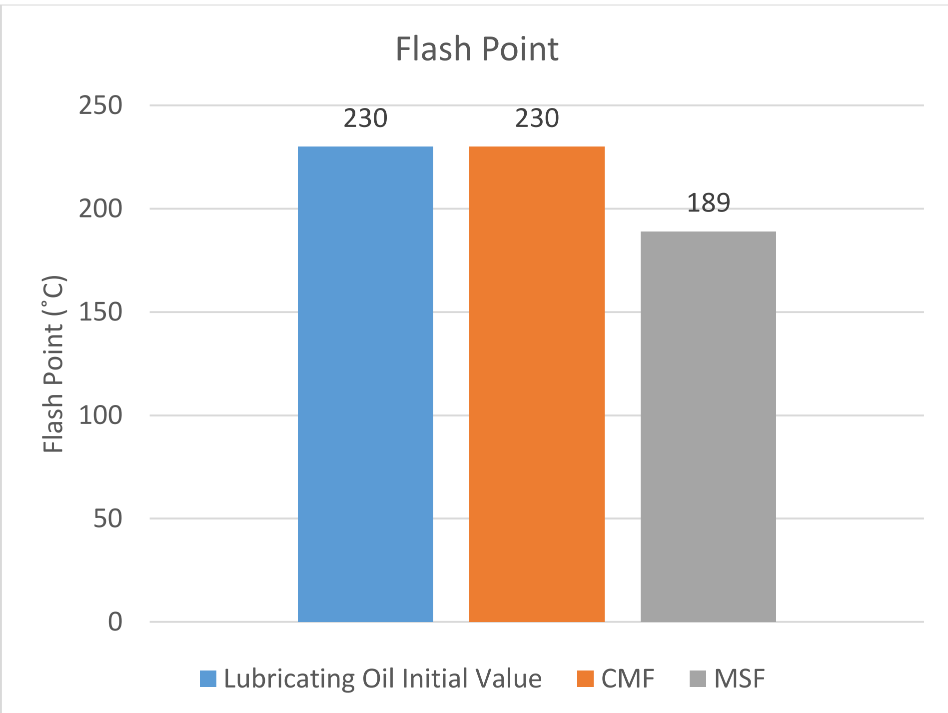

Figure 4.4 Lubricating Oil Flash Point Comparison of Engine Equipped with Conventional Metal Mesh Oil Filter and Modified Sawdust Oil Filter

The flash point of PERTAMINA MESRAN B 40 lubricating oil is 230^{o}C. Figure 4.4 depicts the comparison of lubricating oil flash point from experiment with two kinds of filter. Normally, engine oils have flash points above 200^{o}C. The lubricating oil from conventional metal mesh oil filter experiment has 230^{o}C flash point, which is the same with the initial flash point of PERTAMINA MESRAN B 40. Most likely, the flash point increase because of water contamination in the oil. *(Watson, Wong, Brownawell, & Lockledge, 2009)* found that the more water content in the oil, the flash point value will be higher.

In the other hand, lubricating oil from modified sawdust oil filter experiment has 189^{o}C flash point. The flash point decrease by 41 from its initial value. This is most likely because of fuel dilution. As described above, the process of the raw or unburned fuel mixing with the oil is known as fuel dilution. (Ayub, Engine Lubrication, 2010) stated the influence of engine oils dilution bye fuel on their viscosity, flash point and fire point and found a significant reduction in lubricating oil flash point because of fuel dilution. In the inspection of used oil, a significant reduction in the flash point usually indicates contamination with fuel or other lower flash point fluid.

4.2.4 Pour Point

The pour point of a lubricant is the lowest temperature at which the oil will flow from its container. At low temperatures, the viscosity of the oil will be very high, causing the oil to resist flow. This property is especially crucial for oils that must flow at low temperatures. Pour point should be at least 10°C lower than the lowest anticipated ambient temperature.

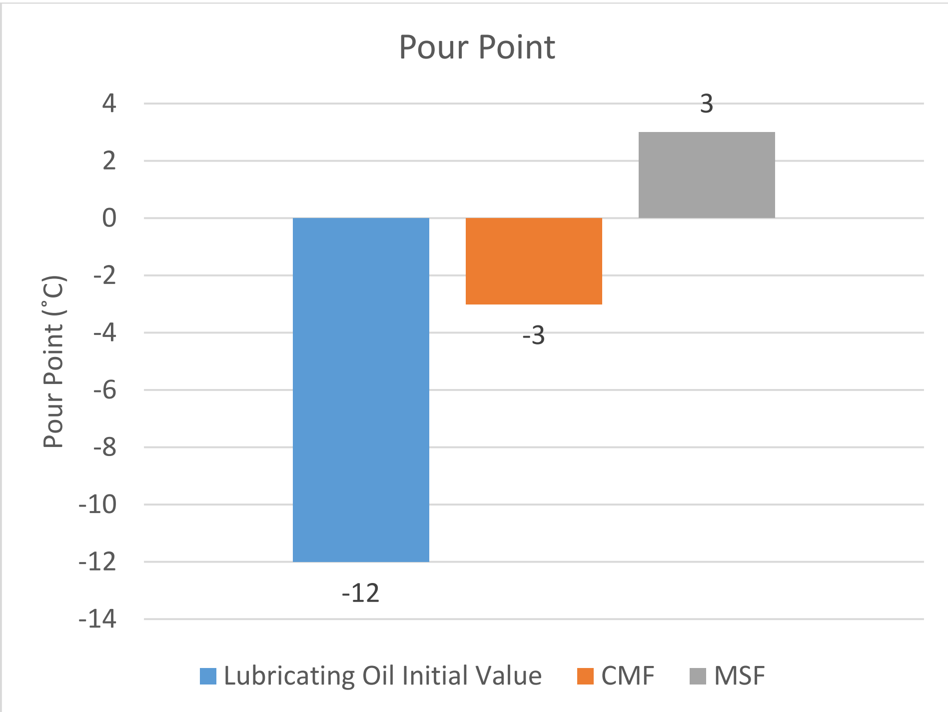

Figure 4.5 Lubricating Oil Pour Point Comparison of Engine Equipped with Conventional Metal Mesh Oil Filter and Modified Sawdust Oil Filter

From Figure 4.5, lubricating oil pour point from conventional metal mesh experiment increase by 9°C from its initial value. In the other hand, lubricating oil pour point from modified sawdust oil filter increase by 15°C from its initial value. Most likely, the increase in pour point from both experiment is because the wax deposition in the lubricating oil.

Most lubricating oils are still manufactured using paraffinic mineral base oil stocks. In paraffinic oils, stiffening is caused by the wax in the oil, which is distinguishable as crystals. Virtually all these mineral base oil contain small amounts of dissolved wax.

When oil ceases to flow this indicates that sufficient wax crystallization has occurred or that the oil has reached a highly viscous state. At this stage waxes or high molecular weight paraffin precipitate from the oil. The waxes form the interlocking crystal that prevent the remaining oil from flowing. This is a critical point since the successful operation of a machine depends on the continuous supply of oil to the moving parts.

As the oil is cooled down, the wax begins to separate as crystals. When cooled down further, the wax crystals start to interlock to form a three-dimensional structure that traps the oil in small pockets within the wax structure. When this wax crystal structure becomes sufficiently rigid at low temperatures, the oil will no longer flow. Although most of the wax is removed during base oil refining, high-molecular weight species are necessary to achieve the desired target viscosity, while wax help contribute to a higher viscosity index, waxes can congeal and cause the lubricant to gel at colder temperatures.

4.2.5 Total Base Number

Total base number (TBN) indicates the quantity of alkaline reserve in the lubricant for controlling the acid contaminations. Lubricant with lower TBN are less effective in suspending the wear causing contaminants and result in engine damage due to corrosion by acid attack. For this reason, TBN is often considered as an indicator of oil degradation. Oils for most diesel engine applications typically have a TBN between 8 and 12 mg KOH/g. Once the TBN drop below 3, this is considered too low and should trigger an oil change.

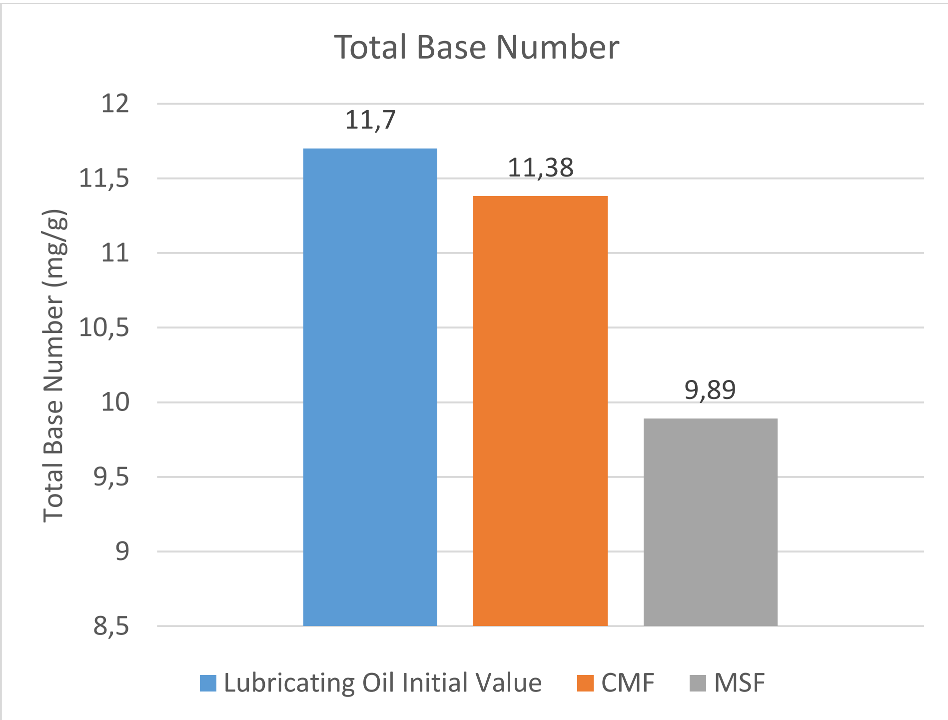

Figure 4.6 Lubricating Oil Total Base Number (TBN) Comparison

In this research, PERTAMINA MESRAN B 40 lubricating oil is used with an initial total base number 11,7 mg KOH/g. After 200 h engine durability test with conventional metal mesh oil filter, the total base number of the lubricating oil reduce from 11,7 to 11,38 mg KOH/g with a reduction rate of 2,73%. In the other side, the total base number from the lubricating oil used in 200 h engine durability test with modified sawdust oil filter reduce from 11,7 to 9,89 mg KOH/g with a reduction rate of 15,47%.

The higher reduction of the total base number in the modified sawdust oil filter experiment is most likely due to the lubricating oil oxidation and additive depletion. Oxidation is the most predominant reaction of a lubricant. It is responsible for numerous lubricant problems such as the reduction of total base number. Oil oxidation is a result of the engine high temperature. Heat is often employed to accelerate the oxidation process because temperature has two effects on any reaction. The first effect involves activation energy. If the system does not contain enough energy to push the reaction over the threshold, nothing will happen. The second effect is related to the speed of the reaction. In the experiment, modified sawdust oil filter experiment have higher engine temperature than conventional metal mesh oil filter experiment, this is most likely caused oil oxidation. Oxidation will approximately double in rate for every 10°C increase in temperature. Which means that the lubricating oil life will be reduce by one-half for every 10°C increase in temperature (Ayub, Engine Lubrication, 2010).

Table 4.4 PERTAMINA MESRAN B 40 Material Safety Data Sheet

STABILITY AND REACTIVITY	
Stability (Thermal Light, etc.)	Stable at temperature < 85°C and will release H_2S if heated > 85°C more than 2 days
Circumstances that must be Avoided	High temperature > 85°C
Incompatibility (Material to Avoid)	Storing oxide and strong acid
Decomposition	-Carbon monoxide. Metal oxide. Elemental oxide. -H2S (at temperature > 85°C)

As PERTAMINA MESRAN B 40 Material Safety Data Sheet stated in Table 4.4, PERTAMINA MESRAN B 40 lubricating oil will release Hydrogen Sulfide (H_2S) when the temperature is more than 85°C. H_2S will form sulfur dioxide (SO_2) and sulfuric acid (H_2SO_4) during combustion which results in a very aggressive corrosion with the end result being a decrease in the total base number due to the characteristic of total base number as acid neutralizer which mainly produced during the combustion process. Therefore, the reduction of the additive contents in the lubricating oil which generally alkaline occur.

For TBN < 2 mg KOH/g the lubricant is considered inadequate for engine protection and is at risk of corrosion. Total base number in the used oil should not be allowed to fall below 50% of the initial value, a drop in total base number is a clear indication that something is abnormal.

The change of total base number in this experiment is not exceed more than half from the initial value so that the lubricating oil in both experiment still remain usable. But, the modified sawdust filter experiment will trigger a lubricating oil change sooner than the conventional oil filter experiment because a low base number represents the potential for corrosion, rust and oxidation.

4.2.6 Content of Wear Metals

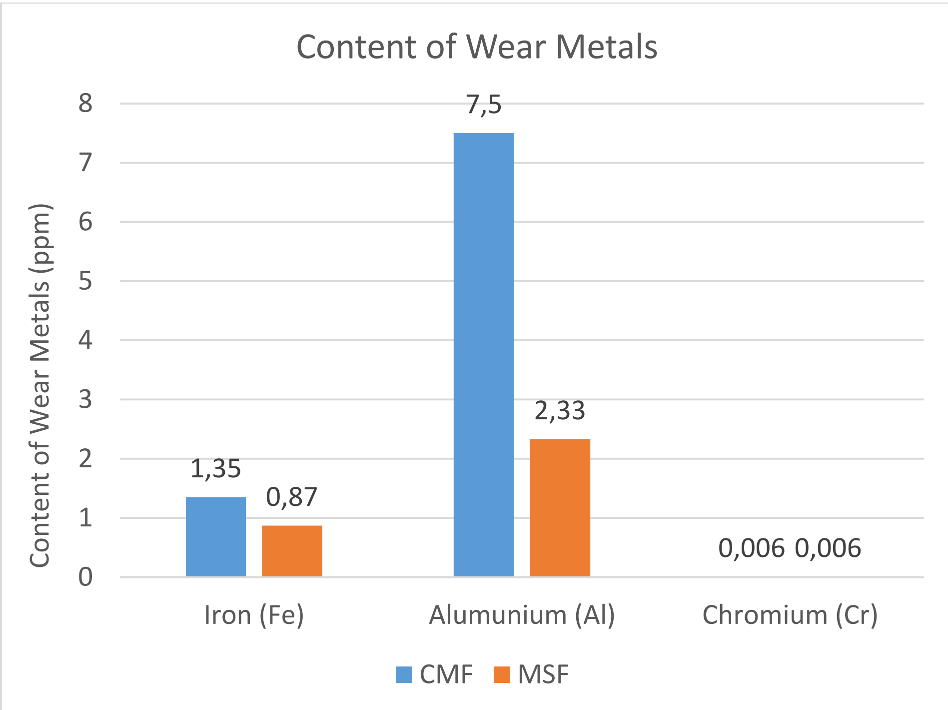

Figure 4.7 Comparison of Wear Metals Content in Lubricating Oil Filtered by CMF and MSF

The modified sawdust was processed as filter media into the oil filter and it was compared with CMF. When the MSF was used, most of the particles can be removed. This can ascribe to the filter out of colloid in oil while the colloid has an adsorption effect on particles. The poor fluidity acidic colloid has a very complex composition and it mainly consists of the aggregation of additive degradation and oil oxide, as well as a small amount of wearing impurity. This due to the efficient adsorption capacity of modified sawdust to acidic colloid, especially since the successful grafting of alkaline amino. Alkaline amino can neutralize the acidic colloids accumulated in oil. As a result, With the removal of colloids, the viscosity of the oil reduced. Before and after the CMF was replaced by MSF, the kinematic viscosity (100ºC) of oil to decreased from 14,9 cSt to 7,25 cSt, which is closely related to the removal of colloids. In transportation sector, the key factor to indicate the oil change in diesel engines and determine drain interval is oil viscosity because it directly reveals the accumulation content of impurity in oil and the deterioration degree of oil.

During the engine running, wear metals produced between the cylinder and the piston adheres to the oil film and then mixed into the lubricant, which will aggravate the deterioration of oil properties. In this research, engine wear was tested by analyzing the wear-metal level of lubricant via ICPS. Wear metal content in engine oil with CMF and MSF are showed in Figure 4.7. Iron and Aluminum show reduction when MSF is used. This indicates that MSF possess higher adsorption capacity than CMF, which is attributed to the interaction between metal particle and the surface hydroxyl and enwrapped in colloid. That is to say, MSF shows dual function in the purification of lubricant oil, filtration and adsorption. From Figure 4.7, researcher can conclude that the equipment of MSF can effectively reduce colloid content and wear metal, thus slow down the deterioration of lubricant oil.

Figure 4.8 Used CMF and Used MSF

Figure 4.9 MSF Equipped Engine Piston (left), CMF Equipped Engine Piston (right)

4.3 Diesel Engine Performance Comparison

4.3.1 Conventional Metal Mesh Oil Filter and Modified Sawdust Oil Filter Specific Fuel Oil Consumption at Rated Speed Condition Comparison against Time

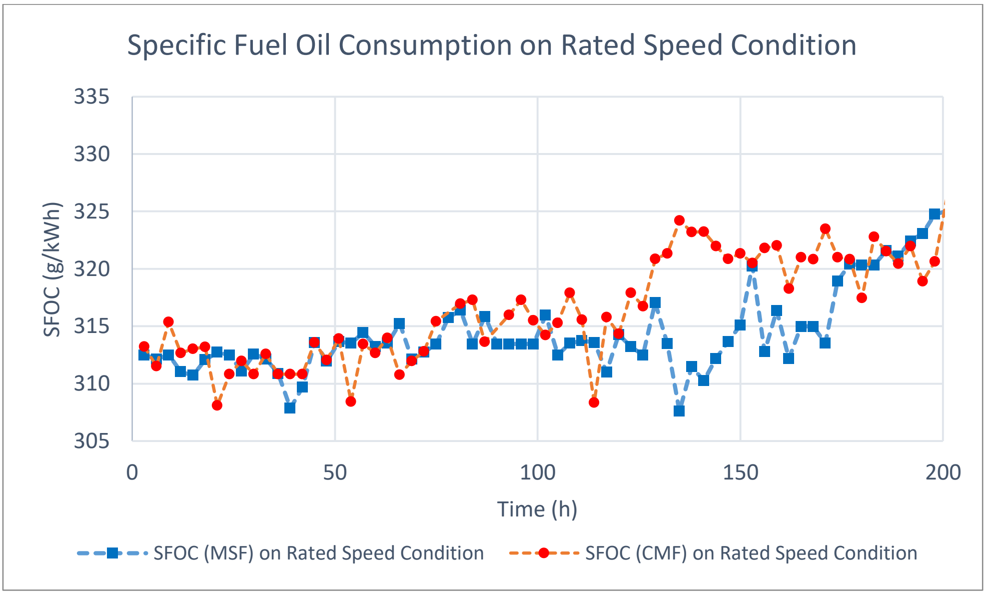

Figure 4.10 Comparison of Specific Fuel Oil Consumption

The SFOC was measured under full throttle output working condition shows the comparison of SFOC for 200 hours' engine durability test with different oil filter, with further increasing in engine running time, SFOC shows an upward trend.

Engine equipped with Modified Sawdust Oil Filter shows lower SFOC than with Conventional Metal Mesh Oil Filter. In the engine, friction coefficient for all the lubrication conditions depends mainly on the lubricant rheology, especially on oil viscosity. When Modified Sawdust Oil Filter was used, the reduction in SFOC is due to the drop of engine oil viscosity and the drop of engine oil viscosity leads to a better mechanical efficiency and a lower SFOC. (Manni, Florio, & Gommellini, 1997) investigated the effect of low viscosity engine oil on fuel consumption and friction benefits and they found a significant difference in friction coefficient for low viscous oil. The average SFOC for Conventional Metal Mesh Oil Filter is 316,1 g/kWh and for Modified Sawdust Oil Filter is 314,2 g/kWh. Statistically speaking, the figure guarantees the researcher to conclude that Modified Sawdust Oil Filter can effectively reduce SFOC relative to Conventional Metal Mesh Oil Filter.

4.3.2 Conventional Metal Mesh Oil Filter and Modified Sawdust Oil Filter Power Output at Rated Speed Condition Comparison against Time

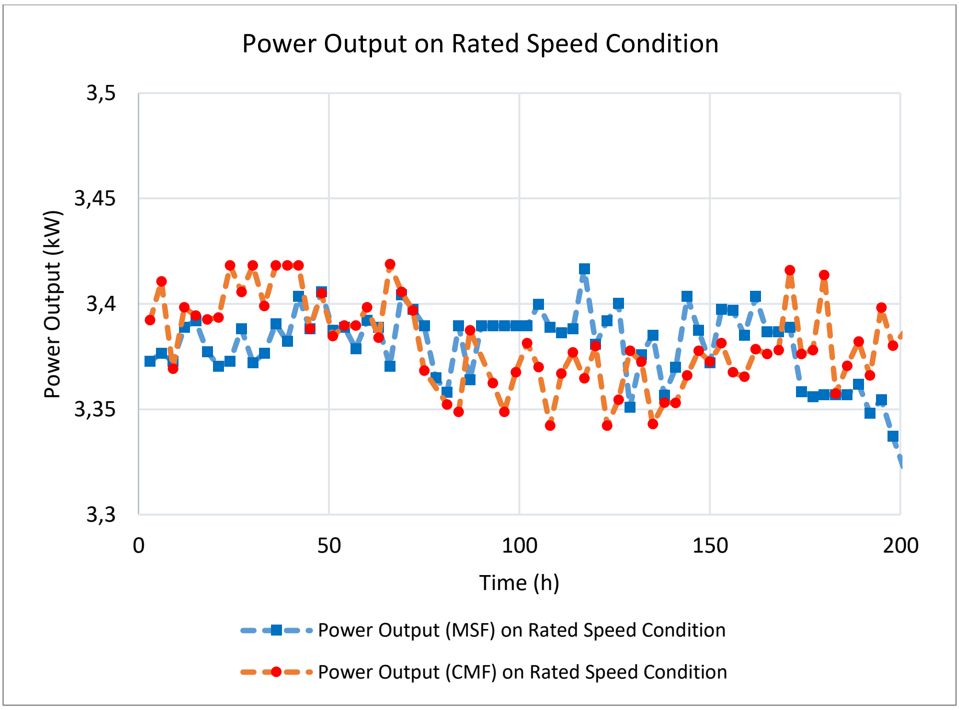

Figure 4.11 Comparison of Output Power

Figure 4.11 shows the change of engine output power versus time for 200 hours' engine durability test equipped with two kinds of oil filter. The figure depicts that engine output power increases with the increasing of engine running time in Rates Speed Condition. The average Power Output for Conventional Metal Mesh Oil Filter is 3,38 kW and for Modified Sawdust Oil Filter is 3,4 kW. This is attributed to the reduction of wear metal content in the lubricating oil. With the use of Modified Oil Filter, wear metal particles in the engine oil are significantly reduced due to the adsorption and filtration effect attributed to the pore structure and surface hydroxyl groups in modified sawdust as discussed above. In this way, the frictional power consumption between piston and cylinder wall reduces on account of the decrease of wear particles in lubricant oil film. Consequently, output power increases correspondingly. The study by (Storey, et al., 2015) has also shown that wear produces Nano-sized debris impacting lubricant oil properties and reducing output power during the engine running. The increase of output power in this research maybe to the decrease of lubricant oil viscosity that reduces friction coefficient on the contact surface of the engine parts and thus more energy can be output as effective energy. (Chen, Wang, Pan, & Pan, 2018) have proposed that higher kinematic viscosity increased piston rings friction and total friction torque, thus reduced output power.

4.4 Engine's Specific Emission Comparison

NO_x, HC, CO, and PM emissions test was conducted by using a gas analyzer to get the desired results. The engine is set at 2200 RPM with 100%, 75%, 50%, and 25% load variation for the emission test.

Table 4.5 NO_x (mg/Nm^3), HC (ppm), CO (%), and PM (mg/Nm^3) Emission Test Results

Lubricating Oil Filter	Load (%)	NO_x (mg/Nm^3)*	HC (ppm)	CO (%)	PM (mg/Nm^3)*
Conventional Metal Mesh Oil Filter	25	64	0	0,012	28,3
	50	97,9	0	0,020	63,7
	75	78,4	0	0,027	49,4
	100	146,6	47	0,015	69,6
Modified Sawdust Oil Filter	25	70,7	0	0,021	21,3
	50	108,3	0	0,031	49,6
	75	88,2	0	0,027	28,3
	100	150,5	21	0,014	49,2

*The N means 'normal', i.e. normal temperature and pressure (25^{o}C and 1 atm)

Table 4.3 shows NOx, HC, CO, and PM emission test results from gas analyzer from two different experiments with mg/Nm^3 for NOx, HC, and CO units and % for CO units. In order for better analysis, these numbers need to be converted according to standards in the IMO MARPOL Annex VI and Euro. In this standard the unit used is gr/Kwh. After conversion, the value of the emissions test is:

Table 4.6 NO_x (g/kWh), HC (g/kWh), CO (g/kWh), and PM (g/kWh) Specific Emission Conversion

Lubricating Oil Filter	Load (%)	NOx (g/kWh)	HC (g/kWh)	CO (g/kWh)	PM (g/kWh)
Conventional Metal Mesh Oil Filter	25	1,60	0	3,35	0,0023
	50	1,19	0	2,71	0,0019
	75	0,93	0	3,59	0,0007
	100	1,39	0,28	1,59	0,0016
Modified Sawdust Oil Filter	25	1,75	0	3,88	0,0017
	50	1,30	0	3,62	0,0011
	75	1,05	0	4,12	0,0005
	100	1,42	0,12	2,22	0,0011

4.4.1 Specific Emission of Nitrogen Oxide (NO_x) Comparison of Engine Equipped with Conventional Metal-Mesh Oil Filter and Modified-Sawdust Oil Filter

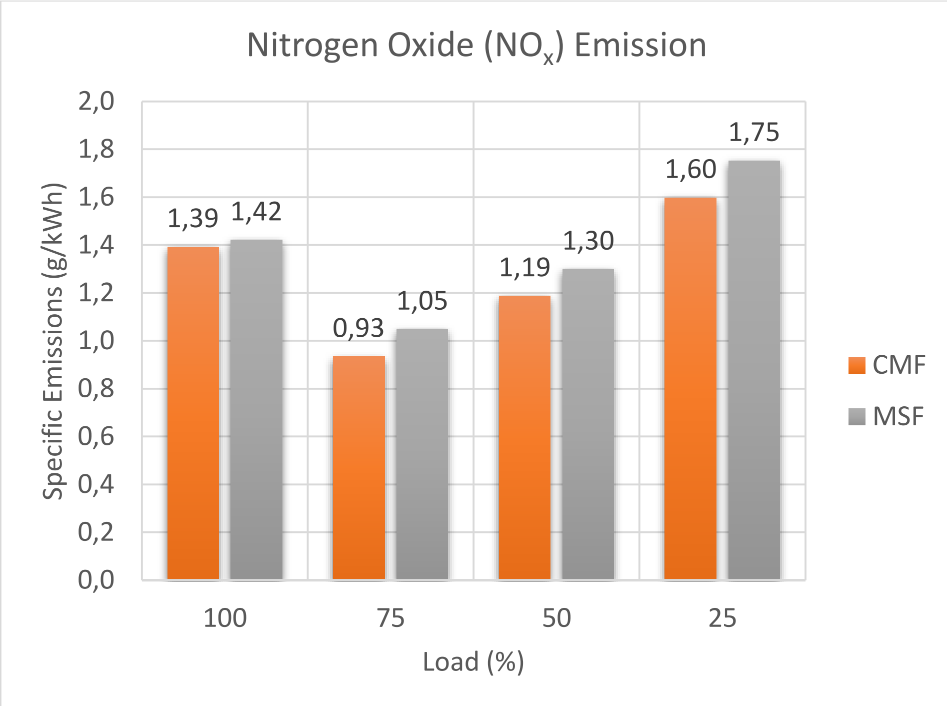

Figure 4.12 Specific Emission of Nitrogen Oxide (NO_x) Comparison

NO_x is one of the main pollutants emitted by diesel engines, which is toxic and the main source of photochemical smog. In most combustion chamber, generation of NO_x is ascribable to high temperature of combustion chamber and oxygen-enriched environment (İleri & Koçar, 2014). The exhaust concentrations of the pollutants of importance are caused by the mean residence time in the combustion zone, the chemical reaction rates, and the mixing rates. Oxides of nitrogen NO_x are produced in the central hot region of the combustor by the oxidation of the atmospheric nitrogen, and most of the NOx emitted in the exhaust is nitric oxide (NO) (Rizk & Mongia, 1992). Figure 4.12 shows the NO_x emissions for MSF compared to CMF with load variations according to IMO regulations. An increase of 3% in NO_x was observed for MSF compared to CMF. In general, attempting to improve engine performance are often accompanied by NO_x increase (Li & Karim, 2005). In this research, NO_x emission shows an opposite trend to HC emission (depicted obviously in Figure 4.14). That is because better combustion of fuel will decrease HC emission, while it will increase the temperature of combustion chamber and thus resulting in higher NO_x emissions.

4.4.2 Specific Emission of Carbon Monoxide (CO) Comparison of Engine Equipped with Conventional Metal-Mesh Oil Filter and Modified-Sawdust Oil Filter

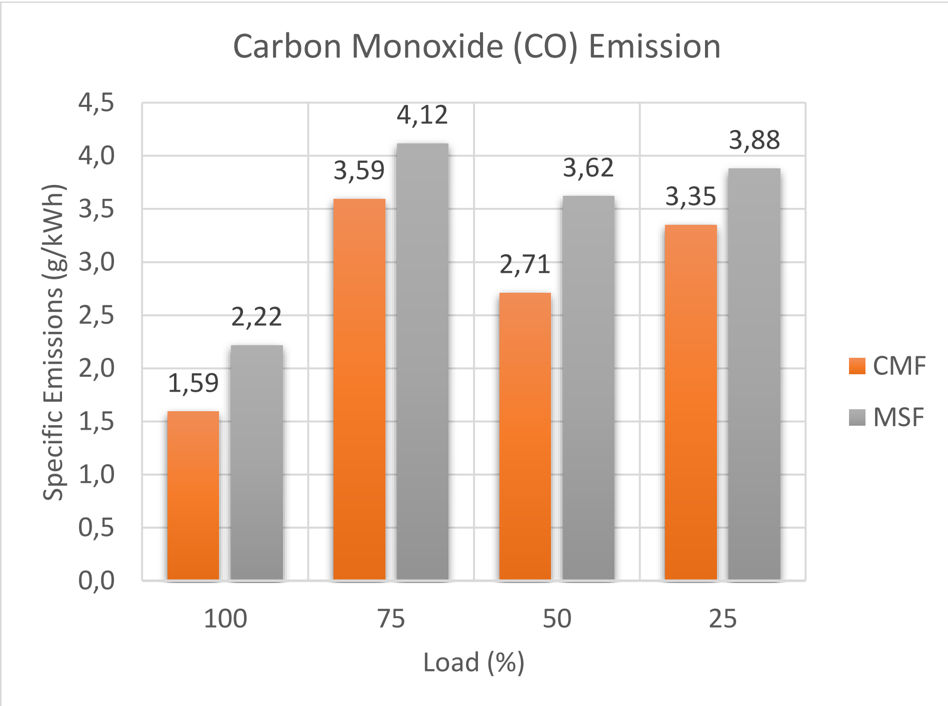

Figure 4.13 Specific Emission of Carbon Monoxide (CO) Comparison

Carbon monoxide (CO) gas forms primarily when carbon fuels are not burned completely (United States Environmental Protection Agency, 2018). This is the fuel that has combusted, but not completely. The presence of the CO pollutants in the diesel engine exhaust in large quantities is an indication of incomplete combustion of fuel due to inadequate burning rates in the primary zone, inadequate mixing, chilling effects of cylinder liner coolant, and insufficient residence time (Rizk & Mongia, 1992). CO is an intermediate product of hydrocarbon fuel combustion, which is mainly due to the slow burning of the soot at the final combustion stage, uneven mixing and inadequate combustion of fuel as well as decreasing of CO post-oxidation in the exhaust emission stage. CO emission of the test engine showed in Figure 4.13 and CO emission is slightly higher than conventional metal mesh oil filter when modified sawdust oil filter is used. It is understandable because most HC species have been converted (depicted obviously in Figure 4.14) and part of the hydrocarbon is inevitably transformed into CO in real combustion condition, and thus CO emission increased slightly.

4.4.3 Specific Emissions of Hydrocarbon (HC) Comparison of Engine Equipped with Conventional Metal Mesh Oil Filter and Modified Sawdust Oil Filter

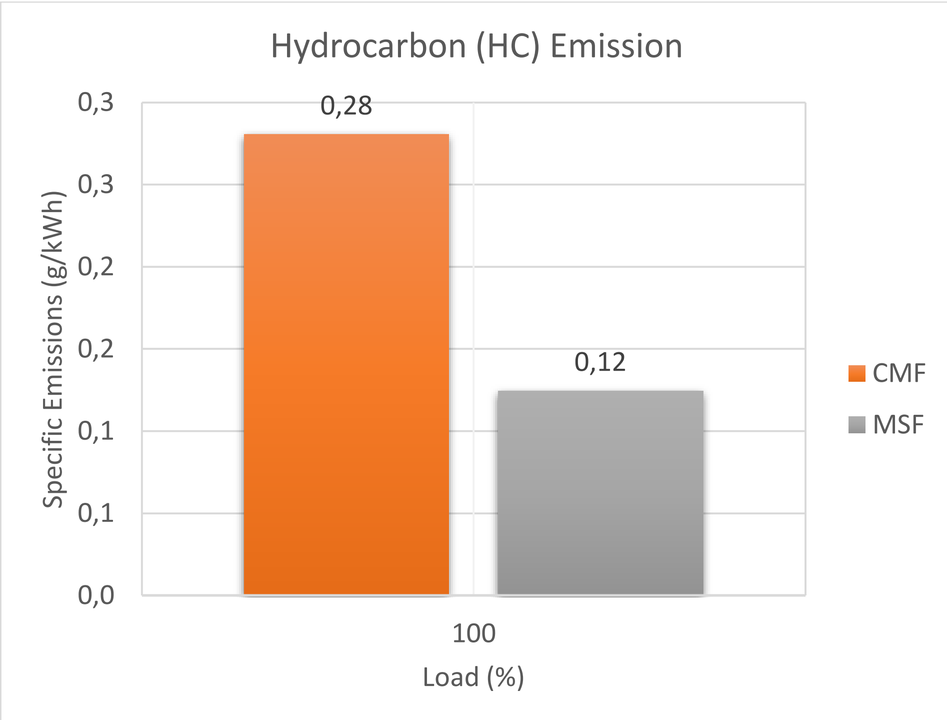

Figure 4.14 Specific Emission of Hydrocarbon (HC) Comparison

HC emission is an indication of incomplete fuel combustion owing to the very short residence time of fuel in the combustion chamber, un-uniform mixing of fuel, decreasing in gas-fuel ratio, flame quenching. The emission of HC for testing engine is shown in Figure 4.14. Modified sawdust oil filter significantly reduce HC emission from 0,28 to 0,12 g/kWh with reduction rate of 57,14%. During the engine running, a thin layer lubricant oil film forms in the surface of the piston and cylinder liner. However, the lubrication regime of the mating surface affects the efficiency and emission output of the engine (Masjuki, Maleque, Kubo, & Nonaka, 1999). When the fuel is burning inside cylinder, the flame will directly contact with lubricant oil film. More low temperature impurity center in lubricating oil, such as wear metals and insoluble colloids, will cause non-uniform fuel combustion and correspondingly increase HC emission. With the use of modified sawdust oil filter, wear metals and insoluble colloids both exhibit decrease which are beneficial to the uniform combustion of fuel and less fuel has been emitted into exhaust gas in the form of HC. The complete combustion is also beneficial to the reduction of SFOC discussed above and improvement of fuel economy. Besides, in the process of fuel combustion, lubricating oil is unavoidably involved in the combustion. The lubricating composition and its combustion are also an important source of HC emission which have been widely reported before (Souza & Corrêa, 2016). therefore, the reduction of impurity components in the lubricating oil directly bring about reduction in the lubricating derived HC emission.

4.4.4 Specific Emission of Particulate Matter (PM) Comparison of Engine Equipped with Conventional Metal Mesh Oil Filter and Modified Sawdust Oil Filter

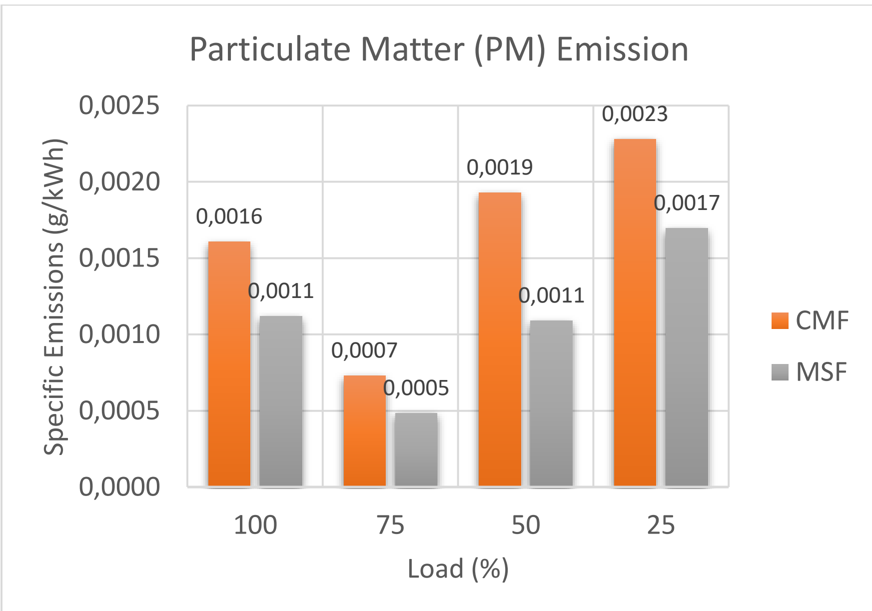

Figure 4.15 Specific Emission Graph of Particulate Matter (PM) Comparison.

Particulate Matter (PM) emission from diesel engine is one of the major sources of suspended particulates, which not only pollutes atmosphere but adversely affects human health by inhalation. The composition of PM is very complex. In general, it includes sulfates, unburned hydrocarbon (HC) species, polycyclic aromatic compounds, and part of wear metal particles accumulated in lubricating oil (Chromas & Ghandhi, 2004). PM emission of the test engine is exhibited in Figure 4.15. Modified sawdust oil filter shows reduction of PM emission for 31,25% than an engine with conventional metal mesh oil filter and this result is in good compliance with HC emission. The unburned HC is considered as the main PM precursor and PM emission will decrease with the decreasing of the unburned HC (Storey, et al., 2015). Besides, in this research, the decreasing of wear metal particles by using modified sawdust oil filter is beneficial to the decline of total PM emission. In previous years, the SAE has reported that the particulate matter emission was found to be dominated by particulate matters derived from the engine oil (Chromas & Ghandhi, 2004). (Chen, Wang, Pan, & Pan, 2018) also reported that the element emissions of the ash forming elements Ca and Zn increased proportionally to the oil consumption. It means that wear metals in lubricant has direct effect on PM emission and the decreasing of metal contents in engine oil will make a positive contribution to the control of total PM emission. (Dong, Han, Liang, & Wang, 2015) found that when the lubricant oil is involved in combustion mean diameter and concentration of the primary particles increased and it mainly contributed to larger size aggregated particles.

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CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this research, MSF was prepared and its effect on the performance, emissions of diesel engine as well as the effect on lubricant oil kinematic viscosity, colloid and the wear metal contents were researched compared to CMF. EMA engine durability test were conducted in a one-cylinder diesel engine at different cycle for 200 h. the main conclusion can be drawn in this research as follows:

1. Compared with CMF, MSF effectively removed wear metal from lubricant oil in the process of engine running, thus preventing the deterioration of kinematic viscosity. This mainly due to the adsorption effect of alkaline amino group in modified sawdust.
2. MSF also reduced wear metal content in lubricant oil, the friction power and increased the output power. Besides, as average reduction of SFOC 0,6-1,05% was obtained for engine with MSF under the same test condition.
3. The use of MSF decreased HC emission by 57,14% and PM emission by 31,25% due to the decline of wear metal particles in lubricant oil, while emission of CO and NOx increase by 1,5% and 3% respectively.

5.2 Recommendation

With the research of analysis of lubricant oil properties filtered with MSF and its effect on engine performance and emission, the author suggested that this research can be developed further. These suggestions include:

1. The next researcher can develop modified sawdust oil filter with different kinds of sawdust and filtrate size variations for better understanding of adsorption ability for different kinds of sawdust
2. To obtain better understanding for the effect of lubricating oil filter to engine emissions, carbon dioxide (CO_2) emission need to be tested and analyzed.

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ATTACHMENTS

A. Conventional Metal Mesh Oil Filter

Condition	Dummy Load	RPM		Altenator		Fuel Consumption	Time	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	620	3,4	0	100	30 minutes	0^{th}-3^{rd} Hours
High Idle	750	1980	1391	201	2,9	320		
Rated Speed	2500	2200	1535	243	11,5	1250	60 minutes	
Max Torque	3000	1900	1320	201	12,36	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	611,8	2,95	0	90	30 minutes	4^{th}-6^{th} Hours
High Idle	750	1980	1383	198	2,89	290		
Rated Speed	2500	2200	1529	244	11,47	1250	60 minutes	
Max Torque	3000	1900	1321	201	12,36	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615,8	2,87	0	100	30 minutes	7^{th}-9^{th} Hours
High Idle	750	1980	1388	194	2,84	250		
Rated Speed	2500	2200	1533	244	11,36	1250	60 minutes	
Max Torque	3000	1901	1322	201	12,36	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	858	607	3,095	0	100	30 minutes	10^{th}-12^{th} Hours
High Idle	750	1980	1385	197	2,85	275		
Rated Speed	2500	2202	1531	246	11,34	1250	60 minutes	
Max Torque	3000	1903	1323	201	12,39	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	880	615	3,315	0	100	30 minutes	13rd-15th Hours
High Idle	750	1983	1385	197	2,86	275		
Rated Speed	2500	2201	1529	244	11,41	1250	60 minutes	
Max Torque	3000	1901	1322	201	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	858	597	3,2	0	100	30 minutes	16th-18th Hours
High Idle	750	1979	1378	200	2,87	250		
Rated Speed	2500	2200	1530	245	11,37	1250	60 minutes	
Max Torque	3000	1902	1323	201	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	919	621	3,35	0	100	30 minutes	19th-21st Hours
High Idle	750	1974	1386	191	2,83	300		
Rated Speed	2500	2200	1526	244	11,39	1230	60 minutes	
Max Torque	1900	1903	1324	201	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	877	616	3,146	0	100	30 minutes	22nd-24th Hours
High Idle	750	1981	1387	202	2,89	250		
Rated Speed	2500	2202	1531	247	11,36	1250	60 minutes	
Max Torque	1900	1901	1319	202	12,36	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	874	612	3,103	0	100	30 minutes	25th-27th Hours
High Idle	750	1981	1387	202	2,89	260		
Rated Speed	2500	2200	1529	246	11,36	1250	60 minutes	
Max Torque	1900	1902	1319	201	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	860	602	3,22	0	100	30 minutes	28th-30th Hours
High Idle	750	1981	1387	202	2,89	250		
Rated Speed	2500	2202	1531	247	11,36	1250	60 minutes	
Max Torque	3000	1902	1319	201	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	854	597	3,19	0	95	30 minutes	31st-33th Hours
High Idle	750	1982	1384	198	2,88	250		
Rated Speed	2500	2201	1530	246	11,34	1250	60 minutes	
Max Torque	3000	1902	1317	201	12,36	1110		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	856	600	3,16	0	100	30 minutes	34th-36th Hours
High Idle	750	1981	1383	197	2,86	260		
Rated Speed	2500	2202	1531	247	11,36	1250	60 minutes	
Max Torque	3000	1903	1320	203	12,4	1110		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	858	601	3,02	0	100	30 minutes	37th-39th Hours
High Idle	750	1981	1393	201	2,89	280		
Rated Speed	2500	2202	1531	247	11,36	1250	60 minutes	
Max Torque	3000	1901	1320	202	12,37	1130		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	870	610	3,07	0	110	30 minutes	40th-42nd Hours
High Idle	750	1982	1388	200	2,9	250		
Rated Speed	2500	2202	1531	247	11,36	1250	60 minutes	
Max Torque	3000	1903	1322	202	12,4	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	860	602	3,04	0	100	30 minutes	43rd-45th Hours
High Idle	750	1980	1387	199	2,89	250		
Rated Speed	2500	2204	1528	245	11,32	1250	60 minutes	
Max Torque	1900	1902	1321	204	12,41	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	854	599	3,03	0	95	30 minutes	46th-48th Hours
High Idle	750	1982	1384	198	2,88	250		
Rated Speed	2500	2201	1530	246	11,36	1250	60 minutes	
Max Torque	1900	1902	1317	199	12,36	1110		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	852	598	2,907	0	100	30 minutes	49^{th}-51^{st} Hours
High Idle	750	1981	1393	200	2,86	250		
Rated Speed	2500	2202	1526	244	11,35	1250	60 minutes	
Max Torque	1900	1903	1320	203	12,39	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	849	597	2,902	0	80	30 minutes	52^{nd}-54^{th} Hours
High Idle	750	1982	1394	202	2,89	290		
Rated Speed	2500	2203	1528	245	11,33	1230	60 minutes	
Max Torque	3000	1901	1319	202	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	853	600	2,916	0	100	30 minutes	55^{th}-57^{th} Hours
High Idle	750	1982	1394	201	2,88	250		
Rated Speed	2500	2203	1528	245	11,33	1250	60 minutes	
Max Torque	3000	1901	1318	202	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	858	606	3,095	0	100	30 minutes	58^{th}-60^{th} Hours
High Idle	750	1981	1390	199	2,85	275		
Rated Speed	2500	2202	1531	246	11,34	1250	60 minutes	
Max Torque	3000	1902	1323	201	12,39	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	856	593	2,93	0	75	30 minutes	61st-63th Hours
High Idle	750	1977	1383	201	2,88	300		
Rated Speed	2500	2202	1525	244	11,34	1250	60 minutes	
Max Torque	3000	1898	1315	202	12,33	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	860	602	3,08	0	100	30 minutes	64th-66th Hours
High Idle	750	1981	1387	202	2,89	250		
Rated Speed	2500	2201	1530	247	11,36	1250	60 minutes	
Max Torque	3000	1902	1317	201	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	858	597	2,98	0	100	30 minutes	67th-69th Hours
High Idle	750	1979	1378	200	2,85	250		
Rated Speed	2500	2200	1529	246	11,36	1250	60 minutes	
Max Torque	1900	1902	1319	201	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	854	599	2,94	0	100	30 minutes	70th-72nd Hours
High Idle	750	1982	1384	198	2,88	250		
Rated Speed	2500	2201	1531	246	11,34	1250	60 minutes	
Max Torque	1900	1903	1320	203	12,4	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	856	603	2,83	0	100	30 minutes	73rd-75th Hours
High Idle	750	1982	1385	201	2,88	250		
Rated Speed	2500	2201	1530	244	11,33	1250	60 minutes	
Max Torque	1900	1901	1322	201	12,36	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	851	598	2,73	0	100	30 minutes	76th-78rd Hours
High Idle	750	1983	1386	201	2,88	250		
Rated Speed	2500	2203	1500	238	11,16	1150	60 minutes	
Max Torque	3000	1900	1297	195	12,19	1000		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	862	606	2,93		100	30 minutes	79th-81st Hours
High Idle	750	1983	1386	201	2,88	260		
Rated Speed	2500	2201	1527	243	11,3	1250	60 minutes	
Max Torque	3000	1903	1323	201	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	852	598	2,773	0	100	30 minutes	82nd-84th Hours
High Idle	750	1982	1385	200	2,87	250		
Rated Speed	2500	2201	1525	242	11,32	1250	60 minutes	
Max Torque	3000	1900	1320	202	12,36	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	877	616	3,09	0	100	30 minutes	85th-87th Hours
High Idle	750	1981	1387	202	2,89	250		
Rated Speed	2500	2202	1531	245	11,35	1250	60 minutes	
Max Torque	3000	1901	1317	201	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	900	621	3,153	0	100	30 minutes	88th-90th Hours
High Idle	750	1980	1383	200	2,88	250		
Rated Speed	2500	2201	1504	240	11,21	1150	60 minutes	
Max Torque	3000	1901	1300	197	12,23	1050		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	860	604	2,97	0	100	30 minutes	91st-93rd Hours
High Idle	750	1981	1390	202	2,84	250		
Rated Speed	2500	2202	1528	244	11,29	1250	60 minutes	
Max Torque	1900	1901	1318	202	12,39	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	853	595	2,829	0	100	30 minutes	94th-96th Hours
High Idle	750	1982	1388	201	2,88	250		
Rated Speed	2500	2200	1527	242	11,34	1250	60 minutes	
Max Torque	1900	1901	1317	202	12,39	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	856	598	2,921	0	100	30 minutes	97th-99rd Hours
High Idle	750	1981	1386	201	2,86	250		
Rated Speed	2500	2201	1529	244	11,32	1250	60 minutes	
Max Torque	1900	1903	1324	202	12,41	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	854	594	2,834	0	100	30 minutes	100th-102nd Hours
High Idle	750	1983	1387	201	2,88	300		
Rated Speed	2500	2201	1529	245	11,32	1250	60 minutes	
Max Torque	3000	1902	1322	202	12,4	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	853	595	2,794	0	100	30 minutes	103rd-105th Hours
High Idle	750	1983	1386	201	2,87	300		
Rated Speed	2500	2202	1530	244	11,33	1250	60 minutes	
Max Torque	3000	1902	1320	201	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	852	597	2,773	0	100	30 minutes	106th-108th Hours
High Idle	750	1982	1385	200	2,87	300		
Rated Speed	2500	2201	1528	242	11,32	1250	60 minutes	
Max Torque	3000	1900	1320	200	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	853,1	598	2,853	0	100	30 minutes	109th-111th Hours
High Idle	750	1982	1384	201	2,85	300		
Rated Speed	2500	2202	1530	244	11,32	1250	60 minutes	
Max Torque	3000	1902	1322	201	12,39	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	858	600,3	2,913	0	100	30 minutes	112th-114th Hours
High Idle	750	1983	1385	201	2,89	300		
Rated Speed	2500	2200	1529	245	11,31	1225	60 minutes	
Max Torque	3000	1903	1320	203	12,35	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	854	592	2,821	0	100	30 minutes	115th-117rd Hours
High Idle	750	1980	1382	200	2,88	275		
Rated Speed	2500	2201	1529	244	11,31	1250	60 minutes	
Max Torque	1900	1901	1321	203	12,35	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	856	598,3	2,873	0	100	30 minutes	118th-120th Hours
High Idle	750	1981	1384	200	2,87	300		
Rated Speed	2500	2201	1531	245	11,33	1250	60 minutes	
Max Torque	1900	1902	1322	202	12,36	1125		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	852	597	2,77	0	100	30 minutes	121^{st}-123^{rd} Hours
High Idle	750	1982	1385	202	2,89	300		
Rated Speed	2500	2201	1528	242	11,32	1250	60 minutes	
Max Torque	1900	1900	1320	200	12,36	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	854,2	595	2,87	0	100	30 minutes	124^{th}-126^{th} Hours
High Idle	750	1981	1381	200	2,88	300		
Rated Speed	2500	2201	1530	243	11,33	1250	60 minutes	
Max Torque	3000	1902	1321	201	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	854	590	2,78	0	100	30 minutes	127^{th}-129^{th} Hours
High Idle	750	1980	1382	202	2,88	350		
Rated Speed	2500	2200	1530	245	11,32	1275	60 minutes	
Max Torque	3000	1900	1317	203	12,35	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	858	601,3	2,83	0	100	30 minutes	130^{th}-132^{nd} Hours
High Idle	750	1981	1384	202	2,88	300		
Rated Speed	2500	2202	1531	245	11,3	1275	60 minutes	
Max Torque	3000	1901	1319	203	12,36	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	853,7	598	2,795	0	100	30 minutes	133rd-135th Hours
High Idle	750	1983	1382	199	2,87	275		
Rated Speed	2500	2201	1529	242	11,33	1275	60 minutes	
Max Torque	3000	1901	1319	200	12,36	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	851,4	596,1	2,83	0	100	30 minutes	136th-138th Hours
High Idle	750	1983	1383	199	2,87	300		
Rated Speed	2500	2202	1530	243	11,32	1275	60 minutes	
Max Torque	3000	1901	1319	201	12,35	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	857,6	603,4	2,89	0	100	30 minutes	139th-141st Hours
High Idle	750	1982	1384	200	2,88	300		
Rated Speed	2500	2201	1528	243	11,31	1275	60 minutes	
Max Torque	1900	1901	1321	202	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	856,3	600,2	2,884	0	100	30 minutes	142nd-144th Hours
High Idle	750	1981	1383	200	2,88	300		
Rated Speed	2500	2200	1529	244	11,32	1275	60 minutes	
Max Torque	1900	1903	1321	202	12,39	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	858,3	601,6	2,931	0	100	30 minutes	145th-147th Hours
High Idle	750	1982	1384	201	2,88	300		
Rated Speed	2500	2200	1530	245	11,32	1275	60 minutes	
Max Torque	1900	1900	1317	203	12,32	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	857	598	2,913	0	100	30 minutes	148th-150th Hours
High Idle	750	1979	1382	203	2,89	275		
Rated Speed	2500	2198	1526	244	11,33	1275	60 minutes	
Max Torque	3000	1902	1320	202	12,36	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	855,5	597,1	2,896	0	100	30 minutes	151st-153rd Hours
High Idle	750	1981	1383	195	2,84	300		
Rated Speed	2500	2201	1529	245	11,32	1275	60 minutes	
Max Torque	3000	1901	1320	201	12,39	1125		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	852,6	595,4	2,763	0	100	30 minutes	154th-156th Hours
High Idle	750	1981	1382	199	2,88	300		
Rated Speed	2500	2201	1529	244	11,32	1275	60 minutes	
Max Torque	3000	1902	1321	202	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	858,3	601,4	2,917	0	100	30 minutes	157th-159th Hours
High Idle	750	1982	1382	203	2,89	300		
Rated Speed	2500	2201	1530	244	11,32	1275	60 minutes	
Max Torque	3000	1903	1321	202	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	855	596,3	2,887	0	100	30 minutes	160th-162nd Hours
High Idle	750	1981	1382	202	2,89	300		
Rated Speed	2500	2202	1531	245	11,32	1265	60 minutes	
Max Torque	3000	1899	1318	200	12,37	1125		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	859	603,4	2,934	0	100	30 minutes	163rd-165th Hours
High Idle	750	1982	1381	201	2,89	300		
Rated Speed	2500	2201	1530	245	11,31	1275	60 minutes	
Max Torque	1900	1901	1320	200	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	856,7	599,3	2,914	0	100	30 minutes	166th-168th Hours
High Idle	750	1980	1381	200	2,88	300		
Rated Speed	2500	2201	1531	244	11,37	1275	60 minutes	
Max Torque	1900	1902	1322	201	12,39	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	851,8	594	2,74	0	100	30 minutes	169th-171st Hours
High Idle	750	1983	1383	201	2,88	300		
Rated Speed	2500	2203	1534	247	11,37	1300	60 minutes	
Max Torque	1900	1902	1321	201	12,4	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	859	603,4	2,934	0	100	30 minutes	172nd-174th Hours
High Idle	750	1982	1381	201	2,89	300		
Rated Speed	2500	2201	1530	245	11,31	1275	60 minutes	
Max Torque	3000	1901	1320	200	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	856,7	599,3	2,914	0	100	30 minutes	175th-177th Hours
High Idle	750	1980	1381	200	2,88	300		
Rated Speed	2500	2201	1531	244	11,37	1275	60 minutes	
Max Torque	3000	1902	1322	201	12,39	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	852	595,3	2,889	0	100	30 minutes	178th-180th Hours
High Idle	750	1981	1381	201	2,88	275		
Rated Speed	2500	2202	1533	247	11,36	1275	60 minutes	
Max Torque	3000	1901	1320	200	12,38	1130		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	856	600,2	2,82	0	100	30 minutes	181st-183rd Hours
High Idle	750	1980	1381	200	2,86	300		
Rated Speed	2500	2200	1528	243	11,33	1275	60 minutes	
Max Torque	3000	1900	1319	201	12,4	1125		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	853,4	592,7	2,79	0	100	30 minutes	184th-186th Hours
High Idle	750	1980	1381	200	2,87	275		
Rated Speed	2500	2201	1529	244	11,33	1275	60 minutes	
Max Torque	3000	1901	1320	201	12,4	1125		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	854	594	2,83	0	100	30 minutes	187th-189th Hours
High Idle	750	1982	1383	202	2,88	275		
Rated Speed	2500	2201	1530	245	11,33	1275	60 minutes	
Max Torque	1900	1899	1317	200	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	858,3	601,4	2,85	0	100	30 minutes	190th-192nd Hours
High Idle	750	1981	1382	202	2,88	300		
Rated Speed	2500	2199	1527	244	11,31	1275	60 minutes	
Max Torque	1900	1900	1319	201	12,4	1125		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	854,4	598	2,83	0	100	30 minutes	193rd-195th Hours
High Idle	750	1978	1383	203	2,89	275		
Rated Speed	2500	2201	1529	246	11,33	1275	60 minutes	
Max Torque	1900	1900	1319	201	12,4	1125		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	857	601,4	2,79	0	100	30 minutes	196th-198th Hours
High Idle	750	1981	1382	200	2,87	300		
Rated Speed	2500	2202	1533	245	11,34	1275	60 minutes	
Max Torque	1900	1899	1319	201	12,39	1125		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	855	597	2,83	0	125	30 minutes	199th-201st Hours
High Idle	750	1980	1382	195	2,85	275		
Rated Speed	2500	2200	1530	245	11,35	1300	60 minutes	
Max Torque	1900	1900	1319	201	12,41	1150		

A. Modified Sawdust Oil Filter

Condition	Dummy Load	RPM		Altenator		Fuel Consumption	Time	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	90	30 minutes	0^{th}-3^{rd} Hours
High Idle	750	1980	1383	201	2,86	250		
Rated Speed	2500	2200	1530	244	11,35	1240	60 minutes	
Max Torque	3000	1900	1320	201	12,36	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	90	30 minutes	4^{th}-6^{th} Hours
High Idle	750	1981	1383	201	2,87	250		
Rated Speed	2500	2202	1531	244	11,36	1240	60 minutes	
Max Torque	3000	1902	1321	202	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	90	30 minutes	7^{th}-9^{th} Hours
High Idle	750	1980	1383	201	2,86	250		
Rated Speed	2500	2200	1530	244	11,35	1240	60 minutes	
Max Torque	3000	1901	1321	202	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	90	30 minutes	10^{th}-12^{th} Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2201	1531	245	11,36	1240	60 minutes	
Max Torque	3000	1900	1320	201	12,36	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	90	30 minutes	13rd-15th Hours
High Idle	750	1983	1385	203	2,88	250		
Rated Speed	2500	2203	1531	245	11,36	1240	60 minutes	
Max Torque	3000	1900	1320	201	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	90	30 minutes	16th-18th Hours
High Idle	750	1980	1385	201	2,87	250		
Rated Speed	2500	2201	1530	244	11,36	1240	60 minutes	
Max Torque	3000	1899	1321	201	12,35	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	90	30 minutes	19th-21st Hours
High Idle	750	1982	1384	202	2,86	250		
Rated Speed	2500	2199	1529	244	11,34	1240	60 minutes	
Max Torque	1900	1903	1322	203	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	90	30 minutes	22nd-24th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1530	244	11,35	1240	60 minutes	
Max Torque	1900	1900	1320	201	12,36	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	90	30 minutes	25th-27th Hours
High Idle	750	1982	1384	202	2,87	250		
Rated Speed	2500	2202	1532	245	11,36	1240	60 minutes	
Max Torque	1900	1901	1322	202	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	90	30 minutes	28th-30th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2201	1531	244	11,35	1240	60 minutes	
Max Torque	3000	1901	1321	202	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	90	30 minutes	31st-33th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2202	1531	244	11,36	1240	60 minutes	
Max Torque	3000	1902	1321	201	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	90	30 minutes	34th-36th Hours
High Idle	750	1981	1384	202	2,87	250		
Rated Speed	2500	2202	1531	245	11,36	1240	60 minutes	
Max Torque	3000	1900	1320	202	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	90	30 minutes	37th-39th Hours
High Idle	750	1980	1385	201	2,88	240		
Rated Speed	2500	2200	1532	245	11,35	1225	60 minutes	
Max Torque	3000	1904	1323	204	12,38	1090		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	90	30 minutes	40th-42nd Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1530	246	11,36	1240	60 minutes	
Max Torque	3000	1900	1320	201	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	43rd-45th Hours
High Idle	750	1980	1383	201	2,87	250		
Rated Speed	2500	2201	1530	245	11,35	1250	60 minutes	
Max Torque	1900	1903	1322	202	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	46th-48th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2203	1531	246	11,36	1250	60 minutes	
Max Torque	1900	1900	1319	201	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	49th-51st Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2202	1531	245	11,35	1250	60 minutes	
Max Torque	1900	1900	1320	201	12,35	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	52nd-54th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2201	1531	245	11,36	1250	60 minutes	
Max Torque	3000	1903	1322	204	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	55th-57th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2202	1530	244	11,36	1250	60 minutes	
Max Torque	3000	1902	1322	203	12,39	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	58th-60th Hours
High Idle	750	1981	1384	202	2,89	250		
Rated Speed	2500	2204	1533	245	11,37	1250	60 minutes	
Max Torque	3000	1899	1321	202	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	61^{st}-63^{th} Hours
High Idle	750	1979	1380	200	2,87	250		
Rated Speed	2500	2201	1531	245	11,36	1250	60 minutes	
Max Torque	3000	1904	1323	204	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	64^{th}-66^{th} Hours
High Idle	750	1981	1385	201	2,88	250		
Rated Speed	2500	2199	1529	244	11,34	1250	60 minutes	
Max Torque	3000	1902	1321	201	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	67^{th}-69^{th} Hours
High Idle	750	1984	1386	203	2,86	250		
Rated Speed	2500	2202	1531	246	11,36	1250	60 minutes	
Max Torque	1900	1900	1320	201	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	70^{th}-72^{nd} Hours
High Idle	750	1981	1385	200	2,85	250		
Rated Speed	2500	2205	1530	245	11,36	1250	60 minutes	
Max Torque	1900	1900	1322	202	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	73rd-75th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1530	245	11,36	1250	60 minutes	
Max Torque	1900	1900	1322	203	13,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	76th-78rd Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1535	244	11,36	1250	60 minutes	
Max Torque	3000	1900	1322	203	13,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	79th-81st Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1529	243	11,34	1250	60 minutes	
Max Torque	3000	1900	1322	203	13,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	82nd-84th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1530	245	11,36	1250	60 minutes	
Max Torque	3000	1900	1322	203	13,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	85th-87th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1534	244	11,35	1250	60 minutes	
Max Torque	3000	1900	1322	204	13,35	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	88th-90th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1530	245	11,36	1250	60 minutes	
Max Torque	3000	1900	1322	203	13,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	91st-93rd Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1530	245	11,36	1250	60 minutes	
Max Torque	1900	1900	1322	203	13,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	94th-96th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1530	245	11,36	1250	60 minutes	
Max Torque	1900	1900	1322	203	13,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	97th-99rd Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1530	245	11,36	1250	60 minutes	
Max Torque	1900	1900	1322	203	13,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	100th-102nd Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1530	245	11,36	1260	60 minutes	
Max Torque	3000	1900	1322	203	13,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	103rd-105th Hours
High Idle	750	1981	1384	202	2,89	250		
Rated Speed	2500	2202	1533	246	11,36	1250	60 minutes	
Max Torque	3000	1902	1324	203	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	106th-108th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2201	1531	245	11,36	1250	60 minutes	
Max Torque	3000	1903	1322	204	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	109^{th}-111^{th} Hours
High Idle	750	1985	1384	200	2,88	250		
Rated Speed	2500	2205	1530	244	11,37	1250	60 minutes	
Max Torque	3000	1906	1325	202	12,36	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	112^{th}-114^{th} Hours
High Idle	750	1980	1383	201	2,87	250		
Rated Speed	2500	2201	1530	245	11,35	1250	60 minutes	
Max Torque	3000	1903	1322	202	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	115^{th}-117^{rd} Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1533	247	11,38	1250	60 minutes	
Max Torque	1900	1900	1322	204	12,39	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	118^{th}-120^{th} Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1534	245	11,36	1250	60 minutes	
Max Torque	1900	1903	1326	202	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	121^{st}-123^{rd} Hours
High Idle	750	1983	1385	203	2,88	250		
Rated Speed	2500	2203	1531	245	11,36	1250	60 minutes	
Max Torque	1900	1900	1320	201	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	124^{th}-126^{th} Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2208	1537	246	11,36	1250	60 minutes	
Max Torque	3000	1909	1320	201	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	127^{th}-129^{th} Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2202	1535	243	11,35	1250	60 minutes	
Max Torque	3000	1902	1324	202	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	130^{th}-132^{nd} Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2202	1530	244	11,35	1245	60 minutes	
Max Torque	3000	1900	1320	201	12,35	1080		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	133^{rd}-135^{th} Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1532	245	11,36	1225	60 minutes	
Max Torque	3000	1900	1319	202	12,35	1080		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	136^{th}-138^{th} Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1536	244	11,34	1230	60 minutes	
Max Torque	3000	1900	1328	200	12,34	1080		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	139^{th}-141^{st} Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1530	244	11,34	1230	60 minutes	
Max Torque	1900	1905	1318	200	12,35	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	142^{nd}-144^{th} Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1530	246	11,36	1250	60 minutes	
Max Torque	1900	1899	1320	201	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	145th-147th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1531	245	11,36	1250	60 minutes	
Max Torque	1900	1908	1322	201	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	148th-150th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2201	1531	244	11,35	1250	60 minutes	
Max Torque	3000	1901	1321	202	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	151st-153rd Hours
High Idle	750	1981	1384	200	2,85	250		
Rated Speed	2500	2205	1530	245	11,36	1280	60 minutes	
Max Torque	3000	1900	1322	202	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	154th-156th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2202	1537	246	11,38	1250	60 minutes	
Max Torque	3000	1900	1325	202	12,36	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	157th-159th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1532	245	11,36	1260	60 minutes	
Max Torque	3000	1900	1320	201	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	160th-162nd Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1530	246	11,36	1250	60 minutes	
Max Torque	3000	1900	1320	201	12,37	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	163rd-165th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1530	245	11,35	1255	60 minutes	
Max Torque	1900	1898	1322	202	12,33	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	166th-168th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1530	245	11,35	1255	60 minutes	
Max Torque	1900	1907	1322	202	12,35	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	169th-171st Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2201	1531	245	11,36	1250	60 minutes	
Max Torque	1900	1903	1322	204	12,38	1100		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	172nd-174th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2201	1531	243	11,35	1260	60 minutes	
Max Torque	3000	1901	1321	202	12,38	1125		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	175th-177th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2202	1530	243	11,33	1265	60 minutes	
Max Torque	3000	1902	1321	201	12,37	1125		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	178th-180th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2202	1531	243	11,34	1265	60 minutes	
Max Torque	3000	1900	1326	202	12,37	1125		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	181st-183rd Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2202	1531	243	11,34	1265	60 minutes	
Max Torque	3000	1900	1326	202	12,37	1125		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	184th-186th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2202	1531	243	11,34	1270	60 minutes	
Max Torque	3000	1900	1326	202	12,37	1125		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	187th-189th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1530	243	11,36	1270	60 minutes	
Max Torque	1900	1900	1320	201	12,37	1125		

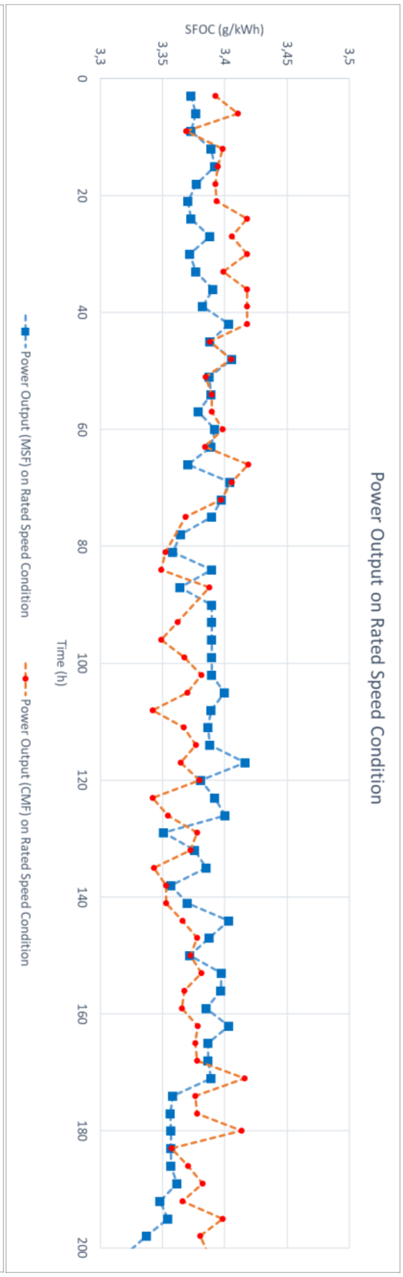
Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	190th-192nd Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1530	242	11,36	1270	60 minutes	
Max Torque	1900	1900	1320	201	12,37	1125		

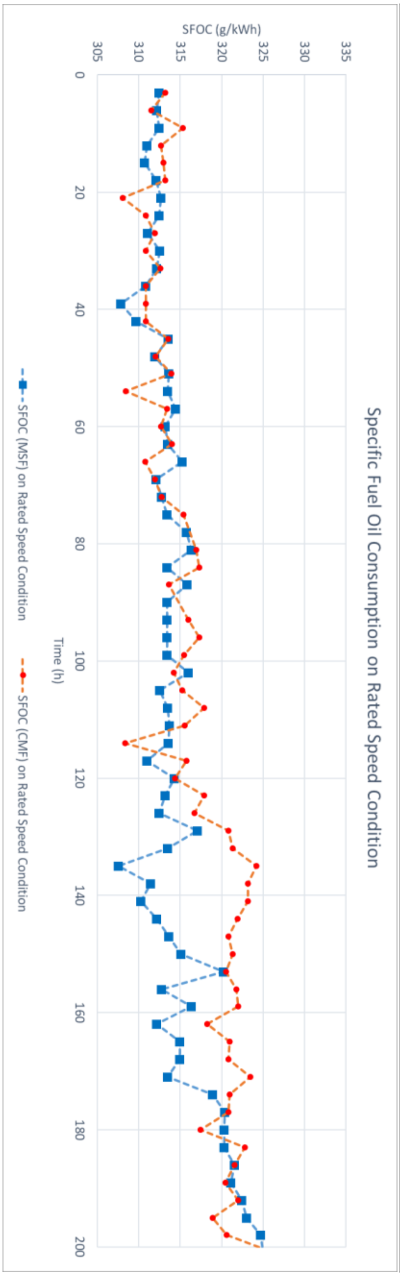
Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	193rd-195th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1532	243	11,35	1275	60 minutes	
Max Torque	1900	1901	1320	202	12,33	1125		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	196th-198th Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1535	242	11,36	1275	60 minutes	
Max Torque	1900	1904	1325	200	12,35	1125		

Type	Dummy Load	RPM		Altenator		Fuel Consumption	Waktu	Data
		Engine	Altenator	V (Volt)	I (Ampere)	Volume (ml)		
Low Idle	0	850	615	2,95	0	100	30 minutes	199th-201st Hours
High Idle	750	1980	1385	201	2,88	250		
Rated Speed	2500	2200	1541	242	11,35	1270	60 minutes	
Max Torque	1900	1897	1327	201	12,37	1225		

ENGINE PERFORMANCE GRAPH





A. Conventional Metal Mesh Oil Filter Lubricating Oil Properties

LABORATORIUM TAKI
(Teknologi Air dan Konsultasi Industri)
Departemen Teknik Kimia FTI - ITS
Kampus ITS, Keputih - Sukolilo, Surabaya, Telp. 031-5922935
Fax. 031-5922935, E-mail : lab.taki@chem-eng.its.ac.id

KETERANGAN HASIL ANALISA
No.23/LTAKI/V/2019

Terima dari : **Youri**
Siskal ITS
Jenis contoh : Bahan bakar
Kode contoh : A. Sampel oli Dexlite
B. Biopelumas minyak jarak
C. Biopelumas minyak jarak bekas
Uji : Kadar air, viskositas 40°C dan 100 °C, flash point

Parameter	Satuan	Hasil analisa			Metode analisa
		A	B	C	
Kadar air	%	3,7333	11,5711	0,1877	Gravimetri
Viskositas 40°C	cSt	80	-	-	Viskometri
Viskositas 100 °C	cSt	14	-	-	Viskometri
Flash point	°C	>230	-	-	ASTM D-93

Keterangan :
- Hasil analisa tersebut diatas berdasarkan contoh yang kami terima

Surabaya, 11 Juli 2019

Siti Nurkhamidah, ST, MS. Ph.D
Kepala Laboratorium TAKI

H A S I L
TEST RESULT

Nomor Seri : **201/LHU/LP/2019**
Serial Number

Nomor Analisis : **631.1/07/19**
Analysis Number
Halaman / ***Page*** : **2 / 2**

Hasil Pengujian Contoh **"Minyak Pelumas Dexlite Pertamina"** sebagai berikut :

No	Jenis Pengujian	Satuan	Hasil Analisis	METODE
1	Fe	mg/l	1,34	Flame AAS
2	Al	mg/l	6,26	Flame AAS
3	Krom	mg/l	<0,006	Flame AAS

A S L I
Original

Mengetahui,
Deputi Manajer Mutu

Budi Noviyanto, S.ST.
NIP 19731125 199403 1 002

Laboratorium Penguji PUSDIKLAT MIGAS
Deputi Manajer Teknis Lab. Kimia dan Lind. Lingkungan

Amelia Eka Lestari, S.ST.
NIP 19830828 200502 2 001

H A S I L
TEST RESULT

Nomor Seri **: 173/LHU/LP/2019**
Serial Number

Nomor Analisis **: 471/06/19**
Analysis Number
Halaman / *Page* **: 2 / 2**

Hasil Pengujian Contoh **"Minyak Pelumas (Dexlite Pertamina)"** sebagai berikut :

No	Jenis Pengujian	Satuan	Hasil Analisis	Metode
1	Viskositas Index	-	99	ASTM D 2270
2	Pour Point	^0C	-3	ASTM D 97

ASLI
Original

Mengetahui,
Deputi Manajer Mutu

Budi Noviyanto, S.ST.
NIP 19731125 199403 1 002

Laboratorium Penguji PUSDIKLAT MIGAS
Manajer Teknis Laboratorium Minyak Bumi

Sahadad, S.ST.
NIP 19680105 199103 1 001

LAPORAN HASIL UJI INI HANYA BERKAITAN DENGAN BARANG YANG DIUJI,
DAN TIDAK BOLEH DIGANDAKAN TANPA PERSETUJUAN TERTULIS DARI LP-PUSDIKLAT MIGAS KECUALI SECARA LENGKAP

Rec. : 08/RT/LP **Rev. : 0**

KEMENTERIAN RISET, TEKNOLOGI, DAN PENDIDIKAN TINGGI
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
LEMBAGA PENELITIAN DAN PENGABDIAN KEPADA MASYARAKAT
Gedung Pusat Riset, Lantai Lobby, Kampus ITS Sukolilo - Surabaya 60111
Telp. : 031 - 5953759, Fax : 031 - 5955793, PABX : 1404, 1405
http://www.lppm.its.ac.id

LAPORAN HASIL PENGUJIAN

Nama Pemilik : Aridhanka Youri Al Kahfi

Alamat Pemilik : Teknik Sistem Perkapalan ITS

Nama Contoh : MESRAN B SAE 40 DEXLITE

Tanggal Terima : 17 Juni 2019

Deskripsi Contoh : Bentuk : ~~Padat~~/Cair/~~Gas~~
Volume : -
Kemasan : Botol

Tanggal Pengujian : 18 Juni 2019
Tanggal Selesai Pengujian : 18 Juni 2019

Kode Contoh : **EI-399**

Jumlah Contoh : 1

Menyatakan bahwa contoh tersebut di atas telah diuji di Laboratorium Energi & Lingkungan – LPPM ITS.

No.	Nama Contoh	Jenis Uji	Hasil	Satuan	Metode Pengujian
1	MESRAN B SAE 40 DEXLITE	*TBN*	11,38	mg/g	ASTM D 2896-03

Suhu : 24,5°C
Humidity : 55%
Analis :,EWY
Sampling : dilakukan oleh Pelanggan

Catatan:
1. Hasil pengujian hanya berlaku untuk sampel yang diuji.
2. Labotorium tidak bertanggung jawab atas kerugian pada pihak ke tiga.
3. Laporan hasil pengujian hanya boleh diperbanyak secara utuh.

Kepala Laboratorium
Energi dan Lingkungan

Dr. Ir. Susianto, DEA
NIP. 19620820 198903 1 004

Koordinator Teknis

Vita Yuliana.S.Si
NIP. 1990201822404

B. Modified Sawdust Oil Filter Lubricating Oil Filter

LAPORAN HASIL PENGUJIAN

Nama Pemilik : Ardi Pangestu W

Alamat Pemilik : Sistem Perkapalan ITS

Nama Contoh : Oli

Deskripsi Contoh : Bentuk : ~~Padat~~/Cair/~~Gas~~
Volume : -
Kemasan : Botol

Kode Contoh : **EI-448**

Tanggal Terima : 28 Juni 2019

Tanggal Pengujian : 03 Juli 2019
Tanggal Selesai Pengujian : 04 Juli 2019
Jumlah Contoh : 1

Menyatakan bahwa contoh tersebut di atas telah diuji di Laboratorium Energi & Lingkungan – LPPM ITS.

No.	Nama Contoh	Jenis Uji	Hasil	Satuan	Metode Pengujian
1	Oli filter MOD	*TBN*	9,89	mg/g	IK/LEL-ITS/TT

Suhu : 22,9°C
Humidity : 59%
Analis :,EWY
Sampling : dilakukan oleh Pelanggan

Catatan:

1. Hasil pengujian hanya berlaku untuk sampel yang diuji.
2. Labotorium tidak bertanggung jawab atas kerugian pada pihak ke tiga.
3. Laporan hasil pengujian hanya boleh diperbanyak secara utuh.

Kepala Laboratorium
Energi dan Lingkungan

Koordinator Teknis

Dr. Ir. Susianto, DEA
NIP. 19620820 198903 1 004

Vita Yuliana.S,Si
NIP. 1990201822404

FR/LEL-ITS/7.8-01 Laporan Hasil Pengujian *Ter/Rev./TP:2/1/30042018*

H A S I L
TEST RESULT

Nomor Seri : **197/LHU/LP/2019**
Serial Number

Nomor Analisis : **512/06/19**
Analysis Number
Halaman / *Page* : **2 / 2**

Hasil Pengujian Contoh **"Minyak Pelumas"** sebagai berikut :

No	Jenis Pengujian	Satuan	Hasil Analisis	METODE
1	Flash Point COC	^{0}C	189	ASTM D 92
2	Viskositas Kinematik pada 40^{o}C	mm^2/s	46,01	ASTM D 445
3	Viskositas Kinematik pada 100^{o}C	mm^2/s	7,247	ASTM D 445
4	Viskositas Index	-	119	ASTM D 2270
5	Pour Point	^{0}C	3	ASTM D 97
6	Fe	mg/l	**0,87**	ICPS
7	Al	mg/l	2,33	ICPS
8	Krom	mg/l	<0,006	ICPS

ASLI
Original

Mengetahui,
Deputi Manajer Mutu

Budi Noviyanto, S.ST.
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Laboratorium Penguji PUSDIKLAT MIGAS
Manajer Teknis Laboratorium Minyak Bumi

Sahadad, S.ST.
NIP 19680105 199103 1 001

PEMERINTAH PROVINSI JAWA TIMUR
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UNIT PELAKSANA TEKNIS KESELAMATAN KERJA
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Website : www.k2.disnakertras.jatimprov.go.id

LHU ini merupakan hasil pada lokasi dan saat pengukuran
LAPORAN HASIL PENGUJIAN
No. LAB. 0034 / VII / 2019

I	**Nama Pengguna Jasa**	:	MAHASISWA ITS
II	**Alamat Pengguna Jasa**	:	Keputih, Sukolilo, Surabaya Jawa Timur
III	**Waktu Sampling**	:	04 Juli 2019
IV	**Waktu Penyelesaian**	:	Jam 08.30, tanggal 09 Juli 2019
V	**Jenis Pengukuran**	:	**Kadar NO_x**
VI	**Hasil Pengukuran**	:	

No	Lokasi Pengukuran	Jam (WIB)	Hasil Pengukuran (mg/m^3)
1	Cerobong Genset Daya 100%, Beban 2500, RPM 2250 (E:1)	09.10	146,6
2	Cerobong Genset 75%, Beban 2500, RPM 2200 (E:2)	09.10	78,4
3	Cerobong Genset Daya 50%, Beban 700, RPM 2200 (E:3)	09.00	97,9
4	Cerobong Genset Daya 25%, Beban 700, RPM 2200 (E:4)	09.10	64
5	Cerobong Genset Variasi Daya 100%, Variasi Beban 2500 (E:5)	09.15	150,5
6	Cerobong Genset Variasi Daya 75%, Variasi Beban 2000 (E:6)	09.15	88,2
7	Cerobong Genset Variasi 50% Variasi Beban 1500 (E:7)	09.15	108,3
8	Cerobong Genset Variasi daya 25% Variasi Beban 700 (E:8)	09.15	70,7

Mengetahui,
KEPALA UPT K2 SURABAYA

Dra. RIRIH WINARNI, MM.
NIP. 19611110 198603 2 017

Surabaya, 09 Juli 2019
MANAJER TEKNIK

SLAMET. SKM
NIP. 19630111 198803 1 012

PEMERINTAH PROVINSI JAWA TIMUR
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Website : www.k2.disnakertras.jatimprov.go.id

LHU ini merupakan hasil pada lokasi dan saat pengukuran

LAPORAN HASIL PENGUJIAN
No. LAB. 0034 / VII / 2019

I	**Nama Pengguna Jasa**	:	MAHASISWA ITS
II	**Alamat Pengguna Jasa**	:	Keputih, Sukolilo, Surabaya Jawa Timur
III	**Waktu Sampling**	:	04 Juli 2019
IV	**Waktu Penyelesaian**	:	Jam 08.30, tanggal 09 Juli 2019
V	**Jenis Pengukuran**	:	**Kadar Total Partikel**
VI	**Hasil Pengukuran**	:	

No	Lokasi Pengukuran	Jam (WIB)	Hasil Pengukuran (mg/m^3)
1	Cerobong Genset Daya 100%, Beban 2500, RPM 2250 (E:1)	09.10	69,6
2	Cerobong Genset 75%, Beban 2500, RPM 2200 (E:2)	09.10	49,4
3	Cerobong Genset Daya 50%, Beban 700, RPM 2200 (E:3)	09.00	63,7
4	Cerobong Genset Daya 25%, Beban 700, RPM 2200 (E:4)	09.10	28,3
5	Cerobong Genset Variasi Daya 100%, Variasi Beban 2500 (E:5)	09.15	49,2
6	Cerobong Genset Variasi Daya 75%, Variasi Beban 2000 (E:6)	09.15	28,3
7	Cerobong Genset Variasi 50% Variasi Beban 1500 (E:7)	09.15	49,6
8	Cerobong Genset Variasi daya 25% Variasi Beban 700 (E:8)	09.15	21,3

Mengetahui,
KEPALA UPT K2 SURABAYA

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Surabaya, 09 Juli 2019
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e-mail : hiperkesjatim@gmail.com; admin@k3.disnakertrans.jatimprov.go.id
Website : www.k2.disnakertras.jatimprov.go.id

LHU ini merupakan hasil pada lokasi dan saat pengukuran
LAPORAN HASIL PENGUJIAN
No. LAB. 0034 / VII / 2019

I	**Nama Pengguna Jasa**	:	MAHASISWA ITS
II	**Alamat Pengguna Jasa**	:	Keputih, Sukolilo, Surabaya Jawa Timur
III	**Waktu Sampling**	:	04 Juli 2019
IV	**Waktu Penyelesaian**	:	Jam 08.30, tanggal 09 Juli 2019
V	**Jenis Pengukuran**	:	**Kadar Total Hidrokarbon (HC)**
VI	**Hasil Pengukuran**	:	

No	Lokasi Pengukuran	Jam (WIB)	Hasil Pengukuran (ppm)
1	Cerobong Genset Daya 100%, Beban 2500, RPM 2250 (E:1)	09.10	47
2	Cerobong Genset 75%, Beban 2500, RPM 2200 (E:2)	09.10	0
3	Cerobong Genset Daya 50%, Beban 700, RPM 2200 (E:3)	09.00	0
4	Cerobong Genset Daya 25%, Beban 700, RPM 2200 (E:4)	09.10	0
5	Cerobong Genset Variasi Daya 100%, Variasi Beban 2500 (E:5)	09.15	30
6	Cerobong Genset Variasi Daya 75%, Variasi Beban 2000 (E:6)	09.15	15
7	Cerobong Genset Variasi 50% Variasi Beban 1500 (E:7)	09.15	0
8	Cerobong Genset Variasi daya 25% Variasi Beban 700 (E:8)	09.15	0

Mengetahui,
KEPALA UPT K2 SURABAYA

Dra. RIRIH WINARNI, MM.
NIP. 19611110 198603 2 017

Surabaya, 09 Juli 2019
MANAJER TEKNIK

S L A M E T. SKM
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Website : www.k2.disnakertras.jatimprov.go.id

LHU ini merupakan hasil pada lokasi dan saat pengukuran

LAPORAN HASIL PENGUJIAN

No. LAB. 0034 / VII / 2019

I	**Nama Pengguna Jasa**	:	MAHASISWA ITS
II	**Alamat Pengguna Jasa**	:	Keputih, Sukolilo, Surabaya Jawa Timur
III	**Waktu Sampling**	:	04 Juli 2019
IV	**Waktu Penyelesaian**	:	Jam 08.30, tanggal 09 Juli 2019
V	**Jenis Pengukuran**	:	**Kadar Karbon Monoksida (CO)**
VI	**Hasil Pengukuran**	:	

No	Lokasi Pengukuran	Jam (WIB)	Hasil Pengukuran (%)
1	Cerobong Genset Daya 100%, Beban 2500, RPM 2250 (E:1)	09.10	0,0015
2	Cerobong Genset 75%, Beban 2500, RPM 2200 (E:2)	09.10	0,0027
3	Cerobong Genset Daya 50%, Beban 700, RPM 2200 (E:3)	09.00	0,020
4	Cerobong Genset Daya 25%, Beban 700, RPM 2200 (E:4)	09.10	0,012
5	Cerobong Genset Variasi Daya 100%, Variasi Beban 2500 (E:5)	09.15	0,014
6	Cerobong Genset Variasi Daya 75%, Variasi Beban 2000 (E:6)	09.15	0,027
7	Cerobong Genset Variasi 50% Variasi Beban 1500 (E:7)	09.15	0,031
8	Cerobong Genset Variasi daya 25% Variasi Beban 700 (E:8)	09.15	0,021

Mengetahui,
KEPALA UPT K2 SURABAYA

Dra. RIRIH WINARNI, MM.
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Surabaya, 09 Juli 2019
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AUTHOR'S BIOGRAPHY

The author named Ardi Pangestu Wuryantoro was born in Jakarta, May 25th, 1997 as the oldest son from Sudiardi and Pangestu. He graduated from Strada Santo Ignatius Elementary School, Strada Santo Fransiskus Xaverius II Middle High School, and SMAN 13 Senior High School. The author continues his study at Marine Engineering Department Double Degree Program, Marine Technology Faculty, Institut Teknologi Sepuluh Nopember (ITS) Surabaya for Marine Power Plant (MPP). The author has been in internship program at PT. Dok Kodja Bahari and PT. PERTAMINA (Persero) Refinery Unit IV Cilacap. Beside academic activity, the author is active in several organizations. The author has joined Himpunan Mahasiswa Teknik Sistem Perkapalan ITS as a Steering Committee in 2017-2018. The author can be contacted via wuryantoro1997@gmail.com