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JUDUL: ANALYSIS OF DIESEL PARTICULATE MATTER OF SINGLE CYLINDER DIESEL ENGINE RUNNING ON TIRE DERIVATED FUEL

SESI PENGAJIAN: 2011/2012

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ANALYSIS OF DIESEL PARTICULATE MATTER OF SINGLE CYLINDER DIESEL ENGINE RUNNING ON TIRE DERIVATED FUEL

NUR AIN AFIQAH BTE ABDUL LATIFF

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

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JULY 2012

EXAMINER'S APPROVAL DOCUMENT

UNIVERSITI MALAYSIA PAHANG
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I certify that the project entitled "*Analysis of Diesel Particulate Matter of Single Cylinder Diesel Engine Running on Tire Derivated Fuel*" is written by *Nur Ain Afiqah bte Abdul Latiff*. I have examined the final copy of this project and in my 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 with Automotive Engineering.

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

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DEDICATION

This report is dedicated to:

Beloved father and mother;

ABDUL LATIFF BIN MOHD AMIN

RAJA MAIMUNAH BINTI RAJA HASHIM

For your love, trust and support along my journey as a student. You are my source of inspiration and spirit for me along my study and life.

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ABSTRACT

This report deals with the diesel particulate matter (DPM) of single cylinder diesel engine, the fuel consumption and also the characteristic of fuel. The objectives of this report are to analyze the concentration, size distribution, size diameter of DPM and the fuel consumption of a single cylinder diesel engine by using tire fuel compared to the diesel fuel. This report describes the procedures for finding the characteristic of fuel besides, the experimental setup and procedures for analyzing the DPM and fuel consumption due to usage of the both fuels without any load exerted on the engine. The engine speed used is variable. The DPM are trapped on the filter with the flow rate of the vacuum pump is 20 ℓ/min. All the data required for the analysis is obtained from the experiments. The concentration of the DPM are analyzed by weighing the filter before taking the sample, after taking the sample with heated it in the oven for two hours at 50 ^{0}C (for PM concentration) and after immersed the filter into dichloromethane for 24 hours with heated it in the oven (for SOF concentration). The DS concentration of DPM is analyzed by finding the difference between PM and SOF concentration. The results obtained from calculating and analyzing the required data are plotted in graph and compared for both fuels. The size distributions of DPM diameter are compared for both fuels usage in forms of bar chart. From the result of the experiment show that the tire fuel in terms of fuel consumption, PM concentration, SOF concentration and DS concentration are applicability in diesel engine. Meanwhile, based on the analysis of size distribution, the tire fuel produced a lot of small particles that can affect human health thus it is not suitable to use in the future as an alternative fuel.

ABSTRAK

Laporan ini membentangkan hasil eksperimen berkaitan pembebasan diesel partikel dari enjin diesel satu silinder, penggunaan bahan bakar dan juga ciri-ciri bahan api. Tujuan laporan ini adalah untuk menganalisis kepekatan, taburan saiz, saiz diameter diesel partikel dan penggunaan bahan bakar enjin diesel satu silinder dengan menggunakan minyak tayar dibandingkan dengan minyak diesel. Laporan ini menjelaskan prosedur untuk mencari ciri-ciri minyak selain persediaan eksperimen dan prosedur untuk menganalisis diesel partikel dan penggunaan bahan bakar dengan menggunakan kedua-dua minyak tanpa sebarang beban dikenakan ke atas enjin. Kelajuan enjin yang digunakan berubah-ubah. Diesel partikel telah terperangkap pada *filter* dengan aliran pam vakum adalah 20 ℓ/min. Semua data yang diperlukan untuk analisis diperolehi daripada eksperimen. Kepekatan diesel partikel dianalisis dengan menimbang berat *filter* sebelum sampel diambil, selepas sampel diambil dengan memanaskannya didalam ketuhar selama dua jam pada suhu 50 ^{0}C (untuk kepekatan PM) dan selepas *filter* direndam didalam *dicholoromethane* selama 24 jam seterusnya memanaskannya didalam ketuhar (untuk kepekatan SOF). Kepekatan DS diesel partikel dianalisis dengan mencari perbezaan diantara kepekatan PM dan SOF. Taburan saiz diameter diesel partikel bagi kedua-dua minyak yang digunakan dibandingkan dalam bentuk carta bar. Keputusan yang diperoleh daripada pengiraan dan analisis data diplot dalam graf dan dibandingkan bagi kedua-dua minyak. Hasil daripada kajian ini menunjukkan minyak tayar dari segi penggunaan bahan bakar, kepekatan PM, kepekatan SOF dan kepekatan DS boleh diaplikasikan pada enjin diesel.Sementara itu, berdasarkan analisis taburan saiz diameter partikel, minyak tayar menghasilkan banyak partikel-partikel kecil oleh itu ia tidak sesuai untuk digunakan pada masa akan dating sebagai bahan api alternatif.

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

CHAPTER 2 LITERATURE REVIEW

CHAPTER 3 METHODOLOGY

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Aa	Cohesion are projection
Ap	Only one ball dust
BDC	Bottom dead center
BHP	Brake horse power
Ca	Calcium
CI	Compression ignition
CN	Cetane number
CO_2	Carbon dioxide
CPC	Condensation Particle Counter
Da	Diameter for one particle
da	Diameter of the dust in cohesion
DPM	Diesel particulate matter
DS	Dry soot
EC	Elemental carbon
EDB	Electrical diffusion battery
HC	Hydrocarbons
HEI	Health effect institute
NIOSH	National Institute Occupational Safety and Health
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NOx	Nitrogen oxide

np	Number of particle
P	Phosphorus
PAHs	Polycylic aromatic hydrocarbons
PM	Particulate matter
RCD	Respirable combustible dust
RPM	Revolution per minute
SEM	Scanning electron microscopy
SMPS	Scanning mobility particle size
SO_2	Sulfur Dioxide
SOF	Soluble organic fraction
TDC	Top dead center
TEM	Transmission electron microscope
TPO	Tire pyrolysis oil
US EPA	United States Environmental Protection Agency
VOF	Volatile of fraction
Zn	Zinc

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Nowadays, the current issue that always discussed among people worldwide is related to global warming and air pollution. Global warming occurs when the Earth heats up (temperature rise). It is happen because the greenhouse gases in atmosphere (carbon dioxide, water vapor, nitrous oxide and methane) trap heat and light from the Earth's atmosphere. Meanwhile, air pollution happens when the air contains gases, dust, fumes or odor in harmful amounts which could cause damage to plants and materials. The main factor that contributes to global warming and air pollution is by burning the fossil fuels such as gasoline and natural gas. The fossil fuels that burnt will release the greenhouse gases such as carbon dioxide (CO_2) and also the particulate matter (PM). CO_2 is the major pollutant that generates global warming and PM is the particles that release to the air to form air pollution.

Fossil fuels which include oil, coal and natural gas are non-renewable source of energy. Once the amount of fossil fuels in the Earth is used up, these fuels cannot be replaced. The depletion of the world resource, particularly the depletion of fossil fuels becomes the main focus among public and politician after global warming issue. Since the world energy resources have peaked in production and are exceeded by demand, it could cause skyrocketing oil prices and stampede the world into new recession. Historically, global economic growth has never occurred without a simultaneous increase in the use of fossil fuel energy. Without cheap oil, there is no cheap food, water, health care, travel, housing or recreation. (Leng, R.A., 2010). Because of that, there are many alternative fuels that have been developed today in order to replace these natural resources. One of the alternatives is by producing fuel from scrap tires called tire derived fuel or tire fuel.

The smoky black exhaust that is emitted by diesel engines has seen whether on highway or underground. Diesel engines are in common use in heavy duty trucks and buses because of their attractive performance characteristics and low operating cost. The incomplete combustion of diesel fuel results in the formation of solid and liquid particles in the exhaust called diesel particulate matter (DPM) that has been growing concern for over ten years. DPM contains elemental carbon, organic carbon, ash (metallic compounds and trace elements), sulphate, nitrates, adsorbed organic compounds and air toxins, and unidentified compounds. Other components of DPM are sulphuric acid and hydrocarbon or sulphate particles. (Sharp, J., 2003). However, particles in diesel engine exhaust must be concern due to their very small diameter and the mixture of the chemical contain in the particles are hazardous and can give bad effect to health such as lung cancer.

There is limited information about diesel particulate matter (DPM) that related to tire fuel. This study, the diameter, concentration and size distribution of DPM of single cylinder diesel engine running on tire fuel were analyzed. The data analyses are compared when the diesel fuel were used in order to run diesel engine.

1.2 PROBLEM STATEMENT

Nowadays, heavy-duty diesel engines which are trucks and buses are in common use on the road. The increasing of these vehicles will increase the amount of diesel particulate matter (DPM). DPM can affect human health including high blood pressure, heart attack, stroke and also lung cancer. DPM’s danger lies in its small size, large surface area and adsorbed organic compounds. Because of the small size, DPM inhaled into the deep lung and lower respiratory tract where it can damage lung cells. (Sharp, J., 2003).

Besides that, DPM also can affect the environment in many ways such as global warming, air pollution, acid rain and reduces visibility. Environment is very important to human life. If environment have contaminated, human and world will be suffer of disaster.

Today, there are many alternatives fuel have been produced in order to replace the natural resources that may decrease from day to day. Recycling the waste management like tires into fuel is one of the ways to produce alternatives fuel. However, previously the data analysis of DPM by using tire fuel not been investigated in any comparative study.

1.3 PROJECT OBJECTIVES

The objectives of this project are to find characteristics of tire fuel and to analyze concentration, diameter and size distribution of DPM. This project is conducted to analyze the PM, DS, SOF concentration, size distribution and size diameter of DPM when diesel engine running on tire fuel compared to ordinary diesel fuel. The fuel consumption of the engine due to usage of both fuels also compared and analyzed. The engine will run without load exerted to it and with variable engine speed in rpm.

1.4 PROJECT SCOPES

The scopes of this project as below are determined in order to achieve the objectives of the project:

a) Analysis of properties of tire fuel by using bomb calorimeter, octane meter, flash point tester, viscometer and specific gravity meter.
b) Setup experimental rig.
c) Analysis of diameter, concentration and size distribution of DPM by using tire fuel.

CHAPTER 2

LITERATURE REVIEW

2.1 DIESEL PARTICULATE MATTER (DPM)

For over ten years, diesel particulate matter (DPM) has been a growing concern due to the insidious nature of how it affects health such as lung cancer and bronchitis. Heavy duty truck which is used diesel engine and underground mines coal industry are the main source contribute to exposure of DPM. The large numbers of diesel engine in current operations have a huge effect on the current worldwide air pollution problems (Ames W. R., 2007). According to NIOSH (1988), long-term exposure to diesel exhaust has become a concern because diesel emissions are believed to be a potential carcinogen. Since diesel is the dominant fuel used by the commercial transportation sector, the diesel engines are often choice for heavy-duty applications. Thus, the smoky black exhaust that is emitted by diesel engines can be seen whether on highways or underground and might increase from day to day.

2.1.1 Definition of DPM

DPM have been defined in various terms in order to describe the particles emitted by diesel engines. Setten, V., et al. (2001), states that diesel particulate matter is a complex multi component material. It consists of carbonaceous soot particles, which carry many compounds that are sometimes toxic. DPM also defined as the portion of diesel exhaust which is made up of solid carbon particles and the attached chemicals including organic chemicals such as polycyclic aromatic hydrocarbons (PAHs) and inorganics such as sulphate compounds (Grenier, M. et al., 2001). According to Diaz, A. L. et al. (2005), DPM is part of a complex agglomerated mixture composed mainly of elemental carbon (EC) with hundreds of adsorbed organic compounds, sulfates, nitrogen oxides, heavy metals, trace elements and irritants (such as acrolein, ammonia and acids). On the other hand, particulates are defined as any material other than water in the exhaust of an internal combustion engine which can be filtered after dilution with an ambient air (Challen, B. et al., 1999).

2.2 CHARACTERISTICS OF DPM

2.2.1 Composition of Diesel Particulate Matter

Challen, B. et al. (1999), states that the composition of particulate can vary considerably from 5 % hydrocarbons and 95 % carbon to 20 % carbon and 80 % hydrocarbons depending on the engine operating conditions. Diesel exhaust particles mainly consist of agglomerates of carbon particles and a percentage of semi volatile components such as H_2SO_4 and organic species that might condense on the surface of the carbon particles or might even nucleate to form ultra-fine nanometer-sized particles during the dilution and cooling process (Venkatasubramaniam C.K., 2007).

According to Matthey J. (2004), diesel particulate matter is made up of a number of components. The PM’s core is made up of agglomerates of primary soot particles, onto which is adsorbed a layer of condensed hydrocarbons or VOF. Sulfuric acid droplets which is derived from the SO_2 generated from the fuel sulfur during the combustion process can also condense and these sulfate species can further adsorb water. Meanwhile, nitric acid is derived from the engine-out NO_x can also condense on the primary soot particles. On the other hand, oil derived species such as derivatives of Ca, P and Zn can become entrained in the PM.

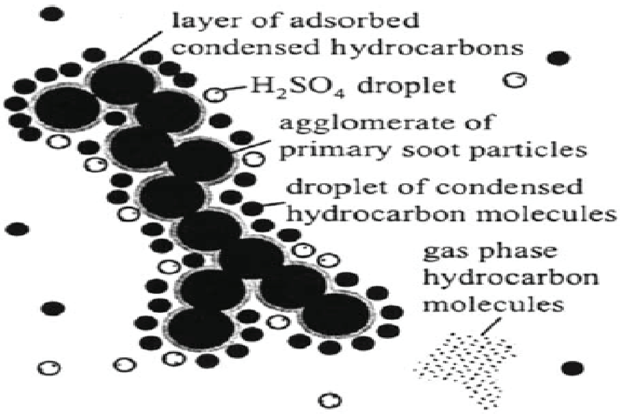


Figure 2.1: Schematic representation of a chain-like aggregate of primary soot particles and associated compounds.

Source: Matthey, J. (2004)

The composition of diesel particulate matter depends on where and how they are collected (Kittelson, 1998). At high temperature, most of the volatile materials (hydrocarbons, sulfuric acid) are in the gas phase which is usually happen in the tailpipe. The volatile materials transform to solid and liquid particulate matter when the exhaust gas cools down and is diluted by the ambient air, nucleation, condensation and adsorption (Klingenberg, H., 1996). Figure 2.2 shows a typical particle size distribution in diesel exhaust.

Diesel particulates consist mainly of combustion generated carbonaceous materials (soot) on which some organic compounds have been adsorbed. Most particulates are generated in the fuel rich zones within the cylinder during combustion due to incomplete combustion of fuel hydrocarbons; some particulate matter is contributed by lubricating oil. The undesirable odorous pollutants will occur due to this phenomenon. When the engine is under load, the maximum particulate emissions will occur. At this condition, maximum amount of fuel is injected to obtain maximum power from the engine and it results in a rich mixture and poor fuel economy (Gupta, N.H., 2006).

Based on Internal Combustion Engine Fundamentals book by Heywood, B.J. (1988) the exhaust particulate is usually partitioned with an extraction solvent into a soluble fraction and a dry soot fraction. Two commonly used solvent are dichloromethane and a benzene-ethanol mixture. Thermogravimetric analysis which is weighing the sample as it is heated would produce comparable results.

Table 2.1: Chemical composition of particulate matter

	Idle	**48 km/h**
Extractable composition	$C_{23}H_{29}O_{4.7}N_{0.21}$	$C_{24}H_{30}O_{2.6}N_{0.18}$
H/C	1.26	1.63
Dry soot composition	$CH_{0.27}O_{0.22}N_{0.01}$	$CH_{0.21}O_{0.15}N_{0.01}$
H/C	0.27	0.21

Source: Heywood, B.J. (1988)
(Internal Combustion Engine Fundamentals Reference Book)

There have some of the data suggest that the particle size distribution is bimodal. The smaller size range is thought to be liquid hydrocarbon drops and individual spherules characterized by number-mean diameters of 10 to 20 nm. Meanwhile, the larger range is thought to be the particles of agglomerated spherules characterized by number mean diameters of 100 to 150 nm (Heywood, B.J., 1988)

According to Burtscher, H. (2004), diesel particles or the other particles from other combustion sources are a complex mixture of elemental carbon (EC), a variety of carbons (HC), sulfur compounds and other species. Particles usually differ in size, composition, solubility and also in toxic properties. Figure 2.2 shows the composition of particles from heavy-duty diesel engines, measured over a transient cycle.

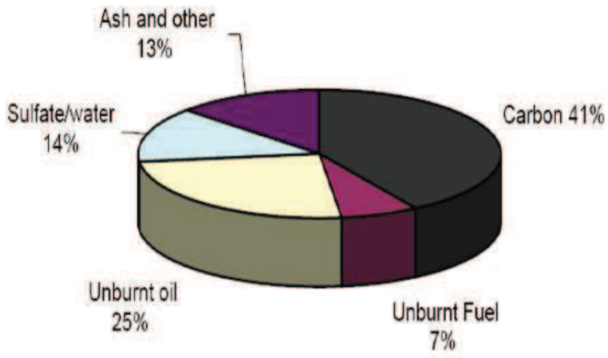


Figure 2.2: Composition of particles from a heavy-duty diesel engine, tested in a transient cycle on an engine test bench.

Source: Burtscher, H. (2004)

2.2.2 Size Distribution of DPM

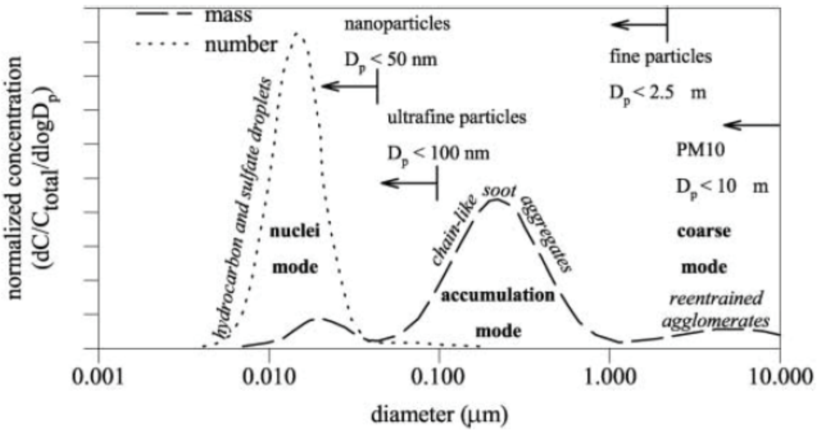


Figure 2.3: Schematic of engine exhaust particle size distribution, both mass- and number-based concentrations.

Source: Kittelson (1998)

Both mass and number distributions are shown in Figure 2.2 with the concentration in any size range definitions for atmospheric particles (PM_{10}, $PM_{2.5}$, ultra-fine particles and nanoparticles). Based on the size particles, there are classified into 3 modes namely nuclei mode, accumulation mode and coarse mode.

Nuclei mode particles are in the size range of 5-50 nm and consist of metallic ash, elemental carbon and semi-volatile organic and sulfur compounds that form particles during dilution and cooling. Furthermore, particles in the nuclei mode contribute to less than 20 % of the total mass but more than 90 % to the total particle concentration. Meanwhile the accumulation mode particles are in the size range of 50-1000 nm. It consists of carbonaceous agglomerates and adsorbed materials. These mode particles contribute between 60-70 % to the total mass. The coarse mode includes all particles greater than 1000 nm in size and contribution of this mode to the total mass is about 5-20 % (Venkatasubramaniam C.K., 2007).

Agglomerates are the typical diesel particles that consist of mainly spherical primary particles have a diameter about 15-40 nm. Meanwhile, the mean diameter of the agglomerated particles (accumulation mode) is almost always in the range 60-100 nm. Furthermore, the size distributions of diesel particles in the accumulation mode normally represented by lognormal distributions with an almost constant geometric standard deviation of 1.8-1.9 (Bustcher, H. 2004)

2.2.3 Measurement Techniques

The purpose of measure the particulate is to determine the amount of particulate being emitted to the atmosphere. There are many techniques to measure the particulate. One of them is by using smoke meters and dilution tunnels. Smoke meters functions to measure the relative quantity of light that passes through the exhaust or the relative reflectance of particulate collected on filter paper and do not measure mass directly. By using this smoke meters, the visible smoke emissions and the indication of mass emission levels are determined. Visible smoke from heavy-duty diesels at high load is regulated. According to the standard mass emission measurement procedure, dilution tunnels are used to simulate the physical and chemical processes the particulate emissions undergo in the atmosphere. The raw exhaust gases are diluted with ambient air to a temperature of 52 ^{0}C or less in the dilution tunnels, and a sample stream from the diluted exhaust is filtered to remove the particulate matter. Most techniques require lengthy sample-collection periods because the emission rate of individual species is usually low (Heywood, B.J., 1988).

2.2.4 Soluble Organic Fraction (SOF) Component

According to Heywood, B.J. (1988) the extractable organic fraction diesel particulate emissions includes compounds that may cause health and environmental hazards. Thus, chemical and biological characterizations of the soluble organic fraction are important. There are two methods can be used to extract organic fraction from particulate samples which are soxhlet and sonification methods. This is because the particulates are mixtures of polar and nonpolar components. So, full extraction requires different solvents. The most commonly extractant used is methylene chloride.

Table 2.2: Components of the soluble organic fraction

Fraction	Components of fraction	Percent of total
Acidic	Aromatic or aliphatic Acidic functional groups Phenolic and carboxylic acids	3-15
Basic	Aromatic or aliphatic Basic functional groups Amines	<1-2
Paraffin	Aliphatics, normal and branched Numerous isomers From unburned fuel and/or lubricant	34-65
Aromatic	From unburned fuel, partial combustion, and recombination of combustion products; from lubricant Single rings compounds Polynuclear aromatics	3-14
Oxygenated	Polar functional groups but not acidic or basic Aldehydes, ketones or alcohols Aromatic phenols and quinones	7-15
Transitional	Aliphatic and aromatic Carbonyl functional groups Ketones, aldehydes, esters, ethers	1-6

Insoluble	Aliphatic and aromatic Hydroxyl and carbonyl groups High molecular weight organic species Inorganic compounds Glass fibers from filters	6-25

Source: Heywood, B.J. (1988)
(Internal Combustion Engine Fundamentals Reference Book)

On the other hand, Pulkrabek, W.W. (2003) has stated that up to 25 % of the carbon in soot comes from the lubricating oil components which vaporize and then react during combustion. The rest comes from the fuel and amounts to 0.2-0.5 % of the fuel. A large expansion occurs because of the high compression ratios of CI engines during the power stroke. Meanwhile, the gases within the cylinder are cooled by expansion cooling the relatively low temperature. This causes the remaining high boiling point components found in the fuel and the lubricating oil to condense on the surface of the carbon soot particles.

This absorbed portion of the soot particles is called the soluble organic fraction (SOF) and the amount is highly dependent on cylinder temperature. Cylinder temperatures are reduced and can drop to as low as 200 ^{0}C during final expansion and exhaust blow down at light loads. Moreover, SOF can be as high as 50 % of the total mass soot. Under other operating conditions when temperatures are not so low, very little condensing occurs and SOF can be as low as 3 % of total soot mass. SOF consist mostly carbon of hydrocarbon components with some hydrogen, SO_2, NO, NO_2 and also the trace amounts such as sulfur, zinc, phosphorus, calcium, iron, silicon and chromium (Pulkrabek, W.W., 2003).

2.3 EFFECT OF DPM

2.3.1 Health Effect

The human body has protective measure against larger particles but it cannot protect itself against particles roughly smaller than 10 µm also known as PM_{10}. Diesel particulate matter is particularly dangerous as many of the particles are very small, making them almost impossible to filter out and very easy for human lungs to absorb (Boxwell M., 2011). According to Van Setten et al. (2001) diesel particulate matter is suspected of causing all kinds of health problems like asthma, persistent bronchitis and lung cancer. Moreover, based on reviewed the relevant scientific aspects from several agencies which are include the epidemiologic, toxicologic and experimental sides of diesel exhaust have classified that diesel exhaust or its particulate fraction is a definite human carcinogen. Meanwhile, the U.S. EPA has considered characterizing diesel particulate matter as being “likely” to cause lung cancer.

Recently, a number of epidemiologic and experimental studies have suggested that the effects of short-term exposure to diesel exhaust particles on the respiratory and immune systems, particularly in individuals with asthma and other allergic disease may also be concern. Since PM contains a number of constituents, the individual associated risks as well as the toxicity variance for organic compounds reactions within ambient air. Particle size and formation also governs deposition within human lung tissue (Ames W. R., 2007). The Health Effects Institute (HEI) states that lung cancer is most likely related to high exposure levels of the particulates rather than the gases and organic compounds. On the other hand, the State of California included the diesel exhaust as a cancer causing chemical in 1990 and after an extensive research; they have listed diesel exhaust as a “toxic air contaminant” in 1998.

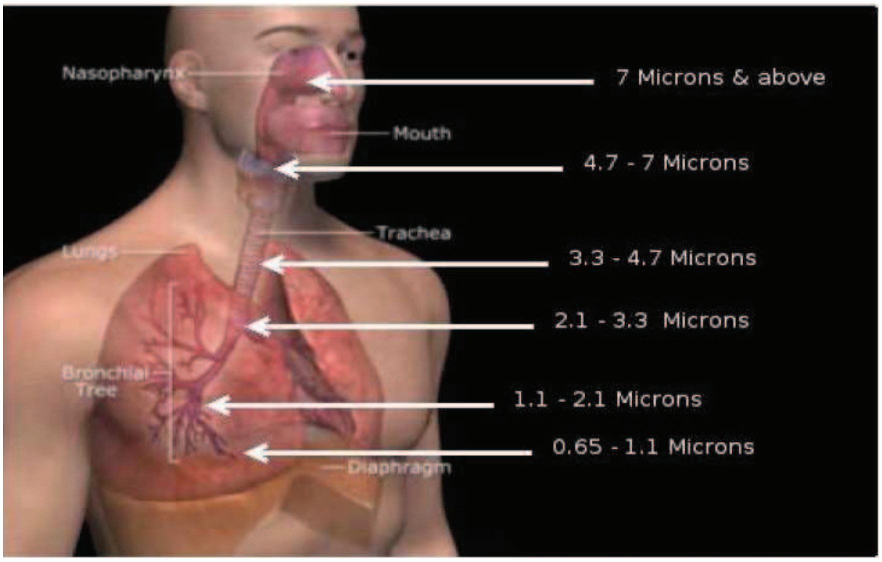


Figure 2.4: Transport of DPM with breath according to their size

Source: Prasad, R. et al. (2010)

According to Prasad, R. et al. (2010) there have many adverse health effects by particulate matter (DPM_{10}, $DPM_{2.5}$) such as bronchitis, chronic cardiovascular, cancer and also premature death that have been found by many toxicological and epidemiological studies. Moreover, diesel exhaust contains a variety carcinogenic compound such as formaldehyde, acetaldehyde, dioxins and polycyclic aromatic hydrocarbons (PAHs). The population based case control studies have identified statistically significant increases in lung cancer risk for truck drivers, rail, road workers and heavy equipment operators. This is because the entire occupational are exposed to the diesel exhaust and diesel particulate matter.

2.3.2 Environmental Effects

Ames, W.R. (2007) stated that the large numbers of diesel engines in current operation have a huge effect on the current world wide air pollution problems. While the diesel engines are more fuel efficient and emit less carbon (CO_2) on a work basis than their gasoline counterparts, they emit significantly high mass rates of particulate matter (PM). Most of investigators found that soot in air pollution affects agriculture, water budget and climate at the local, the regional and the global level. This particulate matter or soot can cause the glaciers or ice in arctic region absorbs solar heat directly. This problem can contribute to melting Himalayan glaciers and causing the ice to melt. Since the ice melt, the water level of sea quickly rise and can lead flooding (Prasad, R., 2010).

According to Wibawaningrum, R. (2005) diesel particulate matter (DPM) is a major cause of visibility impairment in many parts of the U.S. The visual range is reduces 70 % from natural condition. Furthermore, the fine particles can remain suspended in the air and travel long distances. Besides the air pollution, global warming and reduce the visibility, DPM also can cause the water and soil pollution. Since the atmospheric have been contained many air pollutants released from diesel exhaust, the ecosystems and their components such as forests, water bodies and soils will affects too. Prasad, R. (2010) has stated that water and soil are contaminated indirectly by dry and wet deposition of diesel exhaust emitted to the atmosphere. Wet deposition dominates the transfer of airborne contaminants to the Earth's surface, but dry deposition may be important in arid area where ambient concentrations are high and rainfall is limited.

2.4 SYSTEMS FOR MEASURING DPM

2.4.1 Number Concentration

Burtscher, H. (2004) stated that the number concentration is commonly measured exclusively by CPC. There are a lot of problem occur during measure the number concentration. One of the problems is the subject changes due to coagulation. Moreover, diffusion losses are more significant for a measurement of the particle number than of particle mass. This is because weights of the small particles more strongly. The other problem when measuring the number concentration using CPC is the lower size limit of the CPC which is between 3 nm and about 15 nm. This size is depending on the model used. If a substantial number of particles with sizes around the detection limit are present, measurement become unreliable.

There have another way to measure number concentration which is Respirable Combustible Dust (RCD). This method has been developed in Canada to estimate the number concentration of DPM in non-coal mines. In RCD method, respirable dust is collected on a 25 or 37 mm, 0.8 μm silver membrane or pre-combusted, glass fiber filter after passing air through a 10 mm Dorr-Oliver cyclone at a flow rate 1.71 ℓ/min. This flow is controlled using a personal sampling pump and the cyclone used is a respirable dust pre-classifier with a 50 % cut point of 4.0 μm. By weighing the silver membrane before and after the sample is collected, the respirable dust can be determined. The combustion has been controlled at 400 ^{0}C (500 ^{0}C for glass fiber filter) for one to two hours in order to determine the amount of material removal from the silver membrane. As a result, the silver membrane filter lost less mass when combusted compared to glass fiber filter (Watts, F.W. et al., 2000).

2.4.2 Size Distribution

Many systems for determining size distributions in the submicron range are based on mobility analysis or impaction. The most commonly on-line techniques used are the scanning mobility particle sizer (SMPS) and the electrical low pressure impactor (ELPI) (Burtscher, H., 2004). The SMPS systems used to determine the mobility diameter, meanwhile the size distributions in terms of aerodynamics diameter can be obtained by ELPI. This system is based on the same concept as the electrical diffusion battery (EDB) which the particles are first charged by a corona charger. The cascade impactor has 12 stages covering a size range from 20 nm to 10 μm, each one being connected to current amplifier. The time resolution is in the order of one second. The size range of interest for diesel emissions is covered by about 4 to 12 stages, which clearly limits the size resolution significantly. Nucleation mode particles can hardly be measured (Keskinen, J. et al., 1992).

According to Burtsher, H. (2004) an alternative to the more or less on-line techniques described so far is electron microscopy. There have two type of electron microscopy which are scanning electron microscope (SEM) and transmission electron microscope (TEM). The images obtained from this microscope are used to determine size distributions manually or more commonly by automated digital image analysis.

2.4.3 Particle Filter Dust Measurement and Data Arrangement

Wibawaningrum, R. (2005) stated that dust look in the microscope particle it's to be one groups and become only one simple particle. The dust can be burned and then make a fusion to make the particle become cohesion. Thus, the bigger cohesion will be form and can become chain. The size of cohesion to desire from particulate can be calculated by using formula given as follow.

The number of particle:

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

Where, A_a is cohesion are projection

A_p is only one ball dust

Cohesion from V_a (volume):

$$V_a = n_p \left(\frac{\pi . da^3}{6} \right) = \left(\frac{Aa}{Ap} \right)^{1.15} \cdot \frac{\pi . da^3}{6} \tag{2.2}$$

Diameter for one particle:

$$D_a = da \cdot np^{\frac{1}{3}} = d_a \left(\frac{4.Aa}{\pi . da^2} \right)^{0.383} \tag{2.3}$$

Where, d_a is the diameter of the dust in cohesion is almost same

2.5 TIRE DERIVATEDFUEL (TDF)

2.5.1 Pyrolysis Process

Tire fuel is produced from a scrap tires through pyrolysis process. Pyrolysis has been defined as a chemical degradation reaction that is cause by thermal energy in the absence of air (oxygen). This process supposed to be one of the most effective methods for preserving petroleum resources, in addition to preserving the environment by decreasing the volume of non-degradable waste (Zadgaonkar, A., 2006). Buekens, A. (2006) stated that pyrolysis is a process of chemical and thermal decomposition generally leading to smaller molecules. This process can be conducted at various temperature levels, reaction times, pressures and in the presence or absence of reactive gases or liquid and of catalyst.

Rubber tires are the most visible of rubber products. Pyrolysis tires are a feasible, yet technically difficult operation. Various rubber pyrolysis technologies have been developed such as by using fluid bed, rotary kiln, molten salt or cross flow shaft systems. One of the pyrolysis type used for rubber waste is microwave pyrolysis. It results in relatively high molecular weight olefins and a high proportion of valuable products. Moreover, by using this type of pyrolysis, the processing times is short and thus reduce the processing cost. The rubber is transformed from a solid to a highly viscous fluid within milliseconds. Kaminsky, W. (2006) has stated that fluidized sand beds are surprisingly insensitive to the unit size of the feed material for pyrolysis of whole tires. Pieces of scrap tires up to weight of 2.7 kg each were fed and quantitavely pyrolyzed. Most of pyrolysis processes use feed crushed to a 200-20 mm size which involves considerable expenses. The fluidized bed reactor has a square inner size of 900×900 mm and a height of 3200 mm. On top of the titable grate, the fluidized bed extends to a size of 1000×1000 mm to form a freeboard and to provide sendimentation of the sand.

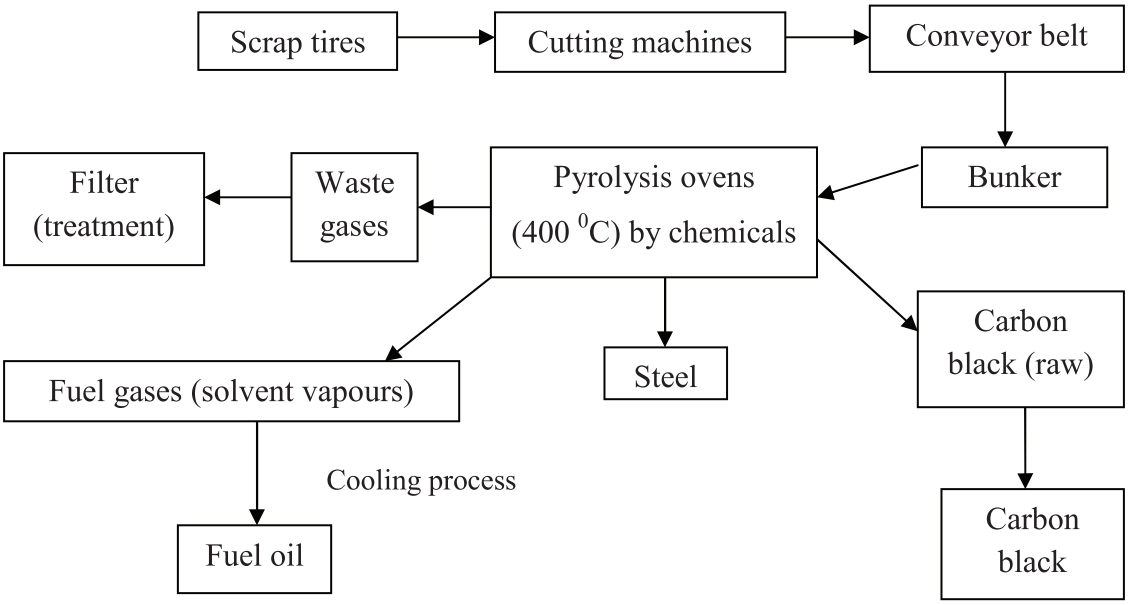


Figure 2.5: Pyrolysis process flow diagram

Source: Murugan et al. (2008)

Tire fuel has been produced in order to find alternative fuels for internal combustion engines because of increase in energy demand nowadays. Many alternate fuels like Alcohols, Biodiesel, LPG, CNG etc have been already commercialized in the transport sector. In this context, pyrolysis of solid waste is currently receiving renewed interest. The waste tires can be simplified to some extent by pyrolysis. The properties of the Tire pyrolysis oil (TPO) derived from waste automobile tires were analysed and compared with the petroleum products. The crude TPO has a higher viscosity and sulphur content compared to diesel fuel. The maximum TPO concentration in the TPO-diesel blend was 70 % and the engine failed to operate satisfactorily beyond this concentration (Murugan, S. et al., 2008).

2.5.2 Fuel Composition and Properties

Waste to energy is the recent trend in the selection of alternate fuels. In order to prevent waste rubber and in particular discarded automobile tires for damaging the environment, it is highly desirable to recycle this material in a useful manner. Tire fuel gives different values of physiochemical properties like heatig value, viscosity, flash point etc compared to diesel fuel. These properties may affect the spray characteristics, performance, combustion and emissions of the engine (Murugan, S. et al., 2008). Tire fuel was found to contain 1.4 % sulphur and 0.45 % nitrogen on mass basis and have similar fuel properties to those of diesel fuel. Moreover, the fuels contained significant concentration of polcyclic aromatic hydrocarbons (PAH) some of which have been shown to be either carcinogenic or mutagenic.

Murugan, S. et al. (2008) stated that at 475 ^{0}C tires pyrolysed at optimum pyrolysis temperature and has the chemical composition: Carbon (84.6 %), Hydrogen (11.2 %), Nitrogen (0.5 %), Sulphur (1.4 %), Ash (0.002 %) and Oxygen by difference (2.2 %). Meanwhile at 500 ^{0}C the chemical compositions of tire pyrolysis oil are: Carbon (85.6±0.5 %), Hydrogen (10.1±0.1 %), Nitrogen (0.4±0.03 %), Sulphur (1.4±0.2 %), Ash (not available) and Oxygen by difference (2.5±0.5 %). The chemical composition of the tire pyrolysis oil has difference percentage at difference temperature and difference type of tires used for the process. Because of that tire pyrolysis oil and diesel have difference properties. The table below shows the difference between TPO and diesel.

Figure 2.6: Tire fuel

Table 2.3: Comparison of waste tire pyrolysis oil and diesel

Property	**Waste tire pyrolysis oil**	**Diesel**
Density @ 30°C in (g/cc)	0.935	0.840
Ash content (%)	0.31	0.045
Gross calorific value (MJ/kg)	42.83	46.5
Kinematic viscosity, cst @ 40°C	3.2	2.0
Cetane number	-	55
Flash point (°C)	43	50
Sulphur content (%)	0.95	0.045

Source: Mani, M. et al. (2009)

The explanation about the properties above in details as follow:

i. Cetane Number/Cetane Index

Cetane number (CN) expressed the ignition quality of the fuel. More fuel tendency to ignite at higher cetane number. Since the diesel engine dispense with an externally supplied ignition spark, the fuel must ignite spontaneously (auto-ignition) and with minimum delay (ignition lag) when injected into the hot, compressed air in the combustion chamber.

ii. Flash Point

The flash point is the temperature at and above which a liquid gives off enough flammable vapour to form a mixture with air that can be ignited by contact with hot surface, spark or flame. Lower the flash point, greater the fire hazard.

iii. Density

The energy content of fuel per unit of volume increases with density. When engine runs on fuel that has a high type dependent density, engine performance and soot emissions increases as fuel density decreases, these parameter drop.

iv. Viscosity

Viscosity is a measure of a fuel’s resistance to flow due to internal friction. Higher viscosity can causes higher peak injection pressure at high temperatures in non pressure regulated systems. Moreover, high viscosityalso can change the spray pattern due to the formation of larger droplets.

v. Sulphur Content

Most of fuel contain bonded sulphur. The actual quantities depend on the quality of the crude petroleum and the component added at the refinery. In order to desulphurized fuel, sulphur is removed from the middle distillate by hydrogenation at high pressure and temperature in the presence of a catalyst.

2.6 DIESEL ENGINE

2.6.1 History of Diesel Engine

The diesel cycle was invented by Rudolf Diesel and it has the highest thermal efficiency of any internal or external combustion engine, mostly due to its very high compression ratio. Low speed diesel engines (usually used in ships and other applications where overall engine weight is relatively unimportant) often have a thermal efficiency which exceeds 50 % (Bosch, R., 2005).

Diesel engines are manufactured in two stroke and four stroke versions. The more efficient replacement for the diesel engines is stationary steam engines and has been used in submarines and ships since 1910s. In the1930s, diesel engines slowly began to be used in a few automobiles. The diesel engines are used widely in USA for on-road and off-road vehicles on 1970s.

2.6.2 Basic Principles of the Diesel Engine

Holt, D.J. (2004) stated that the diesel engine is a four stroke, compression-ignition engine in which the fuel and air are mixed inside the engine. The air required for combustion is highly compressed inside the combustion chamber. This generates high temperatures which are sufficient for the diesel fuel to spontaneously ignite when it is injected to the cylinder. The diesel engine thus uses heat to release the chemical energy contained within the diesel fuel and convert it into mechanical force.

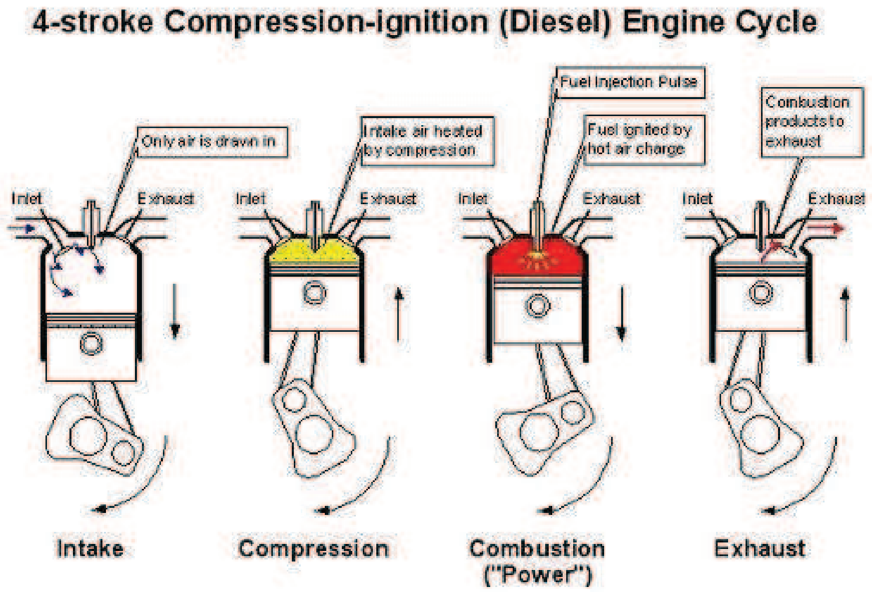


Figure 2.7: Four stroke cycle diagram

Source: Holt D.J. (2004)

Stroke 1 of 4 "Intake": On the *intake* or *induction* stroke of the piston, the piston descends from the top of the cylinder to the bottom of the cylinder, reducing the pressure inside the cylinder. Air is forced by atmospheric (or greater) pressure into the cylinder through the intake port. The intake valve(s) then closed.

Stroke 2 of 4 "Compression": With the both intake and exhaust valves closed, the piston returns to the top of the cylinder compressing the fuel-air mixture. This is known as the *compression* stroke.

Stroke 3 of 4 "Power": While the piston is at or close to Top Dead Center (TDC), the fuel is injected into the combustion chamber and ignited by the heat and pressure of compression (for a diesel cycle or compression ignition engine). The resulting massive pressure from the combustion of the compressed fuel-air mixture drives the piston back down toward Bottom Dead Center (BDC) with tremendous force. This is known as the *power* stroke, which is the main source of the engine's torque and power.

Stroke 4 of 4 "Blow": During the *exhaust* stroke, the piston once again returns to top dead center while the exhaust valve is open. This action evacuates the products of combustion from the cylinder by pushing the spent fuel-air mixture through the exhaust valve(s).

2.6.3 Advantages of Diesel Engine

Diesel engines have several advantages over other internal combustion engines. The diesel engine burn less fuel than a petrol engine performing the same work, due to the engine's higher temperature of combustion and greater expansion ratio. Gasoline engines are typically 25 % efficient while diesel engines can convert over 30 % of the fuel energy into mechanical energy. Furthermore, there have no high-tension electrical system to attend to, resulting in high reliability and easy adaptation to damp environments. The absence of coils, spark plug wires, etc also eliminates a source of radio frequency emissions which can interfere with navigation and communication equipment, which is especially important in marine and aircraft applications.

On the other hand, the diesel engine can deliver much more of their rated power on a continuous basis than a petrol engine. Due to the increased strength of parts used and diesel fuel has better lubrication properties than petrol, the life of a diesel engine is generally about twice as long as a petrol engine. Moreover, diesel fuel is considered safer than petrol in many applications. This is because; diesel fuel will not explode and does not release a large amount of flammable vapor. The low vapor pressure of diesel is especially advantageous in marine applications, where the accumulation of explosive fuel-air mixtures is a particular hazard.

Another advantage of the diesel engine is for any partial load the fuel efficiency (mass burned per energy produced) of a diesel engine remains nearly constant, as opposed to petrol and turbine engines which use proportionally more fuel with partial power outputs. Besides that, the diesel engine generates less waste heat in cooling and exhaust.

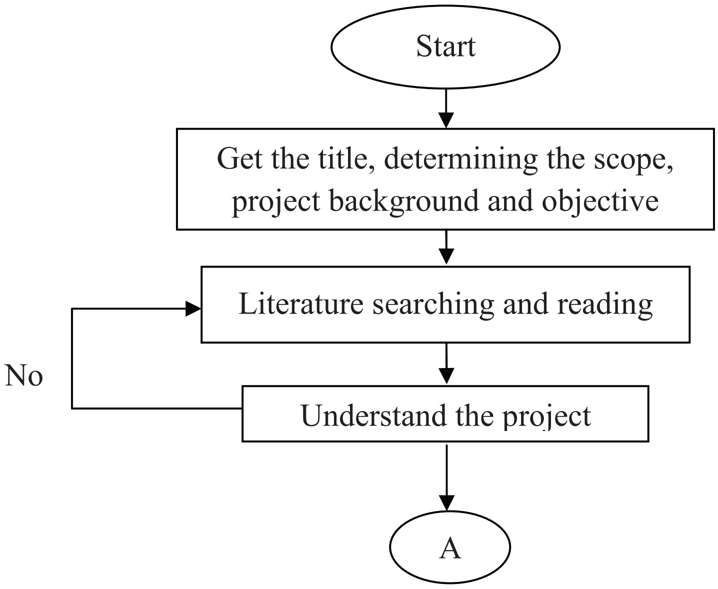
CHAPTER 3

METHODOLOGY

3.1 TYPE OF PROJECT

This project has focused on experimental determination and also theoretical analysis. For experimental determination, the diesel particulate matter (DPM) has been trapped into the filter when the diesel engine running on tire fuel. Then, there are some procedures that must be done and will explain on details in this chapter before proceed with theoretical analysis. For analysis, the comparison between tire and diesel fuel have made by obtaining the graph of PM, DS, SOF concentration and size distribution. Moreover, the diameter of DPM also has been measured.

3.2 FLOW CHART



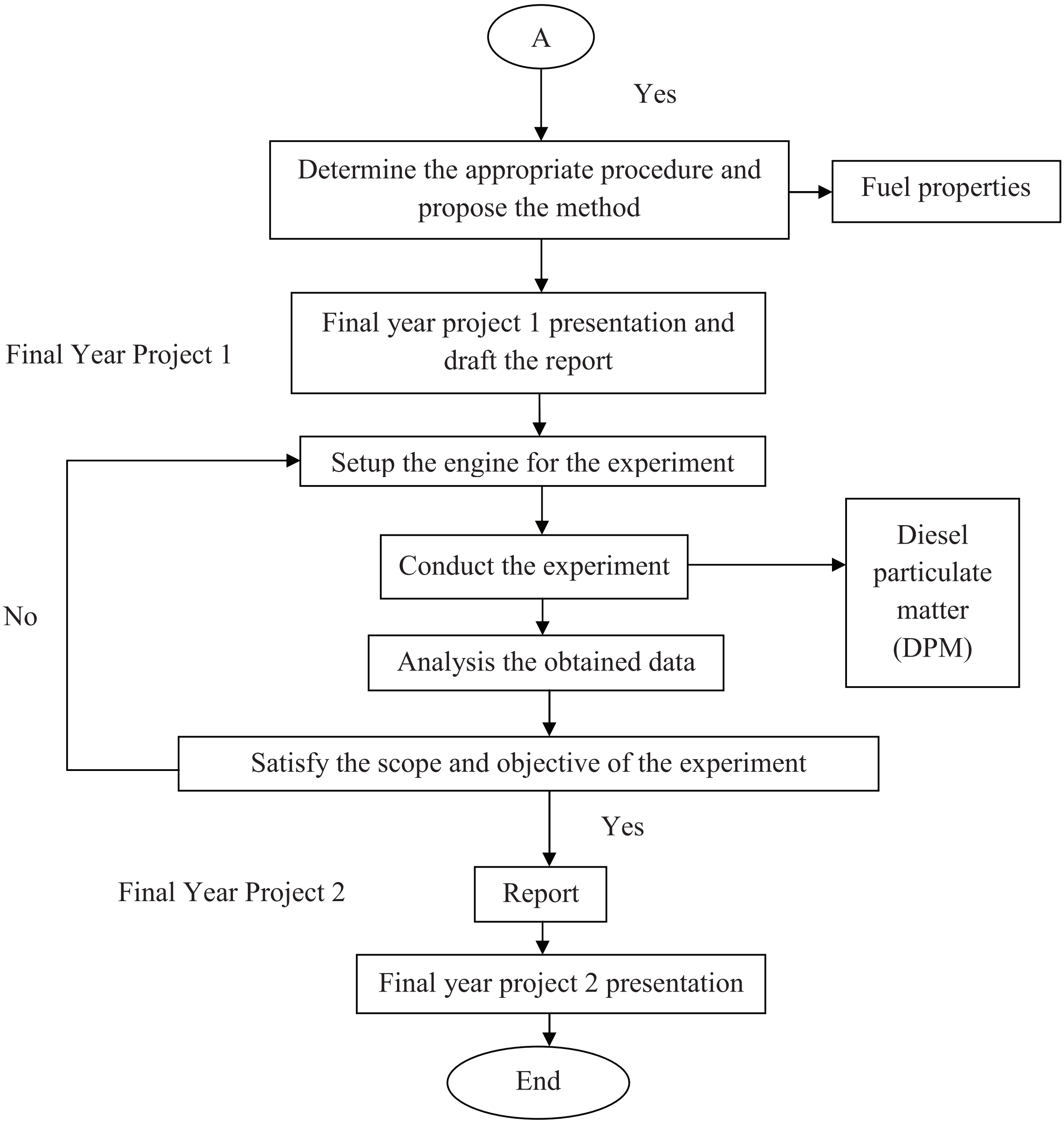


Figure 3.1: Project flow chart

3.3 FLOW CHART DESCRIPTION

The flow chart showed the overall steps that are taken in completion the project. The project begins by determining and understanding about the title of the project. Then, the project scopes and objectives have been determined followed by the background of the project.

Next, the project is continued by searching and reading the literature and the appropriate information for the project. The source of the information includes the books, journals and also information from the supervisor. All the information are collected and analyzed to gain more knowledge about the project.

After reading the literature and understand it, the suitable procedure for the project are determined on how to analyzed PM, DS, SOF concentration and also size distribution. The fuel properties experiment in order to find cetane number, flash point, density, viscosity and gross heat of tire fuel had been done on this time. The procedure will be proposed for Final Year Project 1 presentation. The drafts of the report that include introduction, literature review and methodology have sent to the supervisor after the presentation.

Final Year Project 2 begins by setup the experiment. The single cylinder engine and other tools like oven, filter, weighed balance and vacuum pump are prepared. Since the procedure has been proposed in Final Year Project 1, the experiment has been conducted based on this procedure.

The experiment is conducted and focused on diesel particulate matter. The data are taken and then analyzed according to project objective. If the data satisfied the project scopes and objectives, the project proceeds to the report writing. If the data are not satisfied, the experiment will be repeated until achieved the objectives.

After obtained all the required data, the report writing begin. There have five chapters for this report which are include introduction, literature review, methodology, result and discussion, and conclusion. All the information get are written in this report in order to complete it. The final tasks to complete are Final Year Project 2 presentation and final report submission. After submit the project report, the tasks are complete and the end of the flow chart.

3.4 FUEL CHARACTERISTICS EXPERIMENT

3.4.1 Bomb Calorimeter (Gross Heat)

Figure 3.2: Bomb calorimeter

A bomb calorimeter is used to measure calorific or gross heat value of material. It has measured the heat of combustion of particular reaction. Bomb calorimeter has to withstand the large pressure within the calorimeter as the reaction is being measured. Electrical energy is used to ignite the fuel; as the fuel is burning, it will heat up the surrounding air, which expands and escapes through a tube that leads the air out of the calorimeter.

3.4.2 Octane Meter SHASX-200 (Cetane Number)

Figure 3.3: Octane meter

The octane meter has expansion of adaptation capabilities of the device for various application conditions. This equipment can measure the cetane number by pouring the fuel or oil in the octane meter detector about 5-10 mℓ. Since it is automatic, the value of cetane number will be displayed at the screen.

3.4.3 Portable Density/Specific Gravity Meter

Figure 3.4: Specific gravity meter

Specific Gravity Meter as known as portable density is used for measuring density of substance. The fuel is sucked into the equipment by pressing the suction button. Before that, make sure there is no bubble in the tube. Then, the measurement of density can be appeared at the screen.

3.4.4 U-tube Viscometer

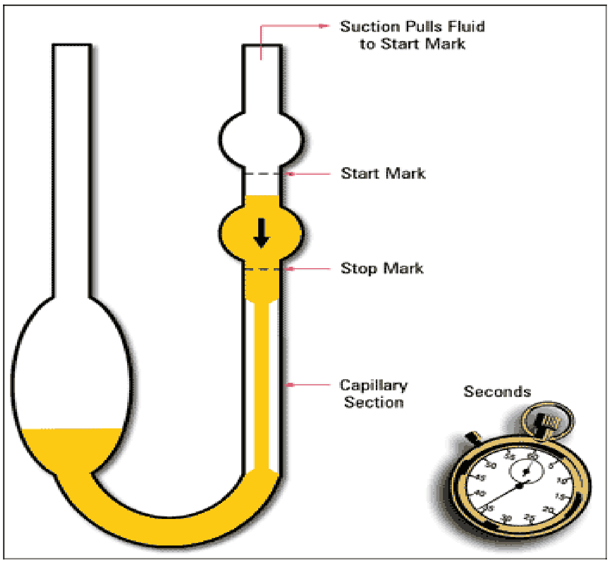


Figure 3.5: Ostwald viscometer

Figure 3.6: Viscometer used in lab

Viscometer is functioned to measure kinematic viscosity and viscosity. In this U-tube viscometer, there have two bulbs at capillary side. The liquid has been drawn into the top bulb by suction. Both of the bulbs have a mark and the time taken start after the fluid reach at the mark of the top bulb. Then, the time will stop when the fluid reach the mark at the bottom bulb. The procedure has been shown in figure above. The value of viscosity and kinematic viscosity can be determined by using the formula below.

$$\text{Kinematic Viscosity (cSt)} = \text{Efflux Time} \times \text{Constant Viscosity} \tag{3.1}$$

$$\text{Viscosity (cP)} = \text{Density} \times \text{Kinematic Viscosity} \tag{3.2}$$

3.4.5 Flash Point

Figure 3.7: Petrotest

Petrotest is used to measure the flash point of the fuel. The flash point has two type of experiment which is open and closed cup. For this experiment, the closed cup experiment has been used. The test cup has been filled with a fuel test and fit with a cover. The fuel is heated and stirred at specific rates. The ignition source is attached to the cup with suitable intervals of temperature until flash appeared at certain temperature

3.5 APPARATUS

3.5.1 The Diesel Engine

Figure 3.8: Engine side view

Figure 3.9: Engine front view

In this experiment the engine used is diesel engine type YANMAR TF 120. This engine is single cylinder and also water cooled. Diesel engine will used to produce the exhaust emission and also particulate matter. The particulate matter has been trap at the exhaust manifold which is one of the engine parts.

Table 3.1: Engine Specifications

Engine Specifications	
Brand	YANMAR
Model	TF 120
Displacement	636 cc
Max output	12 Bhp @ 2400rpm
Continuous output	10 Bhp @ 2400rpm
Fuel tank capacity	11 liter
Cooling system	Water cooled, radiator
Starting system	Starter or manual cranking
Dimensions (L/W/H)	685 cm/350 cm/530 cm
Weight	102 kg

3.5.2 Exhaust Gas Particle Trap

Figure 3.10: Exhaust gas particle trap

Figure 3.11: Reservoir tank

Diesel engine produces soot or particulate matter as a product of combustion. The exhaust gas particle trap is functioned to avoid the soot from reaching the gas analyzer. This is because the exhaust analyzer could be damage if this soot enters to it. It worked by cooling the exhaust gas through the “water jacket” along the tube that the exhaust gas going through. Thus, the particle in the exhaust gas loosing energy and become heavier. So, the particle will drop into the beaker that acts as a trap.

3.5.3 Vacuum Pump

Figure 3.12: Vacuum pump

Vacuum pump function is to suck the exhaust emission from the diesel engine. Before the suction process, this vacuum pump must be calibrated at 20 ℓ/min by using the calibrator.

Table 3.2: Vacuum Pump Specifications

Vacuum pump specifications	
Dimensions	178 mm W × 115 mm H × 206 mm D
Weight	2.24 kg (without battery) 3.56 kg (fitted with P901201 3.2Ah battery) 4.84 kg (fitted with P901202 2.7Ah battery)
Casing IP rating	IP20
Flow range	2-26 litre/min
Maximum sample back pressure	62 kPa (250 inches H_2O)
Power supply	12V leads/acid battery
Storage/operating temperature	-5 to +50 ^{0}C
Charging temperature	-5 to +45 ^{0}C
Relative humidity	0 to 95% RH

3.5.4 Calibrator

Figure 3.13: Top view of calibrator

Another apparatus for this experiment is calibrator. Calibrator functioned is to control exhaust flow during the suction. The exhaust flow must maintain at 20 l/min when the sample are taken. The calibrator is used to calibrate the vacuum pump at 20 l/min before suction process begin. Figure 3.6 shows the picture of calibration.

3.5.5 Oven

Figure 3.14: Oven to heat the filter

In order to complete this project, oven is one of the important apparatus that needed. The function of this oven is to heat the filter before used it and trap the particulate matter. The purpose of heating the filter is to relieve the moisture from the filter. This heating process is about 2 hours with constant temperature of 50 ^{0}C.

3.5.6 Weight Balance

Figure 3.15: The weight balance

This weight balance is used to weigh the filter after heating in the oven. Weight of the filter before and after take the sample will be recorded. Thus, the concentration PM, SOF and DS will be known. Figure 3.8 shows the picture of the weight balance.

3.5.7 Filter and Filter Holder

Figure 3.16: Filters

Filter is used to trap particulate matter from the exhaust emission of the diesel engine. Meanwhile, the filter holder functioned to hold the filter during the suction process. The inlet of the filter holder will attached to exhaust particle trap and the outlet will attached to the vacuum pump. The figure below shows the picture of filter and the filter holder.

Table 3.3: Filter Specifications

Filter Specifications	
Material	Composite
Merk	Advance
Kinds	PG-60
Side	47 mm^2
Quality	100 leaf
Serial Number	305/9713
Manufacturer	Toyo Roshi Kaisya, Ltd

Figure 3.17: Filter holder

Filter holder is used to hold the filter during the experiment. The filter is put inside the holder and the holder has attached to the vacuum pump. The vacuum pump is sucked the exhaust flow and the particulate matter are trapped to the filter.

3.5.8 Petri Dish

Figure 3.18: Petri dish

Petri dish is used to place the filter after heating and collecting the sample of DPM from the engine. The filter is placed by using Vanier Caliper to Petri dish.

3.5.9 Exhaust Gas Analyzer

Figure 3.19: Exhaust analyzer

The exhaust gas is analyzed using exhaust analyzer. The model used is Hand Held 4 & 5 Gas Analyzer Auto 4-2 & Auto 5-2. The exhaust gases that can be analyzed by using this apparatus are CO, CO_2, O_2, NO, NO_x and also CO_K.

Table 3.4: Exhaust Analyzer Specifications

Parameter	Resolution	Accuracy	Range
Carbon Monoxide	0.01 %	±5 % of reading	0-10 %
Oxygen	0.01 %	±5 % of reading	0-21 %
Hydrocarbon	1 ppm	±5 % of reading	0-5000 ppm
Carbon Dioxide	0.1 %	±5 % of reading	0-16 %
Nitric Oxide	1 ppm	±4 % of reading	0-5000 ppm

3.5.10 Exhaust Gas Temperature Sensor

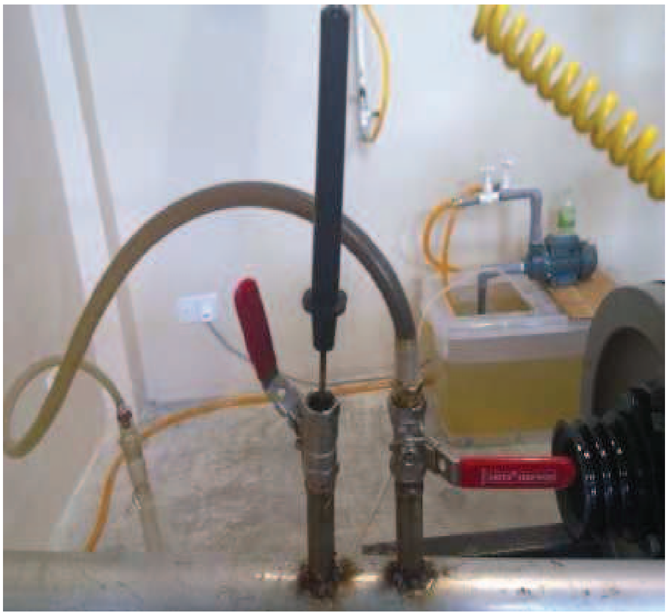


Figure 3.20: Thermocouple

Figure 3.21: Temperature display unit

The exhaust gas temperature is measured using thermocouple and the temperature obtained will be shown at the display unit. Thermocouple will be attached to the exhaust manifold and it will detect the temperature during the experiment.

3.5.11 Tachometer

Figure 3.22: Tachometer

Tachometer is functioned to measure engine speed in rpm. The laser from the tachometer is pointed to the flywheel when the engine is run. The speed has been controlled until the needed speed appeared in the screen of the tachometer.

3.6 EXPERIMENTAL PROCEDURE

3.6.1 Diesel Particulate Matter (DPM) Analysis

First, the filter is heated in the oven for two hours at 50°C. Then, the filter weight has measured by using the weighed balance. After that, the engine runs at speed 1200 revolution per minute (rpm). The exhaust gases that come out from the exhaust valve are collected using pipe. The smoke is let through the exhaust particle trap. The water jacket around the exhaust pipe will cause the soot particle to fall at the bottom of the trap. The “clean” exhaust gas is entered the exhaust analyzer and the content of the exhaust gas will be analyzed. The amount of the content can be measured directly from the exhaust analyzer display unit. For DPM analysis, the small particles will be trapped on the filter after sucked by using vacuum pump. The procedure for taking the sample of particulate matter is repeated at speed 1500rpm, 1800rpm, 2100rpm and 2400rpm.

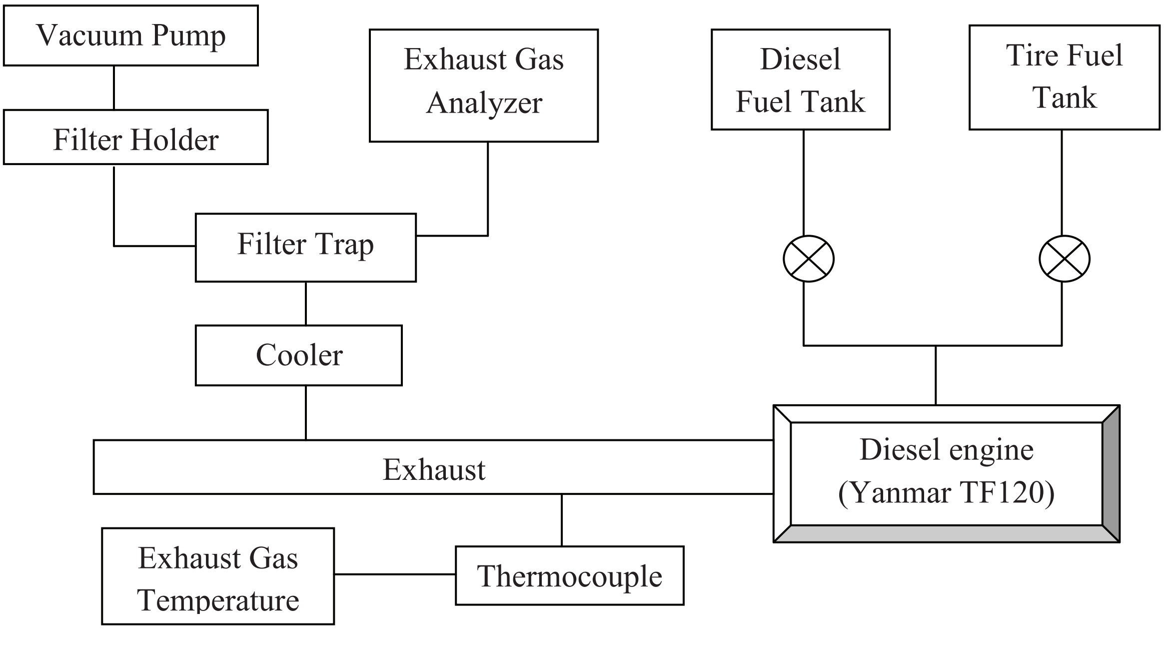


Figure 3.23: Schematic diagram of experiment

After taking all the sample of the particulate matter on the filter for each engine speed, the filter is heated again in the oven at 50 ^{0}C for two hours. Then, the filter is weighed in order to determine the PM concentrations. Next, the filter is immersed into dichloromethane for 24 hours and will be heated again in the oven for two hours at 50 ^{0}C. After that, the filter is weighed again in order to find soluble organic fraction (SOF) concentrations. By subtracting the PM concentrations and SOF concentrations, the dry soot (DS) will be determined. The graph of PM, SOF and DS concentrations for tire fuel are plotted and compared to the diesel fuel.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 FUEL CHARACTERISTICS

Table 4.1: Fuel characteristics of diesel fuel and tire fuel

Property	**Diesel Fuel**	**Tire Fuel**
Density (g/m^3)	0.8416	0.9230
Cetane Number	68.2	-
Kinematic Viscosity @ 40^{o}C (cP)	2.22	5.1
Flash Point (^{o}C)	84	44
Sulphur Content (%)	0.042	0.811
Gross Calorific Value (MJ/kg)	42.4915	28.6542
Boiling Point (^{o}C)	193	127

Table 4.1 shows the comparison of fuel characteristics between diesel fuel and tire fuel. Based on result above, the diesel fuel has a better quality compare to the tire fuel. The diesel fuel has lower sulphur content and higher gross calorific value than tire fuel. Low sulphur content will produce low SOF concentration of particulate matter. Meanwhile, higher gross calorific value contributes to less fuel consumption. For the cetane number, tire fuel does not have any value. This is because the cetane number of tire fuel is out of range which may have highest or lowest cetane number until it cannot produce any value.

The flash point and the boiling point of the diesel fuel are higher than tire fuel. This is because with high flash point and boiling point, all the components in the diesel fuel can completely combust thus producing low emission and particulate matter.

4.2 FUEL CONSUMPTION

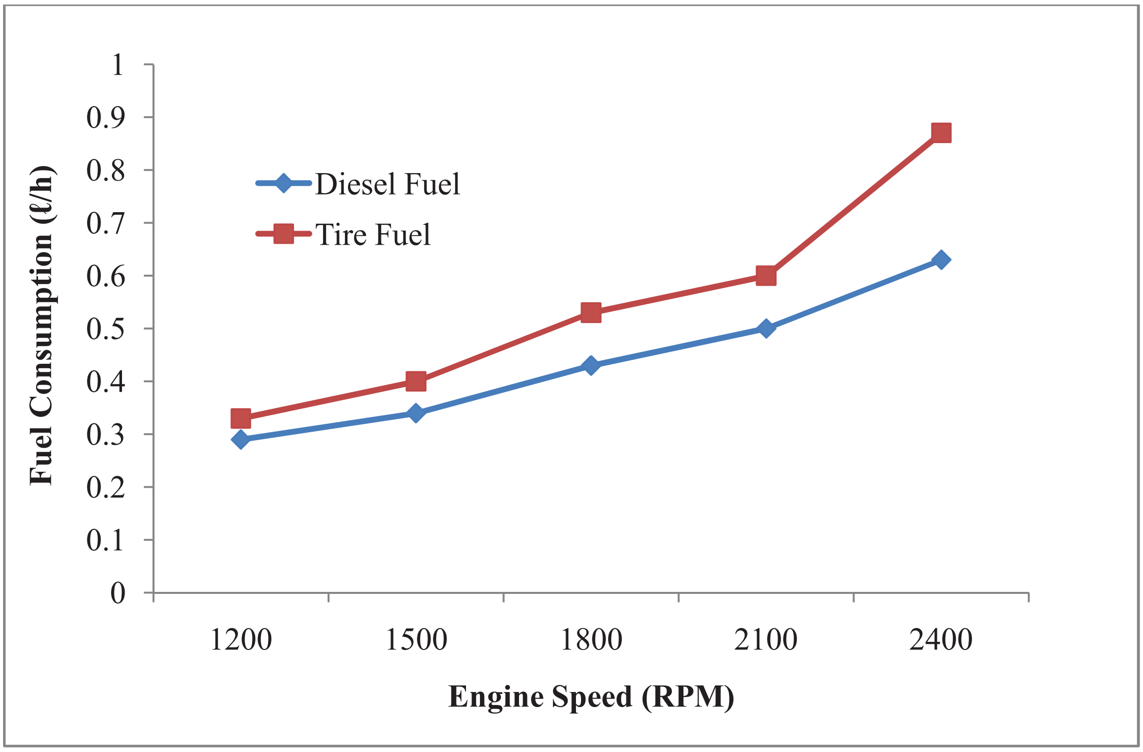


Figure 4.1: Fuel consumption versus engine speed

Figure 4.1 shows the comparison of fuel consumption between tested fuels. It is clearly shown that the fuel consumption due to tire fuel usage is higher than diesel fuel. The average fuel consumption for tire fuel is higher than diesel fuel by 19.78 %. The fuel consumption of the tire fuel is higher probably because the time taken for all the tire fuel that injected into the combustion chamber is longer to completely burned to same amount of diesel fuel. At the end of the power stroke of the engine, there are probably still remaining some tire fuels that are still not burned. When the exhaust gas is pushed out during scavenging process, the unburned tire fuel also pushed out and wasted. This condition may cause the fuel consumption due to usage of tire fuel is higher.

4.3 DIESEL PARTICULATE MATTER (DPM)

4.3.1 Particulate Matter (PM) Concentration

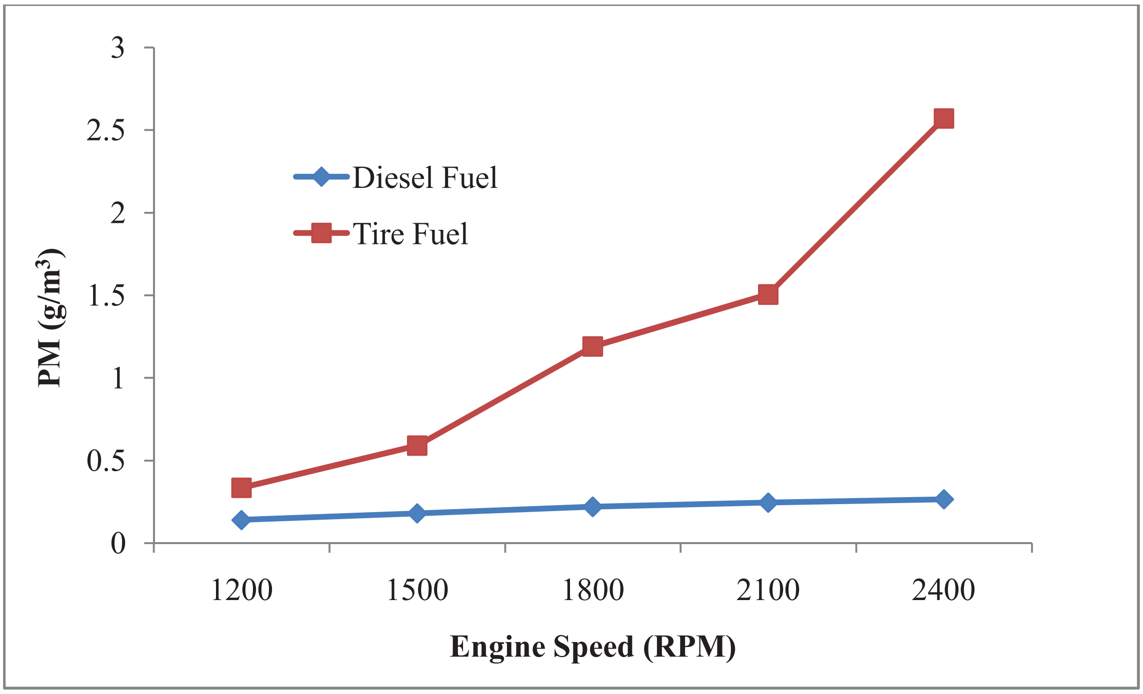


Figure 4.2: PM concentration versus engine speed

Figure 4.2 shows the comparison of PM concentration for the tested fuel. Based on the graph, the PM concentration of the tire fuel is higher than the diesel fuel. At the minimum speed which is 1200 RPM, the value of PM concentration for diesel fuel is 0.14 g/m^3 meanwhile the tire fuel produced 0.335 g/m^3 of PM. At 2400 RPM which is the maximum speed, the PM concentration for the diesel fuel is 0.265 g/m^3 and for the tire fuel are 2.57 g/m^3. The average of PM concentration of tire fuel is higher than diesel fuel by 83.04 %. When the engine speed increase, the PM concentrations for both fuel also increase. The PM concentration of tire fuel is higher than diesel fuel because the tire fuels has not completely burned during the combustion and produces a lot of carbon. The carbon that not completely burned will flow through the exhaust valve and will be trapped to the filter. Moreover, tire fuel forms a lot of carbon black due to combustion during pyrolysis process.

4.3.2 Soluble Organic Fraction (SOF) Concentration

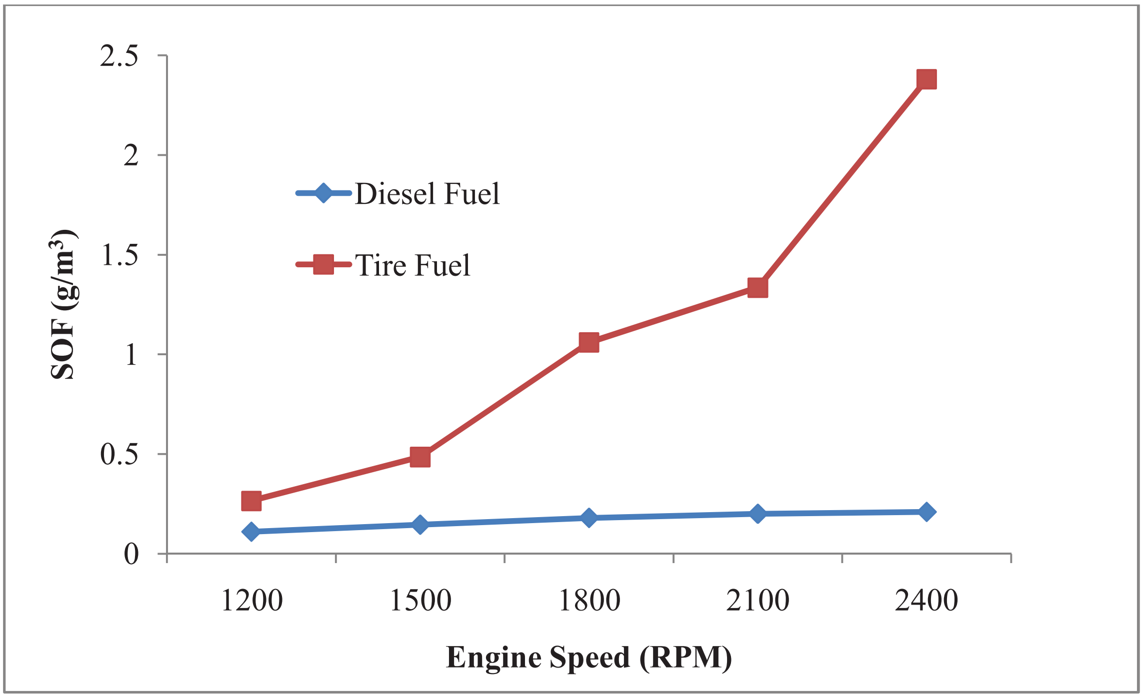


Figure 4.3: SOF concentration versus engine speed

Figure 4.3 shows the comparison between tire fuel and diesel fuel for SOF concentration. The value of SOF concentration of tire fuel is higher than diesel fuel. At the minimum of engine speed which is 1200 RPM, the value of SOF concentration for diesel fuel is 0.11 g/m^3 and for the diesel fuel is 0.265 g/m^3. At the maximum engine speed which is 2400 RPM, the diesel fuel produced 0.21 g/m^3 of SOF concentration meanwhile the tire fuel produced 2.38 g/m^3 SOF concentration. The average of SOF concentration due to usage of tire fuel is higher than the diesel fuel by 84.71 %. The graph shows increasing value of SOF concentration for both fuels with increasing of speed. The SOF concentration for the tire fuel is high because the sulphur content of the tire fuel is 0.811 % higher than the diesel fuel which is 0.042 %. The higher the sulphur content, the higher the SOF concentration.

4.3.3 Dry Soot (DS) Concentration

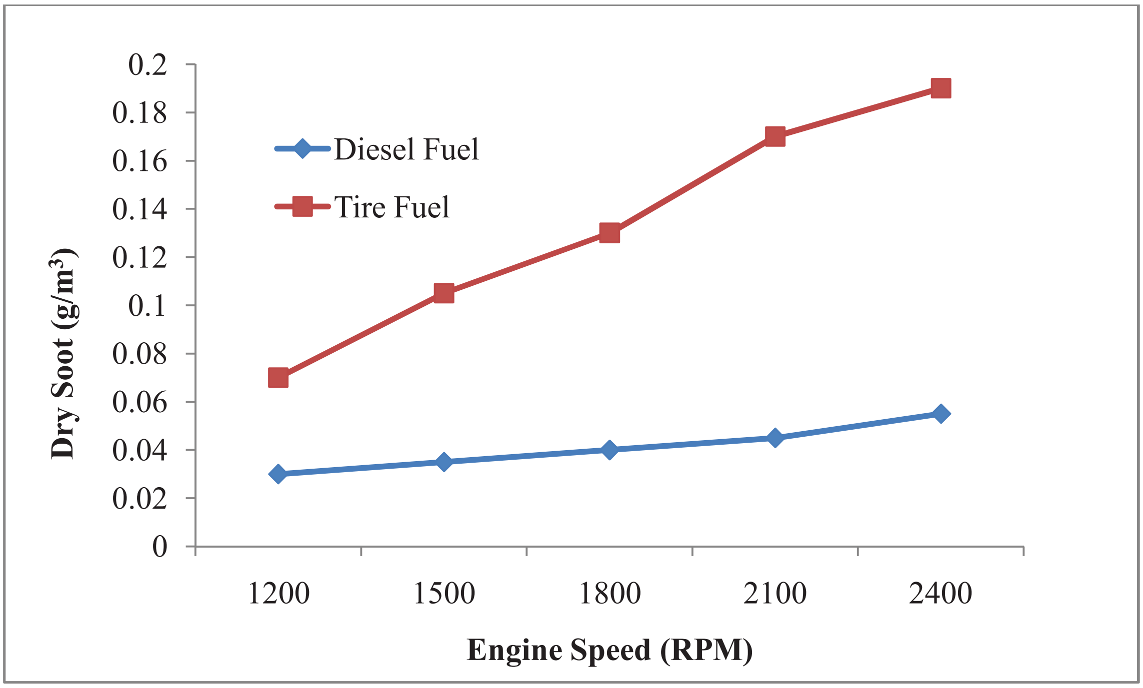


Figure 4.4: DS concentration versus engine speed

Figure 4.4 shows the comparison of DS concentrations for the tested fuel. The value of DS concentration due to usage of tire fuel is higher than diesel fuel. At the minimum engine speed which is 1200 RPM, the value of DS concentrations for the diesel fuel is 0.03 g/m^3 and for the tire fuel is 0.07 g/m^3. At 2400 RPM which is the maximum engine speed, the diesel fuel has been produced 0.055 g/m^3 of DS concentrations whereas the tire fuel had produced 0.19 g/m^3 of DS concentrations. The average of DS concentrations for diesel fuel is lower than tire fuel by 69.17 %. The trend of the graph shows that the DS concentrations increase with increasing of engine speed. Dry soot is the solid particles that have been trapped on the filter. The DS concentration of the tire fuel is higher than diesel fuel because the carbon content in the tire fuel is high. The increasing of the engine speed has been contributed to the formation of the dry soot rapidly.

4.4 EXHAUST GAS TEMPERATURE

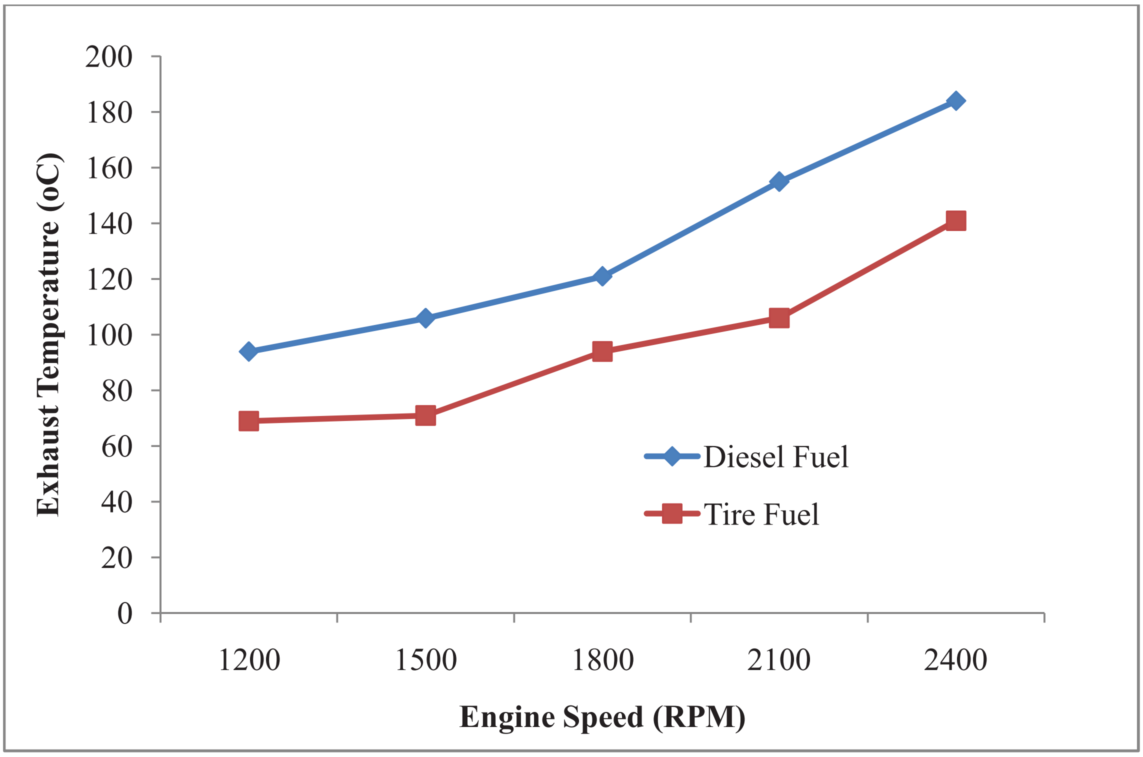


Figure 4.5: Exhaust gas temperature versus engine speed

Figure 4.5 shows the comparison the exhaust gas temperature between diesel fuel and tire fuel. At the minimum speed which is 1200 RPM, the temperature of exhaust gas for diesel fuel usage is 94 ^{0}C and for the tire fuel usage is 69 ^{0}C. For the maximum engine speed which is 2400 RPM, the exhaust gas temperature for diesel fuel is 184 ^{0}C and for the tire fuel is 141 ^{0}C. The average of exhaust gas temperature for diesel fuel usage is higher than the tire fuel usage by 27.12 %. The exhaust temperature of tire fuel lower than diesel fuel may cause by incomplete combustion during the engine run by using tire fuel.

4.5 SIZE DISTRIBUTION OF DPM

4.5.1 Size Distribution of DPM at 1200 RPM

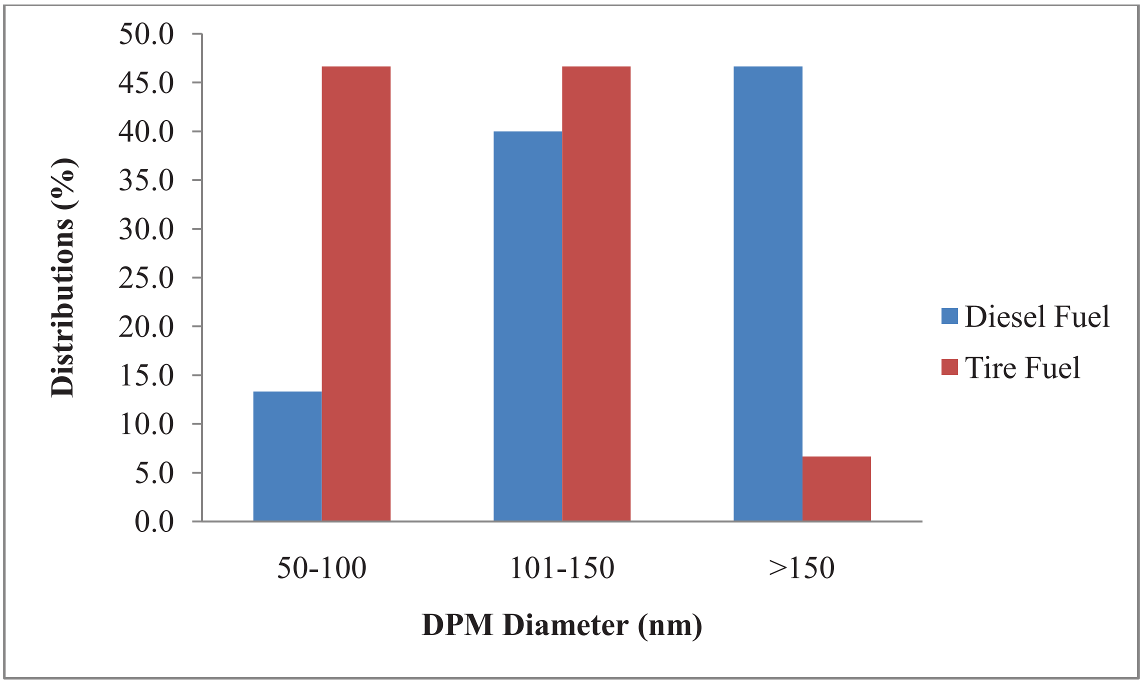


Figure 4.6: Distributions versus DPM diameter for 1200 RPM

Figure 4.6 shows the bar chart of size distribution of DPM diameter for the diesel fuel and the tire fuel at 1200 RPM. For diameter range 50 to 100 nm, the size distributions for the tire fuel is 46.7 % higher than diesel fuel which is 13.3 % only. The both fuel consists most of diameter range 101 to 150 nm and approximately have the same amount of size distributions which is 40 % for diesel fuel and 46.7 % for the tire fuel. For the diameter range more than 150 nm, the diesel fuel is higher than the tire fuel which is 46.7 %. Meanwhile, the tire fuel only have 6.7 % of size distribution of DPM diameter. From the bar chart, the tire fuel have consisted more small particle which below 100 nm compared to the diesel fuel that consisted more large particle which above 150 nm.

4.5.2 Size Distribution of DPM at 1500 RPM

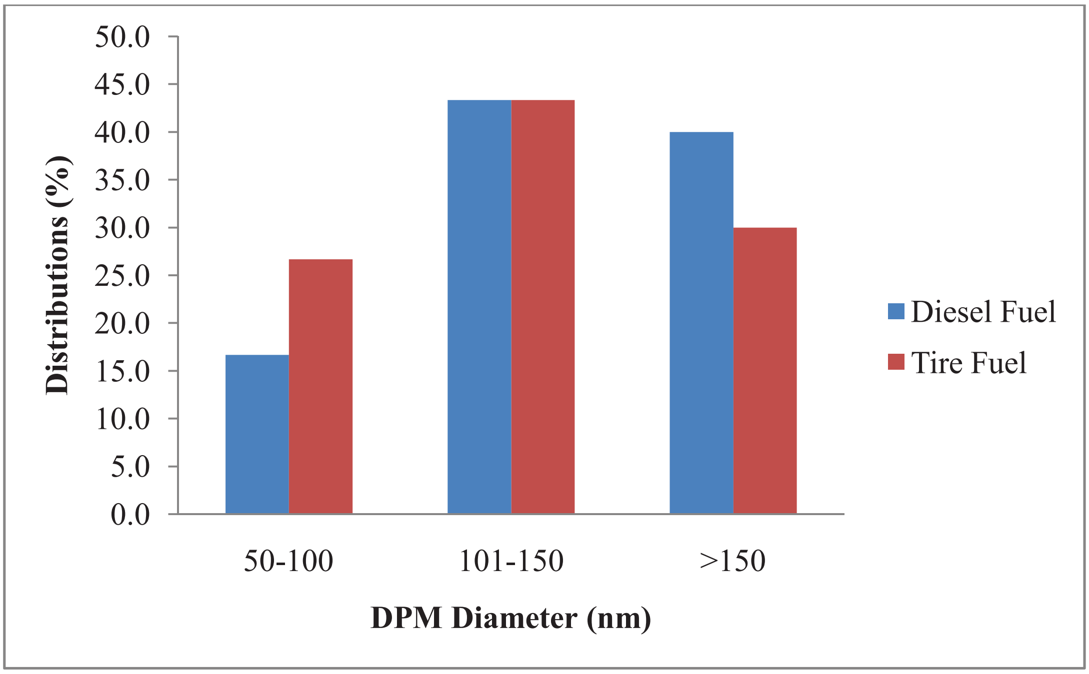


Figure 4.7: Distribution versus DPM diameter for 1500 RPM

Figure 4.7 shows the bar chart of size distribution of DPM diameter for the both fuel usage in this experiment. From the chart, the diameter range 50 to 100 nm shows the distributions of the tire fuel (26.7 %) is higher than diesel fuel (16.7 %). For the diameter range 101 to 150 nm the both fuel recorded the same amount of size distribution which is 43.3 %. The diesel fuel have higher size distribution which is 40 % compared to tire fuel which is 30% for the diameter range more than 150 nm. At this engine speed, the tire fuel still consist many smaller particle compared to the diesel fuel (range 50 to 100 nm. Meanwhile, the diesel fuel have consisted many large particle which is range more than 150 nm.

4.5.3 Size Distribution of DPM at 1800 RPM

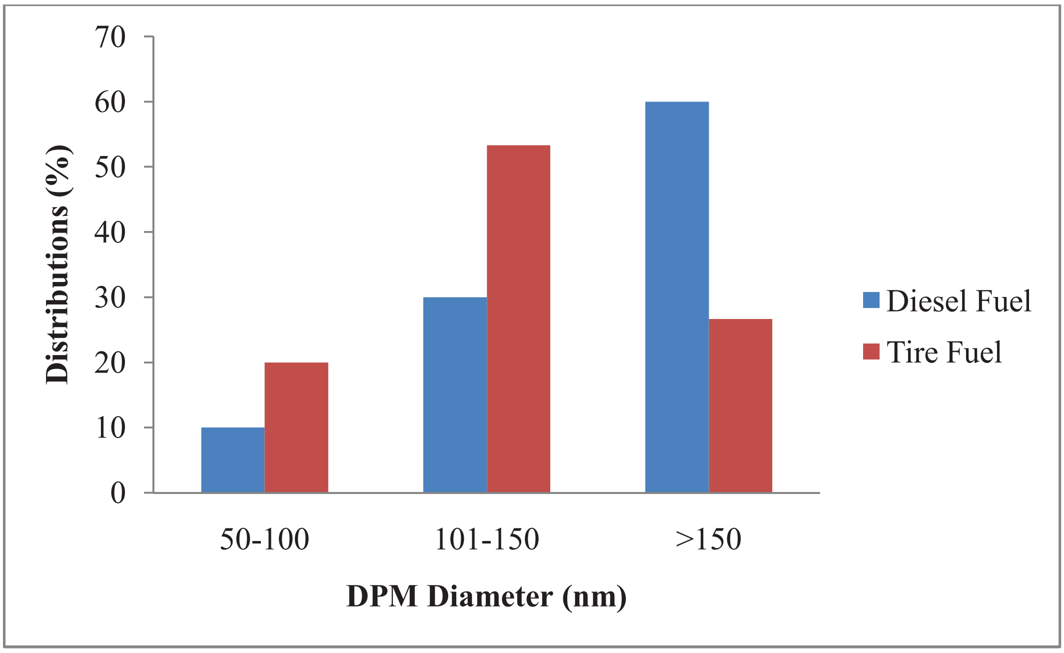


Figure 4.8: Distribution versus DPM diameter for 1800 RPM

Figure 4.8 shows the bar chart of the percentage of size distribution versus the range of DPM diameter at 1800 RPM. The bar chart shows the percentage distribution for the tire fuel which is 20 % is higher than the diesel fuel which is 10 % for the diameter range 50 to 100 nm. For the diameter range 101 to 150 nm, the percentage for size distribution of tire fuel is 53.3 % and the diesel fuel is 30 %. The diesel fuel have recorded the higher percentage which is 60 % compared to the tire fuel which have recorded 26.7 % of size distribution for the diameter range more than 150 nm.

4.5.4 Size Distribution of DPM at 2100 RPM

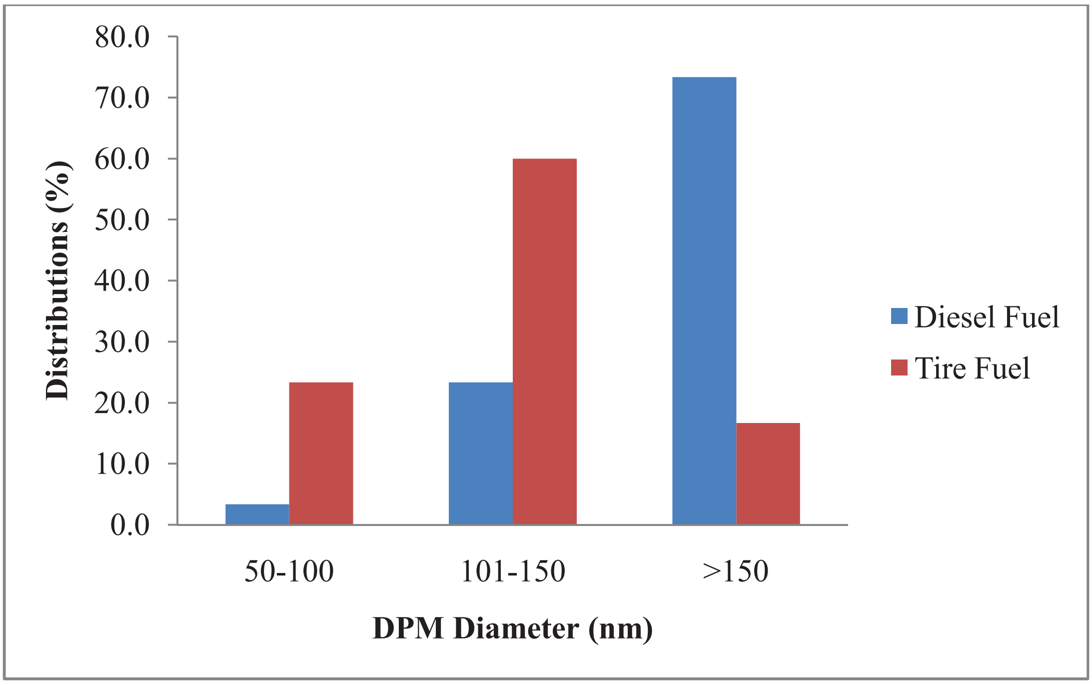


Figure 4.9: Distribution versus DPM diameter for 2100 RPM

Figure 4.9 shows that the bar charts of size distribution of DPM diameter for the engine speed 2100 RPM. At this speed, the percentage of size distribution for the diameter range below 100 nm recorded that the tire fuel is higher than the diesel fuel by 20 % difference. Meanwhile, for the diameter range 101 to 150 nm the tire fuel also higher compared to the diesel fuel by 36.7 % difference. The diesel fuel (73.3 %) has the higher percentage of distribution than the tire fuel (16.7 %) at the diameter range more than 150 nm. This show that the diesel fuel has consisted many large particle compared to the tire fuel which has more particle with size below than 100 nm.

4.5.5 Size Distribution of DPM at 2400 RPM

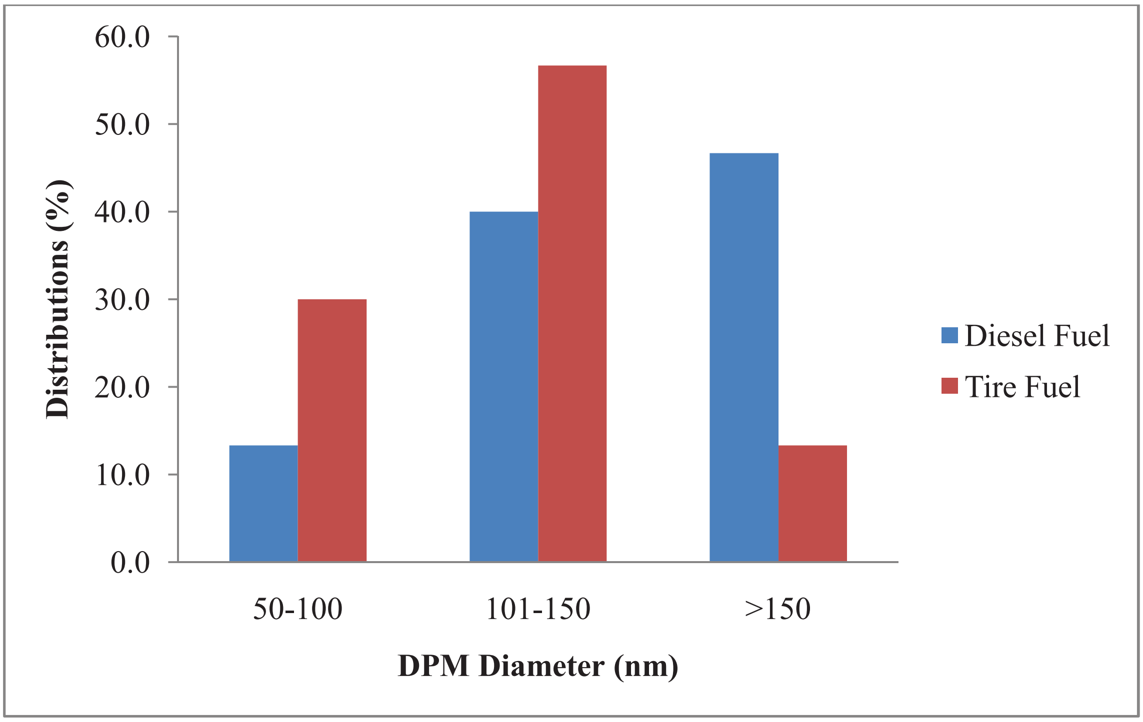
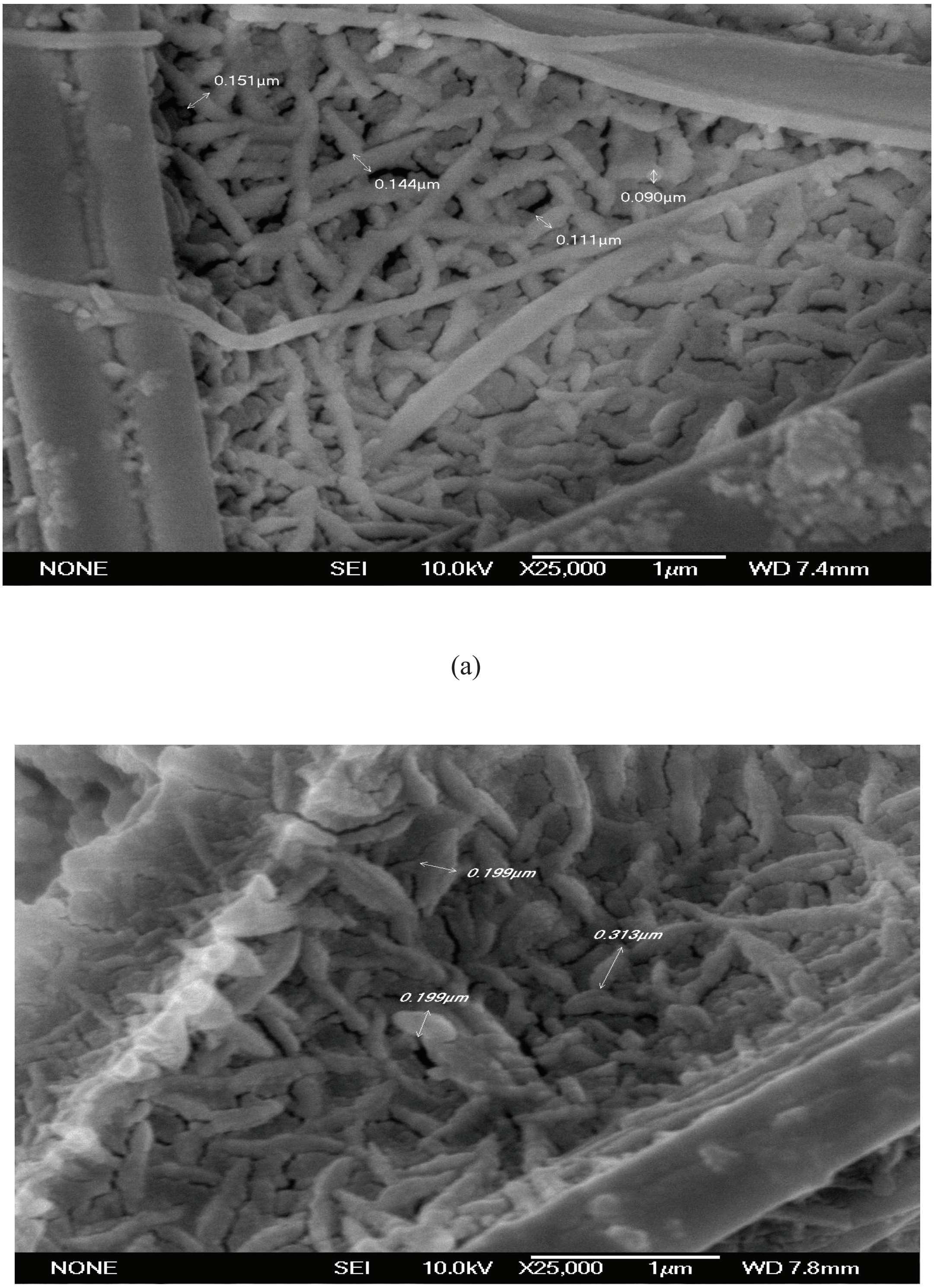


Figure 4.10: Distribution versus DPM diameter for 2400 RPM

Figure 4.10 shows the bar chart of percentage distribution versus DPM diameter at 2400 RPM of engine speed. For the diameter range below than 100 nm and 101 to 150 nm, the tire fuel has higher percentage distribution compared to the diesel fuel. At range below than 100 nm, the percentage of distribution for tire fuel is 30 % and the diesel fuel is 13.3 % whereas for the range 101 to 150 nm the tire fuel recorded 56.7 % and the diesel fuel recorded 40 % of percentage distribution. For the diameter range more than 150 nm, the diesel fuel has the higher percentage than the tire fuel by 33.4 % difference. Based on the trends of bar chart for all speed have shown that the tire fuel produced many small particle which is the diameter below than 100 nm that very harmful to human health. This small particle can easily penetrate into human blood cells and also human lung that contribute to the lung cancer.

4.6 SAMPLE PICTURE OF PARTICLE UNDER SEM



(a)

(b)

Figure 4.11: Particle under SEM (a) for diesel fuel and (b) for tire fuel at 2400 RPM

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The main objective of this project is to analyze the PM, DS, SOF concentrations, size distribution and size diameter of diesel particulate matter (DPM) of a single cylinder diesel engine by using tire fuel compared to diesel fuel. The second objective is to analyze the fuel consumption of the engine due to usage of tire fuel compared to diesel fuel. From the first objective, the experiment is conducted to analyze the PM, DS, SOF concentration, size distribution and size diameter of DPM. From the experiment, the average the PM concentration of tire fuel is higher than diesel fuel by 83.04%. For SOF concentration, the average amount due to usage of tire fuel is also higher than the diesel fuel by 84.71%. Moreover, for DS concentration the tire fuel is higher than diesel fuel by 69.17%.

Based on analysis of size distribution, the tire fuel have produced many small particle which is range below 100 nm compared to the diesel engine that produced many large particle which more than 150 nm. As a result, the particle that produced when the engine run using the tire fuel is more harmful to the human health since the small particle is easy to penetrate into blood cells and lung.

The second objective is achieved by measuring the fuel consumption for both fuel usages. The fuel consumption has been measured manually because there have no flow rate meter. The result obtained are plotted in the graph and analyzed. The fuel consumption for both fuel usages is compared. From the experiment, the fuel consumption for tire fuel usage is higher than diesel fuel by 19.78%.

During the experiment, the engine is not running smoothly when the tire fuel is used in high speed. Furthermore, the particulate matters that have been trapped at the filter become browner with increasing of the engine speed. The exhaust smoke causes irritation to the eyes as well as breathing difficulty.

5.2 RECOMMENDATIONS FOR FUTURE RESEARCH

After all process done in completing the project, there have some recommendation that can be done for the future research. One of the recommendation is installed the hydraulic dynamometer in terms of load. By attaching the load to the engine, the performance of the engine such as torque can be measured and give more information about the engine performance when tire fuel is used.

The other recommendation is detail check on the cetane number of tire fuel by finding the reason why the tire fuel that does not have value for the cetane number. Since the pure tire fuel is not suitable for diesel engine because produced high DPM, blends the tire fuel with diesel fuel and make the comparison of DPM produced after blending it with diesel. Besides that, find an alternative such as produce a perfume in order to reduce the smell of the tire fuel that can make human difficult to breath.

REFERENCES

Ames, W. R. 2007. *Analysis of A 2007 EPA Compliant DPM Sampling System*. West Virginia University: ProQuest Information and Learning Company.

Bosch, R. 2005. *Diesel Engine Management*. West Susses: John Wiley & Sons.

Boxwell, M. 2011. *The 2011 Electric Car Guide*. U.K.: Greenstream Publishing.

Buekens, A. 2006. Introduction to Feedstock Recycling of Plastics. *Feedstock Recycling and Pyrolysis of Waste Plastics; Converting Waste Plastics into Diesel and Other Fuels*. Belgium: John Wiley & Sons.

Burtscher, H. 2004. Physical Characterization of Particulate Emissions from Diesel Engines: A Review. *Journal of Aerosol Science*. **36**: 896-932.

Challen, B. and Baranescu, R. 1999. *Diesel Engine Reference Book 2nd Edition*. Amsterdam: Elsevier Butterworth Heinemann.

Diaz, A. L., Reed, D. G. and Fu, S. J. 2005. Source Apportionment of Diesel Particulate Matter in the Southeastern United States Using Models 3/CMAQ. *4th Annual International Emission Inventory Conference*. April 11-14; Las Vegas, Nevada.

Grenier, M., Gangal, M., Goyer, N., McGinn, S., Penney, J. and Vergunst, J. 2001. Sampling for Diesel Particulate Matter in Mines. *Diesel Emission Evaluation Program (DEEP), Technology Transfer Initiative*. October 2001.

Gupta, N. H. 2006. *Fundamentals of Internal Combustion Engines*. PHI Learning Private Limited Publishing.

Heywood, B. J. 1988. *Internal Combustion Engines Fundamentals*. McGraw-Hill.

Holt, D. J. 2004. The Diesel Engine. Warrendale, PA: Society of Automotive Engineers.

Kaminsky, W. 2006. The Hamburg Fluidized-Bed Pyrolysis Process to Recycle Polymer Wasted and Tires. *Feedstock Recycling and Pyrolysis of Waste Plastics; Converting Waste Plastics into Diesel and Other Fuels*. Germany: John Wiley & Sons.

Keskinen, J., Pietarinen, K. and Lehtimaki, M. 1992. Electrical Law Pressure Impactor. *Journal of Aerosol Science*. **23**: 353-360.

Kittelson. 1998. D. B. Engines and Nanoparticles: A Review. *Journal of Aerosol Science*. **29**: 575-588.

Kligenberg, H. 1996. *Automobile Exhaust Emission Testing*. Measurement of Regulated and Unregulated Exhaust Gas Components, Exhaust Emission Tests. Springer-Verlag: Berlin.

Leng, R. A. 2010. The Impact of Resource Depletion is Being Overshadowed by the Threat of Global Warming. *Journal of Livestock Research for Rural Development.* **22**(2). Australia.

Mani, M., Subash, C. and Nagarajan, G. 2009. Performance, Emission and Combustion Characteristics of a DI Diesel Engine Using Waste Plastic Oil. *Journal of Applied Thermal Engineering*. **29**: 2738-2744. India: Elsevier.

Matthey, J. 2004. Controlling Particulate Emissions from Diesel Vehicles. *Journal of Topics in Catalysis*. **28**: 1-4. United Kingdom (UK).

Murugan, S., Ramaswamy, M. C. and Nagarajan, G. 2008. Performance, Emission and Combustion Studies of a DI Diesel Engine Using Distilled Tire Pyrolysis Oil-Diesel Blends. *Journal of Fuel Processing Technology*. **89**(2): 152-159.

Murugan, S., Ramaswamy, M. C. and Nagarajan, G. 2008. The Use of Tire Pyrolysis Oil in Diesel Engines. *Journal of Waste Management*. **28**(12): 2743-2749.

National Institute of Occupational Safety and Health, (NIOSH). 1988. Carcinogenic Effects of Exposure to Diesel Exhaust. Current Intelligence Bulletin No.50. U.S. Department of Health and Human Services. 88-116.

Prasad, R. and Bella, R. V. 2010. A Review on Diesel Soot Emission, Its Effect and Control. *Bulletin of Chemical Reaction Engineering and Catalysis*. **5**(2): 69-86.

Pulkrabek, W. W. 2003. *Engineering Fundamentals of the Internal Combustion Engine, 2nd Edition*. Pearson Prentice Hall: 289-290.

Setten, V. L. A. A. B., Makkee, M. and Mouljin, A. J. 2001. Science and Technology of Catalytic Diesel Particulate Filters. *Journal of Catalysis Reviews*. **43**(4): 489-564.

Sharp, J. 2003. The Public Health Impact of Diesel Particulate Matter. Sierra Club of Canada, Eastern Canada Chapter.

Venkatasubramaniam, C.K. 2007. *Effect of Dilution Method on Diesel Exhaust Particulate Matter Concentrations and Size Distributions*.West Virginia University.

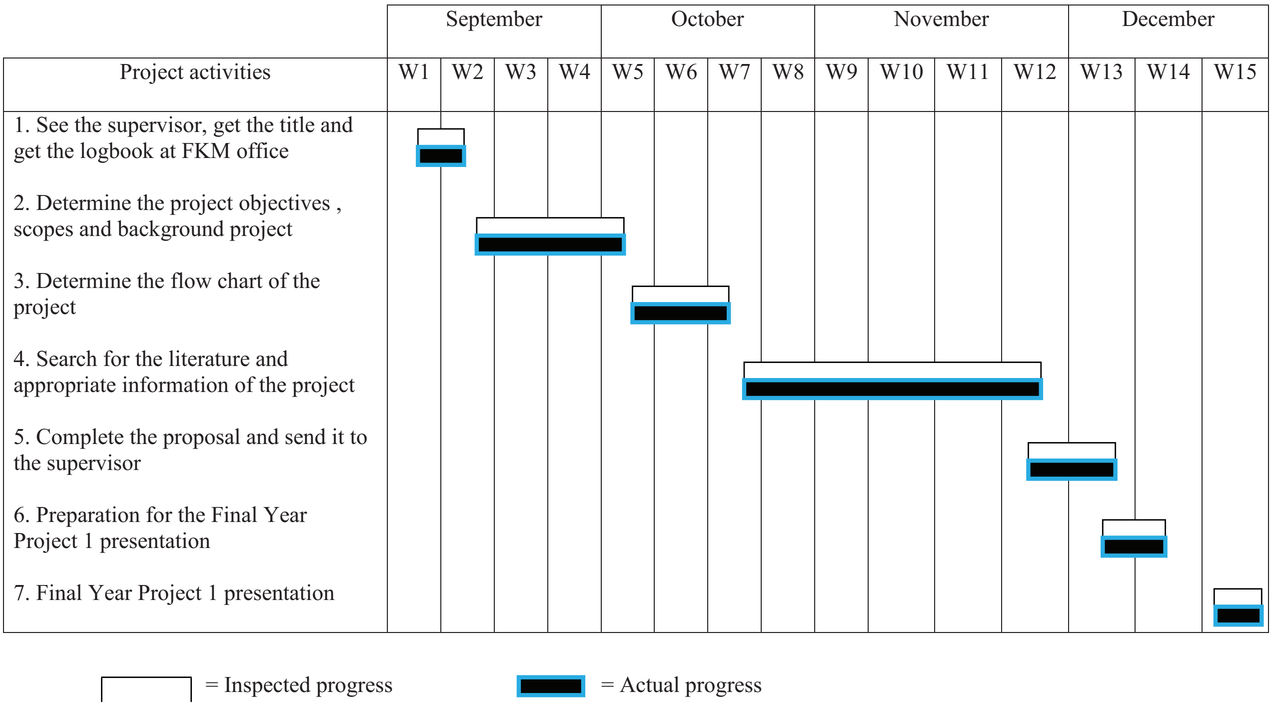
Watts, F. W. and Ramachandran, G. 2000. Diesel Particulate Matter Sampling Methods: Statistical Comparison. Final Report Submitted to the Diesel Emission Evaluation Program. University of Minnesota.

Wibawaningrum, R. 2005. An Experimental Study on Effect of Sulfur Content in MDO to Exhaust Gas. Master Thesis: Campus of ITS Keputih Sukolilo Surabaya.

Zadgaonkar, A. 2006. Process and Equipment for Conversion of Waste Plastics. *Feedstock Recycling and Pyrolysis of Waste Plastics; Converting Waste Plastics into Diesel and Other Fuels*. Nagpur, India.

APPENDIX A

GANTT CHART FOR FINAL YEAR PROJECT 1



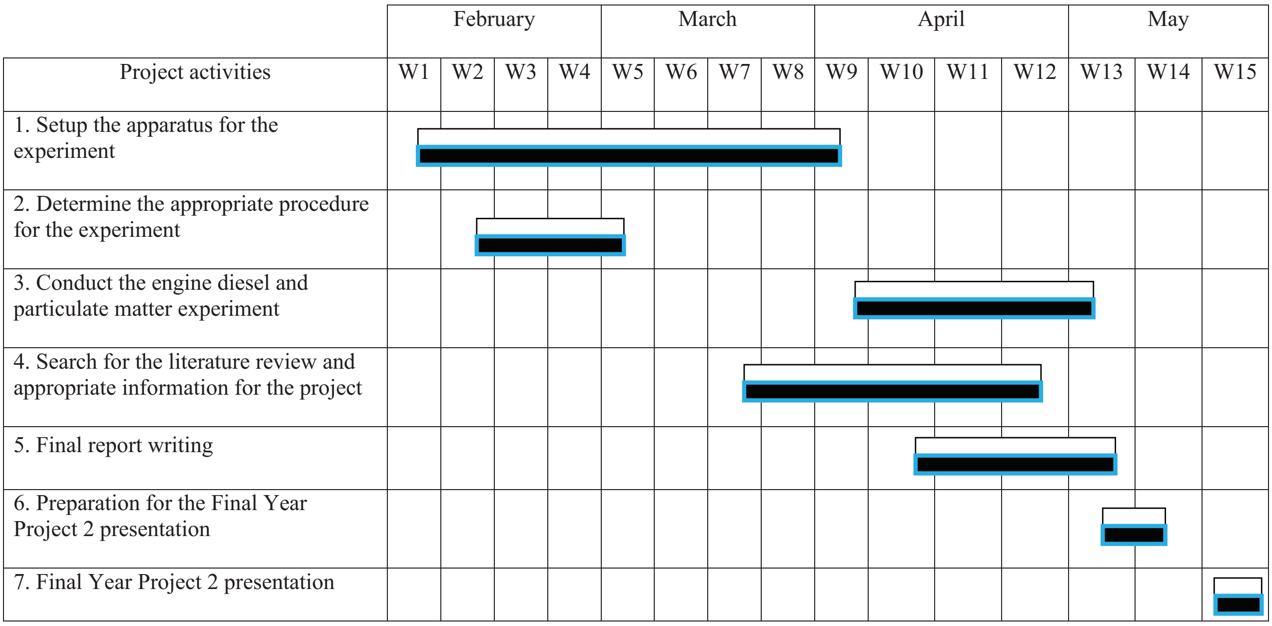
Project activities	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
	September				October				November				December		
1. See the supervisor, get the title and get the logbook at FKM office	■	■													
2. Determine the project objectives , scopes and background project		■	■	■	■										
3. Determine the flow chart of the project					■	■	■								
4. Search for the literature and appropriate information of the project							■	■	■	■	■	■			
5. Complete the proposal and send it to the supervisor												■	■		
6. Preparation for the Final Year Project 1 presentation													■	■	
7. Final Year Project 1 presentation															■

☐ = Inspected progress

■ = Actual progress

APPENDIX B

GANTT CHART FOR FINAL YEAR PROJECT 2

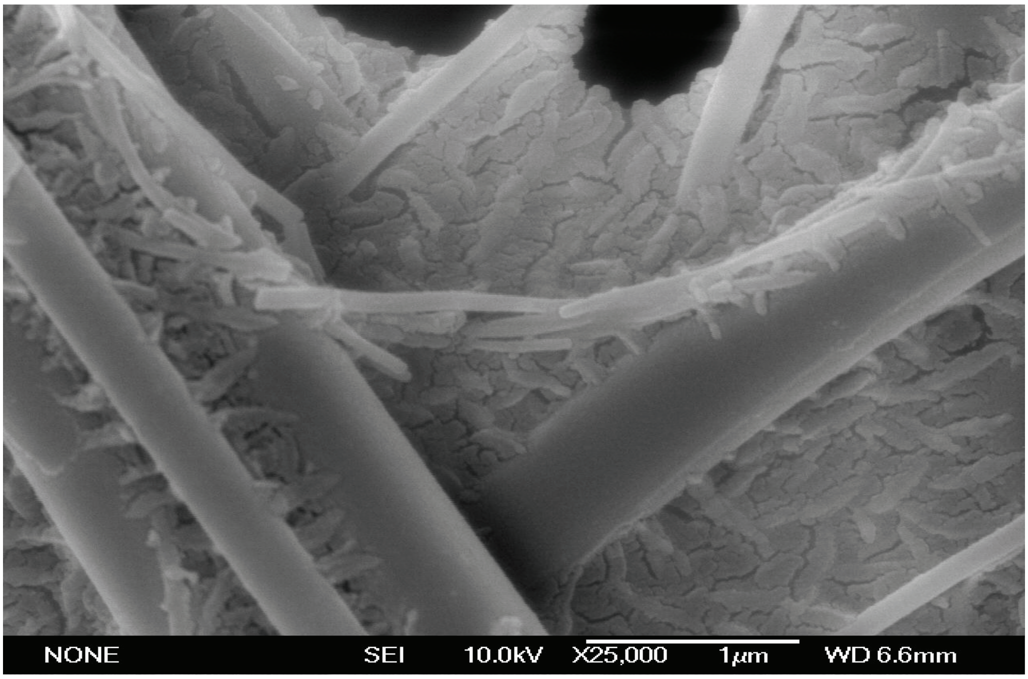


	February				March				April				May		
Project activities	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
1. Setup the apparatus for the experiment	■	■	■	■	■	■	■	■	■						
2. Determine the appropriate procedure for the experiment		■	■	■	■										
3. Conduct the engine diesel and particulate matter experiment									■	■	■	■	■		
4. Search for the literature review and appropriate information for the project							■	■	■	■	■	■			
5. Final report writing										■	■	■	■		
6. Preparation for the Final Year Project 2 presentation													■	■	
7. Final Year Project 2 presentation															■

☐ = Inspected progress

■ = Actual progress

APPENDIX C1



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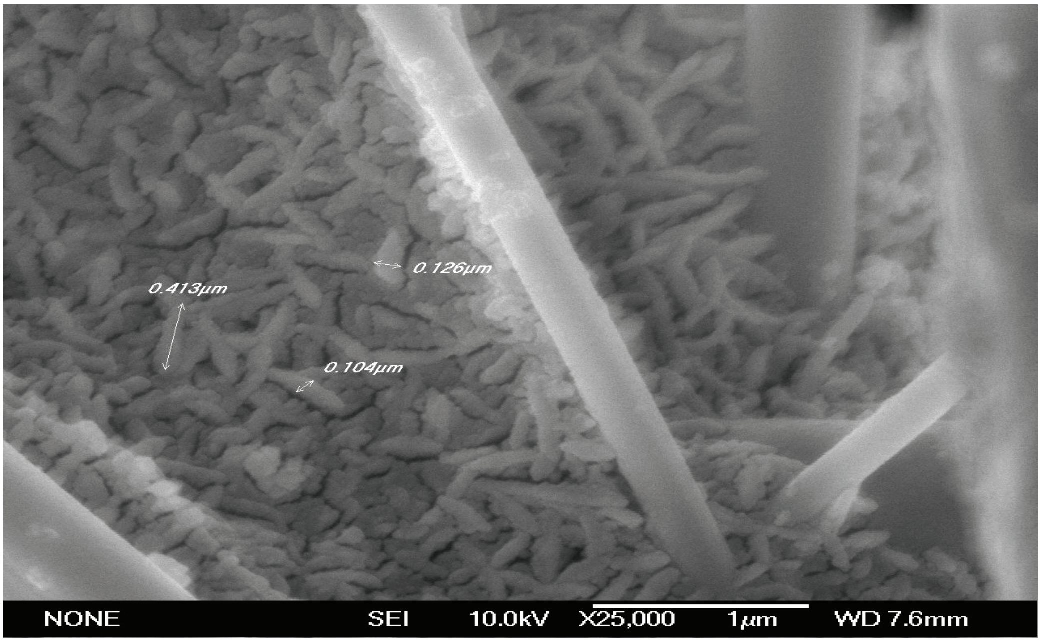
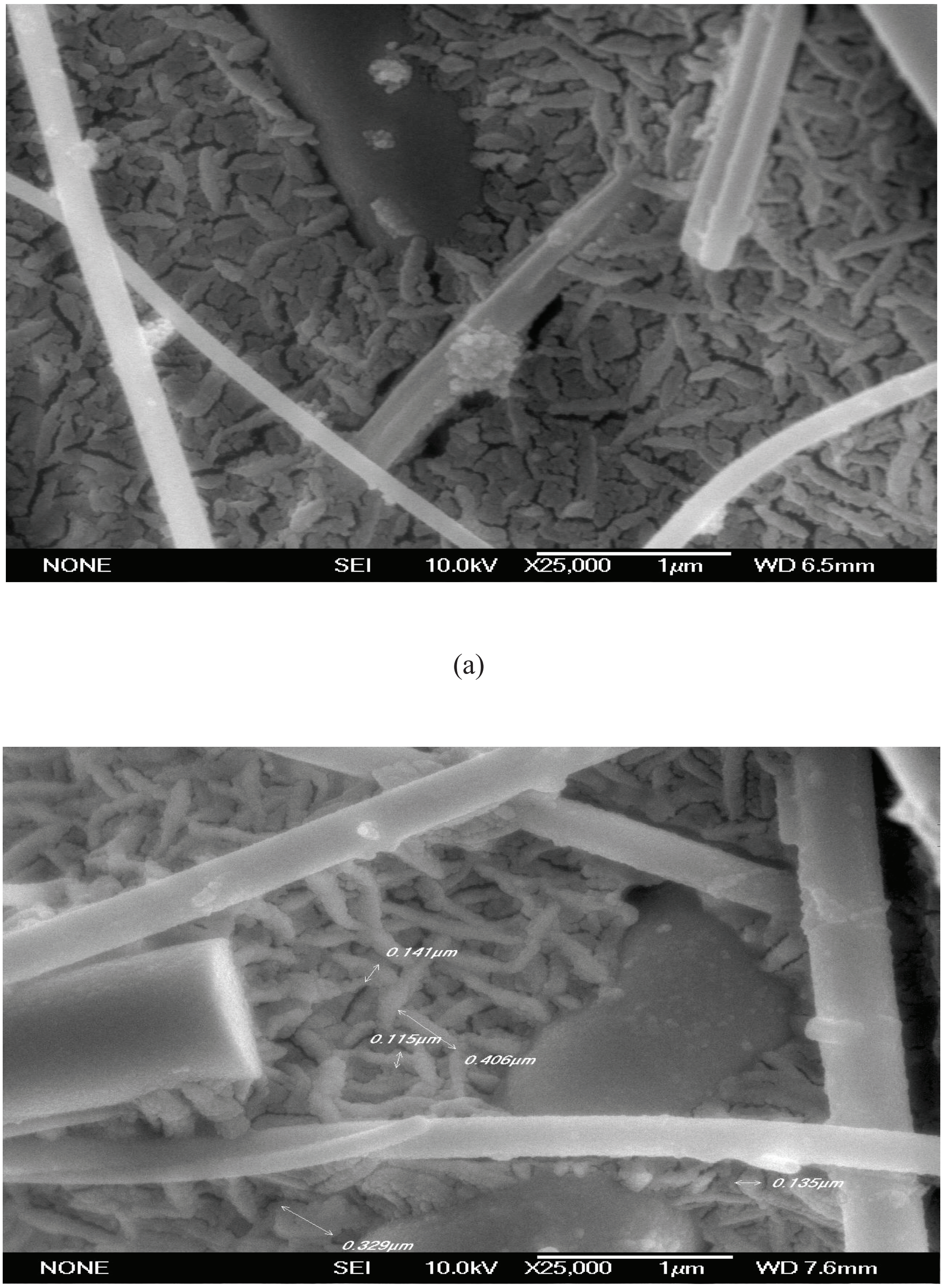


(b)

Figure 6.1: Particle under SEM (a) for diesel fuel and (b) for tire fuel at 1200 RPM

APPENDIX C2

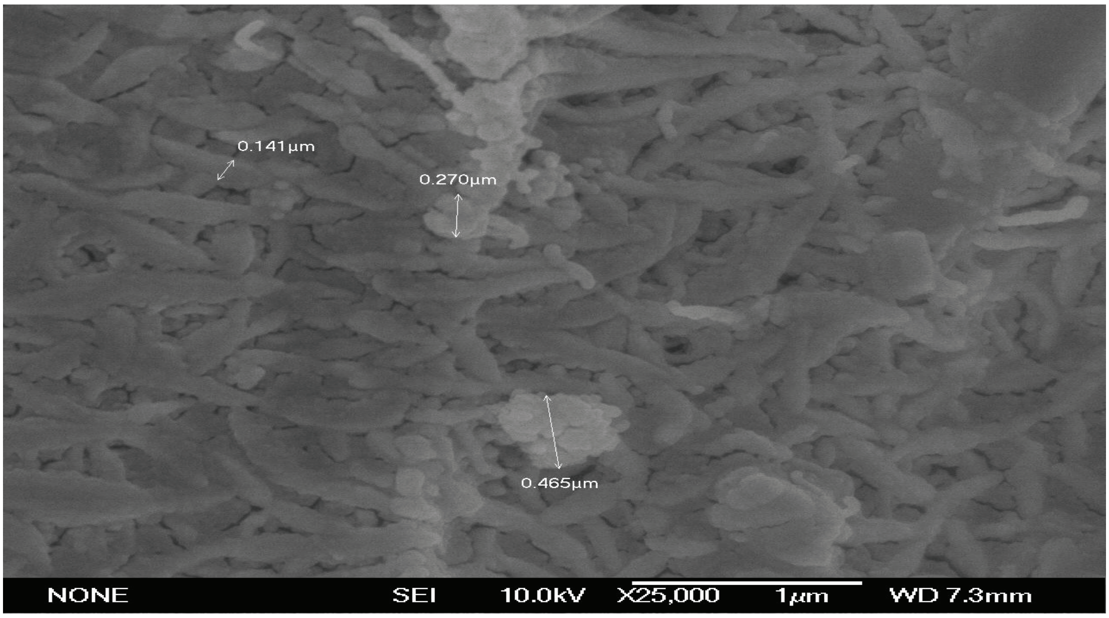


(a)

(b)

Figure 6.2: Particle under SEM (a) for diesel fuel and (b) for tire fuel at 1500 RPM

APPENDIX C3



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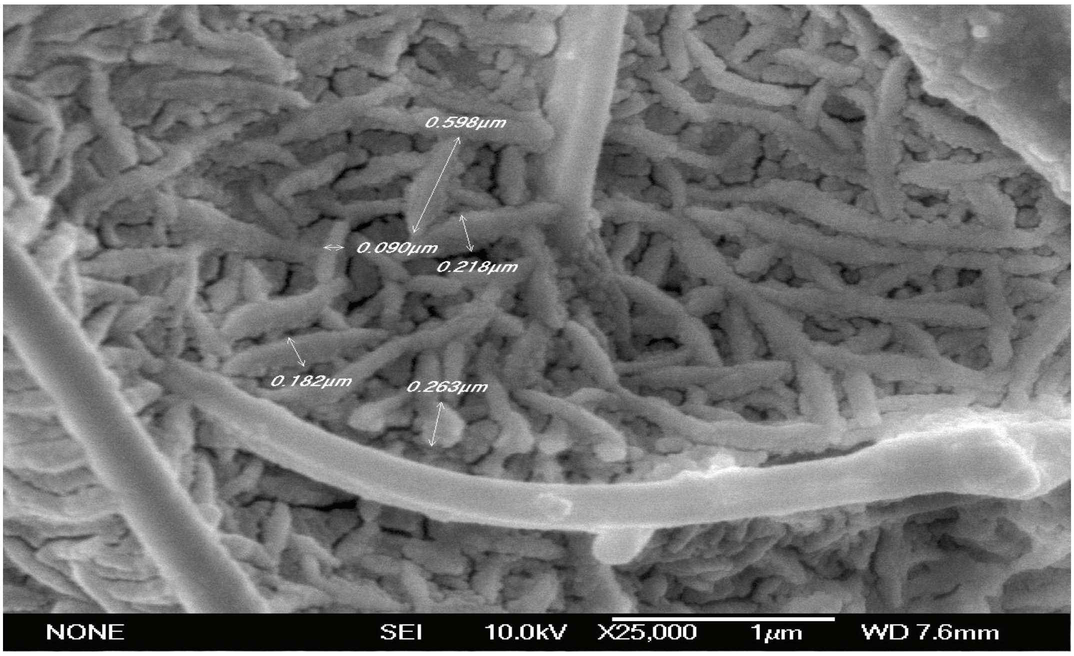
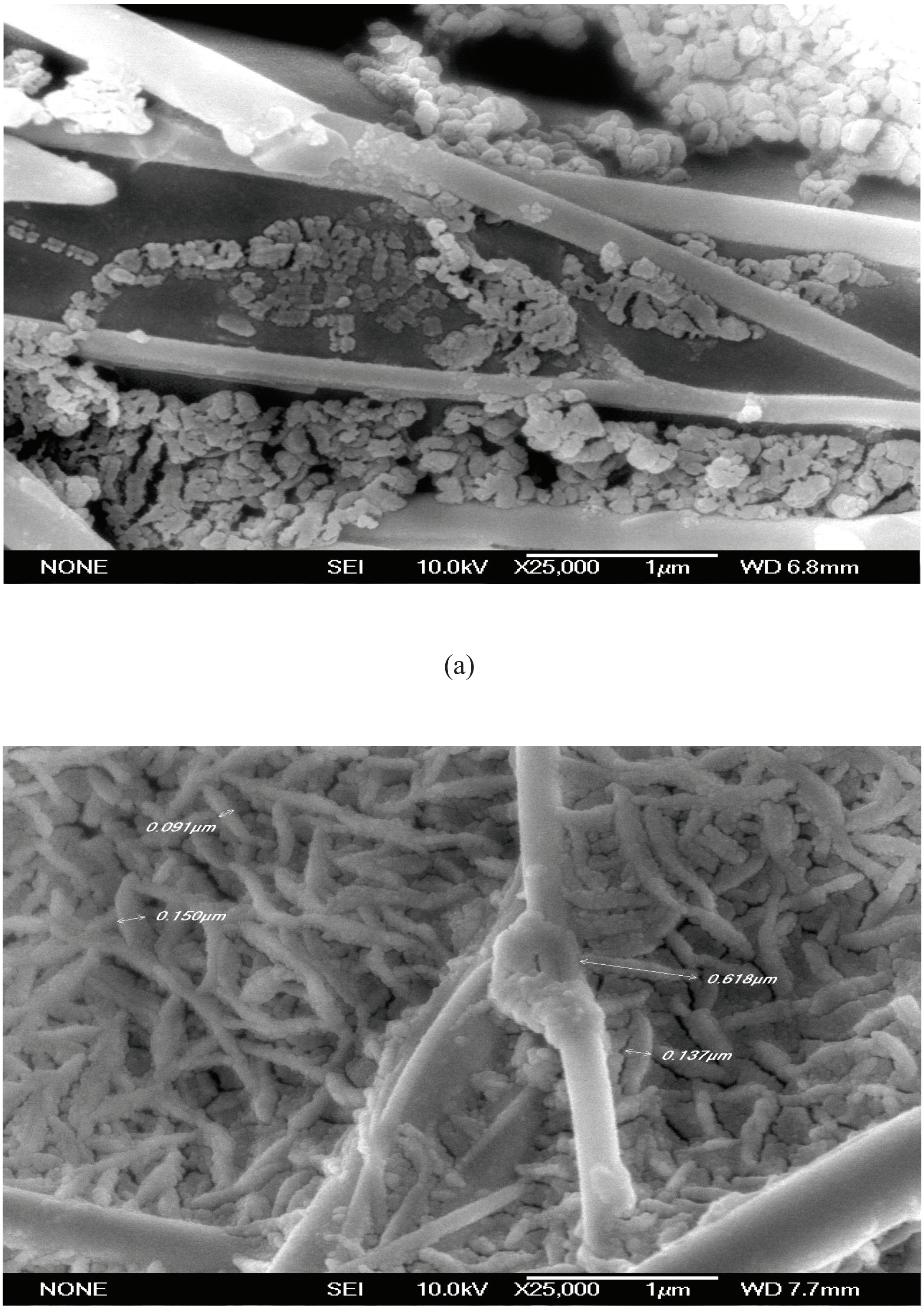


(b)

Figure 6.3: Particle under SEM (a) for diesel fuel and (b) for tire fuel at 1800 RPM

APPENDIX C4



(a)

(b)

Figure 6.4: Particle under SEM (a) for diesel fuel and (b) for tire fuel at 2100 RPM