THE IMPACT OF USING CJC™ FINE FILTER IN DIESEL GENSET AT PULAU REDANG POWER STATION

NIK NURUL FATIMA AZ-ZAHRA BINTI MOHD ROSLI

FACULTY OF ENGINEERING
UNIVERSITI OF MALAYA
KUALA LUMPUR

2019

THE IMPACT OF USING CJC™ FINE FILTER IN DIESEL GENSET AT PULAU REDANG POWER STATION

NIK NURUL FATIMA AZ-ZAHRA BINTI MOHD ROSLI

DEGREE OF MASTER OF MECHANICAL ENGINEERING
UNIVERSITI OF MALAYA

2019

THE IMPACT OF USING CJC™ FINE FILTER IN DIESEL GENSET AT PULAU REDANG POWER STATION

NIK NURUL FATIMA AZ-ZAHRA BINTI MOHD ROSLI

SUBMITTED TO THE
DEPARTMENT OF MECHANICAL ENGINEERING
FACULTY OF ENGINEERING UNIVERSITY OF MALAYA,
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF MECHANICAL ENGINEERING

2019

UNIVERSITY OF MALAYA

ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: Nik Nurul Fatima Az-Zahra binti Mohd Rosli
Matric No: KQK180020
Name of Degree: Degree of Master of Mechanical Engineering
Title of Project Paper/Research Report/Dissertation/Thesis ("this Work"):

The Impact of Using CJC™ Fine Filter in Diesel Genset at Pulau Redang Power Station

Field of Study: Mechanical Engineering

I do solemnly and sincerely declare that:

(1) I am the sole author/writer of this Work;
(2) This Work is original;
(3) Any use of any work in which copyright exists was done by way of fair dealing and for permitted purposes and any excerpt or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledged in this Work;
(4) I do not have any actual knowledge nor do I ought reasonably to know that the making of this work constitutes an infringement of any copyright work;
(5) I hereby assign all and every rights in the copyright to this Work to the University of Malaya ("UM"), who henceforth shall be owner of the copyright in this Work and that any reproduction or use in any form or by any means whatsoever is prohibited without the written consent of UM having been first had and obtained;
(6) I am fully aware that if in the course of making this Work I have infringed any copyright whether intentionally or otherwise, I may be subject to legal action or any other action as may be determined by UM.

Candidate's Signature Date:

Subscribed and solemnly declared before,

Witness's Signature Date:

Name:
Designation:

THE IMPACT OF USING CJC™ FINE FILTER IN DIESEL GENSET AT PULAU REDANG POWER STATION

ABSTRACT

Diesel power plant is the main power supply for the villagers in the island. The operating and maintenance cost for this type of power plants is usually high due to the transportation and accessibility problems. The off-line filtration is introduced to the diesel generator set lubricating system to see its impact on the lubricating oil quality, fuel consumption and energy generated. The cost benefit analysis is conducted to show the economic benefit of integrating the CJC™ Fine Filter into the diesel generating set in Pulau Redang Power Station. This research is intended to reduce the operation and maintenance cost. After installation of CJC™ Fine Filters, there is reduction of contamination elements and kinematic viscosity is improved even after running more than manufacturer's recommended running hours. The fuel consumption 3.75% less than before, the oil changing interval can be extended which resulting to approximately RM14,893.82 life cycle cost saving per year.

Keywords: engine oil filter, lubricating oil, oil change interval, viscosity, total base number

KESAN PENGGUNAAN PENAPIS HALUS CJC™ KEATAS PENJANA DIESEL DI LOJI JANAKUASA PULAU REDANG

ABSTRAK

Loji janakuasa diesel adalah salah satu penjana bekalan elektrik utama untuk pengguna di pulau. Kos bagi penjanaan dan penyelenggaraan adalah tinggi memandangkan terdapat kekangan pegangkutan dan akses ke pulau tersebut. Mesin penapis minyak pelincir luar system diperkenalkan di loji jana kuasa untuk mengenalpasti kesan terhadap kualiti mintak pelincir, penggunaan minya diesel dan pengeluaran tenaga penjanaan. Analisa kos dijalankan untuk mengenalpasti manfaat pemasangan mesin penapis minyak CJC™ di loji janakuasa Pulau Redang. Selepas pemasangan mesin penapis minyak CJC™, kualiti minya pelincir terhadap pengurangan pencemaran oleh bendasing dan kelikatan kinematik walaupun tempoh jam penjanaan melebihi had yang disarankan oleh pihak pengeluar enjin. Pengunaan minyak diesel telah berkurang sebanyak 3.75% dan selang masa penukaran minyak enjin boleh dilanjutkan seterusnya menjimatkan kos sebanyak RM14,893.82 setahun.

Katakunci: penapis minyak pelincir, enjin diesel, loji janakuasa diesel, kelikatan, selang masa penukaran minyak

ACKNOWLEDGEMENT

I would like to express my deepest gratitude and special thanks to my supervisor, Dr. Ong Hwai Chyuan, for giving me the opportunity to work with him and giving me his guidance and advice throughout the research process.

I am grateful to my spouse, Mohd Rasif bin Sidi Ahmad and my parents for their support and encouragement in every stage of my career. Not to forget all my colleagues and friends.

This project is supported by TNB Repair And Maintenance Sdn. Bhd and Enhanced Performance Solution Sdn. Bhd. I also would like to thank Mr. Steffen D. Nyman, Corporate Trainer of C.C Jensen who willing to introduce, train and guide me on the CJC™ Fine Filter state of arts and lastly, my dear colleagues in Pulau Redang Power Station who give significant contributions in this project.

Without the support, assistance, and motivation provided by the great people around me, this project would have never been accomplished. Their valuable suggestions, discussions, and endless enthusiasm were much appreciated.

Thank you.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

ASTM	American Society for Testing and Materials
B.H.P	Brake Horse Power
I.H.P	Indicated Horse Power
ktoe	kilotonnes of oil equivalent
kW	kilo Watt
kWh	kilo Watt hour
l	liter
LCC	Life Cycle Cost
mgKOH/g	milligram pottassiom hydroxide per gram
MW	Mega Watt
ppm	Parts per million
ROI	Return of Investment
TBN	Total Base Number
VI	Viscosity Index

CHAPTER 1

INTRODUCTION

1.1 Research Background

Pulau Redang Power Station located in Pulau Redang, Terengganu is owned by Tenaga Nasional Berhad and operated by TNB Repair and Maintenance (TNB REMACO). It consists of four (4) units of 500 kW Caterpillar D398 diesel generator and alternately running to supply continuous electricity to the villagers. This diesel generator power plant is supplying electricity for the locals for 24 hours and is not connected to the national grid. The generator engines have been used for many years and the efficiency of the generator has been significantly decreased.

According to Noria (Wire, 2018), the cause of machine failure is due to lubricating oil which contributes up to 43% compared to other causes. Even though this diesel generator set has the build-in inline oil filtration unit, it is insufficient and unable to contain the oil contaminants that come from the full running diesel generator set. These directly impact the efficiency of the diesel generator set and also increased downtime to replace the filter and lubricating oil.

The relatively new filtration technology from C.C. Jensen, a CJC™ Fine Filter Technology has introduced a filtration system to remove particles, water, acidity and oil degradation products (Thomsen, Avenue, & Durham, 2006). This filter can be integrated as off-line filtration unit and can be used together with the in-line filtration unit. The CJC™ Fine filter is using the 100% natural cellulose fibers with the oil filtration capacity of up to 4 liters of particles.

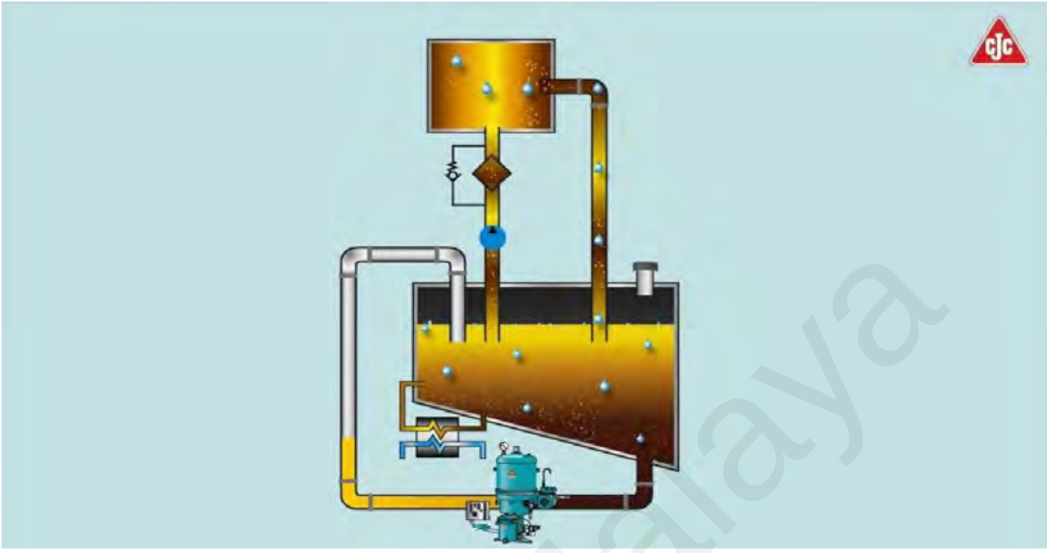

Figure 1.1: CJC™ Oil Filtration Principle

The effectiveness of this CJC™ Fine Filter technology to filter lubricating oil from full running diesel generator set has never been implemented in any TNB power plant. Therefore, this research is intended to measure the impact of using the CJC™ Fine Filter to clean the lubricating oil, increase the efficiency and reduce the operating cost of the generator set in Pulau Redang Power Station.

1.2 Problem Statement

The high contamination of lubricating oil can damage the internal surface of the engine. The current system of the diesel generator requires the existing lubricating oil filter to be changed on regular basis. This will affect the efficiency of the diesel engine and subsequently reduce the power output of the diesel generator. Since the power plant is not connected to the national grid, Pulau Redang power demand relies on the performance of these engines.

Apart from machine breakdown, frequent filter replacement and lubricating oil replacement also contribute to the high downtime of the generator. It is crucial for the power station to maximize availability and reduce the downtime in order to maintain constant power output to the consumer hence reducing operation and maintenance cost.

The high contamination of lubricating oil also will increase the lubricating oil replacement frequency. The used oils need to be disposed properly as schedule waste. Pulau Redang Power Station located in the island which makes the costs of transporting the schedule waste to the mainland for disposal is very high. It is expected that by prolonging the lubricating oil quality, the schedule waste will be reduced.

This research is intended to improve the quality of the lubricating oil by using the CJC™ Fine Filter. The CJC™ Fine filter can filter up to 3 microns particle, able to absorb water and adsorb oxidation in the lubricating oil. The lubricating oil analysis will be based on ASTM standards.

When the quality of the lubricating oil is improved, it is expected for the generator set performance to increase and prolong the quality of the lubricating oil. The overall results are translating into the operational cost.

The capital expenditure on purchasing this filter is expected to reduce the operational expenditure. Thus, the cost benefit analysis is conducted to measure the return of investment and payback period. The result of this research will be used by TNB REMACO as part of the proactive project on reducing the Operation and Maintenance cost.

1.3 Objectives

The objectives of this research report are as follows:

i. To investigate the quality of lubricating oil before and after installing the CJC™ Fine Filter in generator set
ii. To analyze performance of the generator set by using the CJC™ Fine Filter
iii. To analyze the cost benefit analysis of lubricating oil replacement and schedule waste disposal

1.4 Structure of the report

This report consists of five chapters starting with Chapter One as the introduction of the project and ends with Chapter Five as the conclusion of the project. The structures of the report are categorized by chapter.

Chapter One is the introduction that gives brief explanation about the research project. It consists of background of the research, problem statement, objectives and structure of the report.

Chapter Two presents a literature review which covers background discussion of energy demands in rural areas, diesel generators, fuel and lubricating oil tribology and introduction to the CJC™ Fine Filters.

Chapter Three describes the equipment used, installation of CJC™ Filter unit, generator set efficiency, lubricating oil test parameters and cost benefit analysis methods.

Chapter Four analyses the lubricating oil properties, comparing the power output and fuel consumption before installing CJC™ Filter unit and after installing the filter.

Analyzing the oil change interval required before and after filter installation and the impact on the operating cost.

Chapter Five summarizes the results obtained in this research project and presents the main conclusions and suggest a few recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Electricity Scenario in Malaysia

Malaysia is a fast rising developing country that has a constantly increasing energy demand. With a population of 33 million, The energy consumption has increased from 57,218 ktoe in 2016 to 63,069 ktoe in 2017 (EPU, 2018). According to Energy Commission Malaysia, Malaysia has a total of 26,633.2 MW installed generation capacity in Peninsular Malaysia, 2,217.17 MW in Sabah and 4,677.71 MW in Sarawak with the energy demand reaching 22,217 MW in 2017 (MEIH, 2018).

Table 2.1 : Electricity demand and Supply (EPU, 2018)

	2014	2015	2016	2017
Peak demand (MW)	19,845	20,023	21,773	22,030
Installed Capacity (MW)	24,785	25,064	26,524	30,496
Reserve Margin (%)	24,9	25.2	31.0	38.4

After the occurrence of international oil crisis and price leaps in 1973 and 1979 where Malaysia was highly dependent on crude oil, Malaysia then has implemented four fuel diversification policy in order to stabilize the energy consumption (Ong, Mahlia, &

Masjuki, 2011). In the 2017, total electricity generation is 14,155 ktoe and the final energy consumption is 12,606 ktoe.

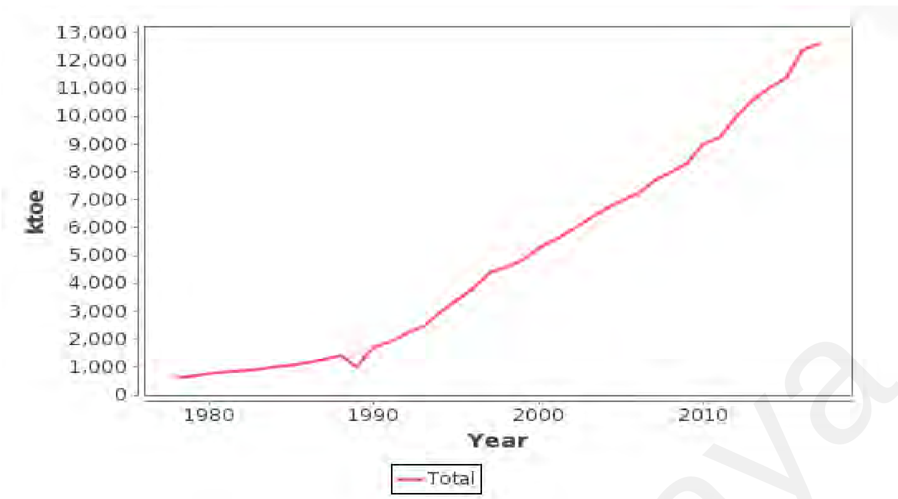

Figure 2.1: Electricity Consumption in Malaysia from 1980 to 2017 (MEIH, 2018)

There are two major power generation plants in Malaysia; thermal and hydro power plants. Thermal power plants primarily use the petroleum products, coal and natural gas. Table 2.2 represents the contribution of fuel sources as primary inputs for power generation.

Table 2.2: Final Energy Consumption by Fuel Type (ktoe)

	Natural Gas	Petroleum Products	Coal and coke
2005	6,981	23,012	1,348
2006	7,562	22,398	1,335
2007	7,709	24,852	1,361
2008	7,818	24,451	1,713
2009	6,802	24,145	1,613
2010	6,254	24,403	1,826
2011	8,515	23,922	1,759
2012	10,206	27,215	1,744

2013	10,076	29,190	1,539
2014	9,641	29,517	1,709
2015	9,566	28,699	1,778

In the Eleventh Malaysia Plan, the Government has expected that the national electricity coverage to be 99% by 2020 (RMK11, 2015). There are 34 thermal power plants operated by Tenaga Nasional Berhad (TNB), Independent Power Producers (IPPs), Sabah Electricity Sdn. Bhd. (SESB) and Sarawak Energy Berhad (SEB). Apart from thermal power stations, hydroelectric power stations are integral to the electricity generation in Malaysia.

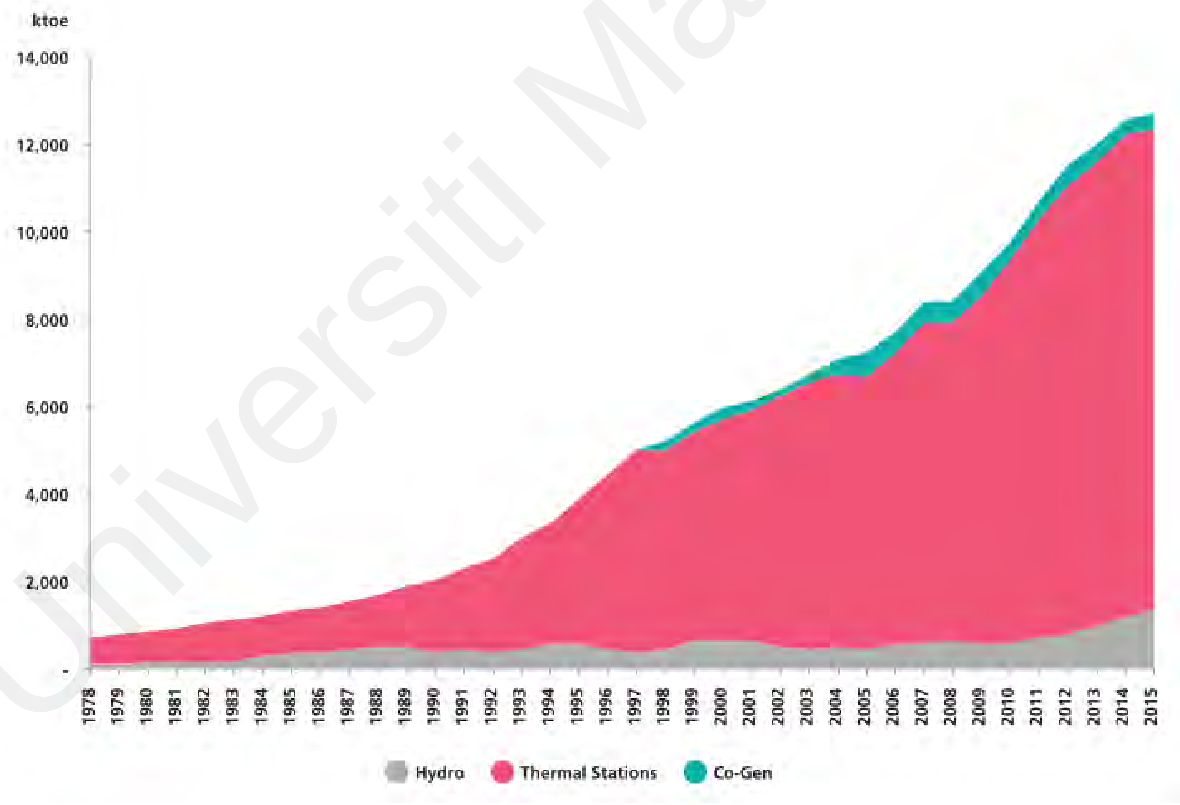

Figure 2.2 : Electricity Generation by Plant Type (EC, 2018)

Alternatives to these power generations, there are biodiesel and renewable energy. These alternatives have been introduced as part of the energy policy to reduce the dependency on the fossil fuel reserves and promote sustainable energy system in

Malaysia. The Malaysian aspiration to become the high income nation may increase the electricity power demands in the future (M. S. N. Samsudin, M. M. Rahman, 2016).

2.2 Off-grid Diesel Engine

The unique landscapes, geographic and history in Malaysia have protracted the infrastructure development between Peninsular Malaysia and East Malaysia. One of the proactive measures in order to close these gaps is to increase the electrification coverage in the selected regions especially in rural areas. There are two factors contributing the electrification in rural areas for Peninsular Malaysia and Sabah and Sarawak. These two factors are the number of people and level of electrification (Izadyar, Ong, Chong, Mojumder, & Leong, 2016).

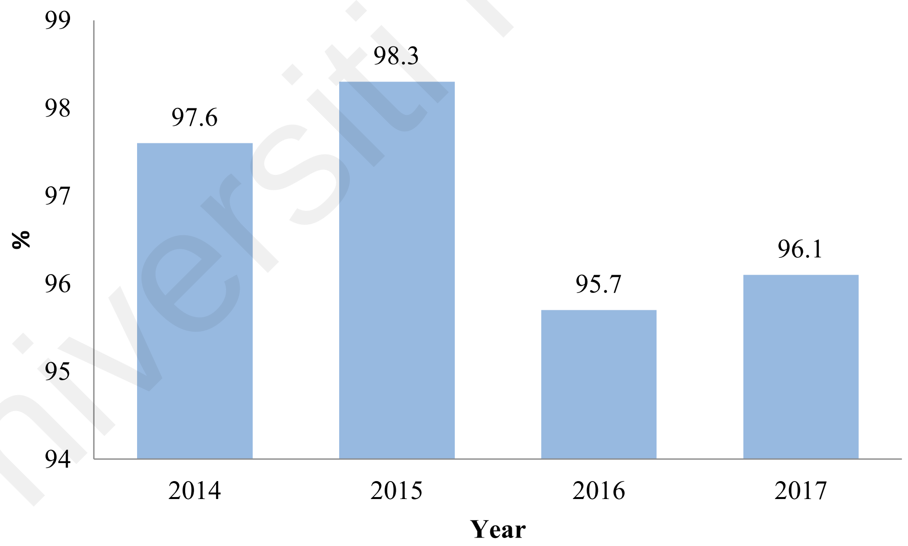

Figure 2.3: Percentage of rural housing units with electricity in Malaysia (EPU, 2018)

The rural and remote housing units that are not connected to the centralized electricity grid are called off-grid area. The causes of this off-grid area are due to the economics factor and geography factor (Izadyar et al., 2016). Despite the rural electrification is being hardly a profitable activity, the main motivation is to extend the benefit stemming from the national economic development to the rural and remote areas and subsequently improving their socio- economics (Dalimin, 1995).

Malaysian Government initiatives in Eleventh Malaysia Plan have allocated RM 3 billion for rural areas development including Rural Electricity Supply (RES) where the objective is to achieve the target of 99% national electrification coverage. The RES program is expected to benefit to more than 40,000 rural households by the year 2020 (RMK11, 2015). The rural electrification program involves extending the existing electric gridlines sources from Tenaga Nasional Berhad (TNB) for Peninsular Malaysia, Sabah Electricity Sdn. Bhd (SESB) for Sabah and Sarawak Electricity Supply Corporation (SESCo) for Sarawak. For the more isolated and economically unfeasible areas, the establishment of stand-alone rural power plant is chosen (Dalimin, 1995; Nasrudin Abd Rahim, Islam, & Rahman, 2010) (Ministry of Rural Development, 2019).

The RES program covered the long-houses in remote areas of Sabah and Sarawak, indigenous villages, villages in off-grid islands and settlement in less than 400 hectares estates. The RES scopes includes the construction of maximum 33 kV distribution line, construction of power stations, rural diesel power stations and to increase the supply from 12 hours to 24 hours (Ministry of Rural Development, 2019). Remote areas which are not economically viable will be connected through stand-alone systems such as generator sets, solar photovoltaic, mini-hydro, and hybrid systems (Nasrudin Abd Rahim et al., 2010).

The current leading alternative for the stand alone system is diesel power plant. Part of the selection criteria on using the diesel generator in the power plant are the accessibility of the rural areas via land or water to transport fuel, the distance from the grid lines being more than 10 kilometres and the area will not receive electricity via grid line at least five years from the installation (Ministry of Rural Development, 2019).

There are three types of diesel generator power supply; government-provided diesel generator sets, commercial generators owned by private business entity and private use diesel generator sets (Dalimin, 1995). Total installed capacity for diesel engines in Malaysia for 2017 is 937.41 MW in with the total generation of 155.77 MW (MEIH, 2018)

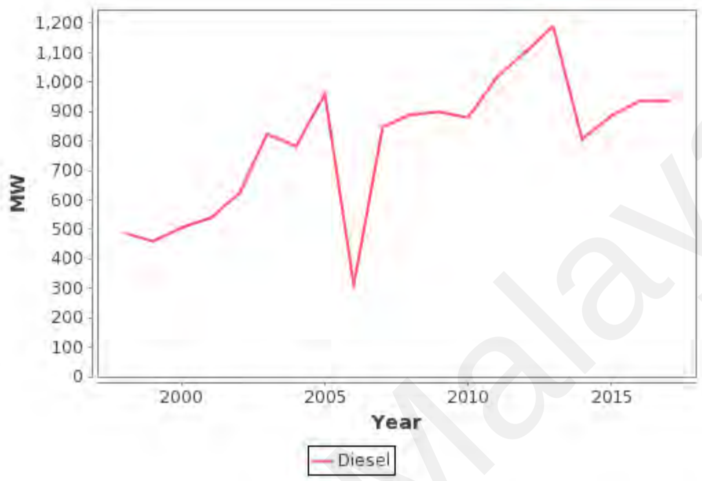

Figure 2.4: Installed capacity for diesel engines (MEIH, 2018)

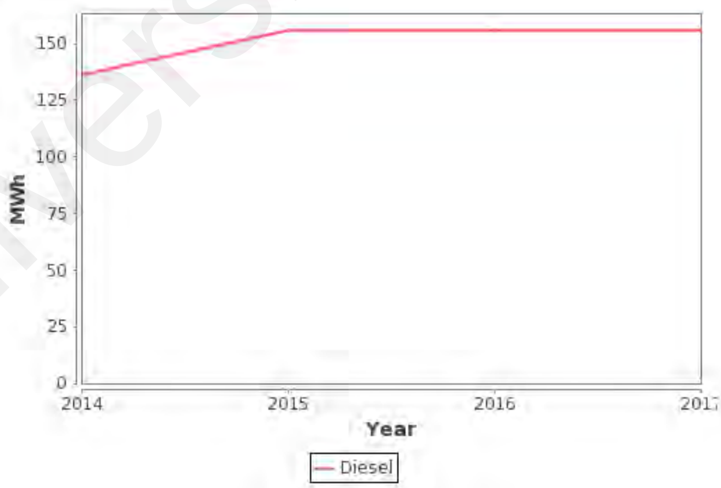

Figure 2.5: Total generation diesel engines (MEIH, 2018)

Under the same RES program, the islands in Peninsular Malaysia are able to obtain full electrification coverage. The villagers on the islands, primarily Pulau Redang, Pulau Perhentian and Pulau Tioman are electrified by conventional diesel power plant.

2.3 Diesel Power Plant

Diesel power plant produces electricity by the means of mechanical power produced by diesel engine as a prime mover to drive the generator. This type of power plant has power rating from 30kW to 6 MW. The main six components in power plants includes; prime mover, generator, fuel storage and handling system, cooling system, exhaust system, electrical substation and control (IDC Technologies, n.d.).

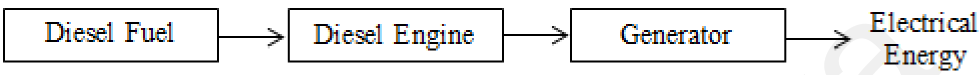

Figure 2.6: Basic Principle for Diesel Engine Power Plant.

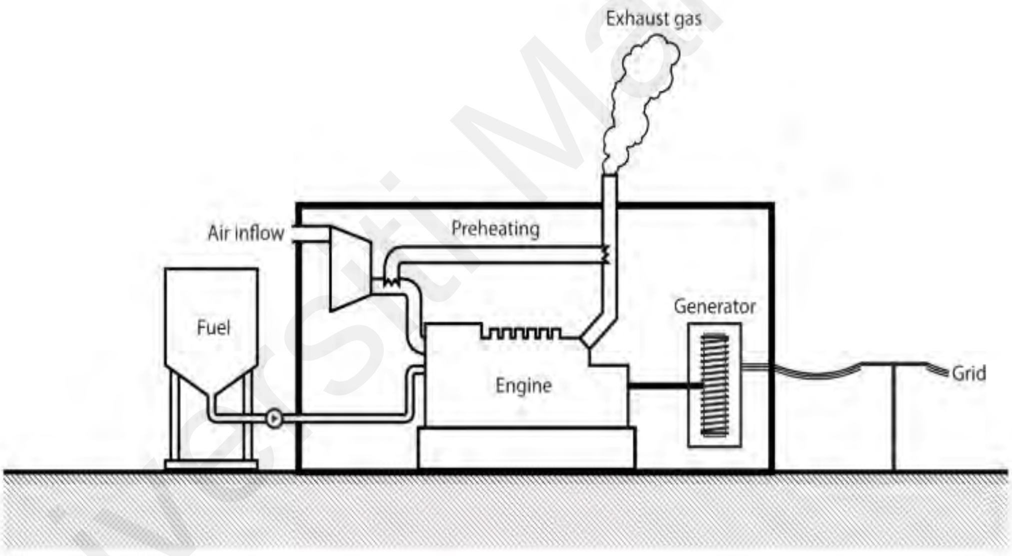

Figure 2.7: Diesel power plant

The working principle of diesel engine consists of intake cycle, compression cycle, expansion cycle and exhaust cycle. Air in the cylinder is compressed to raise the temperature before burning the diesel inside the engine. This process produces high temperature and high pressure and eventually converts heat energy during the combustion process into mechanical energy. The diesel engines coupled to the electrical generator and convert mechanical energy produced into electrical energy (Top EE, N/A). This generator provides the electricity to the central feeder (Blechinger, 2015).

The efficiency of the fuel is described in Eq. 2.1

$$\eta_{fossil} = \frac{E_{el}}{E_{th}} \qquad (2.1)$$

$$E_{th} = V_{fuel} \bullet HV_{fuel} \qquad (2.2)$$

Where E_{th} is the volume of fuel injected (V_{fuel}) and higher heating value HV_{fuel} as represented in Eq. 2.2 and E_{el} is the electrical energy at 50 or 60 Hz.

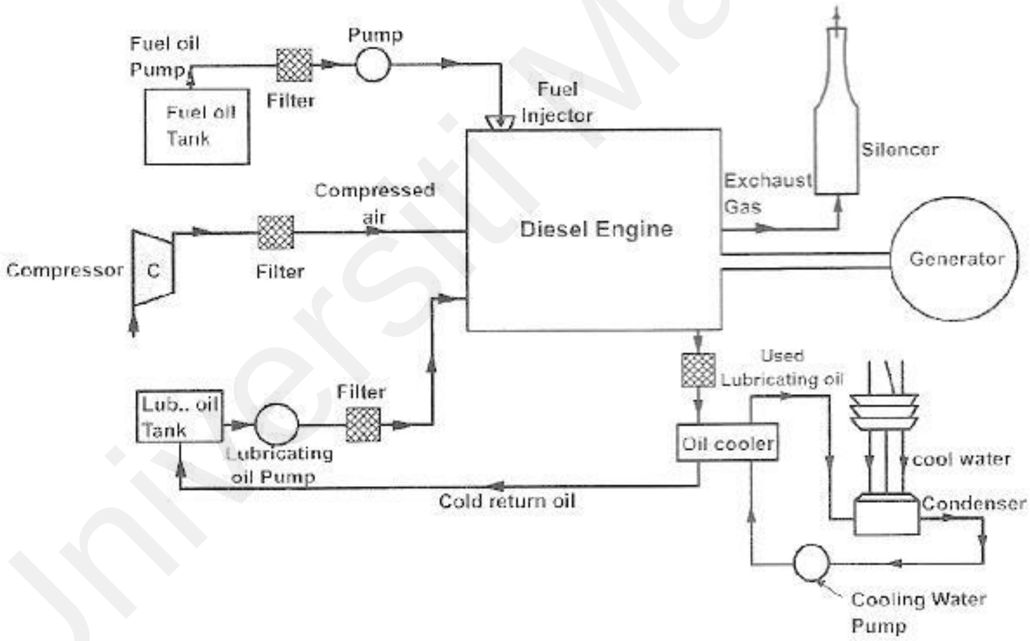

Figure 2.8: General layout of Diesel Power Plant

The main components of diesel engines are drive trains, valve train and timing, governor, turbocharger/blower and after cooler. The drive trains consist of pistons, connecting rods, crankshaft and flywheel. The valve train and timing controls the fuel injection timing using the camshaft, push rods, rocker arms, valve, valve springs and guides. The speed of the engine is controlled by the governor/control system which manages the fuel injected into the engine based on the load changes. Turbocharger works by compressing the air from intake and driven by exhaust gas. The air temperature is reduced by after cooler. The air will be cooled to around 40˚C.

The other main driven equipment apart from diesel engine is generator. The AC generator converts mechanical energy from diesel engine by the means of coupling. The power generated feeds to the grid using step up transformer.

Fuel supply usually delivered using the oil tankers or where the diesel power plants located in the island, the fuel is delivered using barges. The pipes from the jetty are connected to the power plant storage tanks. The components of the fuel system include the strainer and transfer pump. The fuel is injected to the engine using the fuel injection pump. The fuel injection system filters the oil from the impurities and adjusts the atomized fuel injected into the chambers (IDC Technologies, n.d.; Priyanka Mankale, Sunita Tambakad, 2014).

It is crucial to have cooling system to maintain the temperature of the engine in safe operating limit. Typically, the cooling system uses water as the cooling medium and circulates through cylinders and head jacket to cool the component when the heat released from the burning process pass through the component in the engine cylinder. Through the heat transfer process, the cooling water temperature is increased and in order to recirculate the cool water to the system, cooling tower is introduced into the cooling system.

The combustion gas produced by the process is released through the exhaust system. The gas is guided into the atmosphere through the exhaust manifold. A muffler or silencer is integrated to the manifold to reduce the noise. If the turbocharger is used in the system, this exhaust system leads the gas to the turbocharger (Priyanka Mankale, Sunita Tambakad, 2014).

Lastly, the air intake system accommodates the filtered air into the engine and at the same time eradicates the combustion by-products from the chamber. Aside from all these components, a tall chimney is required as the current best practice to contain the pollution caused by the gas released to the atmosphere from the diesel power plant.

2.3.1 Performance of Diesel Engine

Fundamentally, diesel power plant performance is measured by power and efficiency (A.K Raja, Amit Prakash Srivastava, 2006). The performance characteristics for the diesel engine power plant with A.C generator drives at the constant speed and variable load is measured based on the indicated mean effective pressure, indicated horse power, brake horse power, frictional horse power, indicated thermal efficiency, overall efficiency and mechanical efficiency. Mechanical efficiency is defined by ratio of Brake Horse Power (B.H.P) to Indicated Horse Power (I.H.P) described in Eq. 2.3;

$$\eta_{mechanical} = \frac{B.H.P}{I.H.P} \qquad (2.3)$$

B.H.P is the net power at the crankshaft and I.H.P is calculated based on Eq. 2.4;

$$I.H.P = \frac{(P_m.L.A.N.n)}{(4500\ x\ k)} \qquad (2.4)$$

Where P_m = indicated means effective pressure

L = Length of stroke

A = piston areas

N = Speed in RPM

n = number of cylinders

k = 1 for two stroke engine and 2 for four stroke engine

The overall efficiency or Brake Thermal Efficiency is defined by ratio of B.H.P to thermal input as shown in Eq.2.5.

$$\eta_b = \frac{(B.H.P\ x\ 4500)}{W\ x\ C_v\ x\ J} \quad (2.5)$$

Where W is weight of fuel supplied in kg per minute, Cv is the calorific value of fuel in kcal/kg and J is Joules equivalent to 427.

The other efficiencies calculated are (1) economic efficiency; cost of production compare to the energy output, (2) operational efficiency; load factor compare to potential maximum output and lastly, (3) energy conversion efficiency which measures the quantity of heat required to generate 1kWh electricity (Top EE, N/A).

The major advantages of diesel power plants for island areas are low initial cost compare to laying the cables from the mainland. In contrast to other thermal power plant, the thermal efficiency has higher availability to meet the varying load (A.K Raja, Amit Prakash Srivastava, 2006; Patil, n.d.).

However, this type of power plant requires higher running cost, high lubrication cost and it produces high noise level. The diesel generator also has high diesel cost and high maintenance cost which can goes up to RM 40,000 per year for 150kW diesel engine. (Ajan C.W, Ahmed S.S, 2003).

2.4. Lubricating Oil

The lubrication system in the diesel engine is vital to make sure the performance and life of the engine parts are not compromised. The lubricating oil is used to reduce the contact of the moving parts and reduce friction loss (Richardson, 2000), corrosion protection (Chen, Wang, Pan, & Pan, 2019b) and reduces the heat generated during the surface contact. In tribology application, friction coefficient in tribo-contacts is estimated according to prevailing contact regimes; (1) Hydrodynamic lubrication regime separates surface by layer of lubrication fluid. This regime affected by viscosity, load and speed. (2) Boundary lubrication; the surface roughness is in contact. It occurs during the start, stop and shock load condition where anti wear film and surface condition are important. (3) Mixed lubrication combines the fluid-film condition and boundary lubrication. (Echávarri Otero, De La Guerra Ochoa, Chacón Tanarro, & Del Río López, 2017; Holmberg, Andersson, Nylund, Mäkelä, & Erdemir, 2014).

Nowadays, the basic lubricant formulation consists of base oil and additives. The additives is used to extend the oil life. Before the additives was founded, only mineral oil was used. There are three types of lubricating base oil; mineral base oil, synthetic base oil and vegetable (bio-oil) base oil. The additives will be blended with the base oil to become the end products; lubricating oil (Schwindaman, 2005). The mineral oil originated from crude oil and the quality is based on the crude stock and refining process. The man-made synthetic oil is synthesized typically derived from hydrocarbon. The additive is a combination of substances to boost the properties in the base oil and/or to formulate new properties for the lubricating oil. The quality and the formulation of lubricating oil influence the performance of the engine (Chen et al., 2019b).

Viscosity plays major role in lubricating oil properties. The right choice of viscosity is important when choosing the lubricating oil and is determined by Viscosity Index (VI) as per ASTM D341 standards.

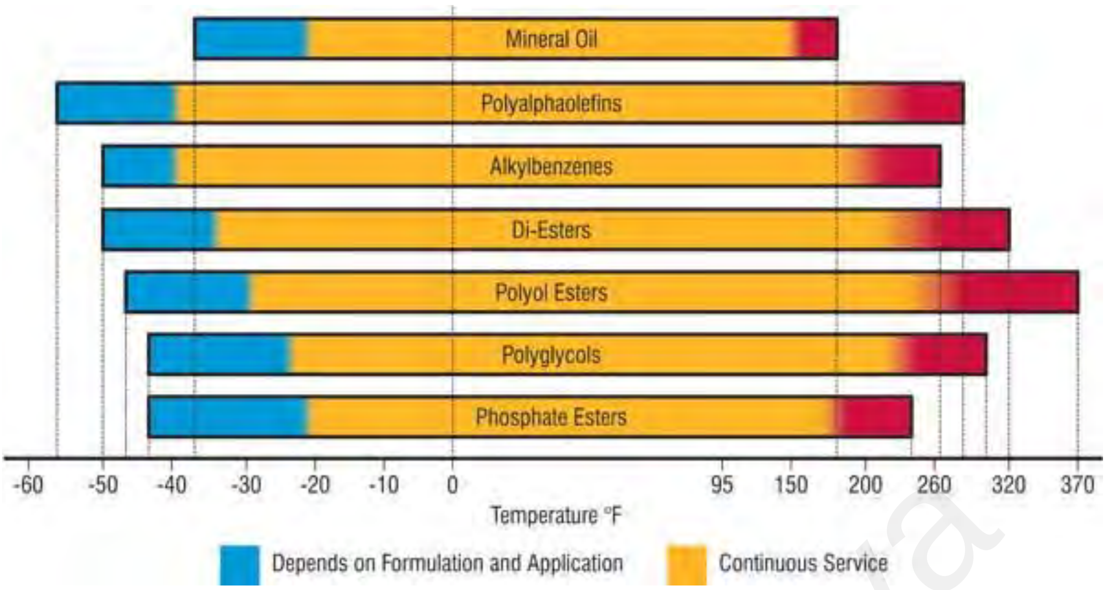

Figure 2.9: Common Synthetic Oils by Effective Working Temperature (Noria Corporation, 2002)

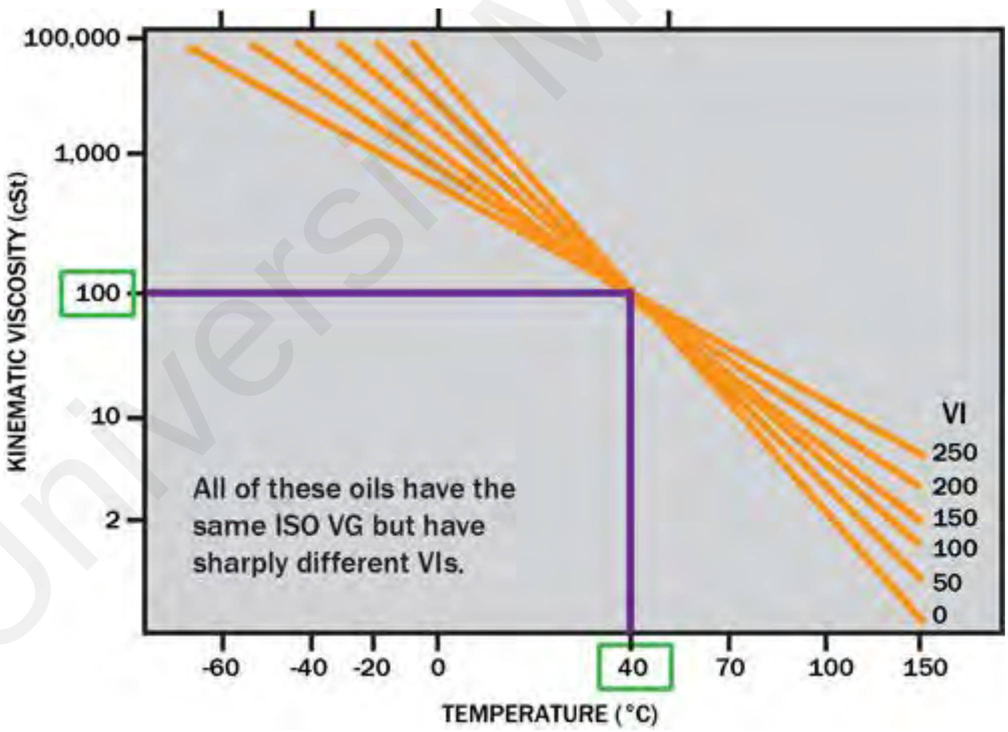

Figure 2.10: Difference kinematic viscosity for lubricating oil (Fitch, 2012)

In the lubrication system, the lubricating oil is filtered to remove impurities. The lubrication oil is stored in the oil tank where the oil will be pumped, passed through the filters and goes to the oil cooler before lubricating the moving parts. The contaminated lubricating oil may cause the adhesive wear, abrasive wear, cavitation wear, corrosive wear, fatigue wear, erosion and fretting inside the engine parts (Vencl & Rac, 2014).

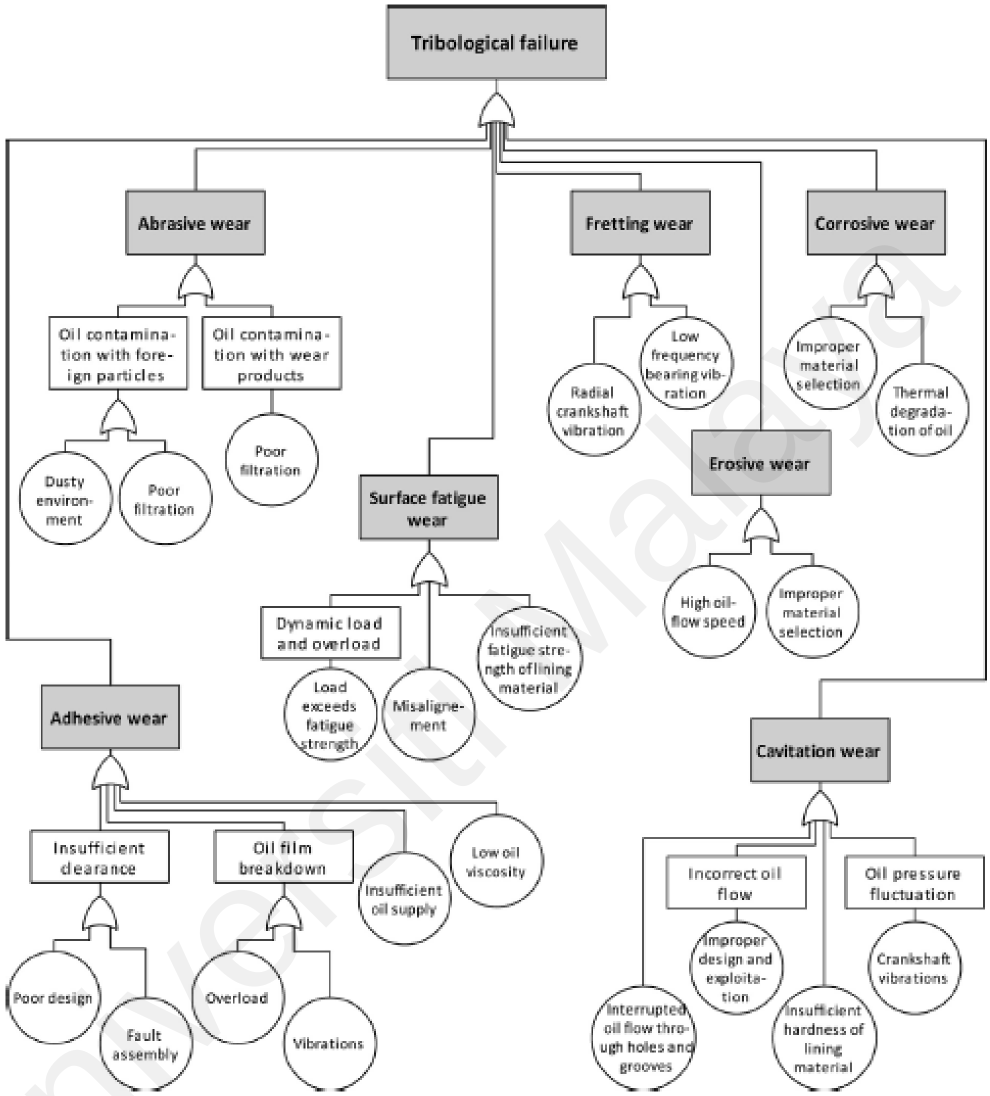

Figure 2.11: Tribological failures fault tree (Vencl & Rac, 2014)

The quality and correct selection of lubricating oil may improve wear protection, increase brake efficiency and decrease of specific fuel consumption (Musthafa, 2016). Maintaining a good quality of oil requires periodic maintenances. Nonetheless, frequent replacement of lubricating oil can incur high cost, environmental pollution and unnecessary usage of fossil resources. (I. Yavasliol, 1997)(Chen, Wang, Pan, & Pan, 2019a).

In order to maintain the oil quality, the lubricating oil must be analyzed. The result will indicate the status of the oil; metal particles from the wear, water and current quality of the lubricating oil. The oil analysis evaluate the oil properties especially viscosity, acidity, additive depletion and oxidation. If needed, the maintenance should be planned or the oil should be replaced. The oil analysis may able to reduce the oil changing interval. Currently, lubricating oil manufacturer usually will suggest the oil change interval.

2.5 Filters in Diesel Engine System

Researchers has been studying the impact of lubricating oil in engine performance for years (Chen et al., 2019b). According to the studies conducted by C.J Thomsen (Thomsen et al., 2006), 80% of machine breakdown is due to contamination in oil and able to reduce machine's lifetime, reliability and efficiency. In-line oil filter are usually located inside the engine as a device to remove oil impurities. More innovative filter with chemical alteration to control engine acidity was introduced (Chen et al., 2019b) for example, altering the filter element with sodium hydroxide by Gulzar et.al (Gulzar, Masjuki, Kalam, Varman, & Rizwanul Fattah, 2015).

Engine oil filter usually uses synthetic fiber, paper or metal mesh and more new researches to use biomass to absorb, adsorb and filtered the contaminated oil (Shukla, Zhang, Dubey, Margrave, & Shukla, 2002). Chen et al (Chen et al., 2019b) had conducted an experiment by using modified sawdust as lubricating oil filter.

Suction filters, pressure filters and return filters are considered as in-line surface filters (Thomsen et al., 2006). They are operating within oil circulation circuit; flows through the filter and the clean oil returns to the tank. However, inline oil filtration is insufficient and expensive.

Off-line filters keeps the overall lubricating oil clean by cleaning the oil directly from the reservoir. It acts as secondary filtration system to provide clean oil to the system, reduces the oil filter change interval and subsequently reducing downtime. The secondary off-line filtration unit can extend the oil life and oil changing will run on condition-based compare to hour-based interval.

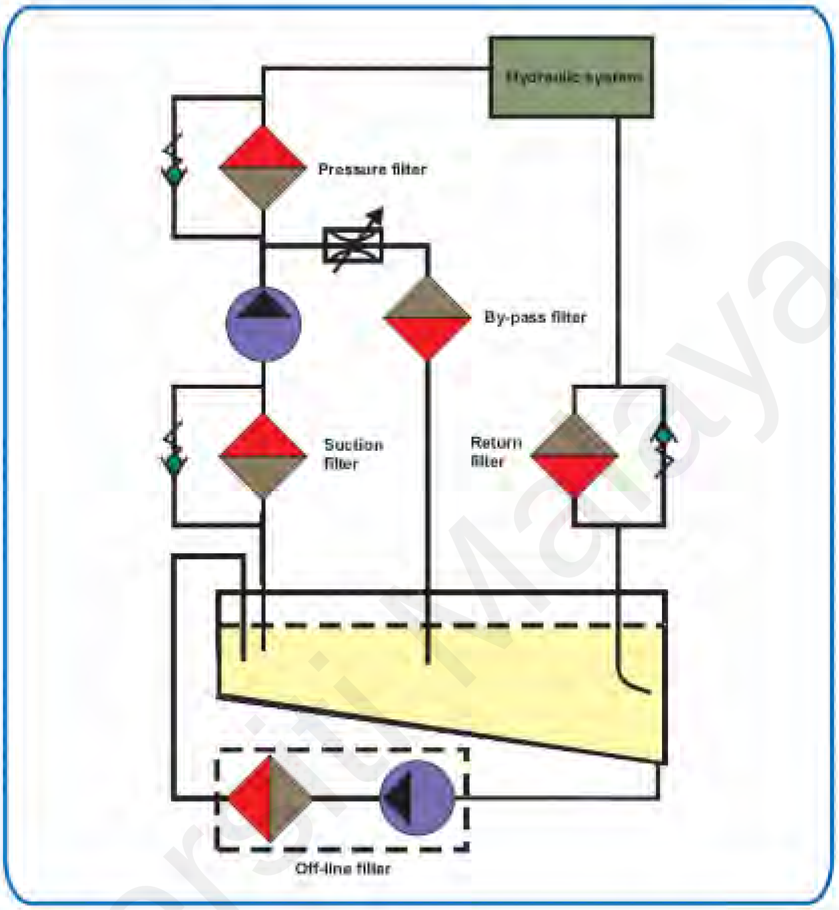

Figure 2.12: Example of Off-line filtration in hydraulic system

Example of off-line filtration system is centrifugal filters and CJC™ Fine Filter. These types of filter, filters large amount of fuel before going into the system. Centrifuge filter separate the solid and water trapped in the wall and using the centrifugal force. The CJC™ Fine filter use the cellulose based filter insert to filters particle through absorption and adsorption process. It draws the oil from the oil tanks and passed through the cellulose filters.

The filter insert used in the off-line filtration system is cellulose based filter. Cellulose filters not only filters particles, but also absorbs the water and adsorbs oxidation. Figure 2.14 below shows the principle of the cellulose depth filter.

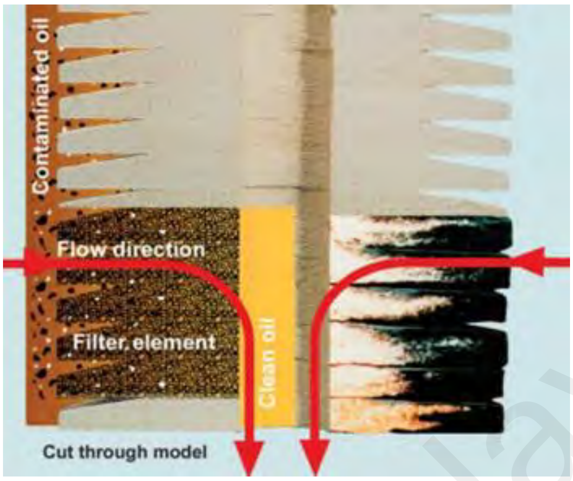

Figure 2.14: Cellulose Filter Principle (C.C.Jensen, 2011)

The lubricating oil flows from the outside into the inside of the filter. During the flow, the contamination elements trapped in the cellulose. The water is absorbed by the fibers and the polar spots adsorb the oil degradation products.

2.5.1 Contamination

There are various impurities that contaminate the lubricating oil. The most common type of the contamination sources comes from wear metal particles, fuel residue, water and damaged lubricating oil properties due to high temperature (Hasannuddin et al., 2018). According to C.C. Jensen, 70% particles in oil are between 1 to 5 microns. Normal inline filtration system is unable to filter these small particles. Soot is basically partially burnt fuel resulting from incomplete combustion process. Soot contamination prevents anti-wear additives and wear in engine parts (Motamen Salehi, Morina, & Neville, 2017).

Water contamination induces cavitation and hydrogen embrittlement in engine parts, reduce lubricating properties. Water contamination occurs due to condensation, water pollution during tank filling or from water contaminated oil (Andria et al., 2019).

Contamination by oxidation occurs due to combination of wear particles, water, air, excessive heat and depletion of additives in lube oil which causes acid, sludge and varnish by-products. These by- products can destroy the parts and poses greater risk to the engine.

Previously mentioned, in-line and off-line filtration are one of many ways to reduce lubricating oil change interval. According to Langfitt et al. (Langfitt & Haselbach, 2016), frequent oil change can reduce engine life.

The lubricating oil cannot be saved by using the filtration process when the lubricating oil has 20% lower viscosity than new oil, high fuel content, low TBN number, depleted additives and wrong oil application.

2.6 Summary

In this research, cellulose filter in the off-line lubrication oil filtration system will be used to measure the impact on the diesel power plant in Pulau Redang. Pulau Redang Power Station is located in Kampung Teluk Siang, Pulau Redang, Terengganu. It consists of 4 units of 500 kW diesel generator sets and installed capacity of 2 MW. This power plant is generating electricity for 24 hours to accommodate the villagers in Pulau Redang with the average load generated of 400 kW per day during the normal season. The electricity demands in Pulau Redang are dependent on dry and monsoon season where the load demand is higher during the holiday (dry) season. The operation of this diesel power plant must not be interrupted since it is the primary electricity supply in the island. This diesel generator set must be kept in good operating order. One of the methods to increase the efficiency of the diesel engine is to reduce the contamination in diesel engine lubrication system.

The off-line filtration method is introduced to support the inline filtration system of the engine. When the lubricating engine quality is under control, the performance and fuel consumption of the engine can be optimized. Currently, the study on impact of off-line filtration unit on genset efficiency is not updated.

The diesel supply is transported using the sea freight; the reduction of fuel usage can impact the operational cost. By maintain good lubrication oil properties, the wear in engine parts can be reduced. Good maintenance of lubricating oil can also impact the downtime. The downtime and sudden breakdown are expected to be reduced. In this research, the lubricating oil from one of the diesel generator set will be analyzed.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explained the research equipment needed and the activities taken for this project. The project started with new serviced diesel generator set running for several hours before installing the off-line filtration system. The power output and fuel consumption are monitored and oil samples are taken before and after installation CJC™ Fine Filter. The oil samples are taken to check the lubricating oil properties, soot, Total Base Number (TBN) and kinematic viscosity. The cost benefit analysis is measured using the Life-cycle cost (LCC) calculation, payback period and return of investment (ROI). The flow work of the project can be seen in the Figure 3.1.

In this research report, a few confidential information are altered to the nearest round number and approximation due to the agreement with the station owner. The end result has been compared and will not compromise the overall study of this research**.**

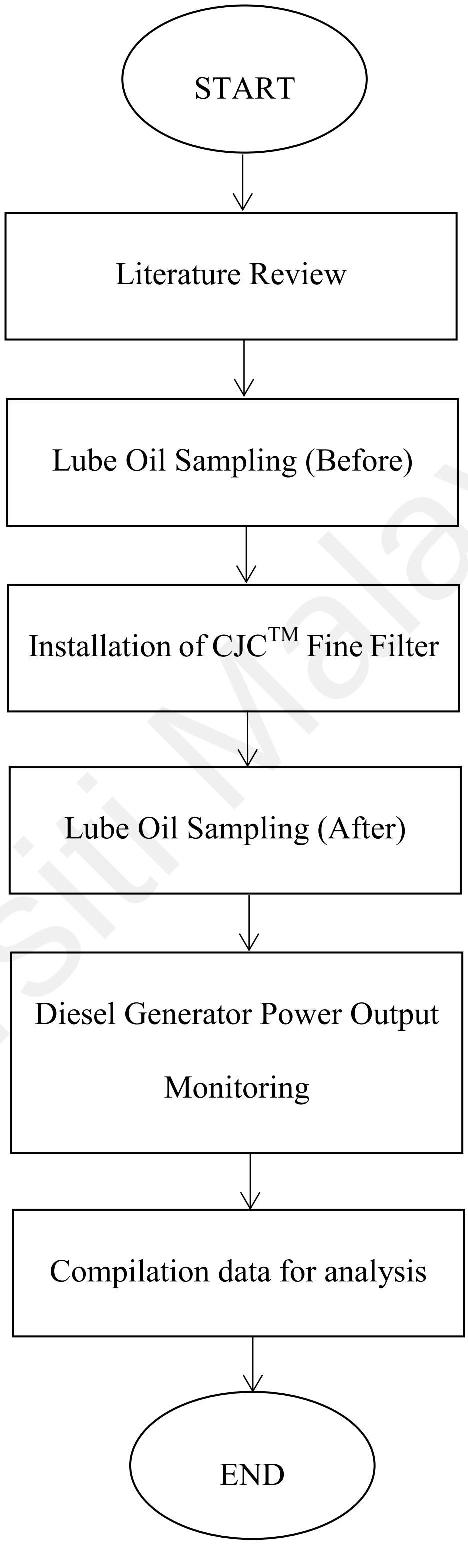

Figure 3.1: Flow Diagram

3.2 Material & Methods

3.2.1 CJC™ Fine Filter HDU

A CJC™ Fine Filter, HDU 27/108 imported from Svendborg, Denmark, is installed and connected to the lubrication oil system of the diesel generator set in Pulau Redang Power Station.

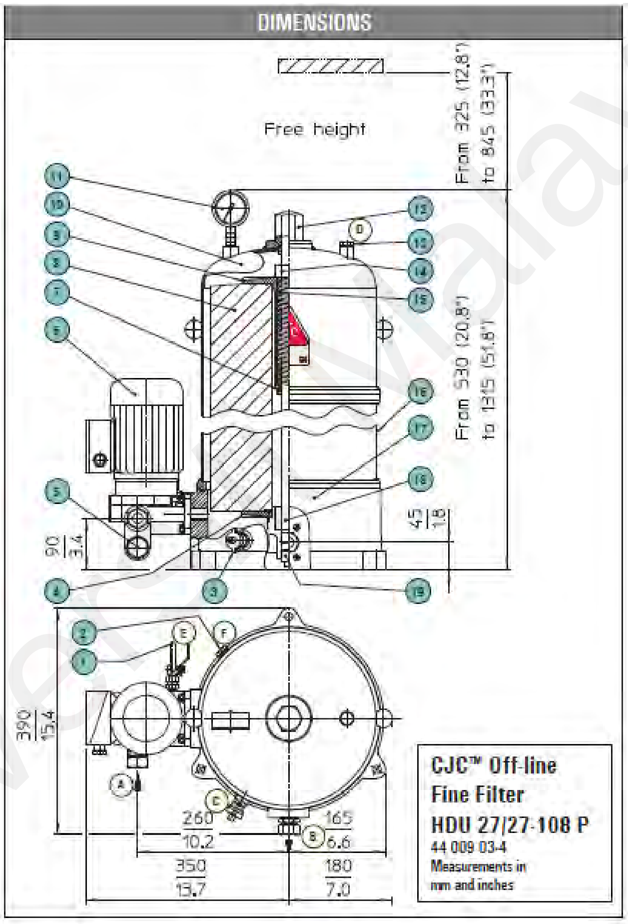

Figure 3.2: General Dimension of CJC™ HDU Fine Filter.

Figure 3.3: CJC™ HDU 27/108 Fine Filter at site

The main components of CJC Fine filter are:

- Filter Housing
- Filter Base
- Pump
- Electrical Motor
- Pressure Gauge
- Filter Insert
- Drain Valve
- Oil Inlet
- Oil outlet
- Sampling point

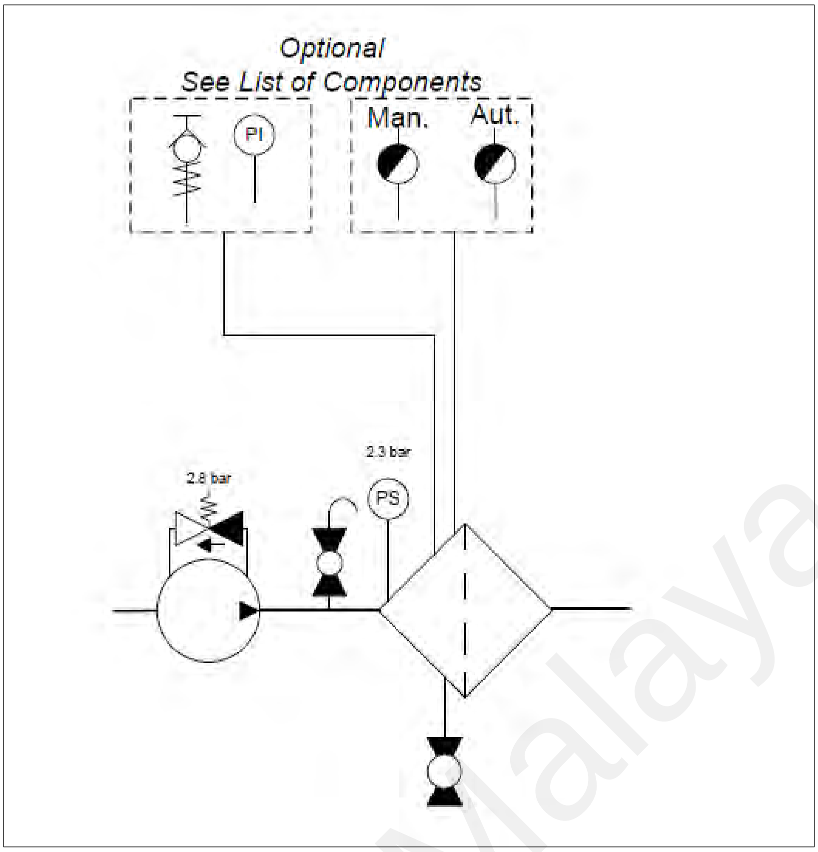

Figure 3.4: P&I Diagram

CJC™ Fine Filter works as off-line filtration system. This filter can continuously running even the diesel generator set is not running. CJC™ Fine Filter is connected to the lowest point of the lubricating oil tank with the pump flow 15% of oil volume. The lubricating oil will be filtered using depth filter insert and clean oil will return to the tank system.

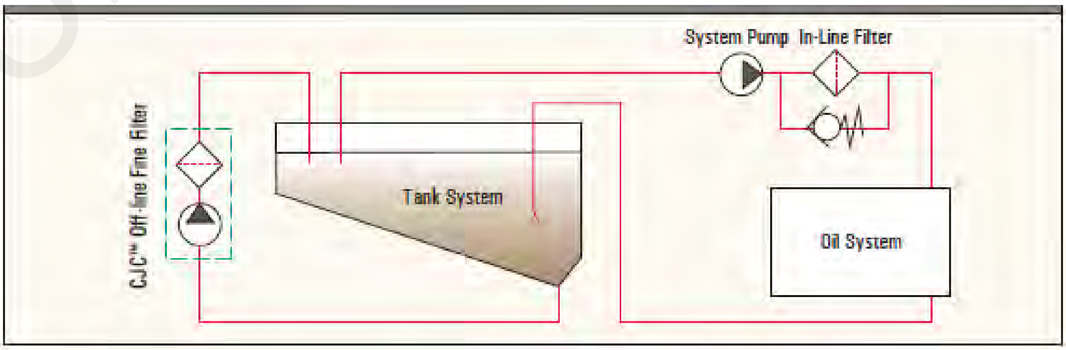

Figure 3.5: CJC™ Fine Filter Working Principle

The oil cleaning methods determine the cleaning action for the lubrication oil. Centrifugal separator is one of the most popular methods especially in marine application. It can reduce water content but has high maintenance cost. The glass fiber based pressure filter, otherwise only able to reduce the solid particle with bigger dirt size which is 10 to 50 micron rating. CJC™ Fine Filter is using cellulosed based filter which is able to reduce solid particles, water and varnish. The cellulose in the filter absorbs water from the oil, withholds particle with absolute filtration of 3 micron and nominal filtration 0.8 micron. The polar fibers attract and hold the varnish through adsorption process.

Figure 3.6: CJC™ A 27/27 Filter Insert

Figure 3.7: CJC™ Filter Insert cross section

Table 3.1: CJC™ HDU 27/108 Fine Filter Specification

Filter	**CJC™ A 27/27 Off-line filter insert**
Usage	Engine lube oil, hydraulic oil, gear oil, quenching oil
Dimension	Diameter 27 cm Height 27 cm
Main Material/ingredient	Wood cellulose
Filtration Degree	98.7% >3nm 50% >0.8nm
Flow	> 45 L/hour
Dirt Holding capacity	4.0 Liter
Particle retention capacity	2000-4000 g
Water Absorption Capacity	750 – 2000m
Varnish Adsorption capacity	1000 – 4000g

3.2.2 Lubricant

The lubricating oil used in this research is Shell Rimula R4X 15W-40. The lubricating oil specification and rheological properties used in this test are tabled below in Table 3.2.

Table 3.2: Lubricating Oil Specification and Rheological Properties

Properties	**Rimula R4 X 15W-40**
Kinematic Viscosity @ 40˚C	109 mm2/s
Kinematic Viscosity @ 100˚C	14.7 mm2/s
Dynamic Viscosity @ -20˚C	6700 mPas
Viscosity Index	139
Total Base Number (TBN)	10.5 mgKOH/g
Density @ 15˚C	0888 kg/l

This lubricating oil already lubricated the diesel engine for 426 hours prior to the CJC™ Fine Filter installation and the manufacturer recommends replacing it every 500 hours. The initial Total Base Number (TBN) is 10.5 mgKOH/g as per shown in the table.

3.3 Test apparatus and method

3.3.1 Diesel Engine

A D398 Caterpillar Diesel Generator Set is used in this experiment. This diesel generator set is one of the four diesel generator unit in Pulau Redang Power Station. This diesel generator set is used alternately with other unit. For this experiment the diesel generator set is running for 426 hour from the CJC™ fine filter installation to the last drawn lubricating sample. The total running hours from the last oil change to the end of experiment is 985 hours.

The specification of the diesel engine is listed in Table 3.3.

Table 3.3: Specifications of the test engine

Diesel Generator Set	
Engine	Caterpillar D 398 PC
Type	V12 4 Stroke-cycle diesel
Bore	159 mm
Stroke	203 mm
Displacement	48.3 liter
Alternator	BEMAC III
Installed Capacity	500 kW
RPM	1000

First, the diesel engine generator is running for few hundred hours after periodical servicing and lubricating oil change. The oil samples are taken during this period. The installed CJC™ Fine Filter is connected to the lubrication tank and the diesel generator set is running for another 559 hours. The diesel engine power output, fuel consumption (Liter/ hour) and fuel efficiency (kWh/hour) before and after CJC™ Fine Filter are recorded.

3.3.2 Lubricating Oil Analysis

The quality of the lubricating oil will be analyzed from the oil sample taken from the diesel engine. The insoluble contents are measured using ASTM D5185-18 standards and the kinematic viscosity is measured using ASTM D7041-16e3 standard. The Total Base Number (TBN) and soot content are using ASTM D2896-15 and ASTM E2412-10 (2018) standard. All the above analysis procedures are conducted by certified laboratory; Canglobal (M) Sdn. Bhd and provided by Enhance Performance Solution Sdn Bhd.

In order to understand oil analysis report, the oil system and oil type need to be determined. As mentioned above, Shell Rimula R4x 15W-40 is used with the initial TBN number of 10.5. The TBN number should not be less than 50% of the original TBN number. The viscosity of the oil must not be below 15% from the initial value as it can destroy the engines parts and oxidation caused by water content, contamination and wear metal/elements is monitored. If the trend increased, the engine parts must have further assessment. Wear metal can be indicated by the presence of Aluminum (Al), iron (Fe), Copper (Cu), lead (Pb). The lube oil contaminants can be shown by the presence of Silicon (Si)

The lubricant oil is sampled 4 times for the oil analysis; the first sample is taken before installation of CJC™ Fine Filter at 426 running hours. The second sample is taken at 713 running hours and the third is taken at 880 running hours. Only two samples are compared to the first sample before installation of CJC™ Fine Filter. The CJC™ Fine Filter is equipped with the drain pipe for oil sampling activities. Oil sample collection procedure is shown in Figure 3.8.

Figure 3.8: Steps for oil sampling

Four (4) oil samples had been taken to be sent for oil analysis.

Figure 3.9: Oil Samples Collected for Oil Analysis.

3.4 Cost benefit analysis

Based on the manufacturer recommendation, the diesel engine must be serviced every 500 running hours. The service activity includes the lubrication oil change. The diesel engine needs approximately 300 liter of lubricating oil for each replacement. The installation of CJC™ Fine Filter is expected to maintain the lubricating oil quality within the range without frequent oil change. Extended drain intervals expected to reduce the operating cost of this particular diesel generator set. According to Langfitt et. al, (Langfitt & Haselbach, 2016) the life-cycle cost (LCC) analysis is used to get the approximate cost using the following equation;

$$LCC = (C_o + C_d + C_l + C_a)\ X\ \frac{H}{I}\ X\ n \qquad (3.1)$$

Where;

C_o = cost of new oil per oil change

C_d = cost of oil disposal per oil change

C_l = cost of labor for an oil change

C_a = yearly cost of oil analysis program (only for interval extension)

H = engine operating hours per year

I = oil change interval in operating hours

n = number of years in analysis

D = real discount rate (optional)

The fuel change interval can be predicted based on TBN number and viscosity value. Using the LCC method, the approximate cost saving can be calculated. The fuel saving from the improvement of diesel engine efficiency was also incorporated.

The payback period method is taken into the cost benefit analysis to calculate the period taken to break even the capital investment from purchasing this filter. It is expected that capital investment may reduce the operational expenditure. The operational expenditure including fuel, manpower cost, lubricating oil and downtime cost are expected to reduce.

Lastly, Return of Investment (ROI) is calculated to measure the efficiency of purchasing the CJC™ Fine Filter. Return of investment averages the profit gains for every year and divided it into the initial investment. If the net return is higher, this capital expenditure can be worthwhile. The formula to calculate the ROI is shown in the Eq. 3.2

$$ROI = \frac{Annual\ Profit}{Initial\ Investment}\ x\ 100 \qquad (3.2)$$

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this Chapter, the results of the power output trend and fuel consumption before and after CJC™ Fine Filter are presented. From the result, the fuel consumption is linked to the improvement of lubricating oil. This improvement might be due to the reduction of friction losses, decrease of kinematic viscosity and good surface contact due to the improved quality of the lubricating oil.

The oil sample analysis is presented and the contamination level through wear element counts, water and soot content, kinematic viscosity and total base number (TBN) are displayed. The relationship between oil impurity and performance is discussed. The effectiveness of CJC™ Fine Filter is discussed.

Finally, the cost benefit analysis is calculated based on Life Cycle cost, payback period and return on investment. These results will be a guideline to measure the impact of installing CJC™ Fine Filter towards the operation and economic efficiency in Pulau Redang Power Station.

4.2 Engine output power versus Fuel consumption

The engine output power has been monitored before and after installation of CJC™ Fine Filter for 34 days. Engine output is monitored to give the indication on the diesel generator set load. The average output power before using the filter is 356.2 kW per hour and after 318.2 kW per hour. The average fuel consumption before installation of filter is 98.82 liter per hour and after installation 85.48 liter per hour. Figure 4.1 depicts the trend of the power output and the fuel consumption rate of the diesel generator set.

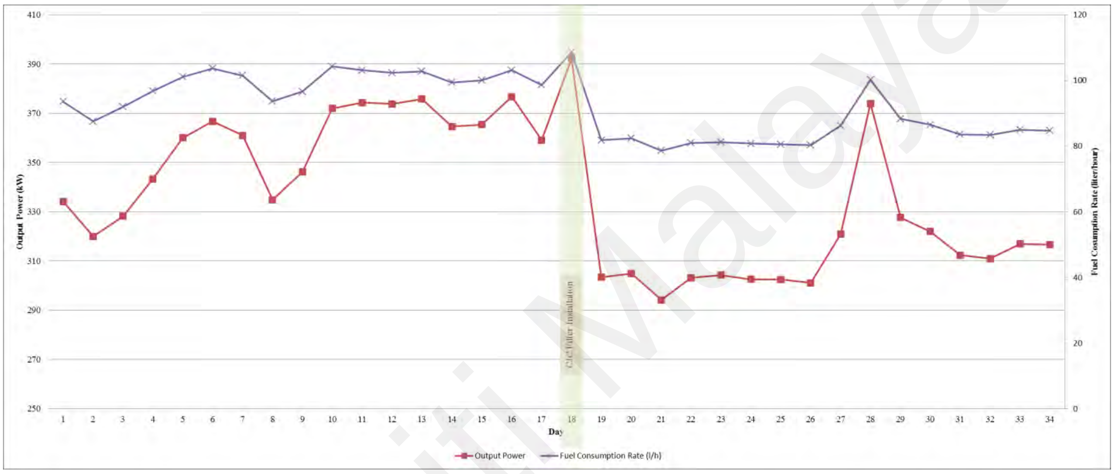

Figure 4.1: Power Output (kWh) and Fuel Consumption Rate (Liter/hour)

The power output before installing the CJC™ Fine Filters range from 370 kW to 390 kW per hour and after installation, it has reduced between 350 kW to 370 kW per hour. The difference of power output is due to the load demand in this particular period. The load demand reduction is around 10.66%. The fuel consumption before installation varies from 60 to 100 liter per hour while after installation of filter; it reduced 30 to 40 liter per hour.

The fuel consumption per hour is reduced to 13.5% after installing the off-line filter. To further asses the relationship between the power output and fuel consumption, Figure 4.2 shows the power generated for one (1) liter of diesel fuel. Before filter installation, average energy generated is 3.60 kWh for every liter and between 3.5 to 3.65 kWh per liter. After installation of filter, the diesel generator set yields higher output of energy generated per liter with average of 3.73 kWh/liter.

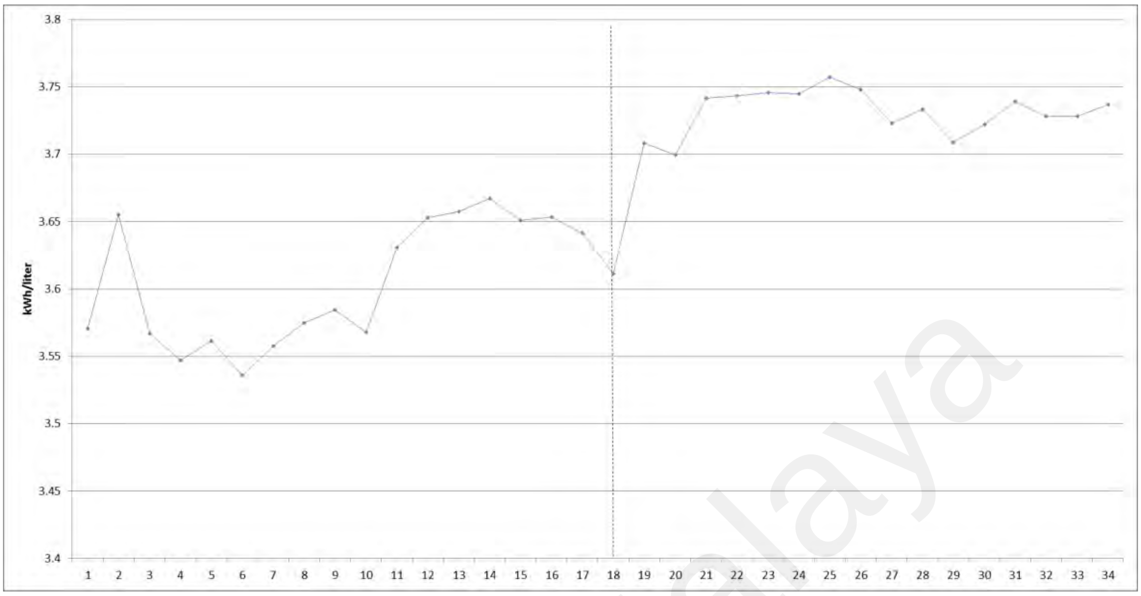

Figure 4.2: Energy Generated for one (1) liter of diesel fuel.

After installation of CJC™ Fuel Filter, the average fuel consumption has been reduced to between 10.1% - 16.1% which falls between 3.7 to 3.75 kWh per liter. These two figures have shown that the usage of the filter has impact on the fuel consumption.

The increase of energy generated per liter may be due to the improvement of lubricating oil which produces more effective energy due to reduction of friction on the contact surface and improve fuel energy consumption. The friction loses is due to the particles or foreign elements in the engine parts especially in ring and cylinder. This area is very sensitive to friction, blow by and compression losses. The foreign particles hinder the movement between moving surfaces and increase the friction. The frictional losses as mentioned before can affect the fuel consumption. The lubrication regime in tribo-contacts may affect the friction in the engine parts. Viscosity of the lubrication oil, engine load and speed impact the tribo-contact conditions. The boundary lubrication can increase the contact and produce effective film on the moving parts hence improves the friction coefficient. High friction in the engine piston requires more energy to move the engines thus led to energy waste.

The combustion process can be interfered by the previous combustion by-product. This by-product mixed with other elements, affects the combustion process and reduces the combustion efficiency. David R. Stanley in his study had concluded, particle with 2 to 22 microns needs to be controlled to reduce engine wear (Stanley, 1988). Engine parts wear especially in piston and cylinder leads to the combustion process leakage. This leakage will consume more fuel when running.

Other factor that may contribute to the reduction of the fuel consumption is oil viscosity. High contamination in lubricating oil will thicken the oil and increase its kinematic viscosity value. Timo Murtonen had studied the effect of kinematic viscosity and its effect on the fuel consumption (Murtonen, 2004). Lower kinematic viscosity led to lower fuel consumption.

Contamination in the combustion chamber can constrain the movement of the parts and the contaminants will unintentionally adhered to the parts surface (Fitch, Clean Oil reduced Engine Fuel Consumption, 2002). This phenomenon called, stiction, can cause power losses and increase fuel consumption. Good lubrication oil can remove stiction and help to regain the power losses.

Based on this result, it shows that fuel consumption correlated to the improvement of lubricating oil. The fuel consumption increased after CJC™ Fine Filter is introduced into the system and promotes fuel economy. The further assessment on the lubricating oil quality after installation of the filter is elaborated in the next section.

4.3 Oil Properties

Basic oil analysis usually analyzes particle count, water content, viscosity and Total Base Number (TBN). Element contamination is responsible for decreasing lubricating oil function in the diesel engine. The presence of Aluminum (Al), iron (Fe), Copper (Cu), lead (Pb) show wear metal element in the lubricating system and lubricating oil contaminants can be shown by the presence of Silicon (Si).

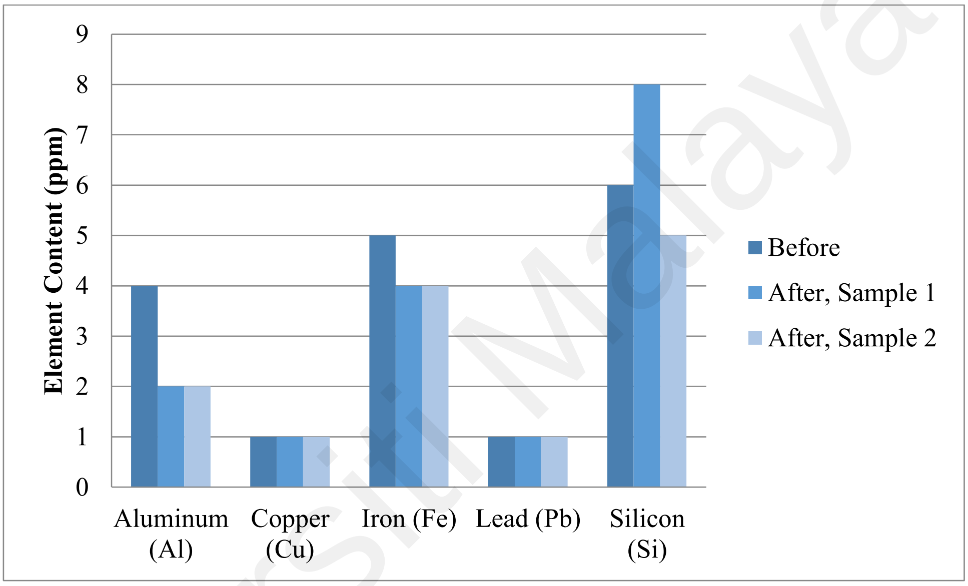

Figure 4.3: Element content before and after CJC™ Fine Filter

In Figure 4.3, the value of the elements decreased when lubricating oil has been filtered by CJC™ Fine Filter. Aluminum content reduced from 4 ppm to 2 ppm, copper is maintained below 1 ppm, iron content is reduced from 5 ppm to 4 ppm and silicon increased in the second oil sample but then reduced from 8 ppm to 5.5 ppm.

The crevice in the cellulose in the filter insert withholds the elements and provides clean oil into the system. According to Chen et. al, new lubricating oil is free from lead and copper and exist when there is abnormal wear in the engine (Chen et al., 2019a). The overly accumulated foreign element in the lubricating oil can intensify the wearing of the parts. The abrasive element can wedged the clearances subsequently degrading the metal.

CJC™ Fine filter has shown its ability to reduce the element in the lubricating oil using its cellulose depth filter capability. These elements trapped in the cellulose and the cleaner lubricating oil is supplied into the engine system. If these elements are not filtered properly, they will accumulate and lubricating oil efficiency will be reduced. These elements can stress the additives in the lubricating oil and diminish the detergent and dispersant inside it. The energy consumption will increase as the lubricating oil properties decrease.

Apart from reducing the lubricating oil properties, wear elements can intensify the wear activity. These abrasive elements collide with the metal parts and destroy the metal surface which resulting more wear particles produced. This has proven that the existing in-line filtration system is unable to control the wear element before off-line filter is introduced.

Another factor on determining the oil quality is by getting the kinematic viscosity of the lubricating oil. Kinematic viscosity is calculated using the dynamic viscosity and divide it with the density of the lubricating oil. Kinematic viscosity can denote any impurities in the oil and oil degeneration. The higher viscosity value may restrict movement of the diesel engine part. Figure 4.4 shows the kinematic viscosity before and after installing the CJC™ Fine Filter.

Based on the previous studies on the improvement of lubricating oil properties using filtration system, the accumulation of impurity can affect the oil viscosity. In based on the result above, the kinematic viscosity is improved when the impurities has been filtered out, thus confirms with the studies conducted by Chen et. al (Chen et al., 2019a).

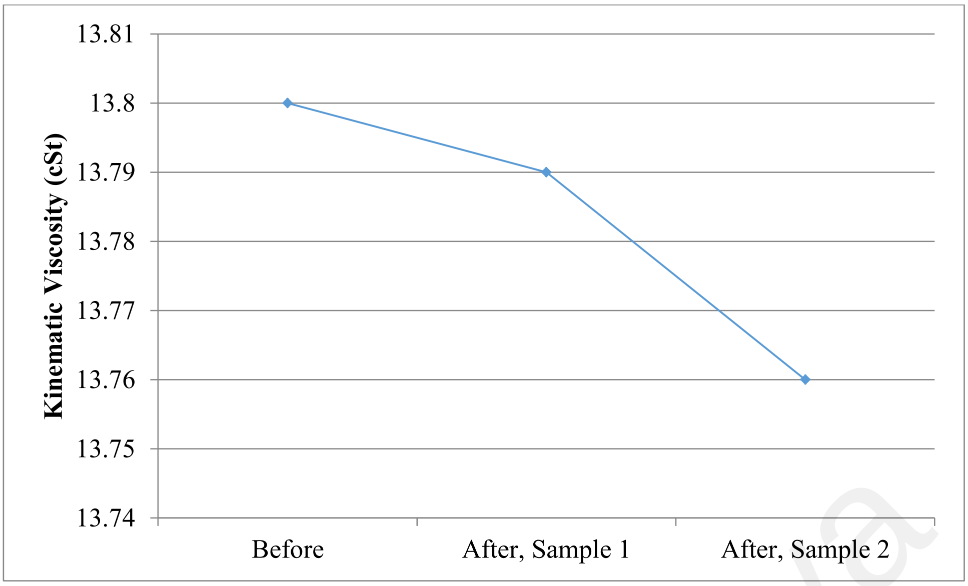

Figure 4.4: Kinematic Viscosity Result

As shown in Figure 4.4, kinematic viscosity has been reduced from 13.8 cSt to 13.76 cSt.

With lower kinematic viscosity, the contact surface between parts can be improved and the friction loss can be reduced. The thinner the oil, the lower the friction drags. Reducing the oil viscosity can also reduce the ability to withhold contaminant. When the thin oil can't accommodate contaminant, these contaminant elements go into the lubricating system and will be filtered out. This result has been reflected in the previous section where the energy generated per liter increase correspondingly and consistent with the Giakomis et al. study where the higher piston rings friction and friction torque can reduce output power (Giakoumis, 2010) .

Lubricating oil analysis result shows the water content and soot in the lubricating oil are within the allowable limit; below 0.05% and <1 ppm respectively. There is not much difference in the water content might be due to the lubricating oil has been changed prior to this experiment. Water content in the lubricating oil acts as catalyst for oil degradation, which led to formation of varnish. If the water is exposed in the combustion chamber where the temperature is high, it will cause the water droplet to implode which resulting to micro pitting. Apart from that, water is widely known to induce corrosion on the metal parts.

The Total Base Number (TBN) is the ability of the lubricating oil to neutralize the acid generated during the combustion process. This acid is formed when the moisture, heat and oxygen are presence simultaneously. Acid can cause chemical corrosion and shorten the lubricating oil life. In order to reduce the acid in the lubricating oil, the neutralization of the acid is done using alkaline. Reduction of TBN number can predicts the health of the lubricating oil. Figure 4.5 shows the TBN result from the samples taken. For this oil analysis, four (4) samples are taken.

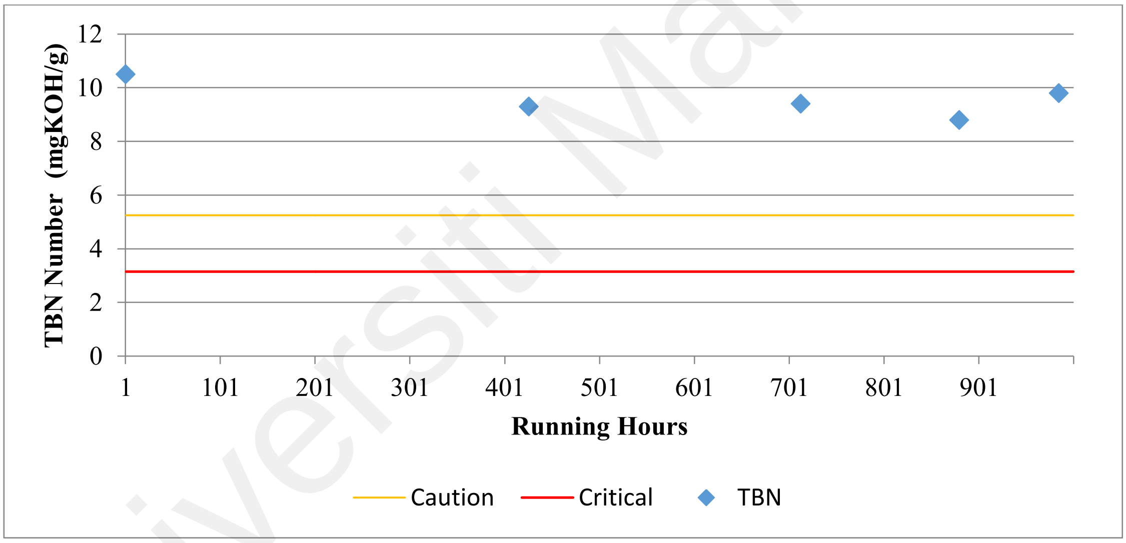

Figure 4.5: TBN trend

In the Figure 4.5, the original TBN number is 10.5 mgKOH/g. After running for 426 hours, the TBN number is reduced to 9.3 mgKOH/g. The TBN number is maintained in between 8.8 to 9.8 mgKOH/g after running for another 559 hours. The caution line is when the TBN number is reduced 50% from the original number and the red line is when the TBN number has reached critical level of 30% from original number which indicates the lubricating oil is no longer able to do its job and should be discarded from the system immediately.

CJC™ Fine Filters retains TBN number using its neutralizing catalyst in its base filter which is ion exchange resin which effectively neutralizing the acid in the lubricating oil. In addition, this filter maintains the water in the lubricating oil low to prevent the formation of acid.

TBN number is the baseline to monitor lubricating oil health. By maintaining the TBN number, the life of the lubricating oil can be prolonged. Oil change frequency can be reduced as long as the TBN number does not reach the 50% reduction from the new oil number. Viscosity and TBN number are accepted worldwide as the indicator for extended oil change intervals (Langfitt & Haselbach, 2016). Based on the trend, the TBN number has shown no significant changes even after running for 985 hours.

Lubrication failure is one of the major contributions to the engine damage. It is important to take a good lubricating oil maintenance practice to maintain the oil conditions. In overall, even after running for more than recommended oil changing interval, the lubricating oil is in good conditions and the parameters are within specifications. The change of the energy generated and the fuel consumption when using the filter attributes to the reduction of the frictional power consumption when the quality of lubricating oil improves.

The CJC™ Fine Filtration system works as integrated system to the existing fuel filter. The quality of the lube oil has to be monitored. There are several cases where the lubricating oil can no longer be saved. As mentioned earlier, the lubricating oil cannot be saved when the lubricating oil has 20% lower viscosity than new oil, high fuel content, low TBN number, depleted additives and wrong oil application

The relationship between TBN number and the life cycle cost of lubricating oil interval is discussed in the next section.

4.4 Cost Benefit Analysis

Apart from oil analysis, the cost benefit analysis is used to determine the impact on the overall cost of installing the CJC™ Fine Filter. Theoretically, by extending the oil change interval, the operation and maintenance cost may be decreased. The operational cost in the Pulau Redang Power Station is high due to the transportation factor. The transportation factor increase the fuel cost, lubricating oil cost, schedule waste removal and manpower cost. In addition, the villagers in Pulau Redang are depending on this plant for their electricity supply. Thus, the engines have to be running for 24 hours and any downtime will incur losses. Longer servicing hour can prolong machine down time and giving other running engine more load to generate electricity.

The cost for the diesel fuel is RM2.15 per liter and the lubricating oil is RM12 per liter including transportation cost to the island. In addition, the cost to dispose used lubricating oil as schedule waste is RM9.60 per liter. The downtime for scheduled maintenance, which is to replace the lubricating oil, oil filter and other spare parts, is around six (6) hours per servicing session. Two technicians are involved to service the engine. Currently, the engine needs to be serviced every 500 running hours as per manufacturer recommendation.

The Life Cycle Cost (LCC) analysis is used to see the correlation between oil change interval and the cost saving gained from it. Using the LCC equation, the cost saving has been plotted for different oil change interval in Figure 4.6.

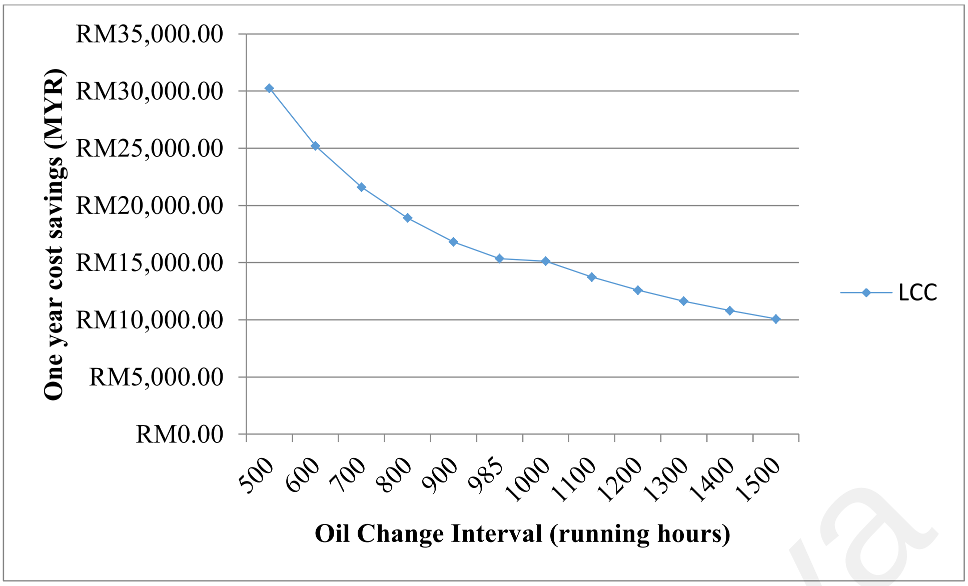

Figure 4.6: One year cost savings attained at different oil change running hours interval

The result showed more frequent oil change will incur higher cost. Based on the oil analysis result, the oil quality is in a good condition even after running for 985 hours. If the oil change happened at every 985 hours, the cost of overall oil changing can be reduced to RM14,893.82 per year.

The LCC is calculated taking into consideration of the down time cost, manpower cost, lubricating oil cost and used oil disposal cost. These overall cost times the frequency of oil changes to get the LCC per year. The reduction of downtime not only beneficial to the LCC, but also will met the government Rural Electricity Supply (RES) objective to maximize the electricity supply 24 hours without disruption.

Each lubricating oil change consumes 300 liters of new oil and subsequently produced approximately 300 liters used oil. Currently, lubricating oil is changed five (5) times a year. If it can be reduced to only 2-3 times a year, the cost can be reduced almost half. Yet, the decision to extend the oil interval must be supported by other factors such as the operating pattern, oil properties especially Total Base Number (TBN) and viscosity, last overhaul session and types of lubricating oil used.

According to the (Langfitt & Haselbach, 2016), the LCC is decreased when the oil changes interval is reduced. However, the oil change interval is dependent to the quality of lubricating oil.

In this research, TBN and viscosity factor has been taken. The TBN number of lubricating oil in this engine is 9.8 from 10.5 of the original TBN number. There is a possibility on extending the oil change interval to more than 985 running hours. The oil should be changed when the TBN number reach critical line; 50% of the original TBN number. The critical number for this lubricating oil is 5.25. The TBN number monitoring can show the degradation trend line. This trend line can be merged together with the LCC graph to find the intersection point which gives the approximate running hours interval to change the oil. CJC™ Fine Filter has indirectly improved the oil changed interval by maintaining the lubricating oil quality. However, due to limited time to conduct this research, the final oil change interval cannot be finalized.

Likewise, the fuel consumption is also reduced. Former average fuel consumption of the diesel generator set was 0.277 liter per kWh produced and has been decreased to 0.267 after installing CJC™ Fine Filter. The average running hour per year for this diesel generator set is around 2,190 hours. Based from previous result, if the average fuel consumption can be maintained for 0.267 liter per kWh generated, total savings from fuel consumption is RM31,200.00 per year.

The fuel savings can directly impact the transportation cost. Normally, diesel fuel will be transported to Pulau Redang 3 to 4 times a year. With reduction of fuel consumption, fuel delivery frequency can be reduced. The cost saving from fuel transportation and the delivery frequency are not in this research paper scopes but further analysis should be made.

While LCC calculate the costs involved on lubricating oil change interval, the cost of installing the CJC™ need to be taken into consideration. The initial investment of installing the filter is around RM52,000.00 including the transportation to Pulau Redang, manpower cost and parts cost.

The payback method is taken into calculation to predict how many years are taken to gain the initial investment. The annual cash inflow gained from the expected cost saving is divided by the initial investment.

The payback period is calculated in the Table 4.1 below;

Table 4.1: Payback Period of the CJC™ Fine Filter

Initial Investment	RM52,000.00
Year 0	(RM52,000.00)
Year 1	RM46,093.00
Year 2	RM46,093.00
Total Gains	**RM40,186.00**

The payback period of installing the CJC™ Fine Filter is approximately 16 months. By using this off-line filter, the LCC savings and fuel savings per year is RM46,093. In less than two years, the cost of initial investment has been recovered.

The payback calculation does not include other operating cost other than diesel generating set operating cost. The cash in-flow is calculated based on the cost saving from the reduction of oil change interval and reduction of fuel consumption as mentioned earlier.

The Return of investment of this machine is 31.68% with annual profit forecasted RM19,893.82. This high ROI is a good indicator for benefits of purchasing this filter. In this section, the Net Present Value (NPV) is not calculated.

All in all, the positive economic evaluation of installing CJC™ Fine Filter impacts the overall Operational expenditure and Capital expenditure of Pulau Redang Power Station.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this research, the usage of CJC™ Oil Filter as off-line filtration systems and its influence on the performance, fuel consumption and lubricating oil properties of the diesel generator set in Pulau Redang Power Station has been studied. The cost benefit resulting from the increase of the engine performance and oil change interval has been calculated. The lubricating oil quality has been retained by using this filter. With the lower oil change interval, the life cycle cost and the frequency of the schedule waste disposal are reduced.

The energy generated per liter has shown some improvement from 3.60 kwh/l to 3.73 kWh/liter. The usage of cellulose filter has proven to reduce the oil contaminant elements and viscosity. The good lubricating oil can prolong the life of the diesel generating parts. The well maintained lubricating oil reduced the fraction between parts and subsequently improves the fuel consumption up to 3.75%.

The relationship between oil change interval to the operating and maintenance cost is calculated. Approximately RM14,893.82 operating life cycle cost can be saved per year and RM31,200.00 of fuel cost can be saved per year. Due to its ability to effectively reduce contamination, improves oil quality, reduces operating and fuel cost, the payback period is approximately 16 months with ROI equals to 31.68%.

The cellulose depth filter has shown its ability to retain contamination and maintain water lever through absorption process. Overall, the installation of CJC™ Fine Filter has shown a positive impact on operation and maintenance cost and it is recommended to extend the usage of this filter to other diesel generating power plant.

5.2 Recommendations

TBN number monitoring should be continued to determine the recommended oil interval and further research on the engine emission before and after installation of CJC™ Fine Filter can be conducted in the future. The influence of this filter on the engine performance has yet to be discovered and extensive studies need to be done. The oil properties should be monitored for at least one year with 500 hours running interval.

In addition, further study can be made to calculate the fuel refiling interval versus the transportation cos and also includes the net present value (NPV) to see the economic impact.

REFERENCES

A.K Raja, Amit Prakash Srivastava, M. D. (2006). *Power Plant Engineering*. New Delhi: New Age International Publisher.

Ajan C.W, Ahmed S.S, A. H. . (2003). On the policy of photovoltaic and diesel generation mix for an offgrid site. *Solar Energy*, *74*, 453–467.

Andria, G., Attivissimo, F., Di Nisio, A., Trotta, A., Camporeale, S. M., & Pappalardi, P. (2019). Design of a microwave sensor for measurement of water in fuel contamination. *Measurement: Journal of the International Measurement Confederation*, *136*, 74–81. https://doi.org/10.1016/j.measurement.2018.12.076

Blechinger, P. F. H. (2015). *Barriers and solutions to implementing renewable energies on Caribbean islands in respect of technical , economic , political , and social conditions*. Retrieved from https://www.researchgate.net/publication/282804308_Barriers_and_solutions_to_implementing_renewable_energies_on_Caribbean_islands_in_respect_of_technical_economic_political_and_social_conditions

C.C.Jensen. (2011). *Clean Oil Guide*. 1–48.

Chen, X., Wang, Z., Pan, S., & Pan, B. (2019a). A novel biomass lubricant filter and its effect on gasoline engine emissions and fuel economy. *Journal of the Energy Institute*, *92*(2), 332–340. https://doi.org/10.1016/j.joei.2018.01.003

Chen, X., Wang, Z., Pan, S., & Pan, H. (2019b). Improvement of engine performance and emissions by biomass oil filter in diesel engine. *Fuel*, *235*(May 2018), 603–609. https://doi.org/10.1016/j.fuel.2018.08.038

Dalimin, M. N. (1995). Renewable energy update: Malaysia. *Renewable Energy*, *6*(4), 435–439. https://doi.org/10.1016/0960-1481(94)00070-M

EC. (2018). *2017 Malaysia Energy Statistics Handbook*. 86. Retrieved from http://www.statcan.gc.ca/pub/57-601-x/57-601-x2012001-eng.pdf%5Cnpapers2://publication/uuid/792EFC7D-A6CF-40B5-A139-8FA59714AA41

Echávarri Otero, J., De La Guerra Ochoa, E., Chacón Tanarro, E., & Del Río López, B. (2017). Friction coefficient in mixed lubrication: A simplified analytical approach for highly loaded non-conformal contacts. *Advances in Mechanical Engineering*, *9*(7), 1–11. https://doi.org/10.1177/1687814017706266

EPU. (2018). The Malaysian Economy. *Southeast Asian Affairs*, (November), 207–222. https://doi.org/10.1355/SEAA08L

Giakoumis, E. G. (2010). Lubricating oil effects on the transient performance of a turbocharged diesel engine. *Energy*, *35*(2), 864–873. https://doi.org/10.1016/j.energy.2009.08.009

Gulzar, M., Masjuki, H. H., Kalam, M. A., Varman, M., & Rizwanul Fattah, I. M. (2015). Oil filter modification for biodiesel-fueled engine: A pathway to lubricant sustainability and exhaust emissions reduction. *Energy Conversion and Management*, *91*, 168–175. https://doi.org/10.1016/j.enconman.2014.11.055

Hasannuddin, A. K., Yahya, W. J., Sarah, S., Ithnin, A. M., Syahrullail, S., Sugeng, D. A., … Ramlan, N. A. (2018). Performance , emissions and carbon deposit characteristics of diesel engine operating on emulsion fuel. *Energy*, *142*(x), 496–506. https://doi.org/10.1016/j.energy.2017.10.044

Holmberg, K., Andersson, P., Nylund, N. O., Mäkelä, K., & Erdemir, A. (2014). Global energy consumption due to friction in trucks and buses. *Tribology International*, *78*, 94–114. https://doi.org/10.1016/j.triboint.2014.05.004

IDC Technologies. (n.d.). *Diesel Power Generating Plants*.

Izadyar, N., Ong, H. C., Chong, W. T., Mojumder, J. C., & Leong, K. Y. (2016). Investigation of potential hybrid renewable energy at various rural areas in Malaysia. *Journal of Cleaner Production*, *139*, 61–73. https://doi.org/10.1016/j.jclepro.2016.07.167

Langfitt, Q., & Haselbach, L. (2016). Coupled oil analysis trending and life-cycle cost analysis for vessel oil-change interval decisions. *Journal of Marine Engineering and Technology*, *15*(1), 1–8. https://doi.org/10.1080/20464177.2015.1126468

M. S. N. Samsudin, M. M. Rahman, M. A. W. (2016). Power Generation Sources in Malaysia : Status and Prospects for Sustainable Development. *Journal of Advanced Review on Scientific Research*, *25*(September), 11–28.

Motamen Salehi, F., Morina, A., & Neville, A. (2017). The effect of soot and diesel contamination on wear and friction of engine oil pump. *Tribology International*, *115*(May), 285–296. https://doi.org/10.1016/j.triboint.2017.05.041

Murtonen, T. (2004). *THE EFFECT OF LUBRICATION OIL ON THE FUEL CONSUMPTION OF HEAVY- DUTY DIESEL ENGINE*.

Musthafa, M. M. (2016). Synthetic lubrication oil influences on performance and emission characteristic of coated diesel engine fuelled by biodiesel blends. *Applied Thermal Engineering*, *96*, 607–612. https://doi.org/10.1016/j.applthermaleng.2015.12.011

Nasrudin Abd Rahim, Islam, M. R., & Rahman, S. (2010). Rural Electrification in Malaysia. *International Conference "Innovations for Renewable Energy,"* (September), 20–23.

Ong, H. C., Mahlia, T. M. I., & Masjuki, H. H. (2011). A review on energy scenario and sustainable energy in Malaysia. *Renewable and Sustainable Energy Reviews*, *15*(1), 639–647. https://doi.org/10.1016/j.rser.2010.09.043

Patil, N. S. (n.d.). *Diesel Electric Power Plant*.

Priyanka Mankale, Sunita Tambakad, J. S. . (2014). *Operation of Diesel Power Plant*.

RMK11. (2015). *Ucapan Perdana Menteri YAB Dato' Sri Mohd Najib bin Tun Haji Abdul Razak Semasa Membentangkan Usul Tentang Rancangan Malaysia Kesebelas*.

Shukla, A., Zhang, Y., Dubey, P., Margrave, J. L., & Shukla, S. S. (2002). *The role of sawdust in the removal of unwanted materials from water*. *95*, 137–152.

Stanley, D. R. (1988). Correlating Lube Oil Filtration Efficiencies With Engine Wear. *Society Of Automotive Engineers (SAE)*.

Thomsen, C. J., Avenue, M., & Durham, C. (2006). Filtration of Oil and Related Benefits. *LUBMAT*, 1–8.

Vencl, A., & Rac, A. (2014). Diesel engine crankshaft journal bearings failures : Case study. *ENGINEERING FAILURE ANALYSIS*, *44*, 217–228. https://doi.org/10.1016/j.engfailanal.2014.05.014

Wire, N. N. (2018). *Machinery Lubrication*. Retrieved from Machinery Lubrication: https://www.machinerylubrication.com/Read/31218/lubrication-failure-study