UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS

JUDUL: ANALYSIS OF REDUCTION OF PARTICULATE MATTER CONCENTRATION AND SIZE DISTRIBUTION OF DI DIESEL ENGINE BY SEA WATER SPRAY

SESI PENGAJIAN: 2011/2012

Saya, **PRAMNATH A/L RAVI (850516-08-5123)**
(HURUF BESAR)

mengaku membenarkan tesis (Sarjana Muda / ~~Sarjana / Doktor Falsafah~~)* ini disimpan di perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Tesis ini adalah hakmilik Universiti Malaysia Pahang (UMP).
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (√)

[ ]	**SULIT**	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
[ ]	**TERHAD**	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi / badan di mana penyelidikan dijalankan)
[√]	**TIDAK TERHAD**	

Disahkan oleh:

______________________	______________________
(TANDATANGAN PENULIS)	(TANDATANGAN PENYELIA)
Alamat Tetap:	Nama Penyelia:
No 12, Taman Ayer Tawar 2, 32400 Ayer Tawar, Perak D.R.	**DR. AGUNG SUDRAJAD**
Tarikh: **18 JUN 2012**	Tarikh: **18 JUN 2012**

CATATAN: * Potong yang tidak berkenaan.

** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh tesis ini perlu dikelaskan sebagai SULIT atau TERHAD.

Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara Penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).

ANALYSIS OF REDUCTION OF PARTICULATE MATTER CONCENTRATION AND SIZE DISTRIBUTION OF DI DIESEL ENGINE BY SEAWATER SPRAY

PRAMNATH A/L RAVI

Report submitted in partial fulfillment of the requirements
for the award of Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JULY 2012

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

We certify that the project entitled "Analysis of Reduction of Particulate Matter Concentration and Size Distribution of DI Diesel Engine by Seawater Spray" is written by Pramnath A/L Ravi. I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

MR. IDRIS BIN MAT SAHAT
Examiner Signature

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality of this thesis is qualified for the award of the Bachelor of Mechanical Engineering.

Signature :
Name : DR.ENG. AGUNG SUDRAJAD
Position : SENIOR LECTURER
Date : 18th JUNE 2012

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :

Name : PRAMNATH A/L RAVI

MATRIC ID : MH08080

Date : 18th JUNE 2012

DEDICATION

I specially dedicate to my beloved family

and friends who have guided

and motivated me to complete this project.

ACKNOWLEDGEMENT

I am grateful and would like to express my sincere gratitude to my supervisor Dr. Eng. Agung Sudrajad for his germinal ideas, invaluable guidance and continuous encouragement. He has always impressed me with his outstanding professionalism. I am truly grateful for his support and guidance throughout completing this project successfully. Other than that, I also would like to thank Mr.Idris Bin Mat Sahat, who reviewed and certified that my thesis is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering.

I would also like to take this opportunity to thank my lab mates and the staffs of the Universiti Malaysia Pahang Mechanical Engineering Department, who helped me in various ways and made my final year project a success.

I acknowledge my sincere gratitude to my family members for their unconditional love and support. I acknowledge the sincerity of my best friend, who consistently encouraged and supported me to carry out my project while facing critical problems.

Finally, to individuals who have involved directly nor indirectly in succession of this research and thesis writing. I could never adequately express my appreciation to all of them. Hope all will continuously support throughout my future undertakings.

Thank you.

ABSTRACT

Air pollution is a major environmental problem in most of the developing countries in the world. Air pollution is largely contributed as a consequence of the combustion of fossil fuels. Air pollutants are able not only to cause harm to our health but also to our environment. The after combustion or exhaust by the internal combustion engines, especially by compression ignition (CI) engines produces a complex mixture of pollutants that comprises both primary emissions, such as diesel soot particles, lead and sulfate particles formed from the burning of sulphur-containing fuel. The aim of this project is to measure reduction of diesel particulate matter (DPM) by diesel engine experiment using seawater spray and to utilize natural seawater. The diesel engine experiment was conducted with YANMAR TF120M single cylinder four stroke direct injection diesel engine set-up at variable engine speed namely at 2400, 2100, 1800, 1500 and 1200 rpm with and without seawater spray. An average of 26.1 % of DPM, 27.8 % of SOF and 19.5 % of DS has been reduced by using the seawater spray system. Overall DPM diameter size distribution able to be reduced.

ABSTRAK

Pencemaran udara merupakan salah satu masalah utama alam sekitar di kebanyakan negara membangun di dunia. Penyumbang utama pencemaran udara adalah pembakaran bahan api fosil. Pencemaran udara bukan sahaja mendatangkan kemudaratan kepada kesihatan kita tetapi juga kepada alam sekitar. Hasil pembakaran enjin terutamanya enjin diesel menghasilkan campuran bahan pencemar yang kompleks yang terdiri daripada partikel, plumbum dan zarah sulfat yang terbentuk dari hasil pembakaran bahan api yang mengandungi sulfur. Tujuan projek ini adalah untuk mengukur pengurangan partikel diesel dengan dan tanpa penggunaan semburan air laut serta menggunakan sumber air laut semulajadi. Eksperimen telah dijalankan dengan menggunakan enjin modal Yanmar TF120M satu silinder 4 lejang suntikan terus pada kelajuan 2400, 2100, 1800, 1500 dan 1200 rpm dengan dan tanpa semburan air laut. Sebanyak 26.1 % DPM, 27.8 % SOF dan 19.5 % DS dapat dikurangkan secara puratanya dengan menggunakan sistem semburan air laut. Diameter saiz taburan partikel diesel dapat dikurangkan secara kesuluruhannya.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

%	Percentage
°C	Degree Celcius
$\mu g/m^3$	Micrograms per Cubic Meter
avg	Average
kg	Kilogram
ℓ/min	Liter per Minute
mg	Milligram
mm	Millimeter
Σ	Total Sum
π	Pi
rpm	Rotation per Minute

LIST OF ABBREVIATIONS

API	American Petroleum Institute
BDC	Bottom Dead Centre
CI	Compression Ignition
CO	Carbon Monoxide
DI	Direct Injection
DOE	Department of Environment
DPM	Diesel Particulate Matter
DS	Dry Soot
EPA	Environmental Protection Agency
FESEM	Finite Element Scanning Electronic Microscope
H_2O	Water
He	Hydrocarbons
NAAQS	National Ambient Air Quality Standards
NO_x	Nitrogen Oxides
O_2	Oxygen
PAHs	Polycyclic Aromatic Hydrocarbons
PM	Particulate Matter
RMAQG	Recommended Malaysian Air Quality Guidelines
SOF	Soluble Organic Fraction
TDC	Top Dead Centre
UMP	Universiti Malaysia Pahang
WAP	Wax Appearance Point

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Air pollution is still a major environmental problem in most developing and developed countries. There are different types of air pollutants that are able to not only cause harm to our health but also to our environment. Air pollution arises largely as consequences of fossil fuels combustion for transport, power generation and other human activities.

Compression ignition (CI) engine also known as diesel engine uses diesel as fuel source to produce thermal energy. Most heavy-duty vehicles operate on diesel engines, because these engines can provide high power-to-weight ratios or high torque and higher thermal efficiency (Rajan et al., 2009). Diesel engine uses the heat of compression to ignite and burn the air-fuel mixture, which is injected into the combustion chamber during end of compression stroke. Unfortunately, after combustion the diesel engine produces harmful waste products. The after combustion or exhaust by internal combustion engines, especially by CI engines produces a complex mixture of pollutants that comprises both primary emissions such as diesel soot particles, lead and products of atmospheric transformation, such as ozone and sulfate particles formed from the burning of sulfur-containing fuel. Usually, internal combustion engines produces four major emissions which is hydrocarbons (He), carbon monoxide (CO), oxides of nitrogen (NO_x), and particulates.

The main focus of this project is to analyze the reduction of diesel particulate matter (DPM) concentration and size distribution of direct injection diesel engine by sea water spray. The main testing apparatus that are used for this project is a single cylinder direct injection diesel engine model YANMAR TF 120M. Figure 1.1 shows global emissions by sector.

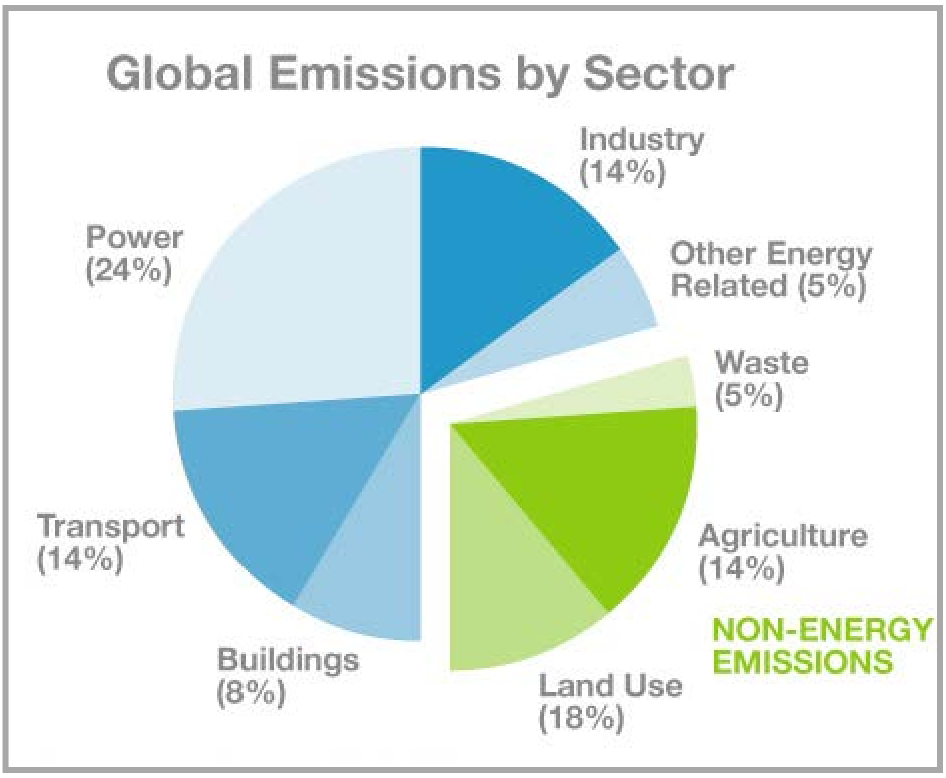


Figure 1.1: Global emissions by sector

Source: http://www.enviro.aero

1.2 PROBLEM STATEMENTS

Nowadays, with the increased usage of diesel engine vehicles, the emission of harmful diesel particulate matter (DPM) from diesel engines has become a serious concern because of its believed threat to cause cancer. Recent studies have linked DPM to acute pulmonary problems (such as bronchitis and asthma) and cardiovascular problems (such as congestive heart failure and ischemic heart disease), which may result in hospitalization or, in some cases, premature mortality (EPA, 1997). Worldwide, it is estimated to cause about 9 % of lung cancer deaths, 5 % of cardiopulmonary deaths and 1 % of respiratory infection deaths (WHO, 2012).

DPM not only contributes to health related problems but also a major cause of hazy conditions resulting in reduced visibility especially during the dry season. To overcome these problems, diesel exhaust after treatment can be utilized to control diesel emissions.

1.3 PROJECT OBJECTIVE

The main objective of this project is to measure reduction of diesel particulate matter (DPM) by diesel engine experiment using seawater spray and the second objective is to utilize natural seawater.

1.4 PROJECT SCOPES

The scopes of this project are to:

a) Design and construct sea water scrubber system
b) Setup sea water spray into diesel experiment rig
c) Experiment with diesel engine
d) Analysis exhaust emission by PM measurement
e) Calculate DPM Size Distribution

CHAPTER 2

LITERATURE REVIEW

2.1 PARTICULATE MATTER (PM)

Particulate matter (PM) is the term used for a mixture of solid particles and liquid droplets suspended in the air. Particulates originate from a variety of natural and human sources. Natural particulates originate from volcanoes, dust storms and forest or grassland fires. On the other side, human activities also generate significant amounts of particulates through burning of fuels in vehicles, power plants and various industrial processes. Particulate matter is characterized according to size. Particles less than 10 micrometers in diameter (PM_{10}) have an aerodynamic diameter between 2.5 mm and 10 mm, also referred to as “inhalable coarse particles”. Meanwhile, particles less than 2.5 micrometers in diameter ($PM_{2.5}$) are referred to as “fine particles” (EPA, 1997).

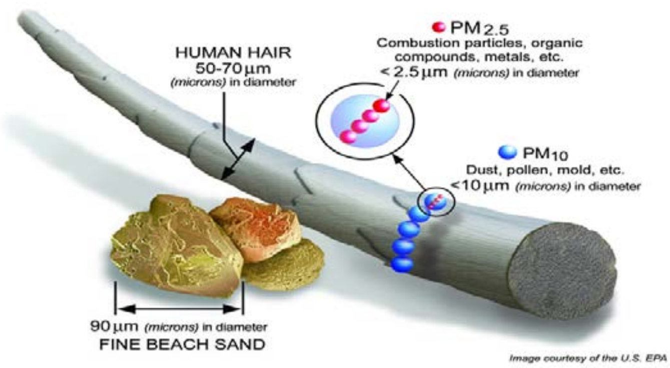


Figure 2.1: Comparison of $PM_{2.5}$ and PM_{10} with human hair

Source: http://www.epa.gov/ord/ca/quick-finder/particulate-matter-image.htm

Several epidemiological studies have linked PM_{10} and particularly $PM_{2.5}$ with significant health problems, including premature mortality, chronic respiratory disease, respiratory emergency room visits and hospital admissions, aggravated asthma, acute respiratory symptoms, and decreased lung function. Like the other criteria pollutants, the elderly, whose physiological reserves decline with age and who have higher prevalence of cardio respiratory conditions, and children, whose respiratory systems' are still developing and who spend more time outdoors, are most at risk from exposure to particulate matter. Particulate matter does not only cause health effects, it but also plays a role in the producing greenhouse effect and global warming, because of its contribution to cloud formation. Particulate matter also reduces visibility (haze), levels of nutrients in soil and diversity in ecosystems.

2.1.1 Diesel Particulate Matter (DPM)

Diesel engines are employed in light-duty applications such as passenger cars, light trucks and in heavy-duty usage for larger trucks, buses, locomotives, ships as well as agricultural and construction equipment. Diesel usage is popular due to its cheaper cost than conventional gasoline. Diesel engines also have several advantages over gasoline or spark-ignition engines. These include increased fuel efficiency, decreased emissions of carbon monoxide and hydrocarbons and 10 % to 25 % less emission of carbon dioxide, which has implications in reducing global warming (Hammerle et al., 1994). However, diesel engines suffer from higher emissions of nitrogen oxides (NO_x) and particulate matter (PM) (Song et al., 2008). Diesel particulate matter (DPM) emitted from diesel engines has been of great concern globally because of adverse effects on human health and the environment (Betha and Balasubramanian., 2011). Particulate matter from diesel engines is basically un-burnt carbon core having adsorbed soluble organic fraction, like un-burnt or partially burnt hydrocarbons and lubricating oil (Dilip et al., 2010).

Diesel particles consist of an elemental carbon core and a large number of adsorbed substances. Some investigations showed that 3-rings and higher polycyclic aromatic hydrocarbons (PAHs) were generally bound to the particles (Lev-On M et al., 2004). Diesel PM are composed of dry soot (DS) and soluble organic fraction (SOF).

The DS consists of small solid carbon particle, sulfate, and metal. SOF consists of volatile materials that are produced from un-burnt fuel, oil lubricator and partially oxidized fuel and oil (Ariana et al., 2007). Several studies have reported public health-related problems such as airway inflammation, cellular inflammation, and lung cancer on exposure to DPM (Betha and Balasubramanian., 2011). Diesel exhaust materials have been estimated to contribute some 20-80% mass of the particle fraction of PM10 (Richards et al., 1997).

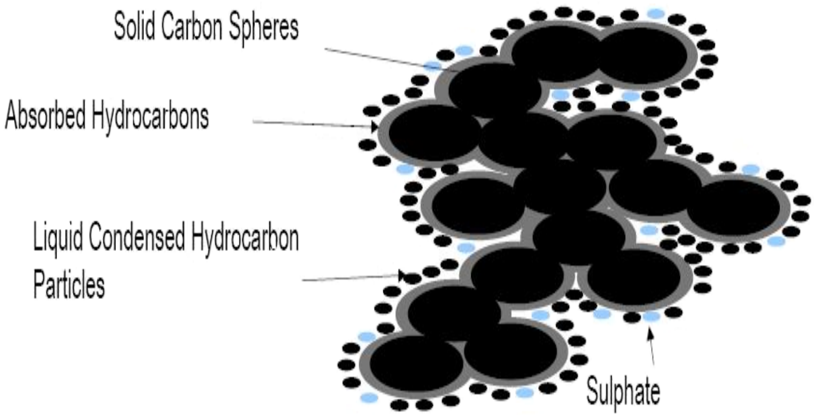


Figure 2.2: Illustration of PM aggregation

Source: Ariana et al. (2007)

2.1.2 Particulate Matter 10 (PM_{10})

PM_{10} are particulates which have aerodynamic diameter smaller than 10 micrometers or more strictly, particles which pass through a size selective inlet with a 50 % efficiency cut-off at 10 micrometers aerodynamic diameter (Zieliński, 1998). This pollutant can cause eye and throat irritation and the accumulation of particulate matter in the respiratory system is associated with numerous respiratory problems namely decreased lung function. High levels of particulate matter can also pose health risk to sensitive groups such as children, the elderly and individuals with asthma or cardiopulmonary diseases.

PM_{10} can also cause undesirable impact on the environment. The presence of high levels of PM_{10} in the atmosphere is a major cause of hazy conditions, resulting in reduced visibility especially during the dry season. Other environmental impacts can occur when particulate matter is deposited onto soil, plants, water or other materials. Depending on the chemical composition of these substances, when particulate matter is deposited in sufficient quantities, it may change the nutrient balance and acidity in soil, interfere with plant metabolism and change the composition of the materials.

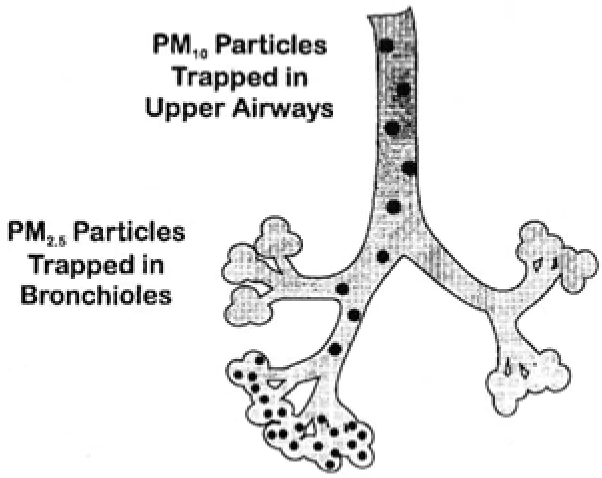


Figure 2.3: Deposition of PM_{10} in the respiratory tract

Source: Ariana et al. (2007)

2.1.3 Health Effects of Particulate Matter

Numerous scientific studies have linked particle pollution exposure to a variety of problems, including (www.epa.com):

- increased respiratory symptoms, such as irritation of the airways, coughing, or and difficulty in breathing; , for example;
- decreased lung function;
- aggravated asthma;
- development of chronic bronchitis;

- irregular heartbeat;
- nonfatal heart attacks; and
- premature death in people with heart or lung disease.

The effects of the particulate matter to both elderly and children by groups are as shown below (www.epa.com):

❖ The Elderly:

- Studies estimate that tens of thousands of elderly people die prematurely each year from exposure to ambient levels of fine particles.
- Studies also indicate that exposure to fine particles is associated with thousands of hospital admissions each year. Many of these hospital admissions are elderly people suffering from lung or heart disease.

❖ Individuals with Preexisting Heart or Lung Disease:

- Breathing fine particles can also adversely affect individuals with heart disease, emphysema and chronic bronchitis by causing additional medical treatment. Inhaling fine particulate matter has been attributed to increased hospital admissions, emergency room visits and premature death among sensitive populations.

❖ Children:

- The average adult breathes 13,000 liters of air per day; children breathe 50 percent more air per pound of body weight than adults.
- Because children's respiratory systems are still developing, they are more susceptible to environmental threats than healthy adults.
- Exposure to fine particles is associated with increased frequency of childhood illnesses, which are of concern both in the short run and for the future development of healthy lungs in the affected children.

- Fine particles are also associated with increased respiratory symptoms and reduced lung function in children, including symptoms such as aggravated coughing and difficulty or pain in breathing. These can result in school absences and limitations in normal childhood activities.

❖ Asthmatics and Asthmatic Children:

- More and more people are being diagnosed with asthma every year. Fourteen Americans die every day from asthma, a rate three times greater than just 20 years ago. Children make up 25 percent of the population, but comprise 40 percent of all asthma cases.
- Breathing fine particles, alone or in combination with other pollutants, can aggravate asthma, causing greater use of medication and resulting in more medical treatment and hospital visits.

2.1.4 Particulate Matter Standards

EPA revised the air quality standards for particle pollution in 2006. The 2006 standards tighten the 24-hour fine particle standard from the current level of 65 micrograms per cubic meter ($\mu g/m^3$) to 35 $\mu g/m^3$ and retain the current annual fine particle standard at 15 $\mu g/m^3$. The Agency decided to retain the existing 24-hour PM_{10} standard of 150 $\mu g/m^3$ (EPA, 2006). Units of measure measurement for the standards are micrograms per cubic meter of air ($\mu g/m^3$).

Table 2.1: National Ambient Air Quality Standards for Particle Pollution

Pollutant	Primary Stds.	Averaging Times
Particulate Matter (PM_{10})	Revoked 150 $\mu g/m^3$	Annual 24-hour
Particulate Matter ($PM_{2.5}$)	15.0 $\mu g/m^3$ 35 $\mu g/m^3$	Annual 24-hour

Source: EPA (2006)

However in Malaysia, standards for air quality are not available. PM_{10} concentrations in ambient air in Malaysia are monitored based on Recommended Malaysian Air Quality Guidelines (RMAQG) at a threshold of 150 µg/m^3 for 24 hour average and an annual means of 50 µg/m^3 (DOE, 1989).

Table 2.2: Recommended Malaysian Air Quality Guidelines

Pollutant	Primary Stds.	Averaging Times
Particulate Matter (PM_{10})	50 µg/m^3 150 µg/m^3	Annual 24-hour

Source: DOE (1989)

2.1.5 Particle Filter Dust Measurement and Data Arrangement

The number of particle is n_p with conclude in cohesion is advocated by (Wibawaningrum, 2004) and calculated by this formula:

$$n_p = \left(\frac{Aa}{a_p}\right)^{1.15} \qquad \text{or : } Aa = a_p \,.\, n_p^{\;0.87} \tag{2.1}$$

Where, A_a is cohesion of projection and A_p is one ball dust. Cohesion from V_a (volume) becomes:

$$V_a = n_p \left(\frac{\pi . da^3}{6}\right) = \left(\frac{Aa}{Ap}\right)^{1.15} . \;\frac{\pi . da^3}{6}$$

Diameter for one particle can be calculated with this formula:

$$D_a = da \,.\, np^{\frac{1}{3}} = d_a \left(\frac{4.Aa}{\pi . da^2}\right)^{0.383} \tag{2.2}$$

Where, d_a is the diameter of the dust in cohesion is almost same. $K_v = 1$, where K_v is factor the number of diameter to calculate fusion volume collection between ball dust.

Then, change cohesion we devise some number of cohesion (Na), calculate all equal value projection area. Then, calculate all equal value projection area, change cohesion device some number of cohesion (Na)

$$A_a = \left[\sum_{i=1}^{Na} Aai^{1,15} \right]^{1/1,15} \tag{2.3}$$

Where, A_{ai} is cohesion projection area in inside of change cohesion and N_a is number of cohesion. Average diameter of dust at position is Np, diameter (dp) of Np simple dust and Da of Na cohesion or change cohesion.

And N = Na + Np which are simple ball dust, cohesion and change cohesion contain the picture at same point are about 100-300 and we define some of average diameter by

(a) $\overline{D_A}$ is Arithmetic Mean Diameter

$$\overline{D_A} = \frac{\sum Da + dp}{N} \tag{2.4}$$

(b) $\overline{Dg}$ = Geometric Mean Diameter or Logarithmic Mean Diameter

$$\overline{Dg} = \exp\left(\frac{\sum \ln Da + \sum \ln dp}{N}\right) \tag{2.5}$$

2.2 DIESEL ENGINE HISTORY

A German engineer named Rudolf Diesel invented the diesel internal combustion engine. Rudolf Diesel has filed the patent of the method and design for the diesel engine on February 27th 1892 at the patent office in Germany. After Rudolf Diesel filed the patent, the inventor attempted to construct the most efficient engine. In year 1893, Rudolf Diesel successfully came out with the first diesel engine model with an efficiency of approximately 26 %. After a few more years, Rudolf Diesel accomplished a great achievement by producing a diesel engine that operates at 75 % efficiency. In the 1920's this diesel engine was then redesigned into a smaller and compact model. The development of the diesel engine is continued and was redesigned by many other inventors (Bosch, 2004).

Diesel internal combustion engine is a heat engine that converts the chemical energy into mechanical energy. From the energy produced, the mechanical parts in the engine will move, such as the piston and the crankshaft. Movement of the mechanical parts will produce kinetic energy that drives the vehicle.

Figure 2.4: Internal combustion engine

Source: Bosch (2004)

2.2.1 Diesel Cycle

Working procedure of a diesel engine is the same as a gasoline engine, but there are a few differences in parts compared to gasoline engine. The diesel engine differs from gasoline engine primarily in the way the combustion process occurs. Fuel ignites on its own for diesel engines where else for gasoline engines, fuel is ignited by the spark created from the spark plug. There are two types of diesel engine, which are the 2-stroke and 4-stroke engine.

Two-stroke engine

Two-stroke cycle diesel engines are very similar to four stroke cycle engines, except that this engines do not have separate intake and exhaust strokes. Instead, exhaust occurs at the end of the expansion or power stroke and continues into the early part of the compression stroke. Meanwhile, in intake process the air flow into the cylinder and exhaust gas flow out of the cylinder are controlled by conventional poppet valves in the cylinder head. Two-stroke engine combustion occurs in region of the top dead centre (TDC) of every revolution.

The advantage of the two-stroke cycle is that it generates more power for a given engine size due to the power generated on every other stroke, rather than every fourth stroke. The disadvantages are the emissions are higher with a two-stroke cycle than with a four-stroke cycle and the fuel efficiency can be marginally poorer. However, the engines are still common in uses such as large marine industries.

Four-stroke engine

The most common type of diesel engine used today has reciprocating pistons and uses a four-stroke operating cycle. In the first stroke (intake stroke), the intake valve opens while the piston moves down from its highest position in the cylinder (TDC) to its lowest position (BDC). Once the piston reaches to BDC position, the intake stroke ends and the compression stroke will start. In this stroke, the piston will move upward and will compress the air to 30 – 55 bars in the combustion chamber.

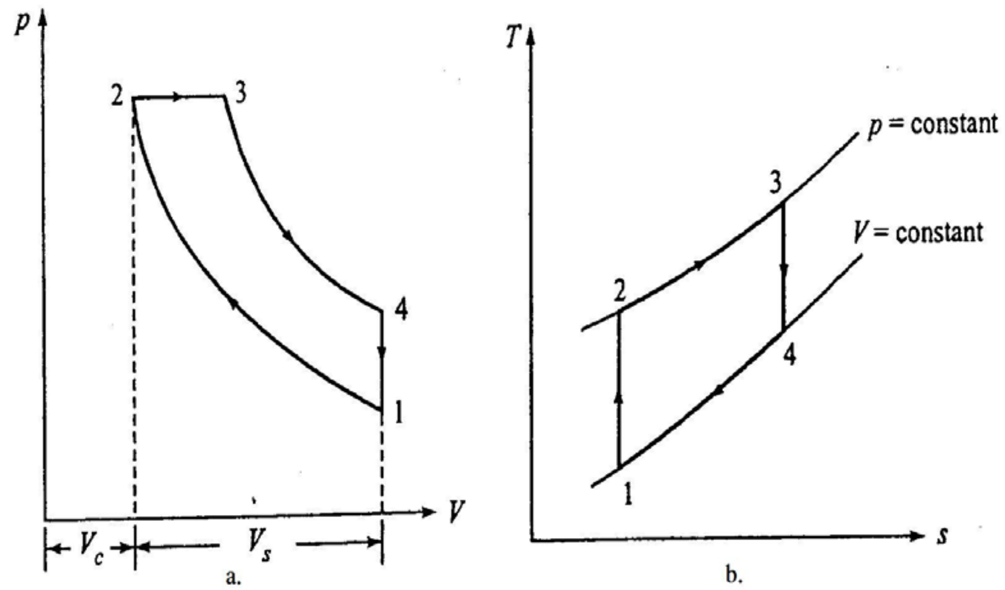


Figure 2.5: Diesel cycle: (a) p-V diagram and (b) T-s diagram

Source: Gupta (2006)

When the piston starts to move upward, both valves is closed as to prevent air leakage from the combustion chamber. Due to compression, the air will be highly charged with thermal energy. This stroke will be over, when the piston reaches TDC position.

When the air is fully compressed, the combustion stroke will start. In this stroke, fuel is injected at just the right moment and ignited. The heat produced by compressed air ignites the fuel in the diesel engine. The energy developed from the combustion will force the piston back down to BDC position again. When this stroke occurs, both valves are closed. Once the piston reached BDC position, the piston will move back to TDC position again, this movement of the piston is marked as the exhaust stroke.

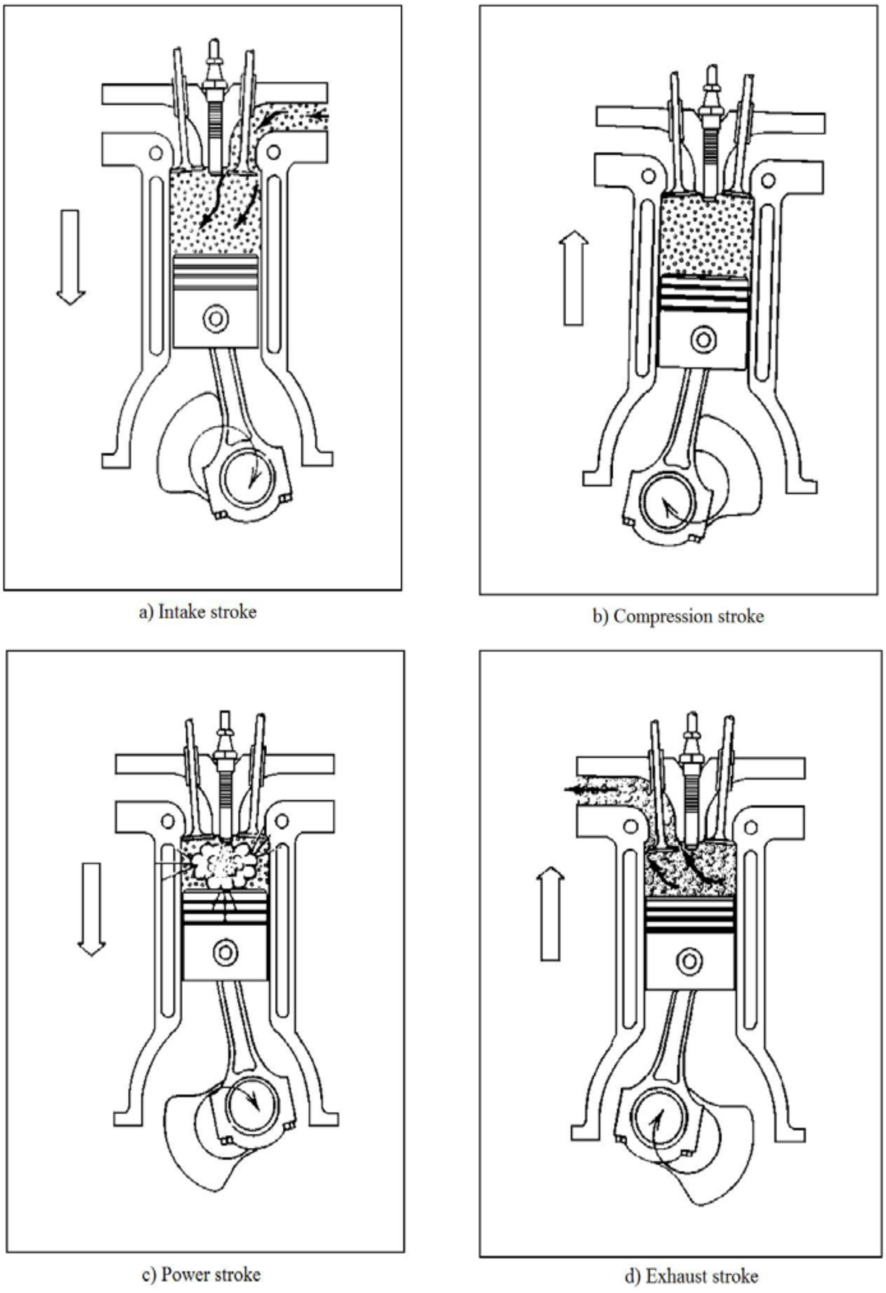


Figure 2.6: Operating cycle of a four-stroke diesel engine

Source: Bosch (2004)

When this stroke occurs, the intake valve is closed where else the exhaust valve is opened. When the piston moves to TDC position, it will force the exhaust gas to move out from the combustion chamber. After the exhaust stroke is over, the cycle will continue with intake stroke again as shown in Figure 2.6.

2.3 DIESEL FUEL CHARACTERISTICS

Diesel engines are designed to use diesel oil as fuel. Diesel fuel is also made from petroleum. Normally, the petroleum is separated into three major components: gasoline, middle distillates, and all remaining substances. Diesel fuel comes from the middle distillate group, which has properties and characteristics different from gasoline.

Density

Diesel engines have a predictable variation in power output depending on the density of the fuel used. Relative density of fuels is usually expressed in degrees American Petroleum Institute (API) gravity. A fuel with a high density will have a low API gravity, and vice versa. The formula for determining API gravity is:

$$\text{API Gravity (deg.)} = (141.5/\text{Specific Gravity @ } 60^{\circ}\text{F}) - 131.5 \qquad (2.7)$$

Engines using fuels with a high density (low API gravity) will produce more power than those using fuels with lower densities (higher API gravities) because the thermal energy content of the fuel is higher. Low API gravity fuels have higher energy content than high API gravity fuels. A general rule of thumb is that there is approximately a 3 percent to 5 percent decrease in the thermal energy (Btu) content of fuel for every 10-degree increase in API gravity.

Viscosity

In addition to power variations due to the fuel density, variations in power output can be due to differences in fuel viscosity. Diesel fuel must be able to flow easily through the fuel system and be sprayed by the injectors. This requires the diesel fuel to have a low viscosity. The viscosity of diesel fuel directly affects the spray pattern of the fuel into the combustion chamber. Viscosity must be just high enough to provide lubrication to the fuel injectors and fuel pump. However, it must not be so high as to produce large droplets that are hard to burn. On the other hand, fuel with too low viscosity can create the following problems:

- Power variations due to changes in density with temperature changes. Viscosity deteriorates as temperatures increase.
- Hard restart with a hot engine.
- Rough idle.
- White exhaust smoke.
- Loss of torque due to the fine mist igniting too rapidly.
- Inadequate lubrication and cooling of the injection pump and nozzles.

Cloud Point and Pour Point

Since diesel fuels contain a wax base called paraffin, ambient temperatures affect diesel fuel more than it does to gasoline. As ambient temperatures drop to the wax appearance point (WAP) or cloud point of the fuel, the wax crystals grow larger. If cold enough, the crystals will enlarge enough to restrict the flow of fuel through the filters and lines. Eventually, the fuel will stop flowing as a result of the wax crystals plugging the fuel filter of lines. The better the quality of the fuel, the lower the cloud point achieved. As ambient temperatures continue to drop, the fuel will reach its pour point where it solidifies and no longer flows.

Volatility

Diesel fuel is not as volatile as gasoline. The amount of carbon residue left by diesel by diesel fuel depends on the quality and the volatility of that fuel. Fuel that has a low volatility is much more prone to leaving carbon residue. The small, high-speed diesels found in automobiles require a high quality and highly volatile fuel because they cannot tolerate excessive carbon deposits. Large, low-speed industrial diesels are relatively unaffected by carbon deposits and can run on lower quality fuel.

Cetane Rating

Diesel fuel's ignition quality is measured by the cetane rating. Much like the octane number, the cetane number is measured in a single-cylinder test engine with a variable compression ratio. The diesel fuel to be tested is compared to cetane. The higher the cetane number assigned to the diesel fuel, the shorter the ignition lag time (delay time) from the point the fuel enters the combustion chamber until it ignites. Cetane rating for diesel fuel and the octane rating for gasoline are not the same. The higher the cetane rating, the easier the fuel is ignited, whereas the higher the octane rating, the slower the fuel is ignited. The possible problems resulting from use of a fuel with too low of a cetane rating shown as below:

- Poor ignition quality.
- Long ignition lag.
- Abnormal combustion.
- Abnormally high combustion pressure.
- Uneven thrust on piston and cylinder.
- Loud engine knock.

Fuels with a high cetane number will burn as soon they are rejected, so no knock occurs. The lower the cetane number, the higher the temperature required to ignite the fuel. If the cetane number is too low for the conditions, the fuel will take too long to light and will build up in the cylinder. Engine knocking can occur under this condition when the fuel is burnt in too much quantity and out of control.

Flash Point

Flash point does not affect diesel engine operation but a lower-than-normal flash point could indicate contamination of the diesel fuel with gasoline or a similar substance.

Sulfur Content

The sulfur content of diesel fuel is very important to the life of the engine. Sulfur in the fuel creates sulfuric acid during the combustion process that can damage engine components and cause piston ring wear.

Diesel Fuel Grades

Minimum quality standards for diesel fuel grades have been set by ASTM International. The commonly used fuel grades are described.

Grade 1

Grade 1 (number 1) diesel fuel is thinner, more volatile and it is used at very low temperatures. It has the lowest boiling point and the lowest cloud and pour points. As a result, grade 1 is suitable for use during low-temperature operation. Grade 1 may be specified for use in diesel engines involved in frequent changes in load and speed such as those found in city buses and delivery trucks. The API gravity of number 1 is between 48 and 34 degrees, thus it has a Btu rating per gallon of 134,637.

Grade 2

Grade 2 (number 2) diesel fuel has a lower volatility than number 1 fuel. Number 2 diesels is the most commonly specified fuel to be used for most driving conditions. Number 2 fuel has a higher boiling range, cloud point and pour point as compared with number 1. The API gravity of number 2 diesel is between 40 and 24 degrees, thus it has a Btu rating per gallon of 139,457.

Grade 4

Grade 4 has a very high boiling range and is designed for use in low-speed engines running under a constant load. Grade 4 is used mainly in stationary power plants and ships and not as an automotive fuel. In colder climates, number 1 diesel fuel is blended with the number 2 to improve starting. In moderately cold climates, the blend may be 90 percent number 2 and 10 percent number 1. In very cold climates, the blend may be as high as 50/50. Diesel fuel economy can be expected to drop off during the winter months due to the use of number 1 diesel in the fuel blend.

Cleanliness

It is imperative that the fuel used in a diesel engine is clean and free from water. Unlike the case with gasoline engines, the fuel is the lubricant and coolant for the diesel injection pump and injectors. Good quality diesel fuel contains additives such as oxidation inhabitors, detergents, dispersants, rust preventives and metal deactivators.

Additives

Additives, a long-standard feature in gasoline's, has become commonplace as quality improvers in diesel fuels. The various agents are generally combined in additive packages to achieve a variety of objectives. The total concentration of additives is normally about < 0.1 %. This does not change physical parameters of fuels such as density, viscosity or the boiling curve.

Lubricity enhancers

It is possible to improve the lubricity of diesel fuel which has poor lubrication properties by adding fatty acids, fatty-acid esters or glycerin. Biodiesel is also a fatty-acid ester. In this case, if diesel fuel already contains a proportion of biodiesel, no further lubricity enhancers are added.

Cetane Improvers

Cetane improvers are nitric acid esters of alcohols added to shorten ignition lag. They reduce emissions and combustion noise.

Flow Improvers

Flow improvers consist of polymer substances that lower the filtration limit. Normally, it is added in winter to ensure trouble free operation at low temperatures. Although flow improvers cannot prevent the precipitation of paraffin crystals from diesel fuel, it can severely limit their growth.

Detergent additives

Detergent additives are used to keep the intake system clean. They can also inhibit the formation of deposits and reduce the buildup of carbon deposits on the injection nozzles.

Corrosion inhibitors and Antifoaming agents (defoamants)

Corrosion inhibitors are deposited on the surfaces of metal parts and protect them against corrosion if water is entrained. Adding defoamants helps to avoid excessive foaming when the vehicle is refueled quickly. Effects of the diesel-fuel additives shown in Table 2.3;

Table 2.3: Effects of the most important diesel-fuel additives

Additives	**Effects**
Cetane improvers	Increase cetane number
Detergents	Keep nozzle cleaner
Flow improvers	Improve reliability at low temperatures
Wax anti-setting additives	Improve storage properties at low temperatures
Lubricity	Reduce fuel-injection component wear especially with hydrogenated low-sulfur fuels
Antifoarming additives	Make refueling easier (reduce tendency to slosh over)
Anticorrosive additives	Protect the fuel system

Source: Bosch (2004)

2.4 SEAWATER CHARACTERISTICS

Seawater is composed mostly of water (H_2O). Salinity is the term used to describe the concentration of inorganic dissolved salts in seawater. These dissolved ions make seawater a good conductor of electricity. The characteristics of the seawater are shown in Table 1.

Table 2.4: Characteristics of natural seawater sample

Parameters	Value	Parameters	Value
pH	8	Ca^{2+}(mg/L)	421
TDS (mg/L) Total Dissolved Solids	34,475	Mg^{2+} (mg/L)	1,395
Cl^{-} (mg/L)	19,860	Ba^{2+} (µg/L)	8
SO_4^{2-} (mg/L)	2,665	Sr^{2+} (µg/L)	765
HCO_3^{-} (mg/L)	251	Boron (mg/L)	4.7
Na+ (mg/L)	14,039	DOC (mg/L) Dissolved Organic Carbon	1.45

Source: Oh et al. (2009)

CHAPTER 3

RESEARCH METHODOLOGY

3.1 PROJECT FLOW CHART

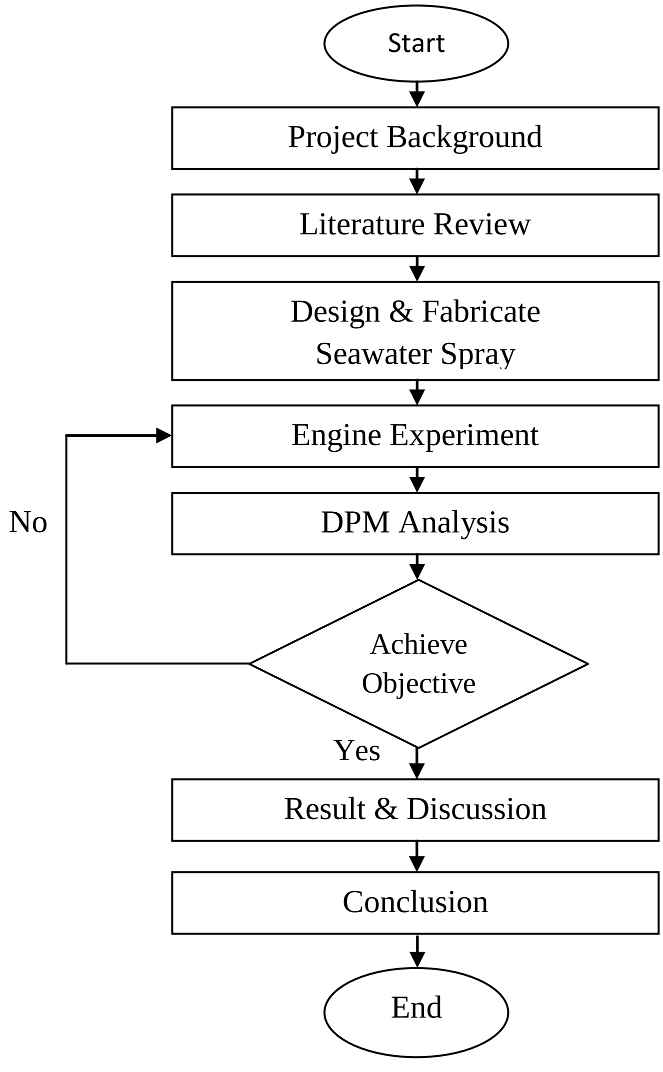


Figure 3.1: Project flow chart

3.2 PROCESS FLOW DESCRIPTION

In order to complete this project as per schedule, flow chart as in Figure 3.1 was used as a guideline. This project was started by conceiving the title and defining the objectives and scopes of the project. The objectives and scopes were the navigator of this project.

After specifying the project background, objectives and scopes, the project was continued by findings for literature review. The literature review was carried out by reviewing journals, books, research on the internet and other related sources. In this part, data by previous researchers were gathered and used as a guidance and additional information. Concurrently, the seawater spray tank was designed using solid work and fabricated using stainless steel. After that, the project was continued by setting up the fabricated seawater spray tank on experiment rig where the electrolyzed seawater were pumped using a plastic impeller centrifugal pump.

Moving forward, the project was followed by research methodology. In this part, the methods to conduct the engine experiment were delivered. Through experiment with variable engine speed, samples were taken by using filter before and after seawater spray system to find the reduction in the amount of particulate matter produced.

After completing the experiment, the experimental outcome data were analyzed based on the project objective and scopes. The findings and the obtained experimental data were compiled into a chapter which includes introduction, literature review, methodology, analysis, discussion and conclusion according to the format provided by the faculty. Finally, PowerPoint slides were prepared for presentation of this project.

3.3 LITERATURE REVIEW

Literature review helps to gather information about the seawater spray system and to understand the objective of the project. Sources of the information are books, journals, internet and the project supervisor. The books referred provided information on diesel engine management, diesel engine fuel and emissions. Meanwhile, journals provided more information about the seawater scrubber, methods used, percentage of reduction and seawater electrolysis. Journals mostly were downloaded from the internet which is in (.pdf) format. Project supervisor's advice and guidance made the findings more related to achieve the project objective.

3.3.1 Books

Book is a good source to gather information about a specific matter that is related to the research. Books such as Diesel-Engine Management from Bosch and Automotive Fuels and Emissions provided significant give more information regarding diesel fuel and fuels characteristics. These books can be found in UMP Library.

3.3.2 Journals

Journal reference was done to understand previous researches that are related to this project. Journals have wide information on proven results from the experiments and analysis. Science Direct website provides quality journals.

3.3.3 Project Supervisor

The information that has been gathered from books and journal became more valuable and helpful with the guidance of project supervisor. Project supervisor's advice and opinion is really helpful to complete this literature review.

3.4 SEAWATER SPRAY DESIGN

Seawater spray tank have to be designed in SOLIDWORK before fabrication. Since the tank will be sprayed with seawater, the material for fabrication that came into consideration is either zinc or stainless steel sheet metal. Considering long term usage, stainless steel sheet metal was chosen to fabricate the tank according to the dimension which was designed in SOLIDWORK earlier. The seawater spray tank consists of one exhaust inlet and one exhaust outlet two inch stainless steel pipes. Two, half inch stainless steel pipes was also built for the gas analyzer and exhaust gas temperature sensor. The tank has two see through surface which was made from prospect to view the spraying pattern. It also has a spray jet nozzle which was used for home car wash and three water outlets. Seawater from reservoir tank will be pumped out to the seawater spray tank to treat the diesel engine exhaust gas. The after treat water will be drained through the outlet to the filter before recycle process starts.

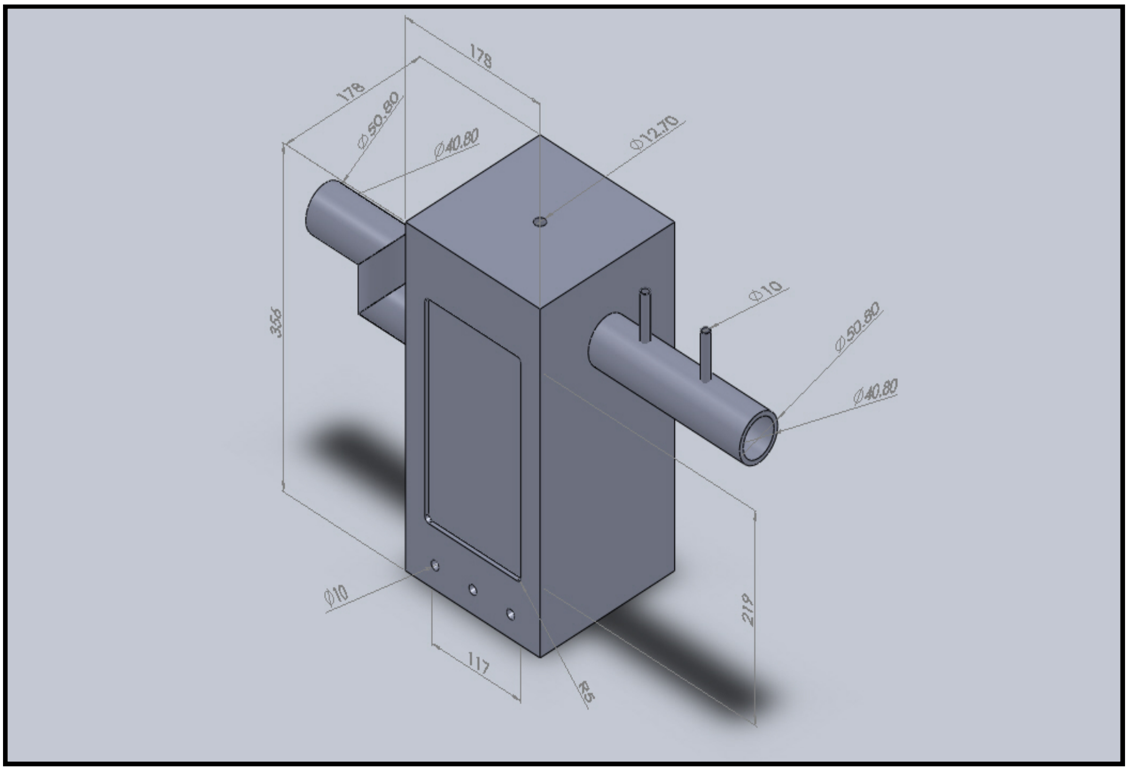


Figure 3.2: Seawater spray tank SOLIDWORK design

3.5 APPARATUS

3.5.1 Diesel engine and specification

The engine model used for this experiment is YANMAR TF-120M. It is a single cylinder water cooled diesel engine. The engine specifications are as shown in the table below:

Table 3.1: Experimental Engine Specification

Description	Specification
Displacement	638 cc
Bore and Stroke	92 x 96
Max Output	12BHP@2400RPM
Continuous Output	10.5BHP@2400RPM
Cooling System	Water cooled, Radiator
Starting System	Electrical and Handle by hand
Dimension (L/W/H)	685/350/530
Weight	120kg

This engine has a total of 638 cubic capacity and has a 12 brake horse powers for maximum output and 10.5 brake horse powers for continuous output. The engine weighs 120 kilograms and it can be started using electrical starter.

Figure 3.3: YANMAR TF-120M Engine

3.5.2 Exhaust gas temperature sensor

Exhaust gas temperature sensor functions to sense the temperature of the exhaust gas. Thermocouple acts as the sensor and it is placed at the specially made slots on the exhaust pipe.

Figure 3.4: Thermostat

Temperature display unit will be fixed together with this thermostat so that the temperature reading could be displayed on it. The seawater spray tank also has a specially made slot for the thermostat to sense temperature of exhaust gas after treatment.

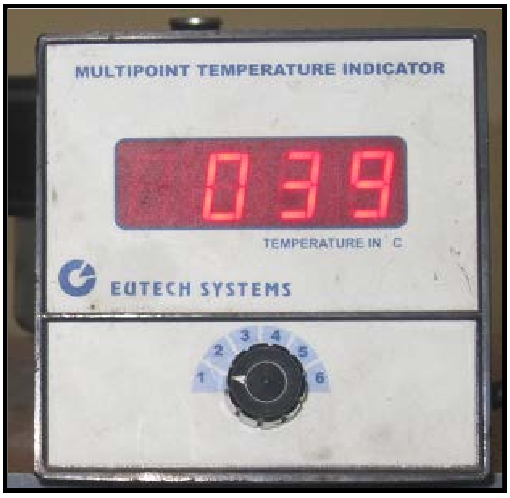


Figure 3.5: Temperature display unit

3.5.3 Electronic Analytical Balance Specification

Sartorius BSA 224 S-CW model is an electrical analytical balance used for weighing the filter to obtain accurate reading. This balance has weighing ranges up to 220 mg.

Figure 3.6: Electronic analytical balance

This model comes with an internal motorized calibration and adjustment weight. Press the CAL key and the balance will calibrate and adjust automatically.

Table 3.2: Experimental Electronic Analytical Balance Specification

Description	Specification
Model	BSA224S-CW
Readability	0.0001g
Weighing capacity	220g
Pan size diameter	90mm
Repeatability	0.0001g
Linearity	0.0002g
Response time	2.5sec (avg)

3.5.4 Oven

This equipment heat-up the filter before it used to take sample. The purpose to heat-up the filter is to get rid of particles on the surface and to equalize initial condition where the filter receives heat while collecting the sample in the aluminium filter holder. The filter heat-up process was done at 50 ˚C for two hours.

Figure 3.7: Oven

3.5.5 Disposable Petri Dish

This disposable Petri dish is made of plastic. It is used to store filters which have the sample and it is easy to be labelled too. The dimension of the Petri dish used for this experiment is 90mm x 15mm.

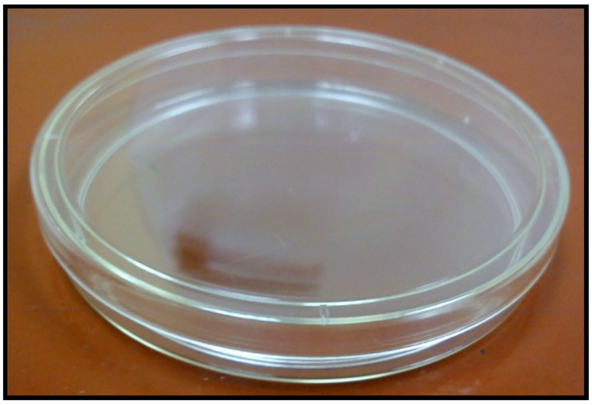


Figure 3.8: Disposable Petri dish

3.5.6 Filter

The filter is used to trap diesel particulate matter from the diesel engine exhaust gas. The filter will be fixed in the aluminium filter holder which will be connected to the air sampling pump.

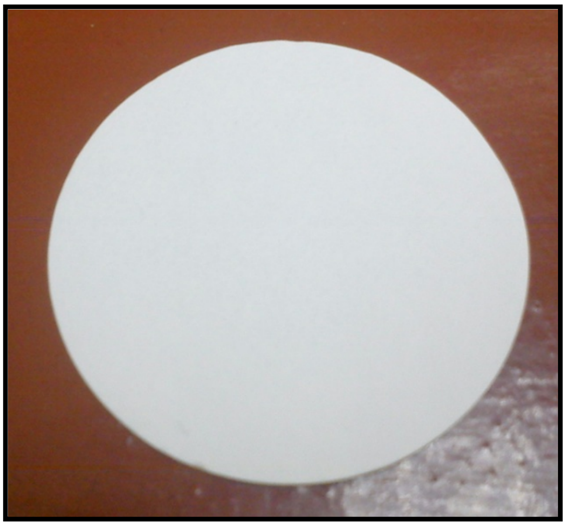


Figure 3.9: Filter

Table 3.3: Filter Specification

Description	**Specification**
Material	Composite
Mark	Advance
Size	$47mm^2$
Quality	100 leaf
Serial Number	305/9713
Manufacturer	Toyo Roshi Kaisya, Ltd

3.5.7 Dichloromethane

Dichloromethane is used to soak the filter. The filter will be soaked for 24 hours. The filter contains particulate matter including SOF that is not visible prior to soaking the sample filter in dichloromethane.

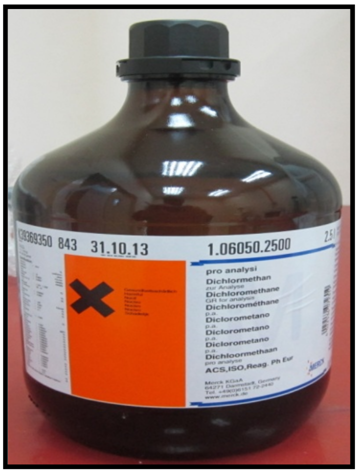


Figure 3.10: Dichloromethane

3.5.8 Air Sampling Pump and Aluminium Filter Holder

Air sampling pump is used to take sample from the diesel engine exhaust gas. This air sampling pump will be connected with a plastic pipe to an aluminium filter holder, where the filter will be placed in. The pump will be calibrated to trap particulate matter at 20ℓ/min (exhaust gas flow rate).

Figure 3.11: (a) Air Sampling Pump and (b) Aluminium Filter Holder

3.5.9 Portable pH Meter

Milwaukee model MW100 is a portable pH meter used to measure sea water pH level due to change in pH level during experiment.

Figure 3.12: Air sampling pump

Table 3.4: Portable pH Meter Specification

Description	Specification
Range	0.0 to 14.0 pH
Resolution	0.1 pH
Accuracy	±0.2 pH
pH Electrode	SE-220
Environment	0 to 50˚C, 95% RH max
Battery Type	1 X 9V alkaline
Battery Life	300hours of use
Dimension	143 X 80 X 32 mm
Weight	220g (with battery) meter only

3.6 EXPERIMENT SETUP

The experiment is conducted according to the engine test procedures. To start the experiment, the engine must be connected with the test apparatus such as seawater spray system, thermocouple, gas analyzer and engine rpm sensor. Once confirmed that all the apparatus are in functioning condition, the diesel particulate matter test can be carried out accordingly. The test can be proceeded with a starting speed of 1200 rpm and gradually proceed to 1500, 1800, 2100 and 2400 rpm respectively. The seawater supplied with a constant flow rate which is 5 ℓ/min and the seawater pH also tested which is 8.1 pH. Diesel particulate matter (DPM) will be trapped in the filter by the vacuum pump before and after seawater spray system.

The filter was heated in the oven at 50 ˚C for two hours. Then, the filter was weighed using the weight balance. This filter will be fixed in the vacuum pump to trap the diesel particulate matter at 20 ℓ/min (exhaust gas flow rate). This step is done before and after the seawater spray system as stated above. The filter which was used to trap the DPM was heated again in the oven at 50˚C for two hours. After that, the filter was weighed to find the DPM concentration. The collected data was recorded.

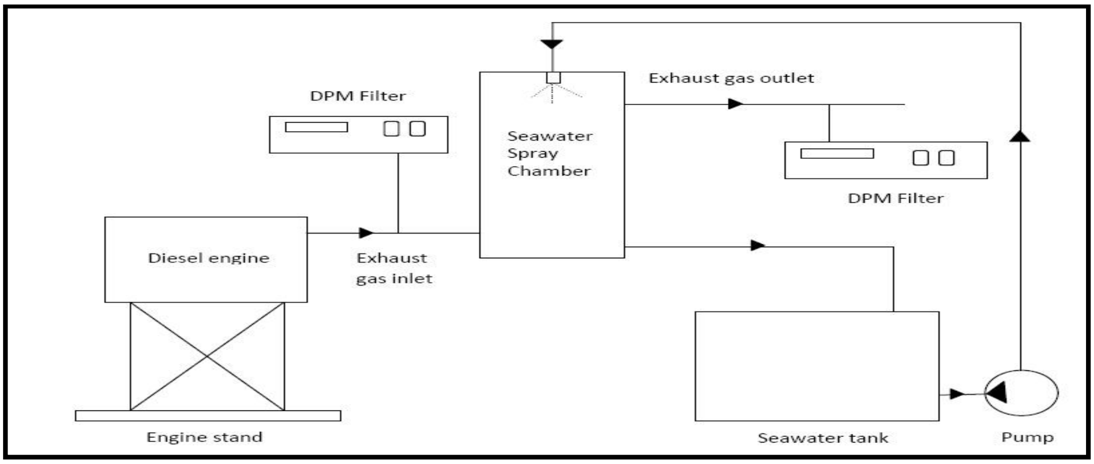


Figure 3.13: Schematic diagram of seawater spray system

The filter was then soaked in Dichloromethane solution for 24 hours. The purpose of soaking filter in Dichloromethane solution is to find out the size of soluble organic fraction and dry soot which contains in DPM. Next, the filter was heated again in the oven at 50 ˚C for two hours before weighing it. Finally, the scanning electronic microscope was used to find DPM size diameter. DPM formula was applied in calculating the diameter and size distribution. These steps were repeated for different engine speed as stated above.

3.7 DIESEL PARTICULATE MATTER ANALYSIS FLOW CHART

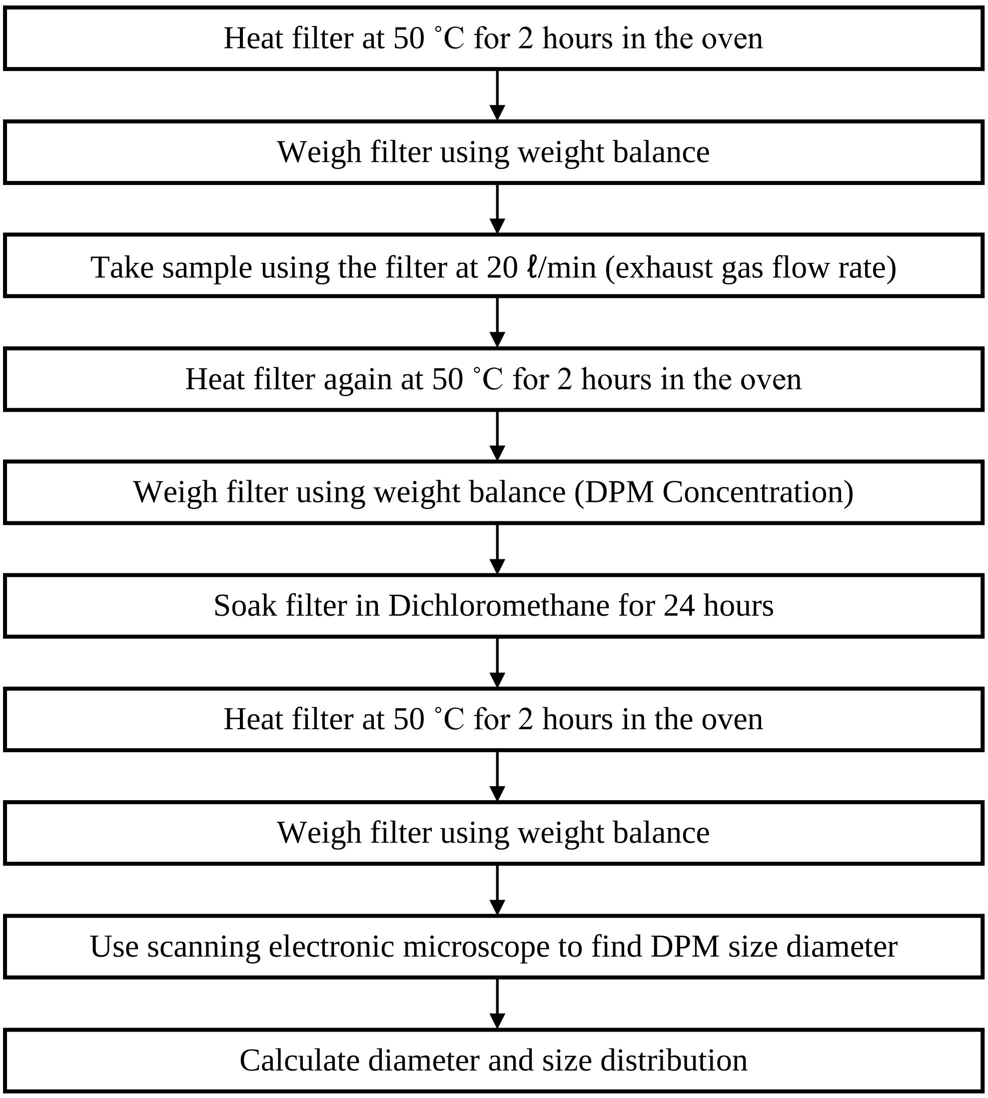


Figure 3.14: DPM analysis flow chart

CHAPTER 4

RESULTS AND DISCUSSION

4.1 FUEL CONSUMPTION

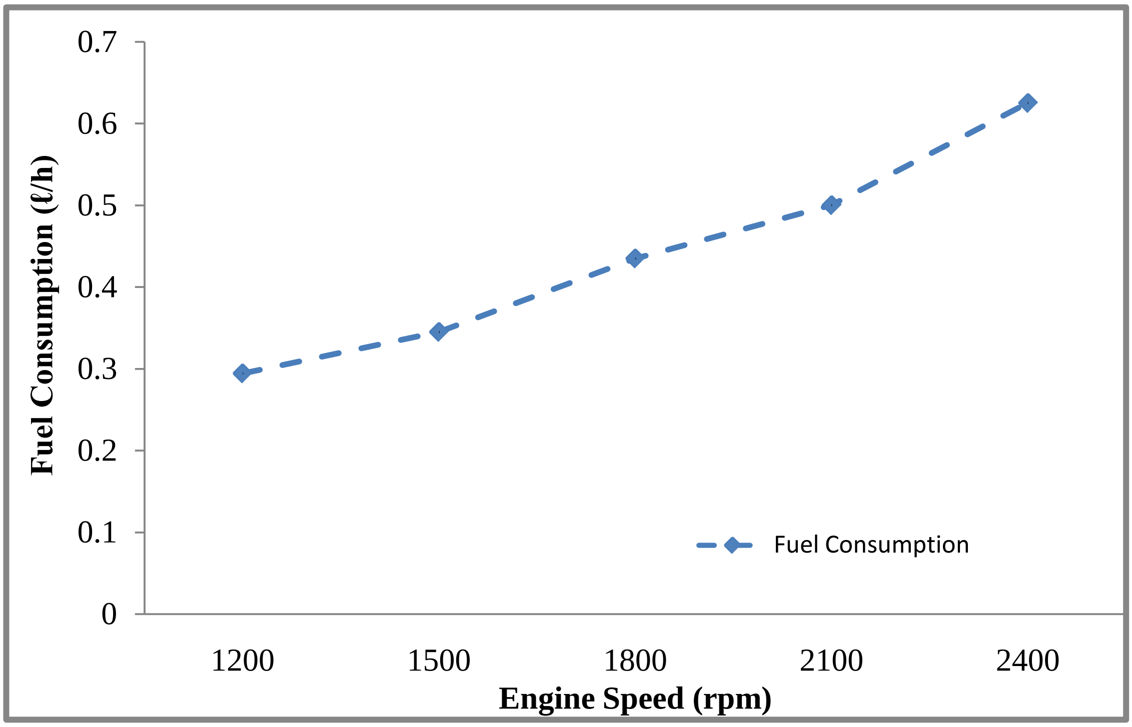


Figure 4.1: Fuel consumption versus engine speed

Fuel consumption (FC) is influenced by engine load and engine speed (rpm). In this experiment, the fuel consumption is calculated based on engine speed without load. Figure 4.1 shows the graph of fuel consumption versus engine speed. The engine was tested at 1200, 1500, 1800, 2100 and 2400 rpm respectively. When the engine speed increases, the fuel consumption also increases gradually due to the difference in air fuel ratio. The FC was measured by unit of liter per hour.

4.2 EXHAUST GAS TEMPERATURE

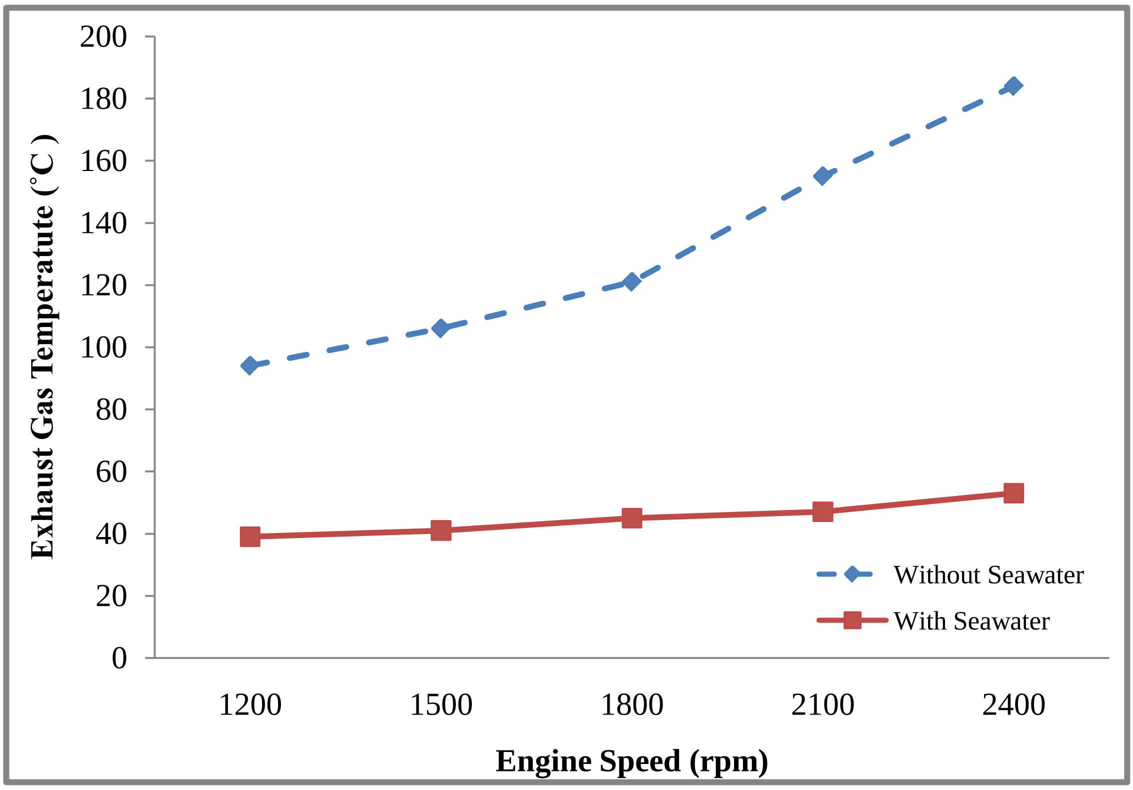


Figure 4.2: Exhaust gas temperature versus engine speed

The comparison of exhaust gas temperature with and without seawater spray versus engine speed (rpm) was also done and the results are as shown in Figure 4.2. Without seawater spray, exhaust gas temperature gradually increases from 94 ˚C to 106 ˚C, 121 ˚C, 155 ˚C and 184 ˚C respective to the increasing engine speed due to the amount of fuel burned in combustion chamber. According to the graph, usage of seawater spray decreases the exhaust gas temperature by 58.5 %, 61.3 %, 62.8 %, 69.6 % and 71.1 % respective to the increasing engine speed. According to Arianna et al. (2006) that the lower exhaust gas temperature will decrease number of particulate matter and also decreases exhaust gas viscosity. Other than that, the seawater spray droplets also traps the diesel particulate matter. In conclusion, by using seawater spray the exhaust gas temperature is lower compared to without usage of seawater spray which is due to the hot gas hit by the seawater spray in the spraying chamber.

4.3 SOLUBLE ORGANIC FRACTION (SOF)

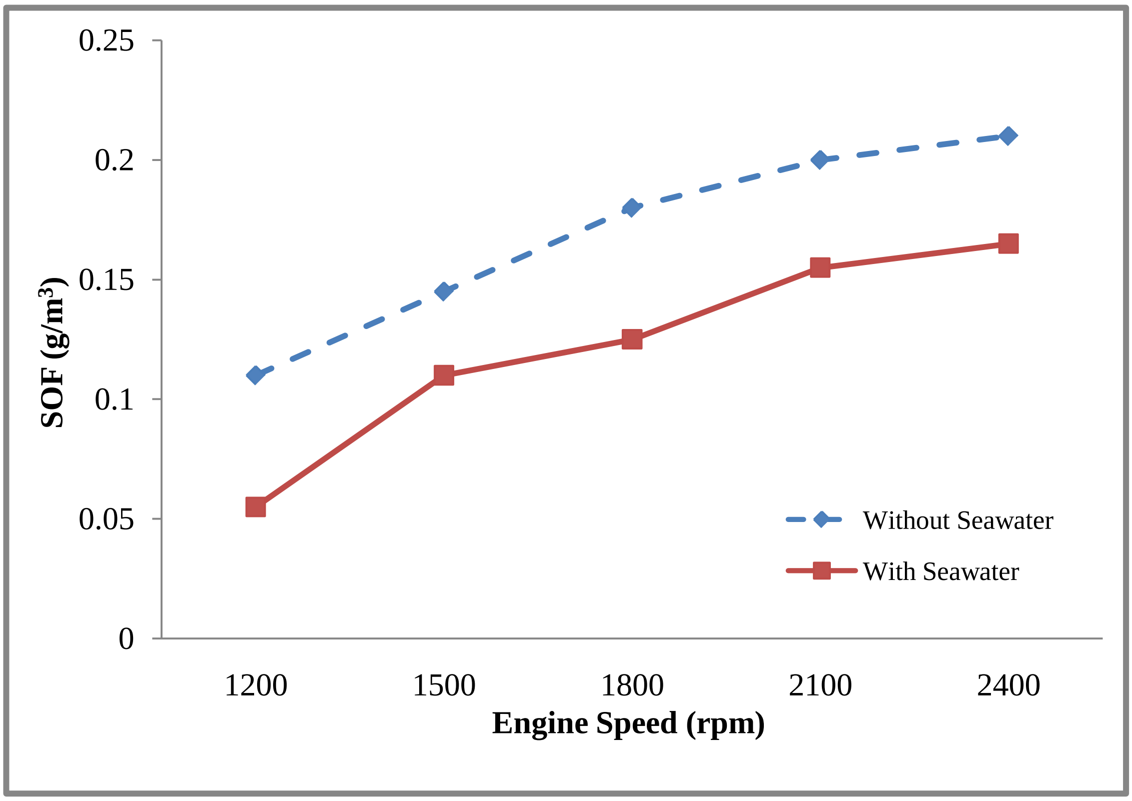


Figure 4.3: Soluble Organic Fraction (SOF) versus engine speed

According to Lin and Huang (2002) soluble organic fractions or termed as SOF, produced from the adsorption or condensation of hydrocarbons with heavy molecular weight onto the surface of the carbon particles which is formed from the sulphur content in fuel and when unburned completely. The SOF in diesel particulate matter consists of aldehydes, alkenes and alkanes, hydrocarbon aliphatic, polycyclic aromatic matter (PAH) and PAH-derivatives. Figure 4.3 shows the graph of soluble organic fraction (SOF) versus engine speed (rpm). The SOF increases gradually from 0.11, 0.145, 0.18, 0.2 and 0.21 g/m^3 respective to the increasing engine speed without using seawater spray due to formation of sulfur content and other composition in diesel fuel. The SOF could be reduced by using seawater spray by 50 %, 24.1 %, 30.5 %, 22.5 % and 21.4 % respective to the increasing engine speed. An average total of 27.8 % SOF was reduced. By using the seawater spray, the water droplets manage to trap the SOF from the exhaust gas which passes by the spraying chamber.

4.4 DRY SOOT (DS)

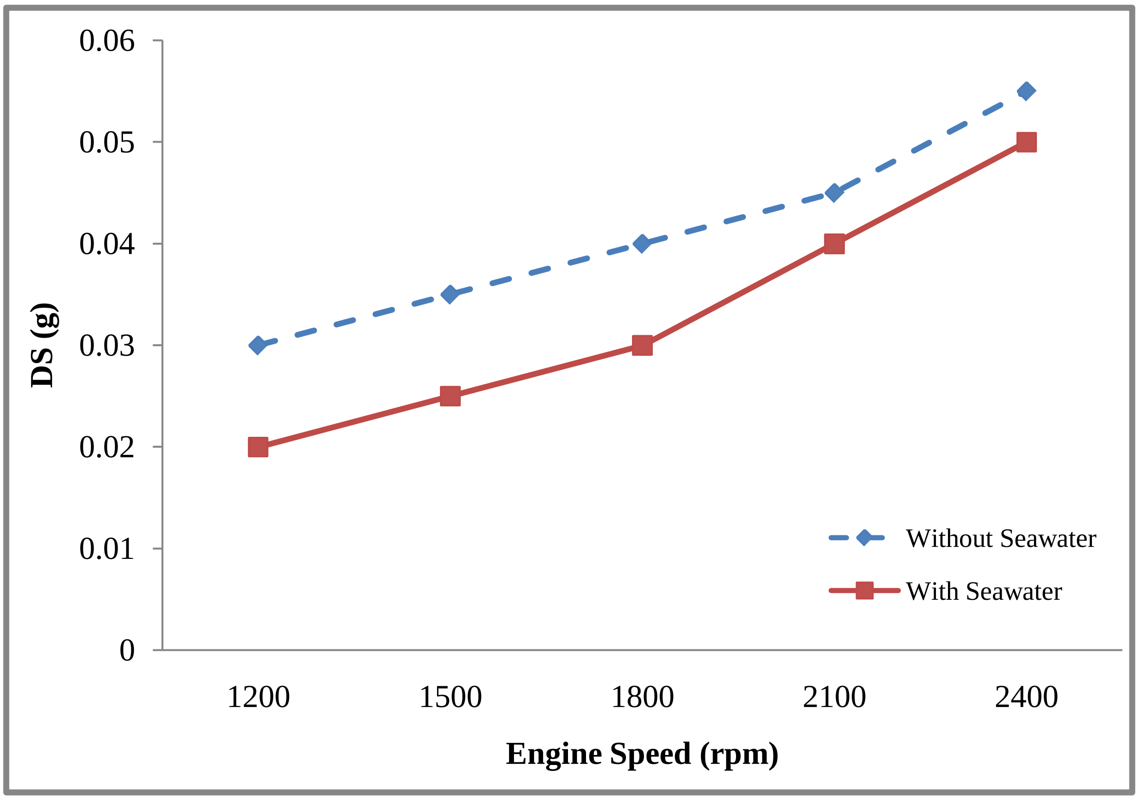


Figure 4.4: Dry Soot (DS) versus engine speed

DS that consist of small solid carbon particle, sulphate and metal are formed during combustion process. Referring to Figure 4.4 which shows the graph of dry soot (DS) versus engine speed (rpm), the DS value increases gradually from 0.03, 0.035, 0.04, 0.045 and 0.055 grams respective to the increasing engine speed without using seawater spray. This is due to carbon and sulfur content in fuel and from incomplete combustion. DS also can be formed from the composition of lubricating oil which burned during combustion. According to the graph, by using seawater spray 33.3 %, 28.5 %, 25 %, 11 % and 9 % DS were able to be reduced respective to the increasing engine speed. An average total of 19.5 % of DS is reduced by seawater spray contact in spraying chamber.

4.5 DIESEL PARTICULATE MATTER (DPM)

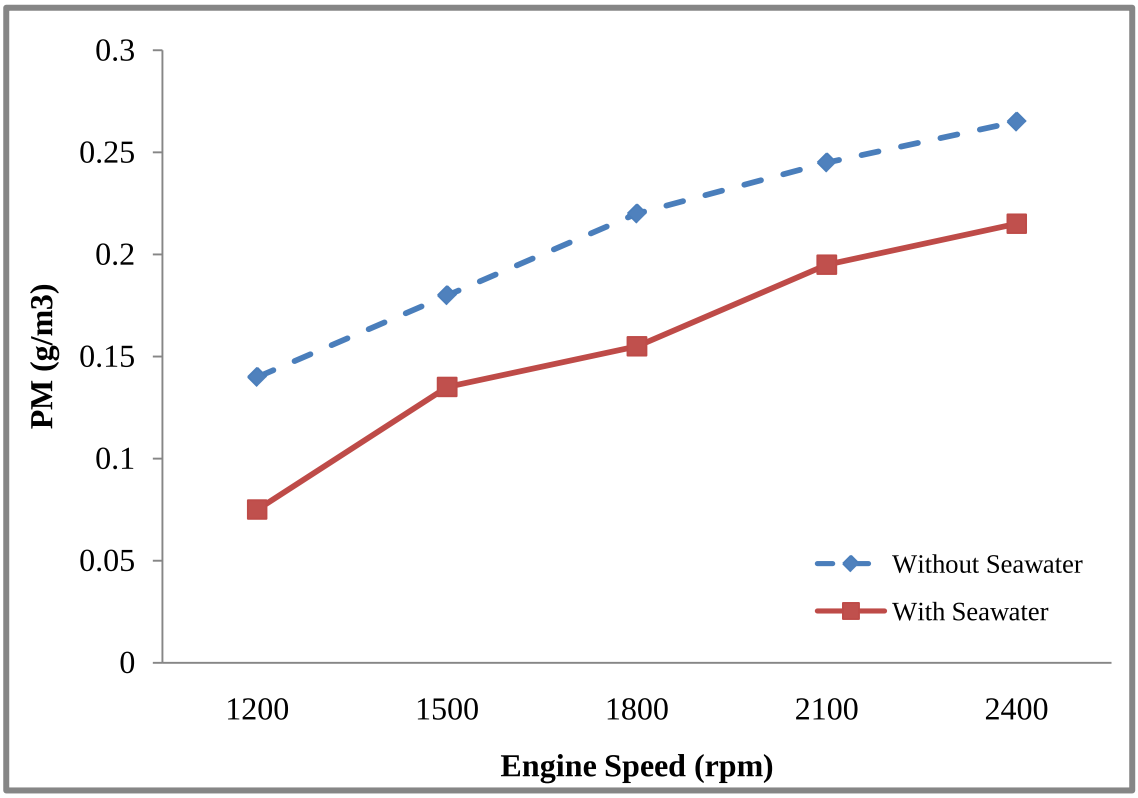


Figure 4.5: Diesel Particulate Matter (DPM) versus engine speed

According to Dilip et al. (2011) particulate matter from diesel engines is basically un-burnt carbon core having adsorbed soluble organic fraction, like un-burnt or partially burnt hydrocarbons and lubricating oil. Figure 4.5 shows the graph of diesel particulate matter (DPM) versus engine speed. The graph trend shows that DPM increases gradually from 0.14, 0.18, 0.22, 0.245 and 0.265 g/m^3 without using seawater spray due to the incomplete combustion. According to the graph, usage of seawater spray decreases the diesel particulate matter by 46.4 %, 25 %, 29.5 %, 20.4 % and 18.8 % respective to the increasing engine speed. According to An and Nishida (2003) seawater is naturally alkaline (pH typically around 8.1) and could remove diesel particulate matter through direct contact with the sprayed seawater droplets. An average total of 26.1 % of DPM were reduced through sprayed seawater droplets in spraying chamber.

4.6 DPM SIZE DISTRIBUTION

4.6.1 DPM Diameter for 1200rpm

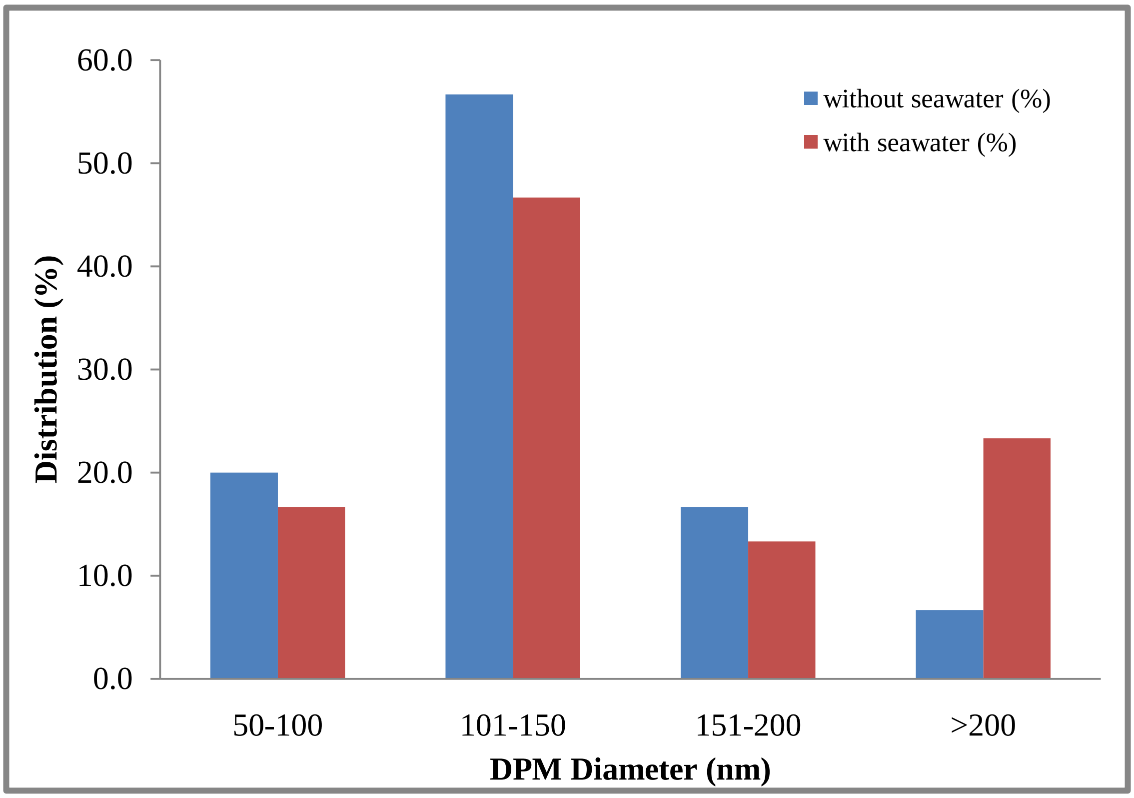


Figure 4.6: Distribution versus DPM Diameter for 1200rpm

Study was also conducted to configure the distribution percentage for various DPM diameter at various speed. Figure 4.6 shows the distribution percentage versus DPM diameter variation for 1200 rpm. The bar chart trend shows that by using seawater spray, the DPM diameter variation are smaller than without using seawater spray for range 50 to 100, 101 to 150 and 151 to 200 nm. The highest DPM distribution is 56.7 % without using seawater spray and 46.7 % with the usage of seawater spray in the range of 101 to 150 nm. Besides that, the lowest DPM distribution is 6.7 % without using seawater in the range above 200 nm and 13.3 % with using seawater in the range 151 to 200 nm. Refer to the appendix C1 for finite element scanning electronic microscope (FESEM) sample pictures.

4.6.2 DPM Diameter for 1500rpm

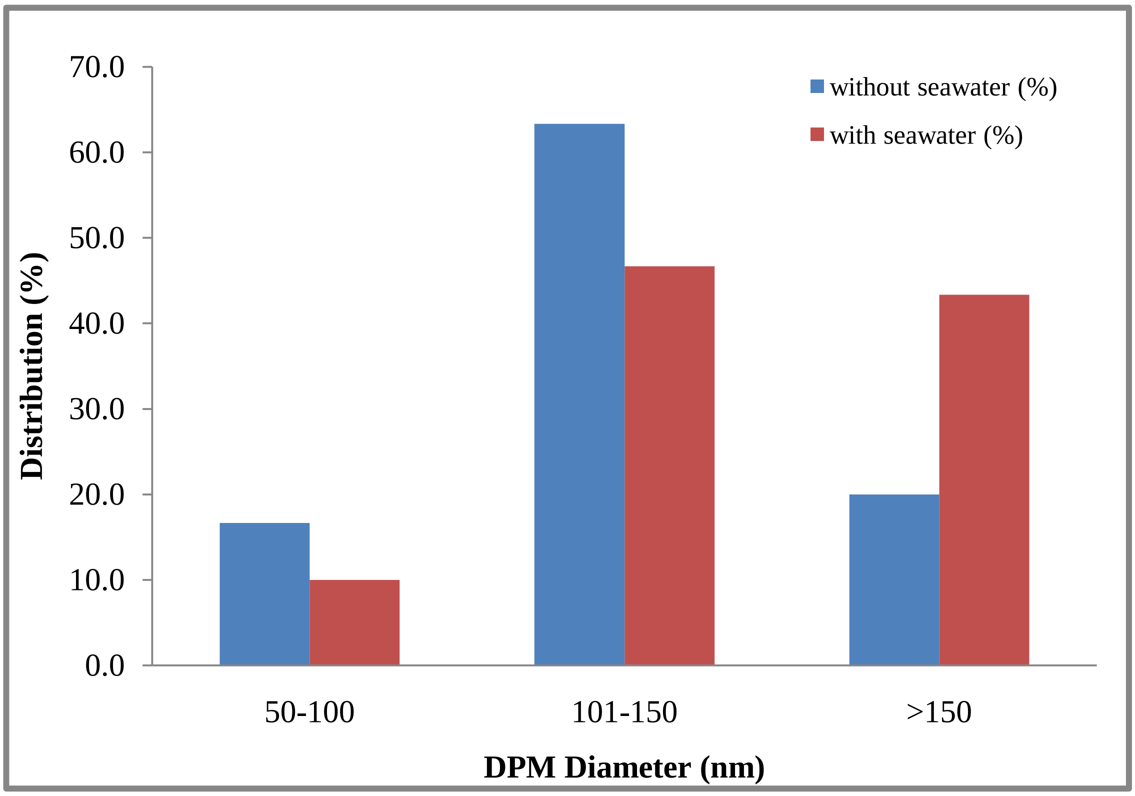


Figure 4.7: Distribution versus DPM Diameter for 1500rpm

The study was carried out at a different speed namely 1500rpm. Figure 4.7 shows the graph of distribution percentage versus DPM diameter variation for 1500 rpm. The bar chart trend shows that by using seawater spray, the DPM diameter variation is smaller than without using seawater spray for range 50 to 100 and 101 to 150. The highest DPM distribution is 63.3 % without using seawater spray and 46.7 % by using seawater spray in the range of 101 to 150 nm. Besides that, the lowest DPM distribution is 16.7 % without using seawater spray and 10 % by using seawater spray in the range of 50 to 100 nm. Refer to the appendix C2 for finite element scanning electronic microscope (FESEM) sample pictures.

4.6.3 DPM Diameter for 1800rpm

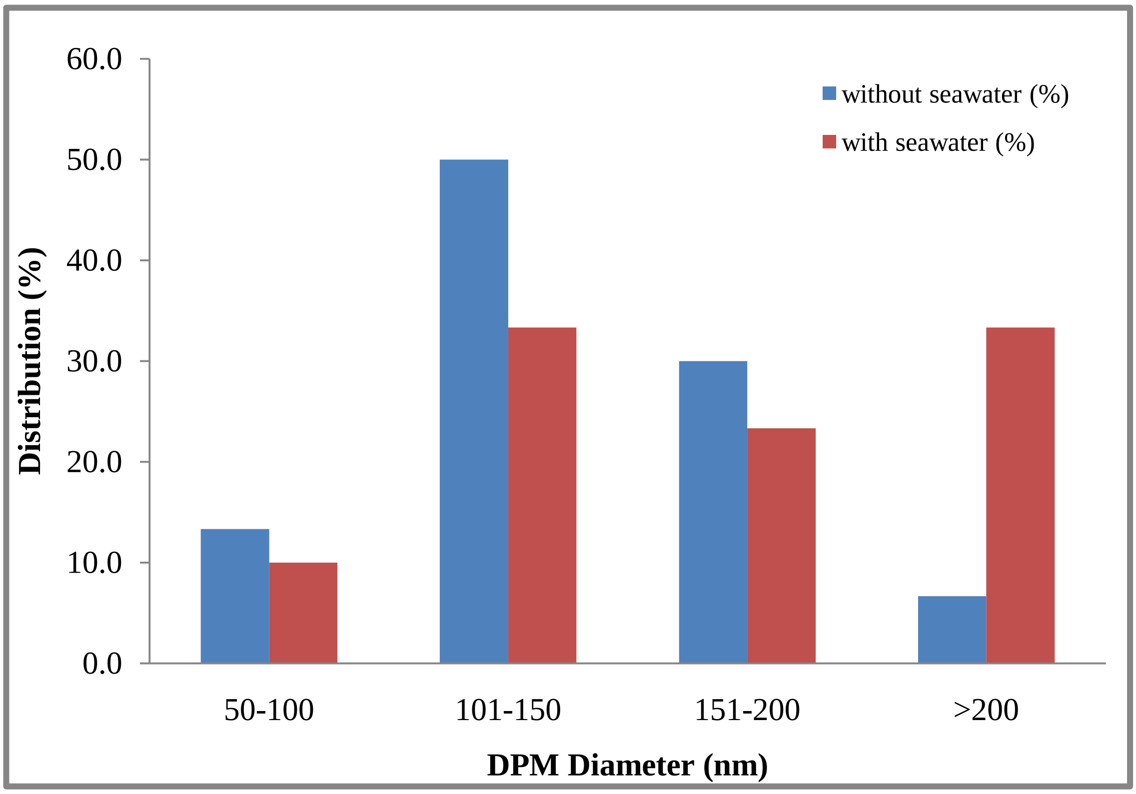


Figure 4.8: Distribution versus DPM Diameter for 1800rpm

A continuation of the experiment above was conducted at 1800rpm. Figure 4.8 shows the graph of distribution percentage versus DPM diameter variation for 1800 rpm. The bar chart trend shows that with seawater spray, the DPM diameter variation is smaller compared without using seawater spray for range 50 to 100, 101 to 150 and 151 to 200 nm. The highest DPM distribution is 50 % without seawater spray and 33.33 % with seawater spray in the range of 101 to 150 and above 200 nm. Besides that, the lowest DPM distribution is 6.7 % without seawater spray in the range above 200 nm and 10 % with seawater spray in the range 50 to 100 nm. Refer to the appendix C3 for finite element scanning electronic microscope (FESEM) sample pictures.

4.6.4 DPM Diameter for 2100rpm

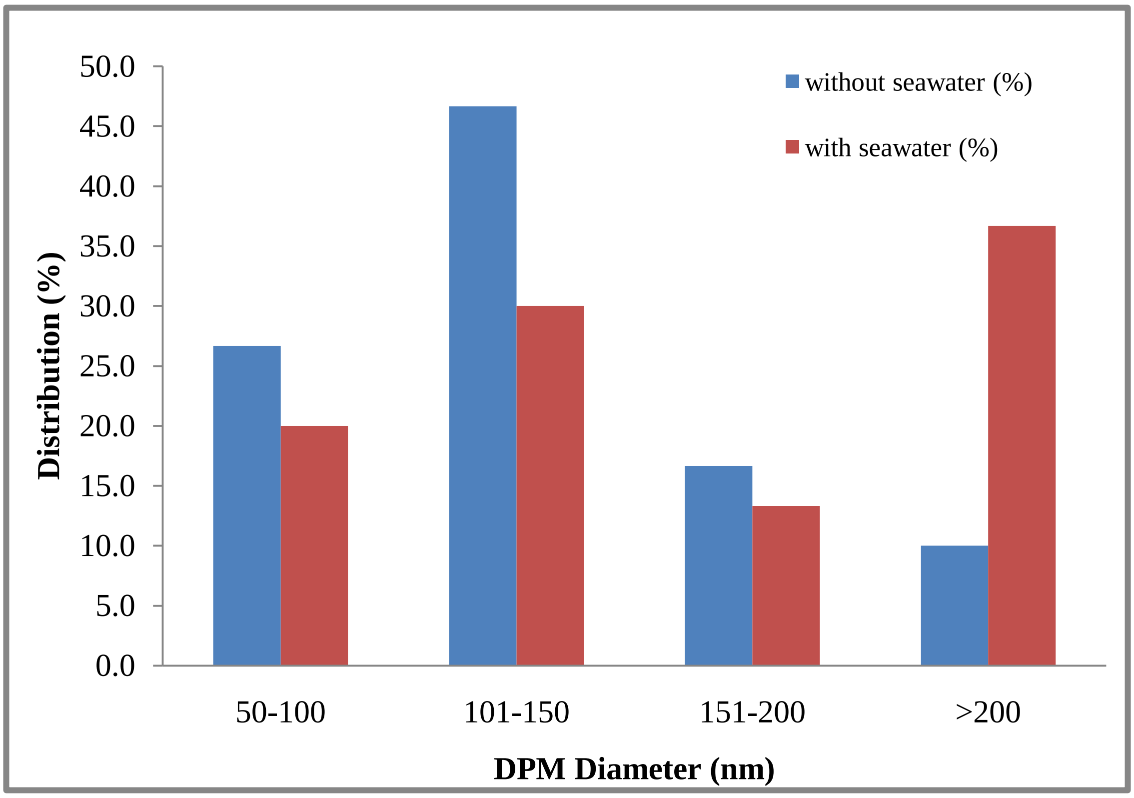


Figure 4.9: Distribution versus DPM Diameter for 2100rpm

Figure 4.9 shows the graph of distribution percentage versus DPM diameter variation for 2100 rpm. The bar chart trend shows that with seawater spray, the DPM diameter variation is smaller compared without seawater spray for range 50 to 100, 101 to 150 and 151 to 200 nm. The highest DPM distribution is 46.7 % without seawater spray and 30 % with seawater spray in the range of 101 to 150 nm. Besides that, the lowest DPM distribution is 10 % without seawater spray in the range above 200 nm and 13.3 % with seawater spray in the range 151 to 200 nm. Refer to the appendix C4 for finite element scanning electronic microscope (FESEM) sample pictures.

4.6.5 DPM Diameter for 2400rpm

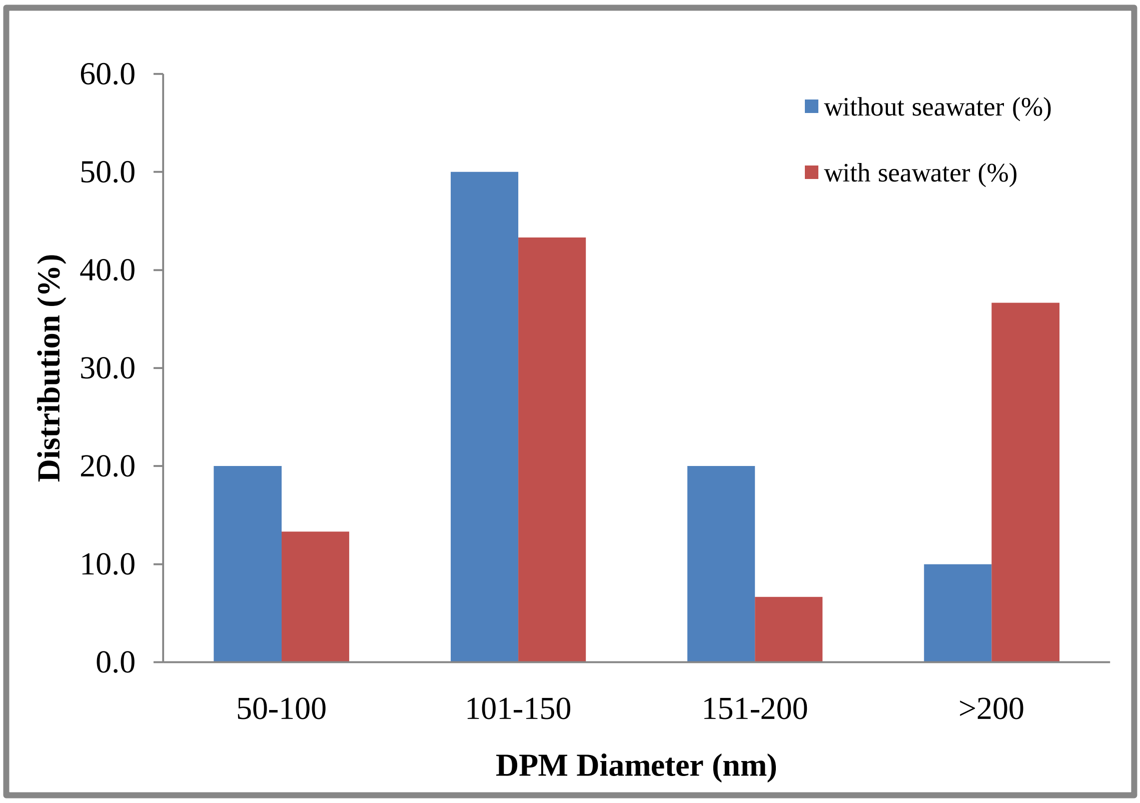


Figure 4.10: Distribution versus DPM Diameter for 2400rpm

The highest speed tested to configure distribution percentage was 2400rpm. Figure 4.10 shows the graph of distribution percentage versus DPM diameter variation for 2400 rpm. The bar chart trend shows that with seawater spray, the DPM diameter variation is smaller compared without using seawater spray for range 50 to 100, 101 to 150 and 151 to 200 nm. The highest DPM distribution is 50 % without seawater spray and 43.3 % with seawater spray in the range of 101 to 150 nm. Besides that, the lowest DPM distribution is 10 % without seawater spray in the range above 200 nm and 6.7 % with seawater spray in the range 151 to 200 nm. Refer to the appendix C5 for finite element scanning electronic microscope (FESEM) sample pictures.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The main objective of this project is to measure reduction of diesel particulate matter (DPM) by diesel experiment using seawater spray and the second objective is to utilize natural seawater.

To achieve the objectives, seawater spray system were fabricated to be tested together with diesel engine. The engine was tested with and without seawater spray for engine speed 1200, 1500, 1800, 2100 and 2400 rpm with no load. The experiment results indicate that diesel particulate matter could be reduced by usage of direct sprayed seawater droplets. An average of 26.1 % of DPM, 27.8 % of SOF and 19.5 % of DS has been reduced by using the seawater spray system. DPM diameter size distribution shows that after using seawater, the particle size less in the smaller range of diameter which harmful to human. Therefore, as a conclusion, the usage of seawater and seawater spray system can reduce certain emissions from diesel exhaust gas.

5.2 RECOMMENDATIONS

For future research studies, a few recommendations to improve the reduction percentage are by fabricating two stage seawater spray system and by adding more spray nozzles on the system to have more contact from the sprayed seawater. Other than that, it is recommended that the diesel engine should be tested with a constant load to find out whether the spray system will be able to reduce particulate matter with load condition because with load condition produces more particulate matter.

REFERENCES

Ariana, I.M., Fujita, H., Nishida, O., Harano, W. and Kawazoe. 2007. Pollutant reduction of diesel exhaust emissions by electroststic precipitator with water treatment system. *Journal of Applied Sciences in Environmental Sanitation.* **2**(1): 13-18.

Ariana, I.M., Nishida, O., Fujita, H., Harano, W. and Fujio, M. 2006. Removal of marine diesel particulate matter by electrostatic precipitator. *International Conference on Electrostatic Precipitation X (ICESP X-Australia 2006).* Paper 4A2.

Betha, R. and Balasubramanian, R. 2011. Emissions of particulate-bound elements from stationary diesel engine: Characterization and risk assessment. *Atmospheric Environment.* **45**(30): 5273-5281.

Bosch, R. 2004. *Diesel-engine management.* Australia: Wiley & Sons

Dilip, K.V., Vasa, N.J., Carsten, K. and Ravindra, K.U. 2010. Incineration of diesel particulate matter using induction heating technique. *Applied Energy*. **88**(3): 938-946.

DOE. 1989. *Recommended Malaysian Air Quality Guidelines.* Malaysia: Department of Environment.

EPA. 1997. *Regulatory Impact Analysis for the Particulate Matter and Ozone National Ambient Air Quality Standards and Proposed Regional Haze Rule*. USA: Environmental Protection Agency.

EPA. 2006. *Particulate Matter (PM) Standarts*. United states: Environmental Protection Agency.

Fierro, M. 2000. Particulate Matter. Bachelor Thesis. University of Florida, USA.

Gupta, H.N. 2006. *Fundamentals of internal combustion engines.* New Dehli: PHI Learning Private Limited.

Hammerle, R., Schuetzle, D. and Adams, W. 1994. A perspective on the potential development of environmentally acceptable light-duty diesel vehicles. *Environmental Health Perspectives.* **102**(4): 25-30.

Heywood, J.B. 1988. *Internal combustion engine fundamentals*. USA: McGraw-Hill.

Hollembeak, B. 2005. *Automotive fuels & emissions classroom manual.* USA: Thomsan Delmar Learning.

Oh, B.S., Oh, S.G., Jung, Y.J., Hwang, Y.Y., Kang, J.W. and Kim, I.S. 2009. Evaluation of a seawater electrolysis process considering formation of free chlorine and perchlorate. *Desalination and Water Treatment* .**18**(2): 245-250.

Rajan, K. and Senthil Kumar, K.R. 2009. The Effect of Exhaust Gas Recirculation (EGR) on the Performance and Emission Characteristics of Diesel Engine with Sunflower Oil Methyl Ester. *International Journal of Chemical Engineering Research*. **1**(1): 31-39.

Richards, R.J. 1997. Small particles, big problems. *Biologist*. **44 (1),** 249-251.

Song, R., Liu, J., Wang, L. and Liu, S. 2008. Performance and emissions of a diesel engine fuelled with methanol. *Energy & Fuels.* **22**: 3883-3888.

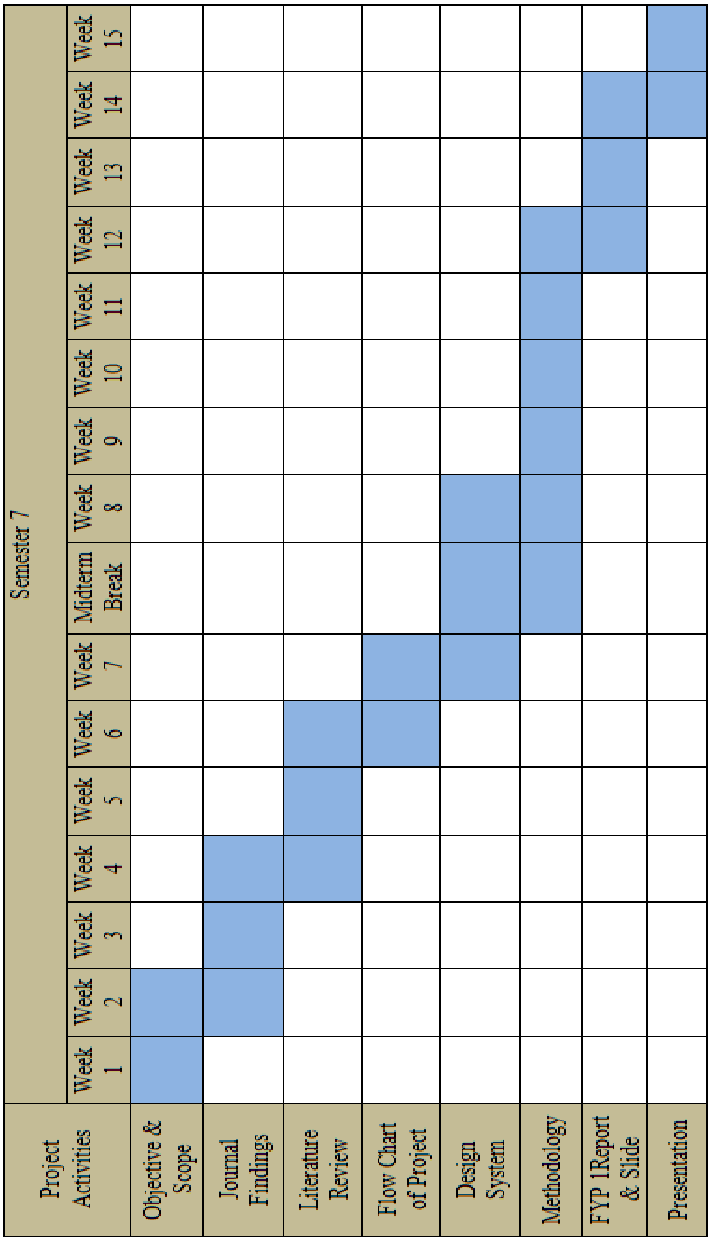
WHO. 2012. *Outdoor Health Pollution*. Switzerland: World Health Organization.

Wibawaningrum, R. 2004. Experimental Study on Effect of Sulfur Content in MDO to Exhaust Gas. Bachelor Thesis. University of Kobe, Japan.

Zieliński, H., Mudway, I.S. and Kelly, F.J. 1998. PM10 and the respiratory tract: What do we know? *Polish Journal of Environmental Studies.* 7(5): 273-277.

APPENDIX A1

Gantt chart for Final Year Project 1



APPENDIX A2

Gantt chart for Final Year Project 2

Project Activities	Semester 8															
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Midterm Break	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
Engine Setup	■	■	■	■	■											
Engine Experiment					■	■	■	■								
DPM Analysis								■	■							
Result & Discussion									■	■	■					
Thesis Writing											■	■	■	■		
FYP 2 Presentation														■	■	
Final Draft & 2nd Reviewer															■	
Thesis Submission															■	■

APPENDIX B1

Particulate Matter (PM), Soluble Organic Fraction (SOF) and Dry Soot (DS) Experimental Data for Diesel Fuel without Seawater Spray

Particulate Matter (PM)				
Engine Speed (rpm)	**Filter Weight (g) Before (a)**	**Filter Weight (g) After (b)**	**Particulate Matter (PM) (b-a)=(c)**	**PM (g/m^3) (c/l)*1000=(d)**
1200	0.1209	0.1237	0.0028	0.14
1500	0.1205	0.1241	0.0036	0.18
1800	0.1203	0.1247	0.0044	0.22
2100	0.1202	0.1251	0.0049	0.245
2400	0.1201	0.1254	0.0053	0.265

SOF & DS				
Engine Speed (rpm)	**Dichloro (g) (e)**	**SOF (g) (b-e)=(f)**	**SOF (g/m^3) (f/l)*1000= (g)**	**DS (g) (d-g)**
1200	0.1215	0.0022	0.11	0.03
1500	0.1212	0.0029	0.145	0.035
1800	0.1211	0.0036	0.18	0.04
2100	0.1211	0.004	0.2	0.045
2400	0.1212	0.0042	0.21	0.055

APPENDIX B2

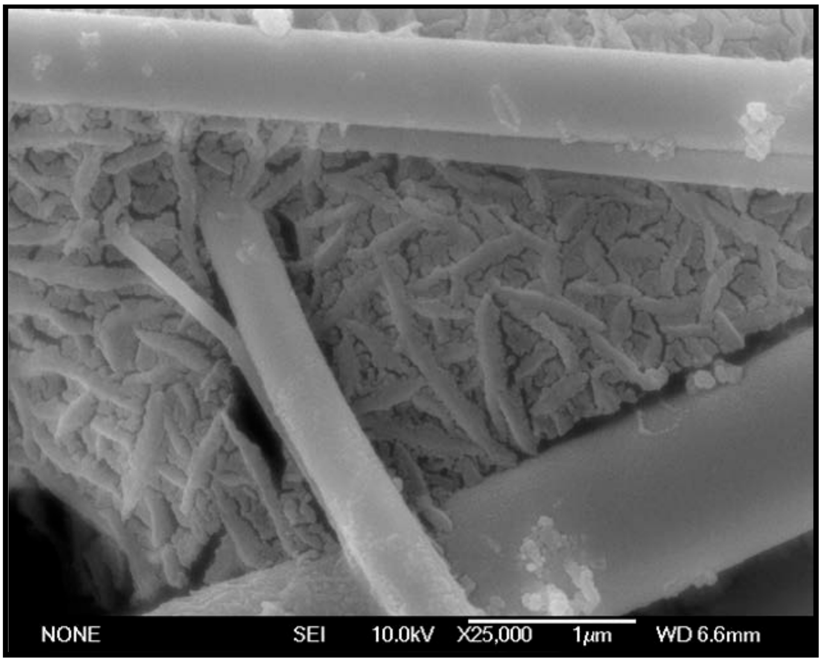
Particulate Matter (PM), Soluble Organic Fraction (SOF) and Dry Soot (DS) Experimental Data for Diesel Fuel with Seawater Spray

Particulate Matter (PM)				
Engine Speed (rpm)	**Filter Weight (g) Before (a)**	**Filter Weight (g) After (b)**	**Particulate Matter (PM) (b-a)=(c)**	**PM (g/m^3) (c/l)*1000=(d)**
1200	0.1211	0.1226	0.0015	0.075
1500	0.1205	0.1232	0.0027	0.135
1800	0.1207	0.1238	0.0031	0.155
2100	0.1203	0.1242	0.0039	0.195
2400	0.1203	0.1246	0.0043	0.215

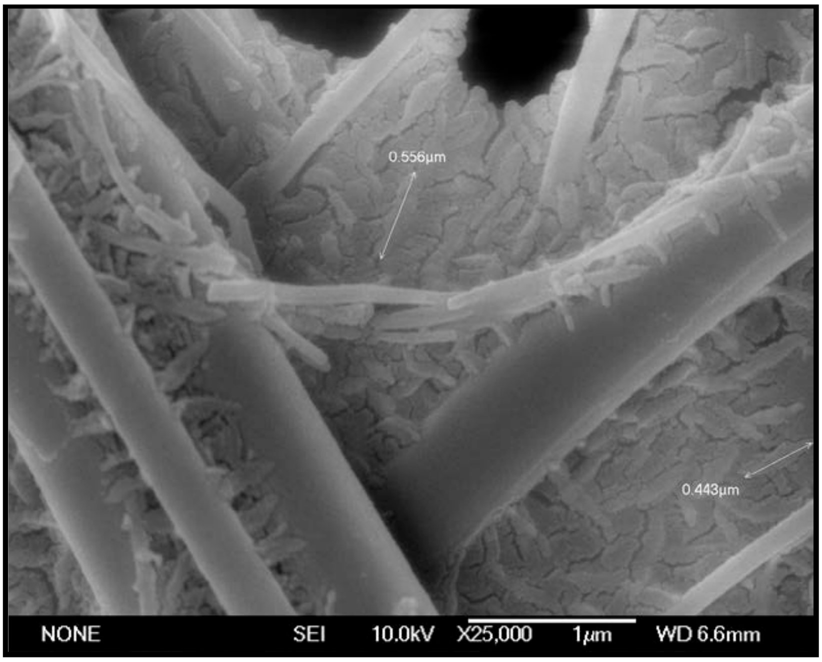
SOF & DS				
Engine Speed (rpm)	**Dichloro (g) (e)**	**SOF (g) (b-e)=(f)**	**SOF (g/m^3) (f/l)*1000= (g)**	**DS (g) (d-g)**
1200	0.1215	0.0011	0.055	0.02
1500	0.1210	0.0022	0.11	0.025
1800	0.1213	0.0025	0.125	0.03
2100	0.1211	0.0031	0.155	0.04
2400	0.1213	0.0033	0.165	0.05

APPENDIX C1

FESEM Filter for 1200 rpm with and without Seawater Spray



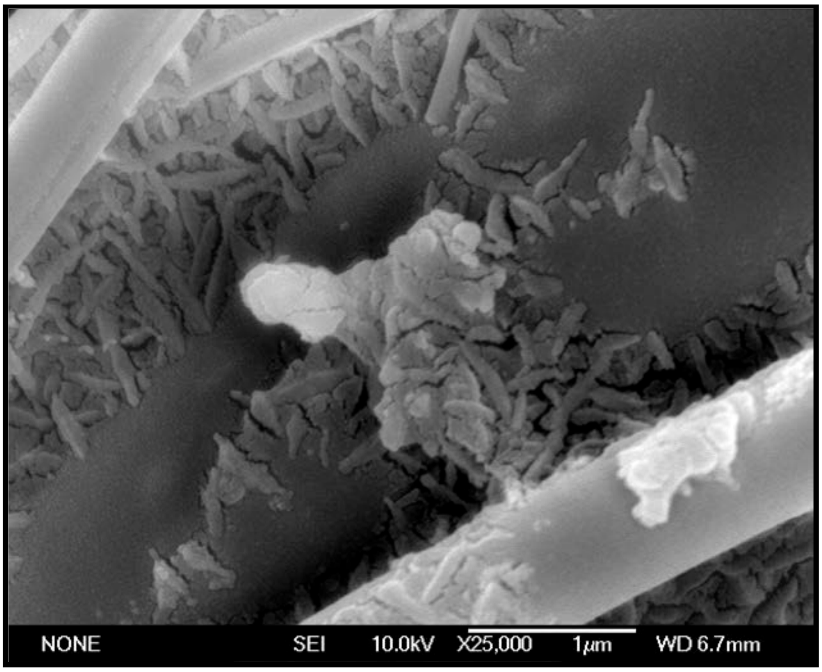
With Seawater Spray (1200 rpm)



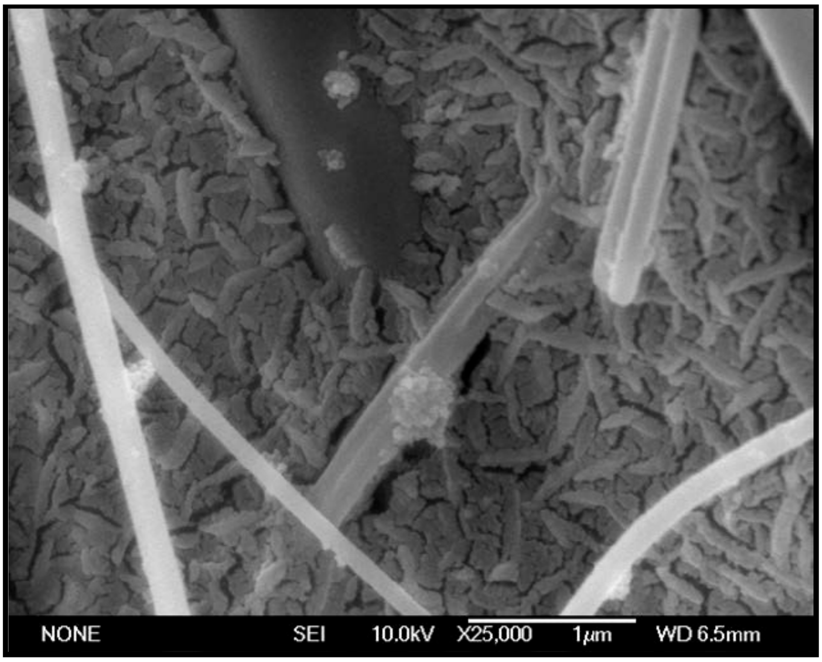
Without Seawater Spray (1200 rpm)

APPENDIX C2

FESEM Filter for 1500 rpm with and without Seawater Spray



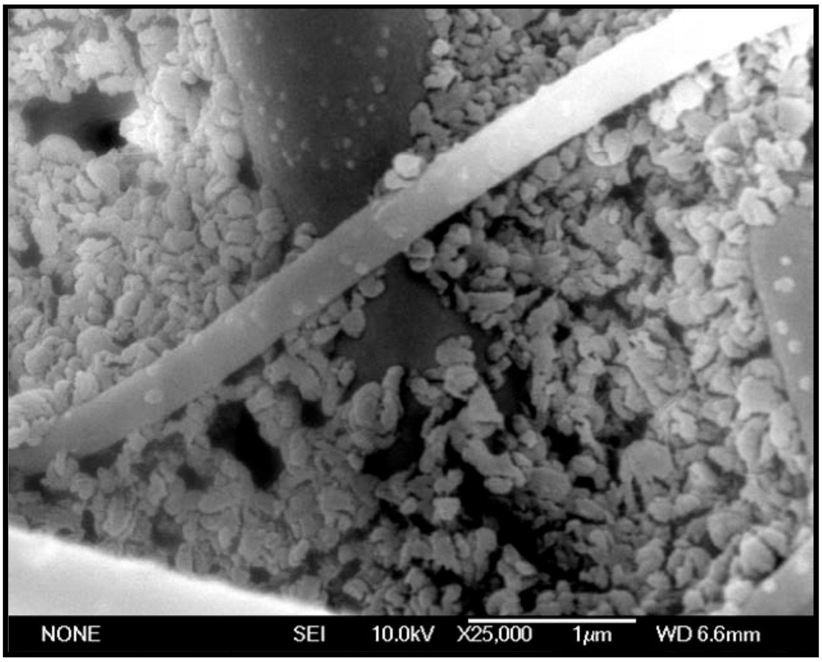
With Seawater Spray (1500 rpm)



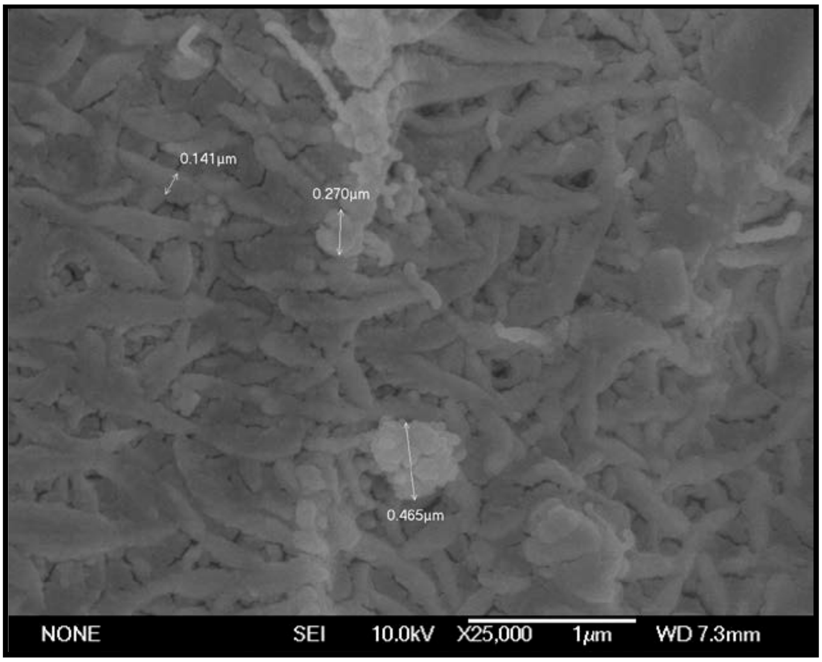
Without Seawater Spray (1500 rpm)

APPENDIX C3

FESEM Filter for 1800 rpm with and without Seawater Spray



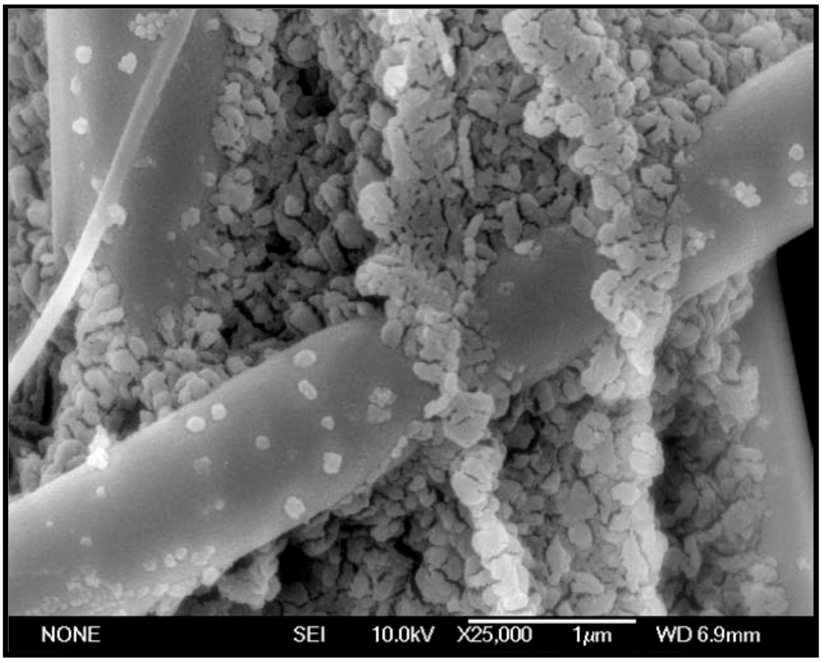
With Seawater Spray (1800 rpm)



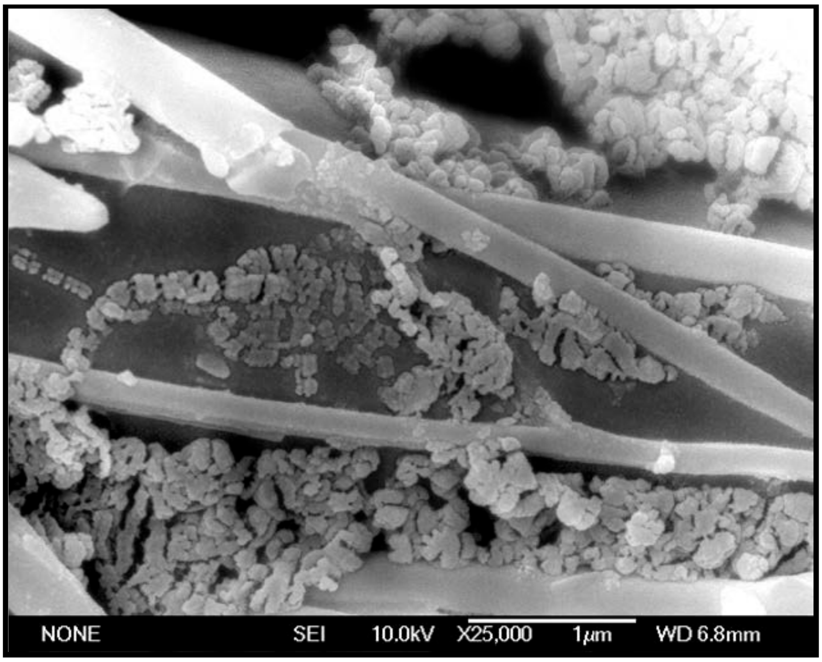
Without Seawater Spray (1800 rpm)

APPENDIX C4

FESEM Filter for 2100 rpm with and without Seawater Spray



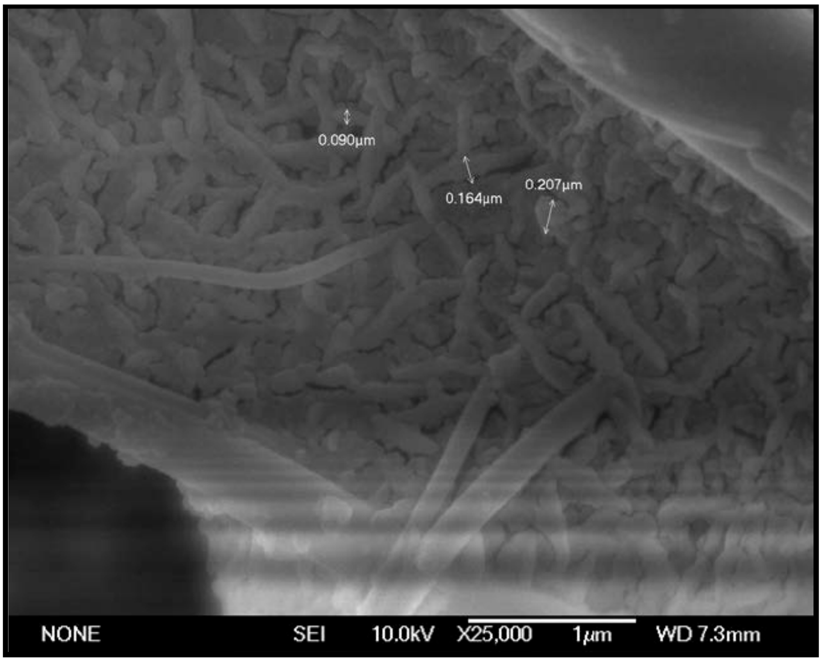
With Seawater Spray (2100 rpm)



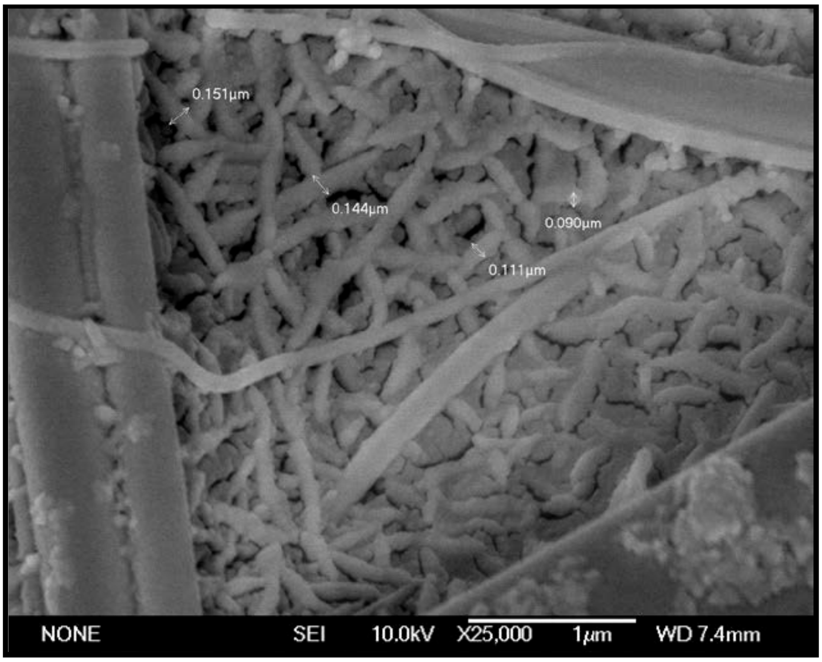
Without Seawater Spray (2100 rpm)

APPENDIX C5

FESEM Filter for 2400 rpm with and without Seawater Spray



With Seawater Spray (2400 rpm)



Without Seawater Spray (2400 rpm)