A STUDY OF DIFFERENT TYPES OF ENGINE OILS ON HIGH COMPRESSION RATIO ENGINE PERFORMANCE

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LIM JIE HAN

A report submitted
in fulfilment of the requirements for the Degree of
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DECLARATION

I declare that this project report entitled "A Study of Different Types of Engine Oils on High Compression Ratio Engine Performance" is the result of my own work except as cited in the references.

Signature : …………………..

Name : LIM JIE HAN

Date : 20 JUNE 2021

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive).

Signature : ……………….

Nameof Supervisor : DR. AHMAD KAMAL BIN MAT YAMIN

Date : 20 JUNE 2021

DEDICATION

I wholeheartedly dedicate this project to my family, friends and loved ones who actively encourage me. To my supervisor, Dr. Ahmad Kamal Bin Mat Yamin.

ABSTRACT

The objective of this study is to investigate the impact of different engine oil towards high compression ratio engine performance. The study focuses on impact of engine grades towards engine power and engine torque against engine speed, while other specifications are ignored. In this study, two different commercially distributed engine oil are chosen as the engine oil test specimen. The models are Yamalube semi-synthetic 4 stroke oil 10w-40 and Yamalube mineral 4 stroke oil 20w-50. The engine oils are tested in Yamaha XJ6 engine, and the test results are taken by using 800-Pro MC/ATV EC Dyno by DYNOmite dynamometer in DYNO-MAX 2010 software. The engine oils are tested in standard operating temperature of the engine. Environmental influence is negligible in this study. In accordance with expected behaviour, viscosity of fluid is decreasing with increasing temperature. SAE grading is used to describe the viscosity performance of engine oil. Higher SAE grading indicates that the engine oil has a higher viscosity and thus it flows slower. In general, engine oil with higher SAE grading is able to provide better lubrication and protection to the engine at high temperature and pressure as it is thicker compared to engine oil with lower SAE grading. However, higher fluid viscosity will lead to higher frictional loss as the fluid resistance is also higher. In fact, by ensuring the engine oil seal will not leak, low viscosity engine oil can decrease the rate of fuel consumption and boost the engine performance as the frictional loss caused by engine oil seal is reduced. In order to study the relationship between the different in engine SAE grading and power or torque loss of the engine, further investigation is required. In short, engine oil with higher SAE grading will give reduced power and torque compared to engine oil with lower SAE grading. The power and torque loss due to different engine oil SAE grading increase as engine speed increase. However, the percentage of power and torque loss decrease as engine speed increase.

ABSTRAK

Objektif kajian ini adalah untuk mengkaji bagaimana minyak enjin yang berbeza mengpengaruhi prestasi enjin nisbah mampatan tinggi. Kajian ini fokus pada kuasa enjin dan tork enjin terhadap kelajuan enjin, sementara spesifikasi lain tidak diambil kira. Dalam kajian ini, dua minyak enjin yang diedarkan secara komersial dipilih sebagai spesimen ujian minyak enjin. Modelnya ialah minyak 4 stroke semi-sintetik Yamalube 10w-40 dan minyak 4 stroke Yamalube mineral 20w-50. Minyak enjin tersebut diuji dalam engin Yamaha XJ6, dan hasil ujian diambil dengan menggunakan 800-Pro MC / ATV EC Dyno oleh DYNOmite dynamometer dalam DYNO-MAX 2010. Minyak enjin diuji pada suhu operasi standard enjin. Pengaruh persekitaran diabaikan dalam kajian ini. Secara umum, kelikatan bendalir menurun apabila suhu meningkat. Penggredan SAE digunakan untuk menghuraikan prestasi kelikatan minyak enjin. Penggredan SAE yang lebih tinggi menunjukkan bahawa minyak enjin mempunyai kelikatan yang lebih tinggi dan dengan itu minyak akan mengalir dengan lebih perlahan. Secara umum, minyak enjin yang menpunyai penggredan SAE yang lebih tinggi boleh memberikan pelinciran dan perlindungan yang lebih baik kepada engin pada suhu dan tekanan tinggi kerana minyak itu lebih likat jika dibandingkan dengan minyak enjin dengan penggredan SAE yang lebih rendah. Walau bagaimanapun, kelikatan cecair yang lebih tinggi akan menyebabkan ketewasn geseran yang lebih tinggi kerana rintangan bendalir juga lebih tinggi. Sebenarnya, dengan memastikan segel minyak engin tidak bocor, minyak engin dengan kelikatan rendah dapat menurunkan kadar penggunaan bahan bakar dan meningkatkan prestasi mesin kerana ketewasan geseran yang disebabkan oleh meterai minyak engin dikurangkan. Untuk mengkaji hubungan antara perbezaan dalam pengukuran SAE enjin dan kehilangan kuasa atau tork enjin, penyelidikan yang lebih lanjut diperlukan. Ringkasnya, minyak enjin dengan penggredan SAE yang lebih tinggi akan memberikan daya dan tork yang berkurang berbanding dengan minyak enjin dengan penggredan SAE yang lebih rendah. Kehilangan kuasa dan tork kerana peningkatan gred SAE minyak enjin yang berbeza seiring dengan peningkatan kelajuan enjin. Walau bagaimanapun, peratusan kehilangan kuasa dan torsi menurun seiring dengan peningkatan kelajuan mesin.

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Last but not least, tonnes of sincere appreciation towards my parents who never paused to support and provide powerful encouragement to me throughout study life. This research could never been come this far without continuous commitment of them. Thank you very much.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Al_2O_3	-	Aluminium oxide
API	-	American Petroleum Institute
AW	-	Anti Wear
B/S	-	Bore to Stroke Ratio
BTE	-	Brake Thermal Efficiency
BHP	-	Brake Horsepower
CFD	-	Computational Fluids Dynamics
CI	-	Compression ignition
CR	-	Compression Ratio
DOHC	-	Dual Overhead Camshaft
EP	-	Extreme Pressure
HSDI	-	High speed direct injection
JASO	-	Japanese Automotive Standards Organization
MATLAB	-	Matrix Laboratory
MoS_2	-	Molybdenum disulphide
NO_x	-	Nitrogen oxides
NP	-	Nano Particles
PTFE	-	Polytetrafluoroethylene
SAE	-	Society of Automotive Engineers
TCP	-	Tricresyl phosphate
WHP	-	Wheel Horsepower
Wt%	-	Weight Percentage
Zn-DTP	-	Zinc dithiophosphate

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Engine oil, motor oil or as known as lubricant of engine, is lubricant that is used in internal combustion engine. Its primary features are to reduce the friction or wear in the engine, as well as clean the oil sludge and varnish. The engine oil also neutralizes acidic substance that was produced by the fuel or oxidation of lubricant. It is able to enhance the sealing of piston rings. It can also bring away the heat that was generated from the friction of the moving parts in order to cool down the engine.

Before the discovery of petroleum-based motor oil, animal fat was used to keep complex machines moving. The person that invented the earliest motor oil was Dr. John W, Ellis. Dr. Ellis was, in fact, a physician who had established practices in Massachusetts, Michigan, and Pennsylvania. He even spent several years teaching at medical schools in Ohio and New York. At age 50, Dr. Ellis's journey was just beginning. He travelled to Titusville in the early 1860s to research the properties of crude oil in hopes of implementing it for medical purposes, but he quickly realized there was no wonder tonic to be found. He did, however, notice it had vast potential for mechanical purposes. After developing his own equipment to test the crude's capabilities, Dr. Ellis discovered a new process that improved its lubricating qualities by using steam heat rather than direct heat. As fortune would have it, Dr. Ellis quickly found a way to capitalize on his newfound discovery. In 1866, Ezekiel Crocker Leonard, Dr. Ellis's wife's sister's husband, was struggling to maintain his oil refinery in Binghamton, NJ, so he consulted Dr. Ellis for assistance. This new partnership resulted in the Continuous Oil Refining Company, whose purpose was to manufacture lubricating oil from petroleum for steam engines and other machines. (The Original Behind the Original: A Brief History of Valvoline Founder Dr. John Ellis, Sep 4, 2020)

Since the primary function of engine oil is to act as lubricant for an engine, it is necessary define the term "lubrication". Lubrication is the applications of several type of matter or object between two moving surface that was rubbing against each other to minimise the level of wear and friction. Lubrication have been utilized by nature since the appearance of animal. Animal body part such as fluid in bone joints serves the purpose of lubricating the joints and bones of animals. As wisdom of human species grow, ancient people used wet soil and reeds as simple lubricant for pulling heavy object such as timbers and rocks. As wagons are invented, friction and wear in the moving parts are inevitable. At first, animal fat and other simple lubricant are used to lubricate the wagons. This continues until petroleum industry advances in the 19th century. Crude oil was used to replace animal fat to become the primary material for making lubricants. As technology advance, the ability to lubricate of crude oil improved gradually. This is primarily because of the rising number of machines that required high level of lubrication such as the automobile vehicle, the airplane, the diesel locomotive, the turbojet, and machinery in the factory. Due to this factor, the development petroleum-based lubricants has a positive impact in accelerating the development of various industrial. (The Editors of Encyclopaedia Britannica, July 20, 1998)

For modern engine oil, viscosity is one of the main properties to differentiate between different engine oil. The value of fluid viscosity represents the thickness of the fluid or a measure of its hindrance to flow. A well performed engine oil should have low enough viscosity for it to flow freely in the engine parts under all circumstances, while at the same time having sufficient viscosity to lubricate the parts properly.

The working temperature will affect the properties of the engine oil. When a car engine is ignited, the engine often starts working at low temperature. Hence, the engine oil must flow well at low temperature, as friction and wear of the engine's moving parts can be minimised upon starting the engine. On the other hand, the engine oil should also be able to sustain high enough temperature. In fact, oil is largely composed of hydrocarbons which can be ignited. For this purpose, "flash point" is being introduced. Flash point represents the lowest temperature when the oil started to vaporise, and the vapour can be ignited. Hence, flash point of the engine oil governs its possibility to burn.

Other than that, total base number is also a property to describe an engine oil's performance. It gauges the reserve alkalinity of an oil, in other word, its ability to cancel out acidic substances. When the engine is working for a long period of time or distance, acidic substance will be formed. Hence, it is crucial to control the total base number of the engine oil for better engine efficiency and longer operating life.

From here, we can say that engine oil with different content and additives will exert different level of performance under different environment. Hence, scientist and engineer introduced single-grade oil and multi-grade oil for different working situation. In short, single-grade oil's grade only represents the viscosity of the oil when it is warm (100°C). This type of oil is expected to carry out lubrication task perfectly only at high temperature. At relatively low temperature, single-grade oil cannot flow properly. Hence, single-graded oil cannot lubricate the machine properly at low temperature. On the other hand, multi-grade oil is introduced to overcome this problem. Scientist and engineer formulate multi-grade oil by adding additive and polymer in the oil. It gives much better viscosity rating to the oil at lower temperature, while still maintaining appropriate lubricating performance by giving stable operating viscosity at higher operating temperature. Hence, multi-grade oil is expected to perform better than single-grade oil in various circumstances.

SAE Viscosity Grade	Low-Temperature (°C) Cranking Viscosity[3], mPa-s, Max	Low-Temperature (°C) Pumping Viscosity[4], mPa-s Max with No Yield Stress[4]	Low-Shear-Rate Kinematic Viscosity[5] (mm²/s) at 100 °C, Min	Low-Shear-Rate Kinematic Viscosity[5] (mm²/s) at 100 °C, Max	High-Shear-Rate Viscosity[6], (mPa-s) at 150 °C, Min
0W	6200 at-35	60 000 at -40	3.8		
5W	6600 at-30	60 000 at -35	3.8		
10W	7000 at -25	60 000 at -30	4.1		
15W	7000 at -20	60 000 at -25	5.6		
20W	9500 at -15	60 000 at -20	5.6		
25W	13 000 at -10	60 000 at -15	9.3		
8			4.0	<6.1	1.7
12			5.0	<7.1	2.0
16			6.1	<8.2	2.3
20			6.9	<9.3	2.6
30			9.3	<12.5	2.9
40			12.5	<16.3	3.5 (0W-40, 5W-40, and 10W-40 grades)
40			12.5	<16.3	3.7 (15W-40, 20W-40, 25W-40, 40 grades)
50			16.3	<21.9	3.7
60			21.9	<26.1	3.7

Figure 1.1: Multi-grade oil meets viscosity requirement at both high and low temperature (Internet Source, Retrieved 13 January 2021).

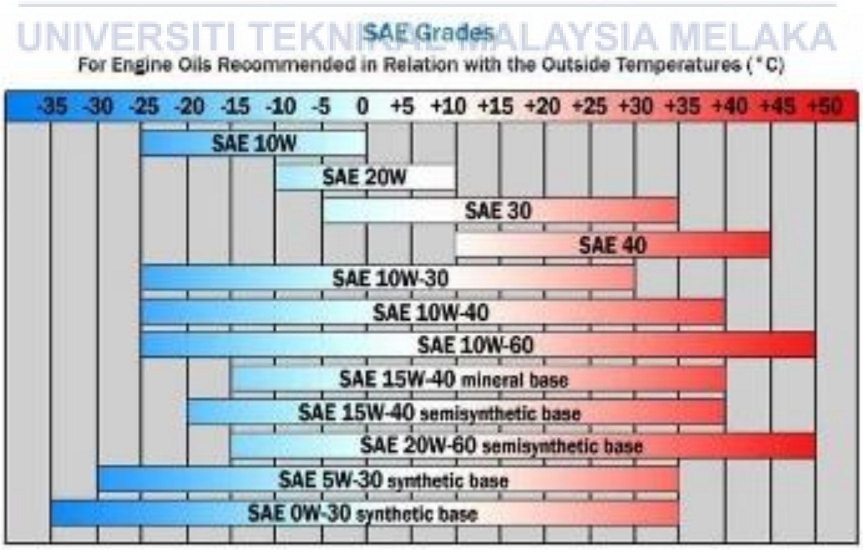

Figure 1.2: Recommended SAE graded engine oil at various temperature (Internet Source, Retrieved 13 January 2021).

In short, engine oil is one of the most important part for an engine to perform well. To meet various requirement from many different type of engine, as well as different working environment, manufacturer used additive in engine oil as high performance engine oil can only be achieved with a balanced formula. Typical engine oil usually consists of base oil, and other additives such as flow improvement additive, extreme pressure additive, anti-wear additive, detergent and dispersant as well as other components. Hence, this study was carried out to investigate how different types of engine oils will affect the performance of high compression ratio engine.

1.2 PROBLEM STATEMENT

In general, four stroke engine cycle engine work in four stages, including intake, compression, power and exhaust. Among these four, the compression stroke is related to the compression ratio of the engine. At the end of intake stroke, the drawn air-fuel mixture will be trapped in the combustion chamber of the engine when the intake valve close. The compression stroke initiate by pushing the piston upward and compressed the air-fuel mixture. The compression ratio represents the maximum cylinder volume to minimum cylinder volume ratio. Hence, high compression ratio indicates high air-fuel mixture pressure when the compression stroke end. (Kristen Lee, 2018)

In this study, an engine with high compression ratio is used as test subject to carry out our research. Since the compression ratio is high, we can expect engine will has higher operating pressure and temperature. In fact, an engine is a very complex system that contain around 30 moving parts. There is a lot of factor that could greatly affect a high compression ratio engine performance, including engine oil, fuel, working environment, condition of the moving parts, and even different technology that has been implemented in engine by different manufacturer could make two engines with similar displacement perform differently. It is hard to determine which factor will affect an engine performance the most, so this study will focus solely on how engine oil affect high compression ratio engine.

Many drivers now a day, know very little about engine oil. They often neglect suggestion from the manufacturer and choose a cheaper engine oil as they think it performs the same. These drivers will probably suffer from low engine power, high fuel consumption and even short engine life in the future. Hence, this study also serves the purpose of showing how wrong type of engine oil can damage the engine. High compression engine ratio required a type of engine oil that suit its characteristic's for better engine performance and longer operating life. To fully understand how engine oil affect engine performance, we need to understand the design of the engine, and the content of the engine oil. Therefore, performing an experiment will show an actual results of the engine oil effect on high compression ratio engine performance. (Hall-Geisler, 2000)

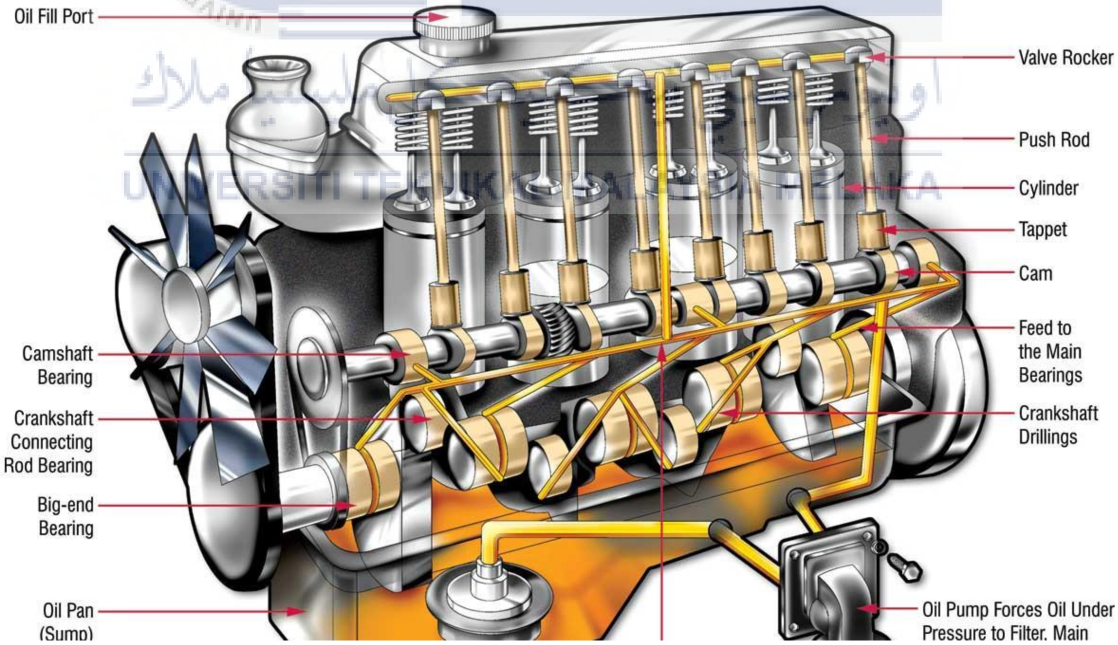

Figure 1.3 How engine oil flow in engine (Internet Source, Retrieved 13 January, 2021).

1.3 OBJECTIVE

There are several objectives in this project, the objectives are stated as below:

1. To investigate the impact of different engine oil towards the power performance of the engine.
2. To investigate the impact of different engine oil towards the torque performance of the engine.
3. To investigate the impact of environmental factor towards the properties of the engine oil.

1.4 SCOPE

There are several scopes in this project, the scopes are:

1. The test subject is engine provided by university authorities; all of the experiment will be carried out using this test subject.
2. The experimental research is focus on the engine performance, such as power, torque and RPM, while factor such as temperature, pressure, exhaust, level of vibration will not be manipulated.
3. The engine used is Yamaha XJ6S/ XJ6SA Diversion engine, the results only applicable to engine with similar arrangement, and displacement.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION TO BASIC KNOWLEDGE AND PRINCIPLE

2.1.1 WHAT IS FRICTION

Friction is the opposition force to a motion of a moving object. In fact, scientist do not consider frictional force as a fundamental force. Instead, they believe friction is caused by the intermolecular forces between the particles in the two contacting surfaces. Generally, friction can be categorised into two different type, which is static friction and kinetic friction. In short, static friction works between two surfaces of zero of same velocity. Kinetic friction will engage between two objects when they are in motion or have a velocity difference.

In liquids, fluid friction is the opposed force of the layers or particle in a fluid. In general, fluids that have higher viscosity are thicker and have higher resistance to movement. For example, honey is thicker than water, thus having higher viscosity. Besides, solid material will experience internal molecular friction as well. For instance, internal friction in a material will be created then when the solid gets pressurised or compressed. Friction is an important puzzle for completing many daily processes and activity. When two objects are rubbed against each other, a portion of the energy of motion will loss in the form of heat energy. Friction is also the main culprit for the wearing damage on basically everything including bike gears and car engine. Hence, the main task lubricants is to cut down and minimise the damages caused by friction and wear between moving parts (Ghose, 2013)

2.1.2 FRICTION AND WEAR

Friction and wear are closely related but are distinct phenomena. The mechanisms of wearing will contribute to occurrence of friction because force is applied, and energy will be consumed when wear occur. Generally, wear phenomena are referring to the damage to a solid surface. When wear occur, material will lose its weight or volume gradually. This is due to the relative movement between the two-contacting surface of the solid. In short, level of wear is determined as the volume or weight loss from solid that has a contacting surface with other solid. (Jiménez, et al, 2011)

Friction is the opposition force to the rubbing movement between two solids at the contact interface, and wear is the volume loss at the contact surfaces generated as the result of repeated friction. Wear is caused as the result of fracture in the contact region for mechanical wear or the removal of products grown on the contact surfaces by tribo-chemical reaction and/or corrosion for tribo-chemical wear. (Kato, 2011)

2.1.3 TYPE OF LUBRICANTS

Lubricants can be categorised into 4 main types, which is gaseous lubricants, liquid lubricants, semi-liquid/plastic lubricants or solid lubricants. (Kumar, et al, 2015)

Solid lubricants operate by introducing a layer consist of low shear strength substance in the volume between two contacting surfaces. Lubricating solids can be used in various method, the basic principle is similar. Low friction medium or layer will be deposited on the contacting surfaces to minimise the friction wear under dry conditions. Solid lubricants are frequently utilised when there is problem of containment caused by liquid. Sometimes, liquid or gaseous lubricants will fail in extreme environment such as vacuum, high temperature, or high radiation The examples of solid lubricants included

Molybdenum disulphide (MoS_2), graphite, boron nitride, Polytetrafluoroethylene (PTFE), and polyimide Phthalocyanine. (Sunil, et al, 2016)

Besides, liquids lubricant is the most commonly used type of lubricant. This is because other than providing lubrication, they also provide damping and cooling. It also provides a more efficient re-lubrication, as when lubricating film is broken, the fluid lubricant will flow back into that contact area. Liquid lubricants are commonly made from petroleum-based oil, and later additives was added to increase its performance and extend the life. Apart from conventional petroleum-based oil, synthetic fluid lubricants are gradually more available as many high quality crude oil are depleted. The formula of synthetic lubricants can be changed in the manufacturing process to optimize or change certain characteristic to fit in some special application. (Lois J. Gschwender, et al, 2001)

Other than that, semi liquid lubricants or as known as semi fluid grease is also one of the commonly used lubricant in the market. In general, semi fluid lubricants could fall into one of the six different categories which is Asphaltic oils or black oils, Asphaltic cutbacks, Semi-fluid greases. Semi-fluid grease cutbacks, Polymerized lubricant gels and High viscosity synthetics. Semi-fluid lubricants consist of high number of varieties. They are able to fulfil the working condition of many operations too. (Anonymous, 2008)

Lastly, gas lubricant is also a type of lubricant due to they possess remarkable lubricating performance. Gas lubricants can reduce friction and wear significantly as it can prevent the contact of two moving surface perfectly. However, their viscosity also not as high as fluid, thus can be compressed. They are able to lubricate limited such as machine that required extreme positional accuracy as well as low environmental impact. Due to this reason, gas lubricants are very commonly used in medical equipment or measuring and tool machines. (Lentini, et al, 2018)

2.1.4 TYPE OF LUBRICATION

In general, lubrication is divided into three different categories in engineering. These categories are fluid-film, mixed and boundary lubrication. The schematic diagram of three different lubrications are shown in Figure 2.1.

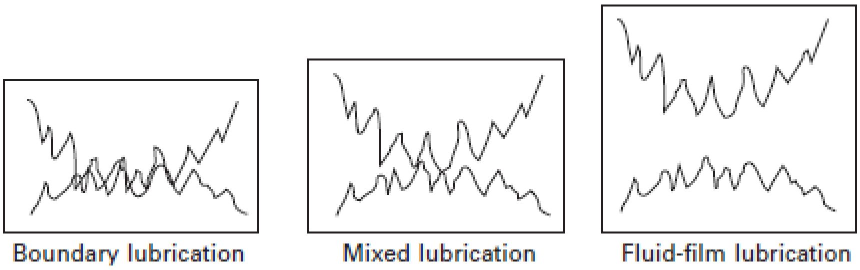

Figure 2.1: Schematic diagram of three different lubrications (Jin and Fisher, 2014).

First of all, the fluid-film lubrication normally happened in between two separating surfaces, and the space is filled with lubricant. The lubricants separate the two surfaces completely. For fluid-film lubrication, lubricant's viscosity is its most important property. In the space filled by lubricant, both frictions will be minimised and reduced. However, we cannot expect friction and wear can be eliminated entirely in the artificial joints and the lubricated surfaces. This is by the reason of the viscous shearing of the lubricant also contribute to certain level of friction. The malfunction of fluid-film lubrication due to start-up and switch-off of the machine also prove that perfect lubrication is impossible. Theoretically, the lubricant was introduced and restricted to the spaces between two separating surfaces by hydrodynamic forces, perform in either sliding or rolling motion to fulfil the role as a lubricant.

Other than that, boundary lubrication occurred when two adjacent surfaces were rubbing to each other. When this happened, it will cause maximum contact of asperities, high heat dissipation and high friction. Boundary lubrication depends a lot on properties of the lubricant. The microscopic-scale boundary lubrication film is crucial in reducing friction and wear. Coefficient of friction in this case is dominant by both lubricant type and surface properties where the viscosity of lubricant in negligible. In many boundary lubrication cases, sacrificial layer is developed to protect the surfaces in contact even lubricant is in service. (Jin and Fisher, 2014)

Lastly, the mixed lubrication was a type of lubrication that consists of a combination of both fluid-film and boundary lubrication regions. It is the major lubrication type in internal combustion engines. In mixed lubrication, the load of the contacting surface is carried by both lubricating film and the uneven surface’s bump simultaneously. In an internal combustion engine, many moving components are operating in mixed lubrication due to frequent high-speed movement. For example, piston ring, cam and engine bearings. Mixed lubrication are especially important for engineers as it is the most accurate prediction of the friction as mixed lubrication talks about the interaction between the complex contacting surface and the oil film thickness. (Xin, 2013)

2.2 PROPERTIES OF ENGINE OIL

2.2.1 IDEAL CHARACTERISTIC OF ENGINE OIL

First of all, engine oil as a type of lubricant, it must exhibit lubricity or oiliness. Engine oil lubricity is not a type of material property that can be measured directly. To determine lubricity, property such as wear will be tested. In short, engine oil lubricity prevents and minimised wear between moving parts inside the engines. (Rodrı´guez-Ferna´ndez, et al, 2019)

Other than that, the wettability of engine oil is also one of the main characteristics that will affect the performance of engine oil. In short, the wettability of a liquid is the how well it can stick to a solid surface. This characteristic is influenced by both the adhesive type (liquid to surface) and cohesive type (liquid to liquid) molecular interaction. (Serban C. Moldoveanu and Victor David, 2017). In fact, a liquid with higher wettability will be able to spread over on a surface better. It can contribute a lot to metal surface adherence as it can spread and cover more area, instead of remaining in a spherical shape. In general, the level of wettability of a liquid can be measured by the contact angle between the surface and the fluid. The contact angle is lower ($\theta < 90°$) when the surface is hydrophilic, and the contact angle will be higher ($\theta > 90°$) when the surface is more hydrophobic. (Hidaka.S, et al, 2006). The schematic diagram of wettability is shown in Figure 2.2.

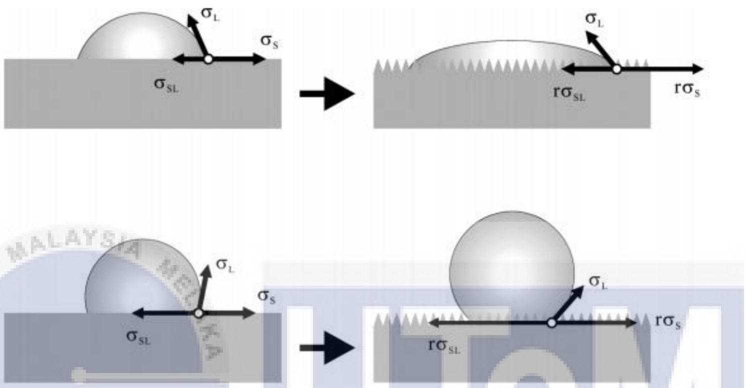

Figure 2.2: Schematic diagram of wettability (Hidaka.S, et al, 2006).

Besides, flash point is also one of the main properties of engine oil. Flash point indicates lowest temperature when the ignition of the vapour of the volatile material will occur. This ignition will be caused when there is an ignition source nearby. Flash point and auto ignition temperature is different thing. The auto ignition temperature is a temperature where the vapour ignites automatically without an ignition source. Hence, engine oil with higher flash point will be considered to be safer than lower one. This is because engine oil with higher plash point will guarantee the safety of lubricant usage. Other than that, engine oil with higher flash point will also be more preferred due to economic and environment concern. This is because low flash point often related to high evaporation rate. For economic purpose, car that required undergo maintenance and needed to refill engine oil more frequently will absolutely become an extra expense for the car owner. Engine oil with low flash point also cause higher rate of combustion gases such as carbon monoxide and carbon dioxide. (Rajesh Kanna, et al,2017)

In contrast with flash point, pour point is also introduced as one of the characteristics of engine oil. Pour point indicates lowest temperature that allow the oil to flow or pour. Pour point is not common in tropical climate country as the temperature there is always relatively stable and higher than in temperature climate country. However, some country located in the temperature climate zone prioritise this characteristic more. This is because their outdoor temperature can often go lower than water freezing point which is 0°c. Engine oil with high pour point will have bad performance under this condition. Engine oil with high pour point will also provide insufficient lubrication for car engine when cold start. (Manikandan, et al, 2017)

In addition, engine oil viscosity affects the performance of engine oil, as well as the performance of the engine. The dynamic viscosity is its measure of opposition force to flow, move or shear while kinematic viscosity is the measure of the fluid flow through a volume of known geometry and dimension under standard gravity. These two basic viscosity measurements are influenced by fluid density, as well as temperature and pressure. Generally, high viscosity engine oil will be more preferred due to its ability to create better fluid-film lubrication. (Abere, 2017)

Viscosity index often confused as the same as viscosity. In fact, these two characteristics are not the same, though viscosity index is dependent on viscosity of the fluid. Viscosity index is referring to the impact of temperature changes on the viscosity of the lubricant. High viscosity index is crucial to maintain a good performance of the lubricant at high temperature. This is because engine oil undergoes thinning process when temperature increase. This viscosity of the engine oil will decrease when the temperature increases gradually. High temperature cause engine oil to break down and thin out. If the thinning process occur continuously, engine oil will start to lose its performance and can no longer serve as friction and wear reduction agent. Viscosity index is a ratio of its highest viscosity at low temperature to lowest viscosity cat high temperature. Engine oil with higher viscosity index shows that the engine oil will carry out lubrication task in a more stable manner even if it undergoes extreme surrounding temperature changes. (Verdier, et al,2008)

2.2.2 OTHER CHARACTERISTIC OF ENGINE OIL

Generally, characteristic of engine oil consists of physical properties, including viscosity and viscosity index as well as flash point and pour point along with some other characteristics such as specific gravity, colour. On the other hand, chemical properties such as water content and total acid and base number can be represented by the concentration of different elements in the engine oil.

Through different operation kilometres, the additives in the engine oil will be depleted. This can be proved by the concentration of some specified elements reduced continuously upon oil usage. In fact, at high engine temperature and long operating period, the additives will be degraded. The oil filter will absorb some of the products resulted from additive degradation. Other than that, minor wear was observed. This is show by the continuously increased concentration of the wear elements in the engine oil.

Besides, TAN and TBN changes in the engine oil will also occur when engine operates for a long distance. This is mainly due to oxidation. The total acid number (TAN) represents the concentration of acidic substances in the engine oil while the total base number (TBN) represent the alkaline substance in the engine oil. In the plots of TAN or TBN versus running kilometres. TAN increase continuously while TBN has a decreasing trend. The increasing trend of TAN mainly cause by oxidation of the lubricant while the decreases of

TBN might be due to the additives is depleted, as most additives possess basic character. (Rahimi, et al, 2012). The pattern is shown in Figure 2.3.

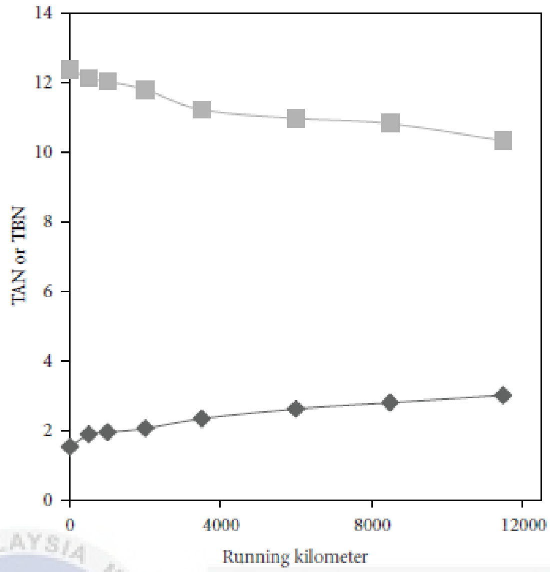

Figure 2.3: Schematic diagram of plots of TAN (bottom) or TBN (top) versus running kilometres (Rahimi, et al, 2012).

2.2.3 ADDITIVES IN ENGINE OIL

Most of commercial lubricants are formulated from base oil. However, mineral oil that made solely from petroleum is unable to perform the task as a lubricant perfectly. As a result, engineer and scientist add in additive in lubricant to increase its performance as well as grant the lubricant properties that it originally does not possess. In fact, lubricants that have additives added in it are far superior that those that don't in term of lubricating performance. Lubricant that was added with additive specified by engineer can be custom fitted to give appropriate level of lubrication to any type of machine. (Srivyas, et al, 2019)

One of the most common additives in the market is EP additive, or as known as extreme pressure additive. This additive is added into lubricant to counter the metal-to-metal contact when operating temperature and pressure are extremely high. When the working environment becoming extremely hot and high pressure, the lubricating film made of lubricant will fail and get squeezed out from the volume between the two moving surfaces. Hence, other kind of lubrication are required in this situation. EP additive function by forming a surface area with low shear strength and friction on the contacting surface. Generally, EP additives are composed of sulphur, phosphorus, chlorine or molybdenum derivatives. It will form a protective coating that function like a solid lubricant when the fluid film lubrication failed, and the moving surfaces contact with each other directly. It can reduce friction and wear, as well as prevent excessive damage to the moving part. (Bart, et al, 2013)

Another common additive in lubricants is anti-wear (AW) additives. It is a type of substance that is active in tribochemical action. In short, tribochemical is a chemical action that will occur in rubbing or abrasive contact. It will also influence as well as influenced by rubbing or abrasive contact. The AW additives function by forming a reaction layer on the moving part's surfaces. The formed layer can react, deform and removed easily. This process can reduce the loading of abrasive tool. As a result, wear reduction performance of the lubricant is improved. The main substances in AW additives are tricresyl phosphate (TCP) and different types of Zn-DTP. (Marinescu, et al, 2013)

Other than that, antioxidants and anti-corrosion additives are also one of the compulsory component to improve the performance of lubricant. Oxidation of engine oil is unavoidable. It will cause the oil to become dark and thick. This is because the chemical component in the engine oil broke down. The resultant product of this process is sludge that insoluble in the engine oil. From this, organic acid will also be produced. These acids are bad for engine parts as it will corrode the metal parts. If the oxidation continues, it will lead to the build-up of polymeric material. Polymeric material consists of oxygenated polymers that have high molecular weight. It will cause thickening of oil as well as varnish and gum deposits on the moving components of the engine. In the oxidation process, an increasing amount of peroxide species or free radical will be produced. The additives will disrupt the process where these insoluble substances are produced. Zinc dithiophosphate (ZDDP) can act as a good antioxidant. It can decompose the peroxide and the free radical. It is also a good anti-corrosion substance as a protective layer will be formed on the surface to deactivate the corrosion substance. (Joerg Wilmink, et al, 2016)

In addition, detergent and dispersant additives are very commonly used in engine oil. The function of detergent and dispersant is to maintain the particulate matter in engine oil in suspension or dispersion, which mean the particulate matter are not allowed to stick to the metal surface or settle in the sump of engine. Particulate matter such as fuel soot, resins and oil oxidation products can be formed in engine. There are three main polar substrates of detergent, which are Sulfonates, Phenates, and Salicylates. Two commonly used metal cation in detergent are calcium and magnesium. The three main polar substrates of dispersant are Succinimides, Succinic esters of polyols, and Mannich bases. It is worth to mention that dispersant typically has higher molecular weight and longer hydrocarbon tails than detergent, but their functions are almost the same. (Awaja, et al, 2006)

2.3 ENGINE PERFORMANCE CHARACTERISTIC AND RELATIONS

2.3.1 ENGINE PERFORMANCE CHARACTERISTIC

There are many characteristics that consider as the main factor to determine an engine's performance. In fact, performance of an engine is often determined by the engine operating behaviour in the speed–load domain. There are some common specifications used in market to show the performance of the engine, such as engine capacity, max power, max torque and acceleration. There are also some other indirect categorises that used to define one engine's performance. For example, the rate of emission, rate of fuel consumption, noise caused from internal friction and vibration, as well as mechanical and thermal loading. It is complex to state the performance of an engine based on only one or two categories. For an instance, same engine that used different type of engine oil exert totally different strong point, engine oil A give the engine better fuel efficiency as well as less internal vibration and noise, while engine oil B let the engine to produce more power and torque at the cost of louder noise. In this case, if we only look at power and torque, engine oil B definitely has the upper hand. However, it is not convincing to only show the horsepower of the engine. Hence, evaluating the engine's performance in multiple angles, aspect and characteristic will truly show how an engine oil will impact the engine performance. (Xin, 2013)

2.3.2 ENGINE PERFORMANCE CHARACTERISTIC RELATED TO TEMPERATURE

Ambient conditions such as humidity and temperature also affect have a great impact on engine's performance. At higher engine load (large displacement engine), the optimal operation ranges (RPM) will become narrow. This is due to engine start to approach the knocking or misfire limit as larger combustion chamber volume can cause the fuel to burn unevenly in the engine. The range of operation is greatly affected by the ambient conditions. Humidity will affect engine's burn rate efficiency. As such, when humidity increase, the chance of engine misfire also increases. On the other hand, cylinder temperature will have an impact on the engine's fuel efficiency, knocking or misfire limit, exhaust gas temperature, NOx emission, heat transfer and knocking tendency. (Wimmer, et al, 2006)

The temperature of coolant and engine oil also has a big influence in the combustion and emission performance of the engine. This factor is important as many trips travelled by car are short distance and duration. This also call for a frequent cold start. When this happens, the engine needs to run frequently without reaching their nominal temperature. This can lead to increased rate of fuel consumption and higher rate of emissions. (Tauzia, 2016)

2.3.3 ENGINE PERFORMANCE CHARACTERISTIC RELATED TO VISCOSITY

The main objective of using engine oil is lubrication. Hence, the viscosity properties can be considered the most important factor to determine the lubrication level of the engine oil. This is due to viscosity of the engine oil governs its lubrication performance. If the viscosity is too low, it cannot give enough lubrication as it cannot form the fluid-film perfectly. If the viscosity is too high, the engine oil is too sticky and cannot flow properly, nevertheless its lubricating performance. Generally, if the properties bring by engine oil additives are not taken into consideration, the kinematic viscosity of the engine oil will decrease when the operation temperature rise. (L.Severa, et al, 2009). The dynamics viscosity of the engine oil also shows an exponential decreasing curve when the temperature increase. (Hlaváč, et al, 2015)

In addition, viscosity of the engine oil will also affect the friction caused by engine oil seal. The main function of engine oil seal is to reduce the possibility of occurrence of leaking in engine when the moving parts is operating especially in the rotating crankshaft. In fact, the engine oil seal stops the leaking of working fluid. It will also resist the invasion of external particle. The engine oil seal is an important factor for an engine to operate in a good condition. However, if the viscosity of the lubricant is too high, frictional loss is unavoidable. Friction due to engine oil seal decrease when using a low viscosity oil. In conclusion, by ensuring the engine oil seal will not leak, low viscosity engine oil decrease the rate of fuel consumption, as the frictional loss caused by engine oil seal is reduced. Engine oil that prevents the occurrence of leaking can support the engine to operate efficiently. (Kim H.G., et al, 2007)

2.3.4 ENGINE PERFORMANCE CHARACTERISTIC RELATED TO COMPRESSION RATIO

As people starts to concern more about fuel shortage and air pollution issue, more research and develop start to focus on building an engine with improved fuel economy and reduced exhaust emission. Other than that, alternative fuel such as natural gas is considered one of the best alternatives to replace conventional fuel. Natural gas possesses high octane level and excellent anti-knock properties that allow for high compression ratio (CR) engine. However, at high engine loads, high compression ratio also leads to increase in NOx emissions. The compression ratio of the engine can go as high as 14.0:1. In short, When CR increase, the brake thermal efficiency also has an increment when the engine is operating at low or medium loads. The gas temperature and pressure in the cylinder will also be increased. Hence, the thermal efficiency increases with the CR increase. (Zheng, et al, 2008)

2.3.5 ENGINE PERFORMANCE CHARACTERISTIC RELATED TO FRICTION LOST

Other than that, engine friction lost governs the vehicle fuel economy. Studies show that more than half of the energy from fuel combustion loses in cylinder cooling and exhaust emissions. This mean that not even half of them is providing the effective power. In addition, the friction of engine parts is responsible for roughly 25% loss of effective power. Hence, it is crucial to reduce engine friction loss in order to enhance the fuel economy. In short, the rate of fuel consumption is greatly associated with engine friction loss. The result of the study shows that a 5.5% reduction of engine friction loss will lead to approximately 1% of vehicle fuel economy improvement. (Mo, et al, 2015)

2.4 HIGH REVVING (HIGH RPM) ENGINE

2.4.1 HIGH REVVING ENGINE USED IN MOTORCYCLE

In general, average motorcycle that one can purchased in the market has a lighter weight compared to car. It is stated that average motorcycle in the market weights around 700 pounds, in other word, just barely over 300 kg. The heaviest motorcycle model in the market now is Harley CVO Road Glide Ultra, weights at 439 kg. On the other hand, the average car weight in 2018 was over 4,000 pounds (over 1800kg). Hence, the engine specification of a motorcycle cannot be compared to a car. (Visordown, 2015)

In fact, motorcycle engines are good in the weight and power department, and arguably they are good in the size department. Bikes are very lightweight compared to car. Hence, it requires very little torque to be able to accelerate and pull away in comfort. Cars on the other hand are much heavier, over 10x the weight of a bike in some cases which requires much more torque. In short, it is not practically to develop bike engine cars as it will encounter problems when face certain situations such as traffic and hill starts. Motorcycle engine are mainly high RPM engine. Motorcycle's engine is considered to be able to create a lot of power for its relatively smaller displacement. (Jake, 2018)

2.4.2 BENEFITS OF HIGH REVVING ENGINE

High RPM engine bring a lot of benefits. The main one is the increased torque and power. This is because increases the engine's cylinder displacement and size will also improve the output power, but generally this reduces its efficiency. However, this does not conclude that low revving engine are always bad in all case. In fact, diesel engines are unable to rev as high as gasoline engine with equivalent displacement, but they're as powerful and more efficient most of the time. Diesels use high compression ratios and reducing the redline. In short, motorcycle's engine mainly is high RPM instead of bigger displacement due to its light weight. An overly heavy engine for example V8 engine will be too burdening to install on a motorcycle. (Fenske, 2016)

Increasing engine speed can definitely increase the energy in the engine. In this case, the increment in energy of exhaust gas. is the biggest. Apart from that, brake thermal efficiency (BTE) experiences some insignificant change with changing engine speed. Even so, changing in exhaust gas energy can range from 24.1% to 36.4%. From this, the conclusion is to choose high RPM when the power is the same. High engine speed helps in increasing the BTE because the exergy of exhaust gas is higher. It is also state that high engine speed and engine load are better choices for turbocharged engine. However, high engine speed often related to high fuel consumption and high NOx emission. The controlling strategies is adjusting the timing if the spark closer to TDC. Installing a turbine to absorb and utilise the exhaust gas energy with a turbo system will increase the effective work as well as the BTE. (Luo, et al, 2017)

2.4.3 DRAWBACK OF HIGH REVVING ENGINE

High revving engine are often linked with high operation temperature of the engine. Hence, heat transfer in the engine is important to define the overall performance of an engine. In an engine, heat can transfer through the side wall of the cylinder. It will influence the indicated efficiency. Reduction of temperature as well as pressure in the cylinder will reduce the work transferred on the piston per cycle. On the other hand, high engine temperatures will also lead to increase in thermal stresses of material. It will also influence the fatigue failure limits of many moving parts. It will also cause fatigue cracking of the cylinder wall as well as cylinder’s bore and valve stems deformation. (Sanli, et al, 2007)

2.5 BORE TO STROKE RATIO

2.5.1 BASIC EXPLANATION REGARDING BORE TO STROKE RATIO

An engine's bore is the diameter of each cylinder in the engine, while the stroke is the distance within the cylinder where the piston travels from the top dead centre (TDC) to the bottom dead centre (BDC). For an engine, the power it can produced is governs by the number of powers stoke, hence it is affected by the speed of the engine. In short, higher RPM, more power strokes, hence more power. The schematic diagram of bore stroke ratio is shown in Figure 2.4.

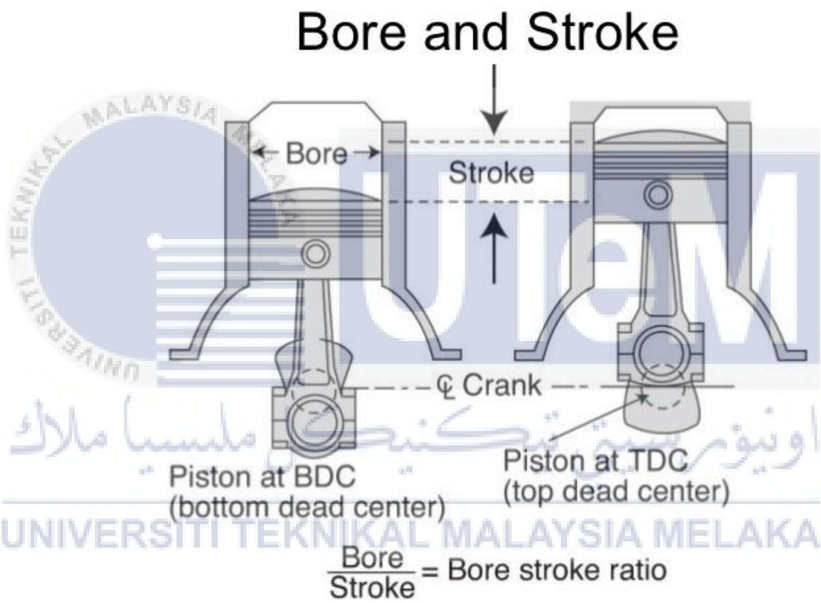

Figure 2.4: Schematic Diagram of bore stroke ratio (Wahid, 2019).

2.5.2 OVER-SQUARE AND UNDER-SQUARE ENGINE

In general, engines with different bore stroke ratio are categorise into three different types. First of all is the over-square or as known as short stroke arrangement. Over-square engine has a bore/stroke ratio larger than 1. This mean that the bore (diameter of the piston) is bigger than the stroke (distance travelled by piston). Engine with this type of arrangement generally has the highest power output and highest redline among other three. This is because the short stroke does not need to travel as far as the stroke in other arrangement for each cycle. Bigger bore also means that the valves installed can be bigger. This cause the piston to be able to absorb and exhaust more air in each cycle. For engine, more air means better combustion efficiency and more power. However, this arrangement also has a major drawback. At low RPM, the engine will choke. This is because at lower RPM, the combustion in the cylinder will be incomplete, causing the engine to lose power. (Brian, 2020)

The second one is under-square arrangement or also called as the long stroke arrangement. In this arrangement, the bore to stroke ratio is smaller than 1. This indicates that the engine has longer stroke and shorter bore compared with others. This type of engine usually has better efficiency. This is because the engine only needs relatively lower RPM to achieve a same piston speed as the over-square arrangement. However, a under-square engine usually has a narrower combustion chamber. This means it has smaller space for installing valves. Less valves mean lesser fuel-air mixture and it will limit the power output. Nevertheless, lesser air-fuel mixture means quicker and more efficient combustions at low RPM. Hence, it will have higher torque at low RPM. This arrangement will also bring higher frictional loss, as piston need to travel longer distance.

The last type is the square type. It has an exact bore to ratio of 1, as the length of the bore and the stroke in this arrangement are exactly the same. This type of arrangement is a middle ground to other two type. It is a good compromise between the low rev, high torque long stroke engines and the high rev, low torque short stroke engines.

In conclusion, these 3 types of arrangement shows the basic of some configuration of the engines. It is not compulsory that comparing engine with these specifications will give a definite result in term of engine's performance. Modern car manufacturers had carried out many experiments. They also used many alternates and technologies to achieve these benefits and overcome the deficiencies. Figure 2.5 shows the different arrangement of bore to stroke ratio (Wahid, 2019)

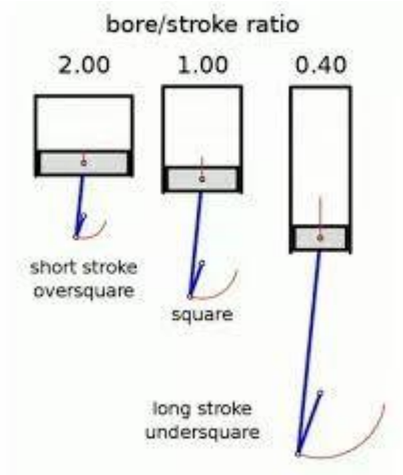

Figure 2.5: Different arrangement of bore to stroke ratio (Internet Source, Retrieved 10 January, 2021).

2.5.3 IMPACT OF BORE TO STROKE RATIO TO ENGINE PERFORMANCE

B/S ratio is a specification that used to determine the performance of the engine. Different bore to stroke ratio will give the engine different strength and weakness. It will also influence the performance of many characteristics of the engine. Bore to stroke ratio will affect the combustion of fuel, as well as the emission of gaseous and particulate substance. In short, the combustion pressure in the long-stroke engine is greater than in the short-stroke engine. This characteristic was influenced by how flame propagate and spread in the cylinder. The turbulent air and fuel mixture flow also influence this characteristic. Due to the difference in combustion speed between these 2 arrangements, long-stroke engine will have a reduced time loss. As a result, the engine showed a higher value of mean effective pressure. The impact of bore to stroke ratio is not significant for NOx emission when using gasoline fuel. The engine geometry greatly influences the particle number (PN) emission. More PN emissions were observed from the short stroke engine. (Jang, et al, 2020)

Bore to stroke ratio also governs the thermal efficiency of the engine. The main conclusion is the heat losses in the engine will be decreased, when the B/S ratio is decreased. This is because for engine with same displacement, long stroke arrangement will have lower surface-to-area exposed compared to short stroke arrangement. This led to increase in indicated thermal efficiency and mechanical efficiency. Lower bore to stroke ratio also improves the fuel consumption. Hence, lower bore to stroke ratio more is beneficial for engine design that require better fuel economy. (Ali, et al, 2016)

Lower B/S ratio also decrease the duration of rapid burning. In general, the overall bore to stroke ratio affects the cycle thermal efficiency in a non-linear pattern. In a rapid burning cycle, approximately 80% of the increment in efficiency is due to reduced heat loss in long stroke engine. While the engine is operating in slow burning cycle, accompany by another 15% exhaust gas recirculation, the heat loss is more dominant. Hence, for fuel economy improvement purpose, long stroke engine (engine with low bore to stroke ratio) has bigger potential to be exploited at low engine speed. This is because the brake fuel economy will be diminished gradually by friction loss at high engine speed. Since passenger car in modern days are operating in low engine speed and partly loaded most of the time, vehicle fuel improvement can be easily achieved easily by using long stroke engine. (Filipi, et al, 2000)

Based on a CFD study that research the impact of different B/S configurations on HSDI CI (High speed direct injection compression ignition) engine efficiency and pollutants, some conclusion can be made by observing the CFD model. For this model, variable such as air management, fuel injection settings and compression ratio of the engine is unchanged. This is to separate and prioritise the effect of the B/S ratio. From the CFD results, lower B/S ratio setup up has higher efficiencies due to having lesser loss in heat transfer and faster combustion. Lower B/S has better mixing and faster combustion in spite of the heat transfer per unit area was higher. From this, the larger surface area from high B/S ratio is proven to be the main reason for the divergence in heat transfer. B/S ratio greatly influence the NOx emissions. From the CFD model, lower B/S ratio also led to lower soot and ash emissions. (Benajes, et al, 2017)

The main point of varying different bore to stroke ratio in engine arrangement is to build engine with either a lot of power or maximum efficiency. This is because how piston move air and burn fuel determines the performance of an engine. The over-square engine, which has a short stroke and long bore, can raise to very high RPM without a very high piston speed. High piston speed will cut down the lifespan of the piston rings. Assuming a maximum piston speed of 25 m/s, the simulated over square engine could rev to16,000 rpm, the square engine will reach the piston speed at 8700 rpm, while the under square engine would stop at 4700 rpm. Power is directly proportional to torque and engine speed. Hence, engines with larger bore is good at producing more power for a relatively smaller size. In comparison, long-stroke engines are more superior in producing torque. Engine can be treated as a complex air pump. Hence, more air flowed through, more power produced. Larger bore will be able to fit in larger intake and exhaust valve as well. (Brandan, 2020)

2.6 ENGINE OIL GRADING

2.6.1 HOW LUBRICANT ARE GRADED

The most important property to grade an engine oil is its viscosity. Viscosity is the property that describes its thickness or its ability to flow or its' resistance to flowing. Lower viscosity indicates the oil can move around in the engine and lubricate the engine's moving part more easily, but it also reduce the oil's ability to adhere to the moving parts. Hence, best engine oil has the value of viscosity that compromise between its ability to flow and ability to adhere to the engine's moving parts. There are two types of engine oil in general, single grade or multi grade. SAE (Society of Automotive Engineers) have developed and set the standards by which various oils are graded. Single-grade oil's grade only represents the viscosity of the oil when it is warm (100°C). This type of oil is expected to carry out lubrication task perfectly only at high temperature. At relatively low temperature, single-grade oil cannot flow properly. Hence, single-graded oil cannot lubricate the machine properly at low temperature. On the other hand, multi-grade oil has been formulated by adding polymers to give a much better viscosity rating at lower temperatures while still maintaining the proper operating viscosity at higher temperatures. This gives the engine critical added protection during warm up. Let's take 10W-40 oil as example. The 40 is equivalent as the 40 in SAE 40. The big different for multi-graded oil is the 10W viscosity rating part. This is viscosity rating when it is cold. The "W" stands for "Winter" or generally refer to cold operating environment. Once "W" is in the grade, it tells that it is a multi-grade oil with viscosity characteristics that is opposite to what you would expect at lower temperatures. (Charles, 2013)

2.6.2 SAE GRADING

To understand more about that the number stated in SAE grading, the term oil weight is introduced. Oil weight is not exactly talking about the weight of the oil in SAE grading. It is a confusing term. This is because the "weight" does not actually refer to how heavy the lubricant is. In fact, oil weight is a term used to describe the viscosity of the lubricant. It was referring to how well a lubricant can flow at a specific temperature. You can imagine that oil with larger oil weight will have higher viscosity, as it is harder to flow when it is "heavier". SAE assigns oil weight number, to oil based on its flow at around 100 degrees Celsius. This temperature is the standard working temperature for engine. The higher the oil weight number, the higher the viscosity, thus the slower it flows. For example, a 20-weight oil is thinner and flow more quickly than a 50-weight oil. However, the earlier one does not offer the same lubrication performance at high temperature and extreme condition than the later one. The "w" means that the lubricant will have different characteristic at different temperature. For example, a 5w30 engine oil will flow like 5 weight oil when start up, even the temperature is below freezing point, and it will function like 30 weight oil once the engine has warmed up to around 100 degrees Celsius. This give appropriate lubrication to the engine when it is started at a cold environment. On the other hand, regular single-grade engine oil cannot compromise for both low temperature starts up situation and high temperature operating situation. Figure 2.6 is the viscosity chart of different SAE grading oil under different temperature. (Benjamin, 2017)

Figure 2.6: Viscosity Chart (Internet Source, Retrieved 10 January 2021).

2.6.3 API SERVICE CLASSIFICATION

The next code to differentiate engine oil is API Service Classification. This sounds complex, but it is actually very easy to understand. In general, API Service Classification talks about the overall generation of the development of engine oil. For example, when first car was build, the oil is only API SA Service Classification. It then advances from SA to SB, SC, SD, SE and keep on advancing until the current API Service Classification which is SN. SI and SK is excluded and skipped. In short, SA is considered to be outdated as it is formulated for use in vehicles built in 1920. However, API Service Classification doesn't affect its selling price. Engine oil earlier than SN (including SA) often priced the same as SN. (API service Classification, 2013). Figure 2.7 explained the API Service Classification.

American Petroleum Institute Gasoline Engine Oil Service Classifications		
Category	**Status**	**Service**
SN	Current	Introduced in October 2010 for 2011 and older vehicles, designed to provide improved high temperature deposit protection for pistons, more stringent sludge control, and seal compatibility. API SN with Resource Conserving matches ILSAC GF-5 by combining API SN performance with improved fuel economy, turbocharger protection, emission control system compatibility, and protection of engines operating on ethanol-containing fuels up to E85.
SM	Current	For 2010 and older automotive engines.
SL	Current	For 2004 and older automotive engines.
SJ	Current	For 2001 and older automotive engines.
SH	Obsolete	
SG	Obsolete	
SF	Obsolete	
SE	Obsolete	CAUTION - Not suitable for use in gasoline-powered automobile engines built after 1979.
SD	Obsolete	CAUTION - Not suitable for use in gasoline-powered automobile engines built after 1971. Use in more modern engines may cause unsatisfactory performance or equipment harm.
SC	Obsolete	CAUTION - Not suitable for use in gasoline-powered automobile engines built after 1967. Use in more modern engines may cause unsatisfactory performance or equipment harm.
SB	Obsolete	CAUTION - Not suitable for use in gasoline-powered automobile engines built after 1951. Use in more modern engines may cause unsatisfactory performance or equipment harm.
SA	Obsolete	CAUTION - Not suitable for use in gasoline-powered automobile engines built after 1930. Use in more modern engines may cause unsatisfactory performance or equipment harm.

Figure 2.7: API Service Classification (Internet Source, Retrieved 10 January 2021).

2.6.4 JASO OIL SPECIFICATION

Other than that, JASO oil specification is created as the Japanese equivalent to API specification. In general, API specification are used for automobile engine but not for motorcycle engine. Before 1998, motorcycle use regular car oil as lubricant. As technology advances, some additive and friction modifier added in the engine oil that said to bring a positive influence to car, was actually damaging to motorcycle, especially to motorcycle gearbox and clutch. In fact, motorcycle use the same oil for the gearbox. Hence, the friction modifier in modern car engine oil will cause the clutch to slip and lead to gearbox pitting. Oil in motorcycles usually run under more intense conditions compared to cars because motorcycles engine has higher RPM redline and a greater power density. In 1998, JASO T903 standard was introduced as the globally recognized standard for 4-stroke motorcycle oils. It explained the required lubrication performance for different motorcycle designs. It is separated into two main performance categories. Firstly, JASO MA oil is used in motorcycle with wet clutch. It has no friction modifier as clutch slipping need to be prevented. JASO

MA oils are used in nearly all type of motorcycle. Besides, JASO MB oil are used in motorcycle with automatic transmission for example scooters. Friction modifier is added in JASO MB oil to improve fuel economy. (Rymax Lubricants, 2020)

2.7 ENGINE OIL UNDER REAL ENGINE CONDITION

2.7.1 TEMPERATURE RELATED STUDY

In this section, some research that observed the characteristic of engine oil under real engine condition will be reviewed. First of all, the temperature is manipulated and the viscosity change in engine oil of several SAE grading is observed by using MATLAB. From the research, for engine oil 10W-40, viscosity reach its minimum value, which it 104.4215 mPa.sec, at 39.2736 °C. As for engine oil 5W-30, its minimum values of viscosity are 66.8957 mPa.sec at a temperature of 40.9076 °C. For engine oil 20W-50, its minimum values of viscosity are 198.3505 mPa.sec at 41.2930 °C. In short, the research shows that temperature of minimum viscosity for all observed engine oil grades in this study is around 40 °C. (Alhaifi, et al, 2017)

2.7.2 DISTANCE OR TIME RELATED STUDY

The performance of synthetic-based lubricant in two different condition, 100-hours aged condition and fresh condition was studied. The tested engine oil is 10W40 synthetic oil. Compared to fresh oil, the aged engine oil shows a higher value of dynamic viscosity. For the aged oil, the dynamic viscosity is 19% and 28.5% greater at 25°C at 75°C respectively. At 40°C, both engine oils provide similar film thickness. However, as temperature increase, the aged engine oil provides a reduced 13.5% film thickness. This was observed in a 75℃, 2 MPa pressure test. At 75 °C, the boundary friction from aged oil is 19.25% higher than from fresh oil. Hence, we can conclude that aged oil has a significant influence on engine power loss due to friction as well as contact wear. (Nikolakopoulos, et al, 2018)

The function of engine oil diminishes as the operating time increase. In this analysis, the changes in piston, piston rings and bearings in observed as the operating time increase. In a gasoline engine, the change in piston, piston rings and bearings is within the limit of the specification as observed in 20-, 30-, and 40- hours test. The change in diesel engine remain within the limits of specification in 100-, 110-, and 120-hours test. For gasoline engine, the bearing lost 23 milligrams in 50h times, and failed completely at the end of 60h times as the specimen loss another 38 milligrams. For diesel engine, reduction in oil protective properties of the engine part is observed at 130- hour. Then, the piston land (raised area between piston and piston ring) and the ring groove (recessed area around the piston) failed and exceed the limit of contamination at 140- hour. As the engine operate, friction and wear can only be minimised by engine oil and cannot be avoided. The wear caused the increase in metallic impurities and further diminished the ability of the oil to lubricate. This led to a further increasing wear in piston, ring and bearing consequently. In conclusion, under normal working condition, the tested lubricant can provide sufficient protection to a gasoline engine up to 7,000 km, and diesel engine up to 5,000 km. The change of engine oil is necessary after these working distance. (Besergil, et al, 2008)

Lubricating oil or engine oil works under extreme working condition such as very high pressure as well as temperature. The oxidization of the oil is unavoidable when the hot oil combines with oxygen in the air. This study focused on monitoring changes in lubricating properties especially TAN. All analysed oil group shows a similar increasing trend from the beginning. The TAN changes intensified after 12,000 km. The observed acid value is four-fold compared to fresh oil after 12 months of operation. (Wolak, 2018)

This research's primary focus is the changes of engine oil's kinematic viscosity and shear stress due to different level of raid (distance travelled). The tested engine oils were two different market engine oils, which are Castrol Magnatec 10W-40 (A) and Shell Helix Ultra Extra 5W-30 (B). Moreover, the samples of used engine oil were obtained from two different vehicles with gasoline engine (Renault Scenic) and diesel engine (Škoda Roomster) respectively. When is raid is 11,653 km, engine oil A from gasoline engine has a decreased in kinematic viscosity of 9.9%, whine engine oil B from diesel engine decreased by 9.3%. At same raid, the reduction of engine oil A's shear stress from the gasoline engine was 9.7%, and engine oil B from diesel engine was 9.1%. The study shows the characteristic changes of kinematic viscosity as well as shear stress related to distance travelled. (Vojtěch, et al, 2013)

2.7.3 FRICTION AND WEAR RELATED STUDY

There are many manufacturers that provide various model of engine oil in the market. In fact, engine oil from different manufacturers even with the identical SAE grade does not imply that it will provide the same level of lubrication for an engine. The study research on comparing commercial mineral lubrication oil (SAE 10W-30) from three different manufacturers. The lubricity of these engine oil at several different temperatures (40˚C, 70 ˚C and 100˚C) will be tested by using four ball wear testers in 60 minutes' time duration. In the test, the engine speed will be changed from 1000 rpm to 2500 rpm. The study give conclusion by observing the wear scar diameter. From the study, some conclusions were made. Viscosity will be reduced by increased temperature. Wear scar diameter also greatly influenced by temperature and speed. Lower wear scar diameter indicates the lubricant has better anti-wear ability. In short, lubricant with same SAE grading will provide different lubricity at different temperature and speed. (Farhana, et al, 2014)

The function of oil film is to minimise wear and reduce friction loss. The friction loss might increase if the oil film lack continuity, or boundary or mixed friction condition. This research studies the influence of oil pressure on friction losses. In short, the results suggest that there are no immediate relations of the friction loss of the engine on oil pressure. All tested condition in this study was proven to be fluid friction. Hence, reduced oil pressure will not cause additional wear. Low engine speed and low engine load is always related to low oil pressure. However, the low oil pressure as stated in this study might not represent the possible lowest value of oil pressure in the engine due to some limitation. Due to fuel economy reasons, vehicle need to produce high power at low end of engine speed, which mean high torque at low RPM. The load of the crank mechanism will be very high in this situation. (Rostek, et al, 2017)

2.7.4 CONTAMINATION OR ADDITIVES RELATED STUDY

The fuel in Otto cycle and Diesel cycle has the possibilities to burn incompletely due to various reasons and limitations. Most of these unburned or partially burn fuel will leave the engine through exhaust gas, while minority of them could enter the housing of the engine and dissolve in the engine oil. This could change the properties of the engine oil, and in worst case, the contaminated engine oil can no longer provide sufficient lubrication. The study focused on three parameters which is viscosity, flash point and fire point. The study was carried out by mixing specified amount of fuel in the tested engine oil. From the result, the oil-fuel mixture with 5 wt% is able to operate stably even after 180 days. For this case, the observed viscosity changes are less than 4%. When more gasoline or diesel fuel is added into the oil, decrease in all three parameters was observed. According to SAE classification, both mineral oil with 5 wt% fuel failed to meet the proposed viscosity range. When the oil is diluted with 5 wt% of fuel, the fire point is still above the maximum expected working temperature (150°C), and this suggest that the oil is still usable in a short term. When the added fuel is 10 wt%, the flash point along with the fire point was decreased to an unacceptable value (less than 50°C). In short, the study suggests that 4-5 wt% of fuel in oil has no risk of ignition under standard condition, while 7-10 wt% of fuel in oil is considered unacceptable. (Ljubas, et al, 2010)

Nano-Al_2O_3 particles was added in SAE 20W-40 engine oil to study for its influence. One of the working principles of nanoparticles (NP) is by using rolling/sliding effect, The study was carried out in two different condition, which is flooded lubrication conditions and starved lubrication condition. Flooded lubrication condition was referring to the engine oil supplied was sufficient to form the boundary film that has the highest thickness theoretically. On the other hand, starved lubrication condition means to reduce the supply of lubricant, which cause the thickness of the film to be reduced significantly and this will lead to increment in friction. From this study, nanoparticle reduce the friction and wear under both conditions. The suspension with 0.5% nanoparticle concentration shows reduction in coefficient of friction by 49.1% in under flood condition and 21.6% in starved condition. Nevertheless, 0.25% nanoparticle concentration provides the best wear reduction by 47.1% compared to the other cases. The Nano-Al_2O_3 particles reduce wear and friction by rolling effect. They act like Nano-bearings between the contacting surfaces. (Mohan. N, et al, 2014)

2.8 METHODS AND EQUIPMENT USED

For this study, the main focus is how engine oils with different specification will affect high compression ratio engine performance. There are many engines performance result that can be obtained, but only a few will be studied due to equipment and other limitation. The tested engine model, engine oil model specification and testing equipment is provided by university. This section reviews the main equipment used in this study.

2.8.1 ENGINE MODEL USED

The used motorcycle engine model is Yamaha XJ6 Diversion. It is a model of high-performance motor manufactured at year 2009-2010. The engine has specification of 600cc, four-stroke, transverse four cylinder, DOHC and four valves per cylinder. The engine is an over-square arrangement with 65.5 mm bore and 44.5 mm stroke. The compression ratio of the engine is 12.2:1. Based on difference variations, the curb weight of XJ6S is 211 kg, while XJ6SA weights at 216 kg. It produces a max power of 78hp/58 kW at 10,000 rpm. It also produces a max torque of 59.7 Nm/kgf-m at 8500 RPM. The clutch is wet multi-plat disc and is has a 6-speed transmission. (Motorcyclespecs, 2009)

2.8.2 ENGINE OIL USED

The recommended engine oil brand by this motorcycle is YAMALUBE. The recommended engine oil grade is API SG or higher and JASO standard MA. Several engine oil model with different SAE grading can be used in this engine, including SAE 10w-30, 10w-40, 10w-50, 15w-40, 20w-40, and 20w-50. For this study, the selected oil grading is SAE 10w-40 and 20w-50 for maximising the difference. The specification of these engine oils are stated at Figure 2.8 and Figure 2.9. These engine oil specifications are solely for reference purpose only. (Yamalube, n.d.)

Specifications

STANDARDS: API SG JASO MA2 Approval Number:		M081 YMC 692
VISCOSITY GRADE	SAE J 300	10W-40
Density at 15°C	ASTM D4052	0.873
Viscosity at 40°C	ASTM D445	95.8 mm²/s
Viscosity at 100°C	ASTM D445	14.3 mm²/s
Viscosity Index	ASTM D2270	155
Flash point	ASTM D92	232°C
Pour point	ASTM D97	-36°C
Total Base Number	ASTM D2896	6.83 mg KOH/g

Figure 2.8: Specification of YAMALUBE Semi-Synthetic 4 Stroke Oil 10W-40 (Yamalube, n.d.).

Specifications

STANDARDS: API SG JASO MA2 Approval Number:		M081 YMC 691	M081 YMC 695
VISCOSITY GRADE	SAE J 300	10W-40	20W-50
Density at 15°C	ASTM D4052	0.874	0.887
Viscosity at 40°C	ASTM D445	98.1 mm²/s	157.7 mm²/s
Viscosity at 100°C	ASTM D445	14.9 mm2/s	18.0 mm²/s
Viscosity Index	ASTM D2270	155	127
Flash point	ASTM D92	220°C	244°C
Pour point	ASTM D97	-35°C	-33°C
Total Base Number	ASTM D2896	6.27 mg KOH/g	6.89 mg KOH/g

Figure 2.9: Specification of YAMALUBE Mineral 4 Stroke Oil 20W-50 (Yamalube, n.d.).

2.8.3 DYNAMOMETER

Dynamometer is an equipment is used to measure the performance of an internal combustion engine (ICE). It operates by measuring the torque and speed (RPM) in a fixed environment, where the engine will not experience extreme environmental temperature changes or significant air resistance. A dynamometer usually consists of many components including a speed sensor and torque or force sensor (Hamada, et al, 2014)

CHAPTER 3

METHODOLOGY

3.1 OVERVIEW

In this chapter, the methodology that has been planned and used in order to proceed in this study will be explained and described. In general, the procedure of this study will be following the proposed flow chart as stated in Figure 3.1. For this study, the main focus is how engine oils with different specification will affect high compression ratio engine performance. The used equipment and consumables are all product from the market. Their models are specified. Hence, it is impossible to isolate some of the variables. For example, the tested engine is not all new, so it might show some unexpected outcome for the test due to unseen condition. In this study, the tested engine model is Yamaha XJ6 Diversion, while the tested engine oil is specified to only two engine oil model which is YAMALUBE with SAE grading of 10w-40 and 20w-50. The result will focus on how different engine oil will affect the torque and power of the engine.

According to the flow chart, the first step is literature review. This part was done and presented in chapter 2, literature review. Literature review is very crucial for this study. As stated before, this study used an actual motorcycle engine and engine oil that was sold in the market currently. An actual engine is quite complex. Different brand of engine oil in the market also has their own distinct formula and additive that make it impossible to predict the behaviour of the engine oil by its own basic properties.

The second step is data inspection. This step was done to inspect the data and specification stated by the manufacturer in default condition. As stated before, the engine is not all new and its condition is not perfect. Hence, there will be an error gap between the stated engine specification and actual engine specification. This might also affect the characteristic of the engine oil indirectly.

The third step is the most important step among all steps in this study. Engine performance test will be carried out with different model of engine oil to obtain its performance result using dynamometer.

The fourth step is experimental research. In this step, results from other similar studies is compared and reviewed. Factor for the trend observed will be proposed.

The fifth step is data collection and validation. From previous step, the collected results are compared and reviewed and the factor for trend observed is proposed and validated. Validation will be done by comparing the results with other studies, as well as with related basic theories and principles. This step will suggest the results obtained from experiment is valid or not. If it fails, the research will be repeated from the second step, data inspection, and the related initial data and values will be recollected and checked to obtain a new set of more accurate results and values.

The sixth step is discussion and analysis. The validated results will then be further studied and explained. The difference between this study and other research will also be listed and studied. The limitation of this study will also be discussed.

This last step is report writing. The entire study details will be recorded and written in a formal report. The report will then be presented and evaluated.

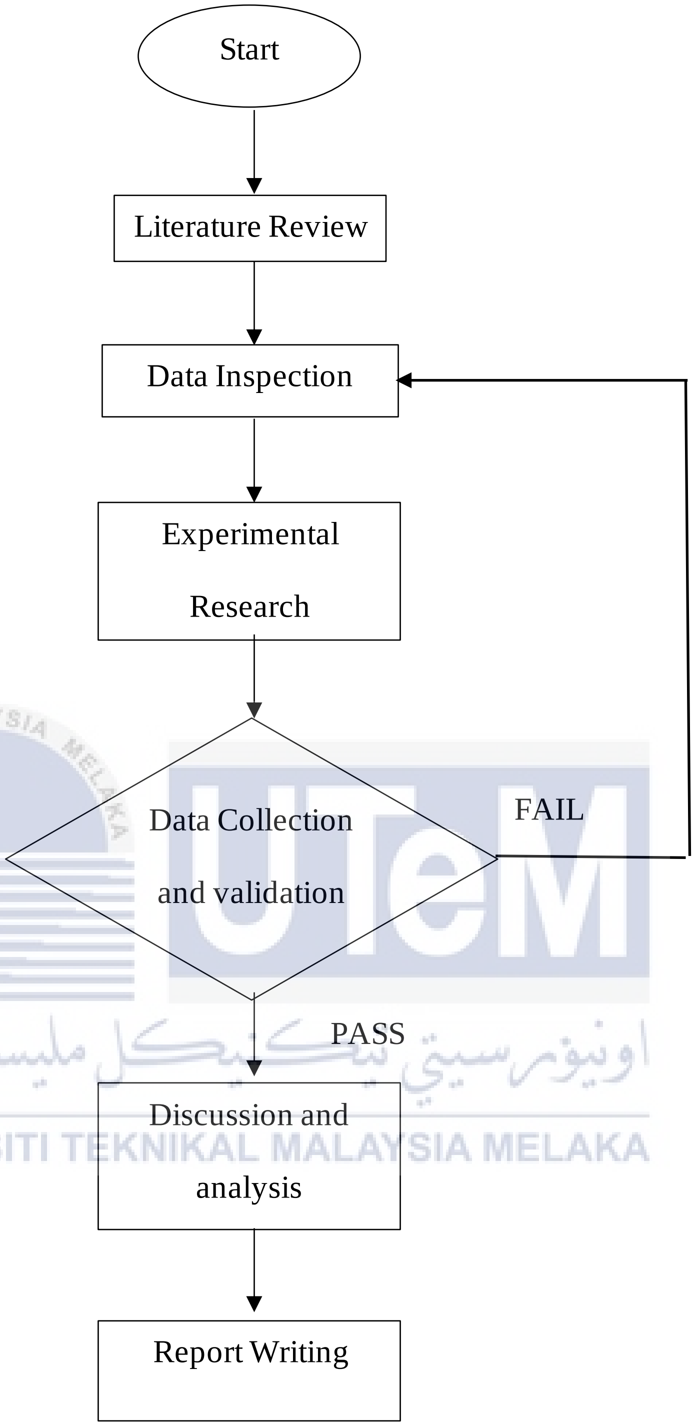

Figure 3.1: Flow Chart of the Methodology.

3.2 LITERATURE REVIEW

In this part, many similar previous work and study will be reviewed. These work and study can come from journal articles, textbooks, or even trusted website. In this part, the fundamental knowledge regarding the title will also be reviewed and explained. This is to further increase the understanding on this topic. Other than focus on this study's results, many things can be learned from the literature review too. Many relevant scientific theories will also be stated in this part. This provide the necessary prove and evidence when hypothesis is suggested and validate the results are validated.

3.3 DATA INSPECTION

Data inspection is done to inspect the basic information and specification of the tested engine and other study related items. This is due to the condition of the engine might not the same as stated by manufacturer due to its age. The ambient environment change might also have an unseen effect on the characteristic of the engine oil. For the engine, it will be run under standard operating environment for the first time to obtain some basic specification such as torque and redline RPM. If the obtained specification has a big difference compared to original specification, this study needed to be paused and the reasons need to be found. The environmental characteristic such as temperature will also be recorded and kept constant to avoid any mistake.

3.3.1 ENGINE CONFIGURATION

The motorcycle model used in this study is Yamaha XJ6 Diversion. It is a model of high-performance motor manufactured at year 2009-2010. Since the engine alone itself is not available from the manufacturer, the experiment will be carried out on whole motorcycle. The engine has specification of 600cc, four-stroke, transverse four cylinder, DOHC and four valves per cylinder. The engine is an over-square arrangement with 65.5 mm bore and 44.5 mm stroke. The compression ratio of the engine is 12.2:1. Based on difference variations, the curb weight of XJ6S is 211 kg, while XJ6SA weights at 216 kg. It produces a max power of 78hp/58 kW at 10,000 rpm. It also produces a max torque of 59.7 Nm/kgf-m at 8500 RPM. The clutch is wet multi-plat disc and it has a 6 speed transmission. The specification of the vehicle and the engine will be listed in Table 3.1.

Table 3.1: Specifications of tested engine and motorcycle vehicle

Motorcycle Vehicle	Overall Dimensions	Length (mm)	2120
		Width (mm)	770
		Height (mm)	1210
	Gross Weight (KG)	211/216	
	Transmission	6 speeds	
Test Engine	Engine type	Liquid cooled, 4 stroke, spark ignition, Inline 4 cylinder, DOHC, four valves per cylinder	
	Displacement (cm^3)	600	
	Bore x Stroke (mm)	65.5 x 44.5	
	Compression Ratio	12.2:1	
	Max Power	78hp/58 kW @ 10,000 rpm	
	Max torque	59.7 Nm/kgf-m @ 8500 RPM	
	Idling Speed	1250-1350 RPM	

3.3.2 ENGINE OIL SPECIFICATION

The recommended engine oil brand by this motorcycle is YAMALUBE. The recommended engine oil graded is API SG or higher and JASO standard MA. In this study, the engine oil grading we had selected is 10w-40 and 20w-50. This is to observe the maximum difference between the two engine oil. The specifications of these engine oils are given at Table 3.2 and Table 3.3.

Table 3.2: Specification of YAMALUBE Semi-Synthetic 4 Stroke Oil 10W-40

STANDARDS	API SG
JASO MA2 Approval Number	M081 YMC 692
Oil Grade	SAE 10W-40
Density at 15˚C	0.873 g/cm^3
Viscosity at 40 ˚C	95.8mm^2/s
Viscosity at 100 ˚C	14.3mm^2/s
Viscosity index	155
Flash Point	232 ˚C
Pour Point	-36 ˚C

Figure 3.2: Image of YAMALUBE Semi-Synthetic 4 Stroke Oil 10W-40 from YAMALUBE official catalogue (Yamalube, n.d.).

Table 3.3: Specification of YAMALUBE Mineral 4 Stroke Oil 20W-50.

STANDARDS	API SG
JASO MA2 Approval Number	M081 YMC 695
Oil Grade	SAE 20W-50
Density at 15˚C	0.887 g/cm^3
Viscosity at 40 ˚C	157.7 mm^2/s
Viscosity at 100 ˚C	18.0 mm^2/s
Viscosity index	127
Flash Point	244 ˚C
Pour Point	-33 ˚C

Figure 3.3: Image of YAMALUBE Mineral 4 Stroke Oil 20W-50 from YAMALUBE official catalogue (Yamalube, n.d.).

The data and image for the product are obtained from the YAMALUBE official catalogue. The appearance and specification of the purchased engine oil might have difference compared to information from YAMALUBE official catalogue. In fact, the previously proposed engine oils were both semi-synthetic. Unfortunately, YAMALUBE Semi-Synthetic 4 stroke oil 20W-50 was not available in Malaysia, so YAMALUBE Mineral 4 Stroke Oil 20W-50 is chosen to replace it as they have similar specification.

Table 3.4: Difference between YAMALUBE Semi-Synthetic 4 stroke oil 20W-50 and Mineral 4 Stroke Oil 20W-50

Semi-Synthetic 4 stroke oil 20W-50	Specification	Mineral 4 Stroke Oil 20W-50
SAE 20W-50	Oil Grade	SAE 20W-50
0.884 g/cm^3	Density at 15˚C	0.887 g/cm^3
155.2 mm^2/s	Viscosity at 40 ˚C	157.7 mm^2/s
18.2 mm^2/s	Viscosity at 100 ˚C	18.0 mm^2/s
131	Viscosity index	127
234 ˚C	Flash Point	244 ˚C
-33 ˚C	Pour Point	-33 ˚C

Figure 3.4: Actual Product of Yamalube Semi-Synthetic 10W-40

Figure 3.5: Actual Product of Yamalube Mineral 20W-50

3.3.3 DYNAMOMETER

Dynamometer is an equipment used to measure the performance of an internal combustion engine (ICE). It operates by measuring the torque and speed (RPM) in a fixed environment, where the engine will not experience extreme environmental temperature changes or significant air resistance. A dynamometer usually consists of several components, including speed sensor, torque or force sensor, a controllable absorber and a motor. The model of provided dynamometer is DYNAMITE DYNAMOMETER. The specification of the dynamometer is 800HP, air-cooled, eddy-current, all-terrain vehicle dynamometer. The model of dynamometer used is 800-Pro MC/ATV EC Dyno by DYNOmite DYNAMOMETER. The software installed in the computer to collect the data is DYNO-MAX 2010 software.

Figure 3.7: 800-Pro MC/ATV EC Dyno. (Internet Source, Retrieved 15 June, 2021).

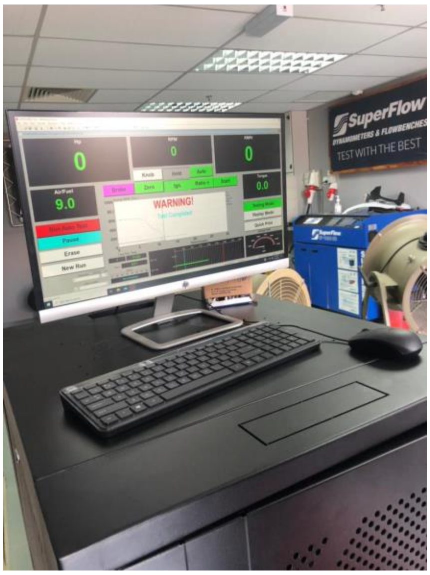

Figure 3.8: Computer used to collect the data.

Figure 3.9: DYNO-MAX 2010 software used to collect the data.

3.3.4 ENVIRONMENTAL INFLUENCE

As the performance of engine and properties of engine oil might differ slightly in different environment, some basic environmental condition, such as temperature, humidity as well as weather will be recorded. This is to ensure the impact from environmental factor can be reduced and minimised, thus increase the credibility of the study. For the record, the time for taking preliminary results is April 9, 2021, 3pm and the time for taking final results is April 23, 2021, 3pm. The official weather for both day is recorded and compared. The results were also compared to investigate the impact of weather towards the results.

Fri 09, Apr 2021

Max: 30°c | Min: 24°c | Sunrise: 07:08 AM | Sunset: 07:17 PM
Moonrise: 05:09 AM | Moonset: 05:26 PM | Phase: Waning Crescent | Illum: 7 %

Time	Weather	Temp	Feels	Wind	Gust	Rain	Humidity	Cloud	Pressure	Vis
00:00		25 °c	27 °c	8 km/h from WSW	14 km/h	0.3 mm	86%	51%	1009 mb	Excellent
03:00		24 °c	26 °c	7 km/h from NNE	14 km/h	0.0 mm	89%	58%	1009 mb	Excellent
06:00		24 °c	26 °c	8 km/h from NNE	14 km/h	0.1 mm	88%	59%	1009 mb	Excellent
09:00		26 °c	29 °c	8 km/h from NNE	12 km/h	0.0 mm	81%	31%	1010 mb	Excellent
12:00		30 °c	34 °c	9 km/h from	10 km/h	0.0 mm	66%	34%	1010 mb	Excellent
15:00		30 °c	35 °c	12 km/h from WNW	15 km/h	0.5 mm	67%	50%	1007 mb	Excellent
18:00		29 °c	33 °c	14 km/h from W	22 km/h	1.4 mm	75%	88%	1006 mb	Excellent
21:00		26 °c	29 °c	10 km/h from WNW	21 km/h	0.8 mm	85%	85%	1008 mb	Excellent

Figure 3.10: Official weather record for April 9, 2021. (Internet Source, Retrieved 10 June, 2021).

Fri 23, Apr 2021

Max: 28°c	Min: 25°c	Sunrise: 07:04 AM	Sunset: 07:15 PM
Moonrise: 04:00 PM	Moonset: 03:39 AM	Phase: Full Moon	Illum: 83 %

Time	Weather	Temp	Feels	Wind	Gust	Rain	Humidity	Cloud	Pressure	Vis
00:00		26 °c	28 °c	13 km/h from NW	21 km/h	0.9 mm	82%	61%	1012 mb	Excellent
03:00		25 °c	27 °c	12 km/h from WNW	18 km/h	1.3 mm	87%	84%	1010 mb	Excellent
06:00		25 °c	27 °c	15 km/h from W	23 km/h	2.0 mm	90%	92%	1010 mb	Excellent
09:00		26 °c	28 °c	9 km/h from WSW	13 km/h	2.0 mm	84%	80%	1011 mb	Excellent
12:00		28 °c	31 °c	12 km/h from W	14 km/h	0.0 mm	71%	39%	1011 mb	Excellent
15:00		28 °c	31 °c	15 km/h from W	19 km/h	0.0 mm	71%	45%	1009 mb	Excellent
18:00		28 °c	31 °c	12 km/h from WSW	17 km/h	0.0 mm	73%	34%	1008 mb	Excellent
21:00		25 °c	28 °c	9 km/h from W	15 km/h	0.0 mm	76%	41%	1010 mb	Excellent

Figure 3.10: Official weather record for April 23, 2021. (Internet Source, Retrieved 10 June 2021).

From the figure, the weather for both days only has a slight difference. Hence, the results are investigated in order to measure the impact of weather towards the results. The results can be compared as the engine oil used for preliminary results is Yamalube Semi-Synthetic 20W-50. On the other hand, Yamalube Mineral 20W-50 is used for final results. These 2 different engine oils should have similar results as their SAE grading is the same.

Table 3.5: Impact of weather towards the results

Date/Test	Power (kW) @ 3000 RPM	Torque (Nm) @ 3000 RPM
April 9, 2021/ Preliminary Result	8.194	26.11
April 23, 2021/ Final Result	8.090	25.74

Considering the engine oil are actually difference for both tests (Yamalube Semi-Synthetic 20W-50 is used for preliminary results and Yamalube Mineral 20W-50 is used for final results), the slight difference for the engine performance in term of power and torque can be justified. The different between two test is less than 1.5%. Hence, it can be said that the impact of different weather towards the results of the test is negligible.

3.4 EXPERIMENTAL RESEARCH

After the specification of the tested item had been defined and other factor that have the possibility to influence the study had been determined, experimental research will be carry out.

3.4.1 EXPERIMENT SETUP

The three main items used in this study is engine, engine oil and dynamometer. Some other equipment is also used to obtain the required data and record the necessary value. The fundamental setup is quite simple. In short, the motorcycle will be fixed by using a motorcycle stand. This is to maintain the motorcycle lifted from the ground, in order to cancel the factor of floor friction or force, if there is any.

Next, the dynamometer will be attached to the wheel of the motorcycle. This is because the engine is not available in engine alone only. Hence, the measured results will be wheel horsepower (WHP) instead of brake horsepower (BHP). The WHP and BHP are similar measurement, but the WHP and BHP from a same vehicle will be different. BHP represent the power output of engine flywheel. It can show the raw power produced by the engine. On the other hand, WHP is power output measured at wheel. WHP will always be lower than BHP because there is loss of power due to the mechanism as well as weight and friction of the vehicle components such as clutch, gear as well as axels, shaft and wheel. A motorcycle usually has 5%-10% power loss to drivetrain. This is important as it explained the reduce power reading compared to factory specification. Other than that, to acquire a more accurate WHP number, the gear ratio had to set as close to 1:1 as possible.

Before the actual test was performed, some preparation was required. There are several processes such as remove the oil tank; the air filter and various other component of the motorcycle are required to be learned and mastered in order to carry out the actual test more fluently after this. Knowledge on how to suck out the fuel from the oil tank, how to change spark plug, as well as how to empty the engine oil tank to make sure there are no used engine oil to contaminate the engine oil specimen used in this test.

Figure 3.11: Preparation process

Figure 3.12: Preparation process

3.4.2 CHANGING OF ENGINE OIL

After the engine and dynamometer setup is completed, engine oil will be poured into the engine to study the impact of engine oil to engine performance. To ensure results with high credibility, the changing of engine oil process is crucial. In fact, it is very hard to remove all old engine oil from the engine by using conventional method.

When a car or motor engine is turned off, the engine oil flowing in the engine will flow back to the oil pan. In this process, a portion of the engine oil will stick or adhere on the engine parts such as crankshaft and unable to flow back to the oil pan. Hence, it is impossible to remove all engine oil cleanly from the engine unless performs an engine flush that use chemical which might cause damage to the engine.

To minimise the impact of previously used oil on the results, several actions has been taken. After the oil port cap had been removed, it takes some time to let all engine oil in the oil pan to flow out. A new engine oil filter was also installed to ensure the performance of new engine oil. After the engine oil had stop flowing out, a high-pressure air gun had been used to push as much used engine oil out from the engine as possible. Finally, the all-new oil specimen will be poured into the oil fill port. According to the guide, the quantity of new engine oil required is 2.8L if the oil filter had been replaced.

Figure 3.13: Opening the oil port and let used engine oil flow out.

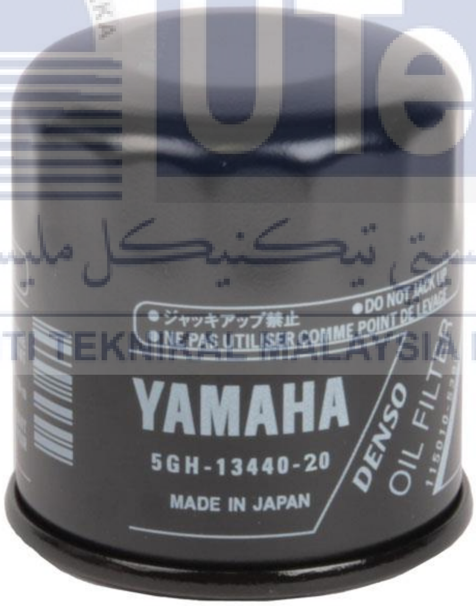

Figure 3.14: Changing of oil filter to ensure quality of new engine oil. (Internet Source, Retrieved 10 June 2021).

Figure 3.15: Waiting as many used engine oil to flow out as possible

Figure 3.16: Using High Pressure Air Gun to push out remaining engine oil.

3.4.3 ACTUAL EXPERIMENT

The next step is the actual experiment. For this part, the first tested engine oil is the Yamalube Mineral 20W-50. After pouring the engine oil, a throughout check had been performed before igniting the engine to prevent engine oil leaking that might lead to engine damage. The engine was switched on after no leaking had been observed.

To ensure a stable result and prevent potential damage to the engine, the engine was left at idle speed to 5-10 minute to let the engine temperature reach the optimum operating temperature. Then, the engine will be revved from 3000 RPM to 8000 RPM. The results will be taken by using the DYNO-MAX 2010 software.

Figure 3.17: Process of taking the results.

For 1 engine oil, a total of three tests were carried out to obtain the average power and torque against RPM graph in order to ensure better accuracy. After three tests has been carried out, the results were analysed and approved by the lab assistant. The results were taken as the final results for Yamalube Mineral 20W-50 engine oil. After that, the changing of engine oil process will be performed again, and another engine oil specimen will be poured in which is the Yamalube Semi-Synthetic 10W-40. The experiment was carried out again to obtain three test results for 10W-40 SAE graded oil. The results will be taken as final results after being approved by lab assistant.

3.5 DATA COLLECTION AND VALIDATION

After the complete results from the power test using dynamometer is obtained, the collected data will be checked and analysed. The data will be validated by using results from other research as well as basic theories and principles. The pattern of the results will be compared. If a big difference exists between this study and other published research, the reasons for this phenomenon will be proposed and discussed. If the results cannot be validated, it means that some unexpected influence occur, and the results obtained have no credibility. The study will be repeated from second step, data inspection. The related initial data and values will be recollected and checked to obtain a new set of results and values. This step will be repeated until the study shows a trustable result that have credibility and can be validated, or the factor for the big difference can be proposed and validated.

3.6 DISCUSSION AND ANALYSIS

The validated result will be discussed and analysed. This is to suggest valid conclusion for this study. This section will also serve the purpose of reviewing the study by suggesting possible engineering solution for performance improvement, as well as educating the reader by relating the results of this study with other published research, as well as provide conclusion with theories and principles. Limitation of the study will be listed out and discussed.

3.7 REPORT WRITING

The details of this study will be written and presented in a written formal report. All information regardless primate sources or secondary sources will be included.

CHAPTER 4

DATA AND RESULTS

4.1 INTRODUCTION

In this chapter, all collected data will be presented and explained. The results from the dynamometer test will be focused on power and torque. There are total of 12 sets of data from the dynamometer test. There are two types of oil specimen, which are YAMALUBE Semi-Synthetic 4 Stroke Oil 10W-40 and YAMALUBE Mineral 4 Stroke Oil 20W-50. The test results are categorized into 2 types, which are power against RPM and torque against RPM. For each type of test, 3 test was carried out in order to obtain the average data to ensure the accuracy of the test results. For all these tests, all other parameters remain unchanged. The fuel used was RON 100 petrol. The spark plug used was iridium spark plug. All the data and results were arranged in timeline order.

4.2 TEST RESULTS FOR SAE 20W-50 ENGINE OIL

In this part, the test results for YAMALUBE Mineral 4 Stroke Oil 20W-50 will be presented. A total of 3 tests were carried out to obtain the average data to ensure the accuracy of the test results.

The raw data for 20W-50 were directly exported from the DYNO-MAX 2010 software. The test was carried out on April 23, 2021. The time is approximately 10 AM. The amount of data from one test is quite a lot (more than 250). Hence, the raw data requires further process and simplification to make it proper and presentable.

Figure 4.1 is the raw data for test 1 part 1. For one test, there are a total of 4 sets of data. The original sets of raw data contain a huge amount of number and value. Hence, all the raw data will be presented in appendix.

For all tests, the power and torque data taken is according to time. As a result, the value of RPM when the set of data was taken is different. In this case, the average value cannot be obtained as the RPM is different. Calculating the average value by taking the closest value is also not a feasible way as it will let the data loss its accuracy and credibility.

To simplify the data, interpolation method was used. The data was simplified and interpolated to every 100 RPM to obtain the average value.

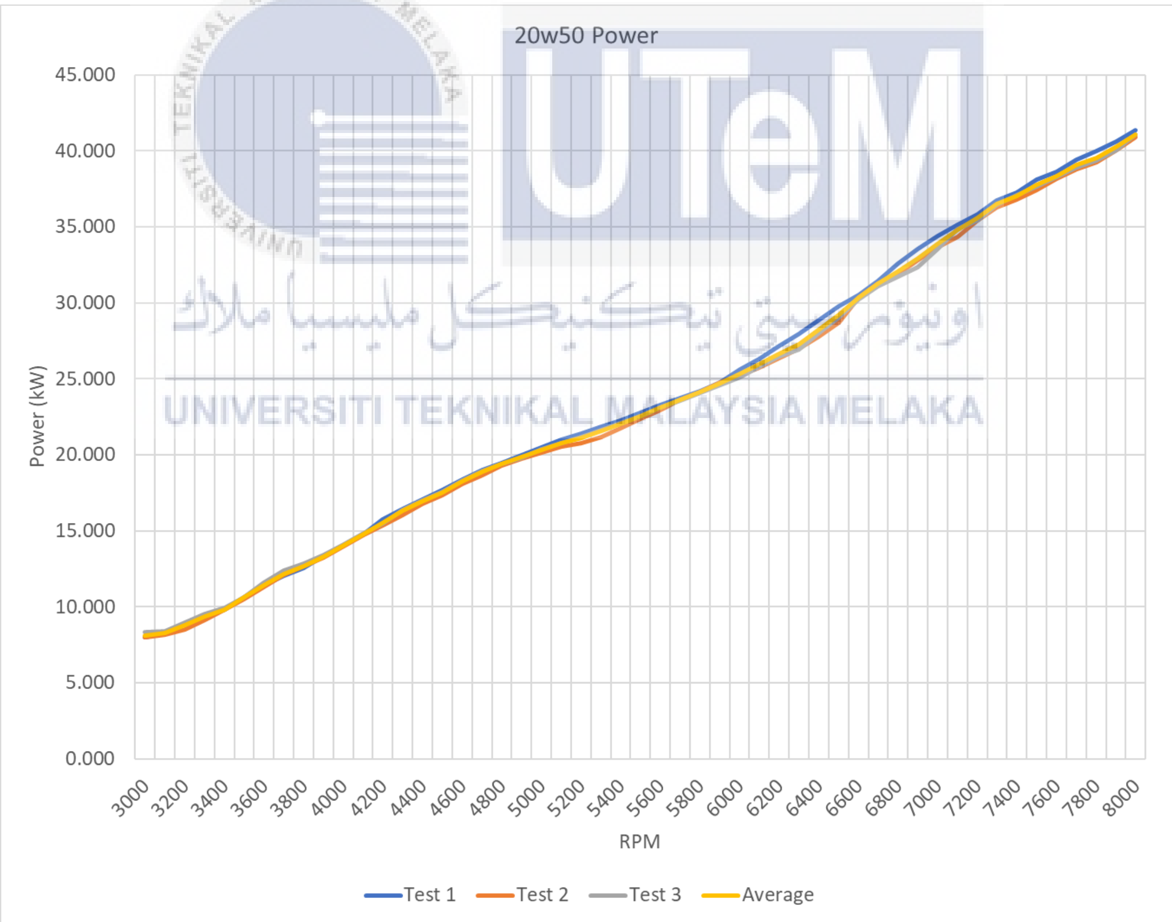

Figure 4.1: 20W-50 power graph

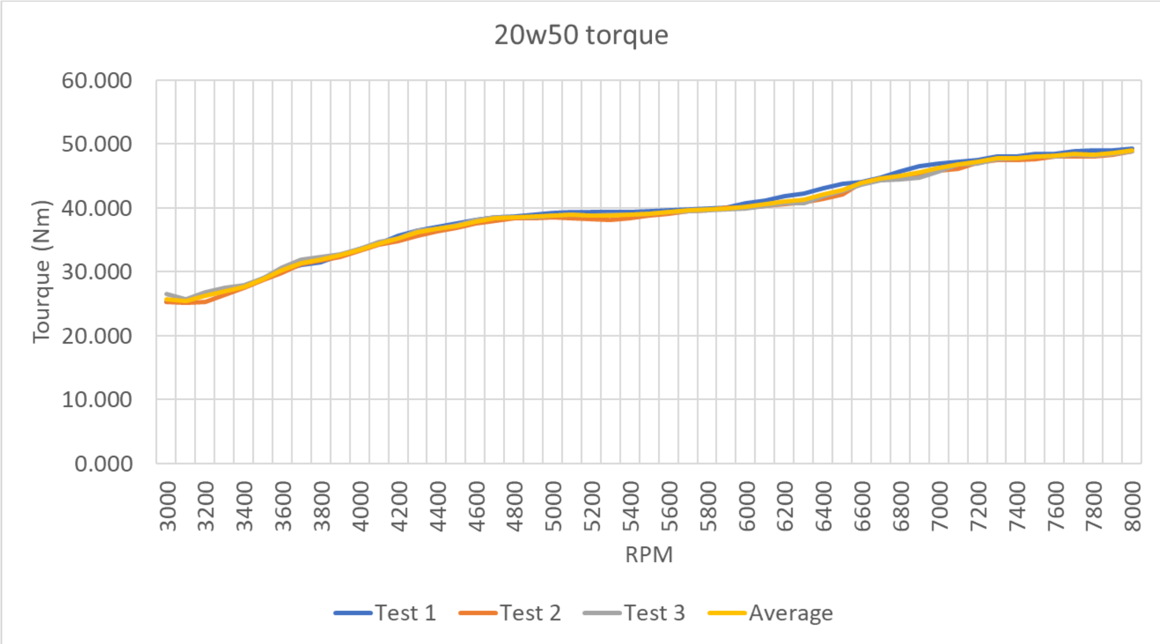

Figure 4.2: 20W-50 torque graph

4.3 TEST RESULTS FOR SAE 10W-40 ENGINE OIL

In this part, the test results for YAMALUBE Semi-synthetic 4 Stroke Oil 10W-40 will be presented. A total of 3 tests were carried out to obtain the average data to ensure the accuracy of the test results. The raw data for 10W-40 were directly exported from the DYNO-MAX 2010 software. The test was carried out on April 23, 2021. The time is approximately 3pm.

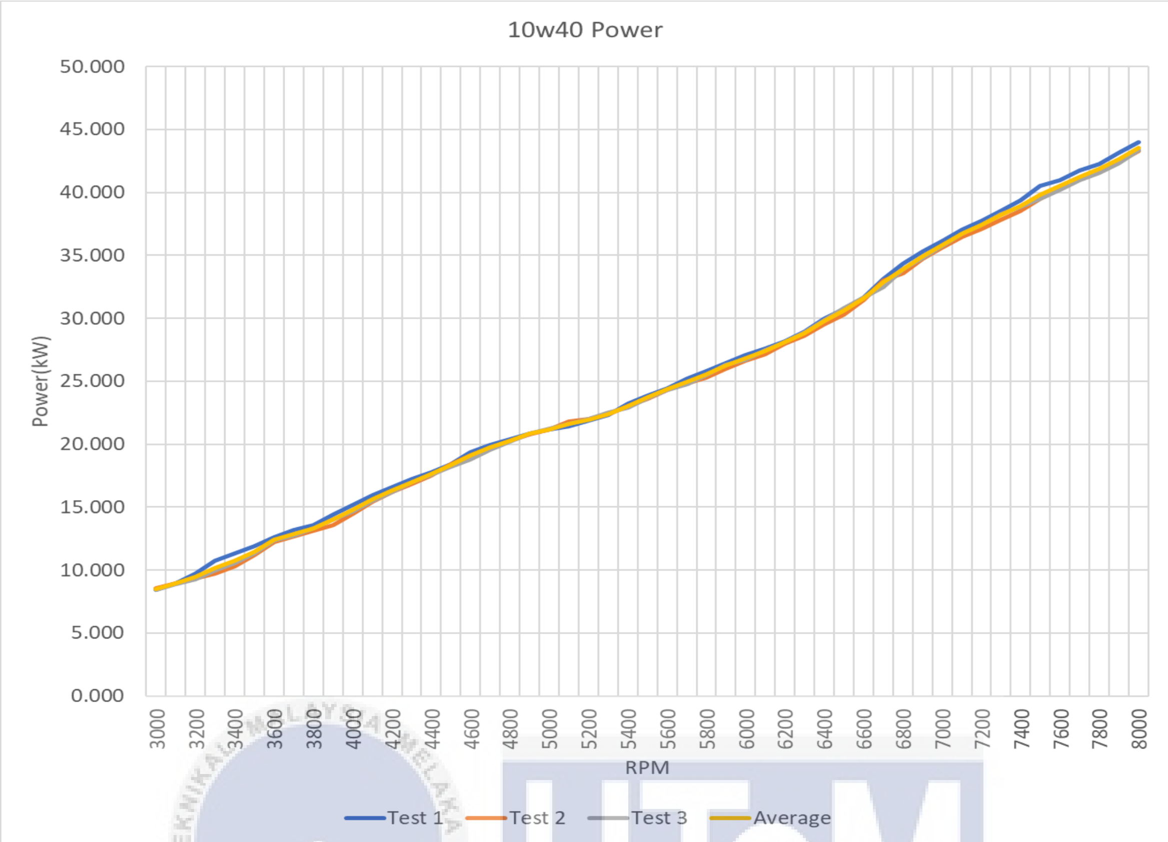

Figure 4.3: 10W-40 power graph

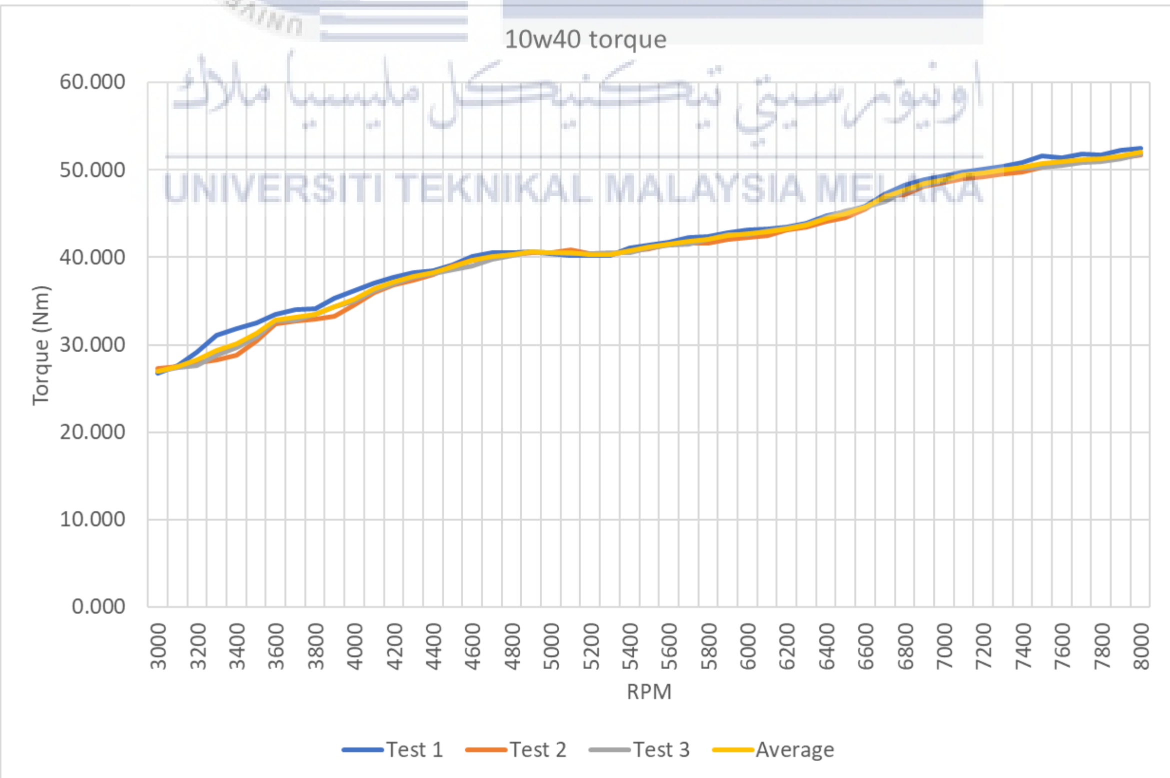

Figure 4.4: 10W-40 average torque graph

4.3 AVERAGE POWER COMPARISON

In the part, the average power data from 20W-50 and 10W-40 is taken out and compared. Figure 4.5 is the graph of average power comparison between 20W-50 and 10W-40 against RPM.

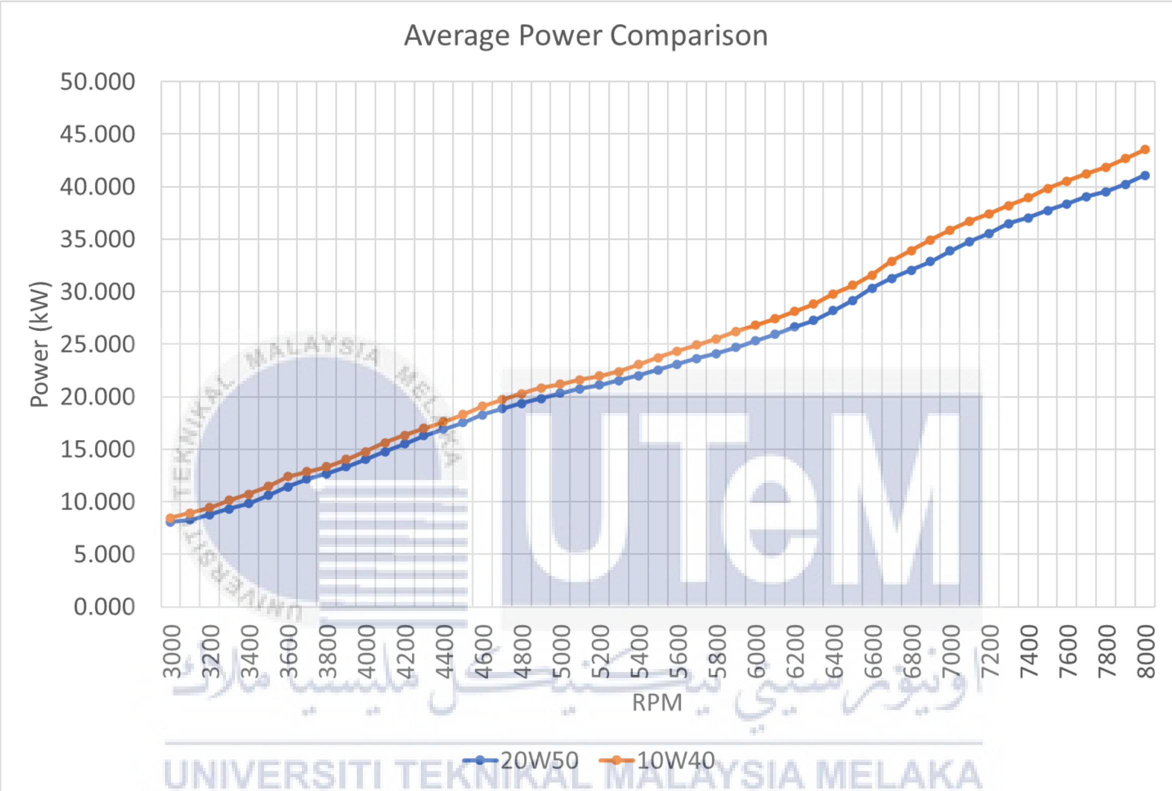

Figure 4.5: Average power comparison graph

4.4 AVERAGE TORQUE COMPARISON

In the part, the average torque data from 20W-50 and 10W-40 is taken out and compared. Figure 4.6 is the graph of average power comparison between 20W-50 and 10W-40 against RPM.

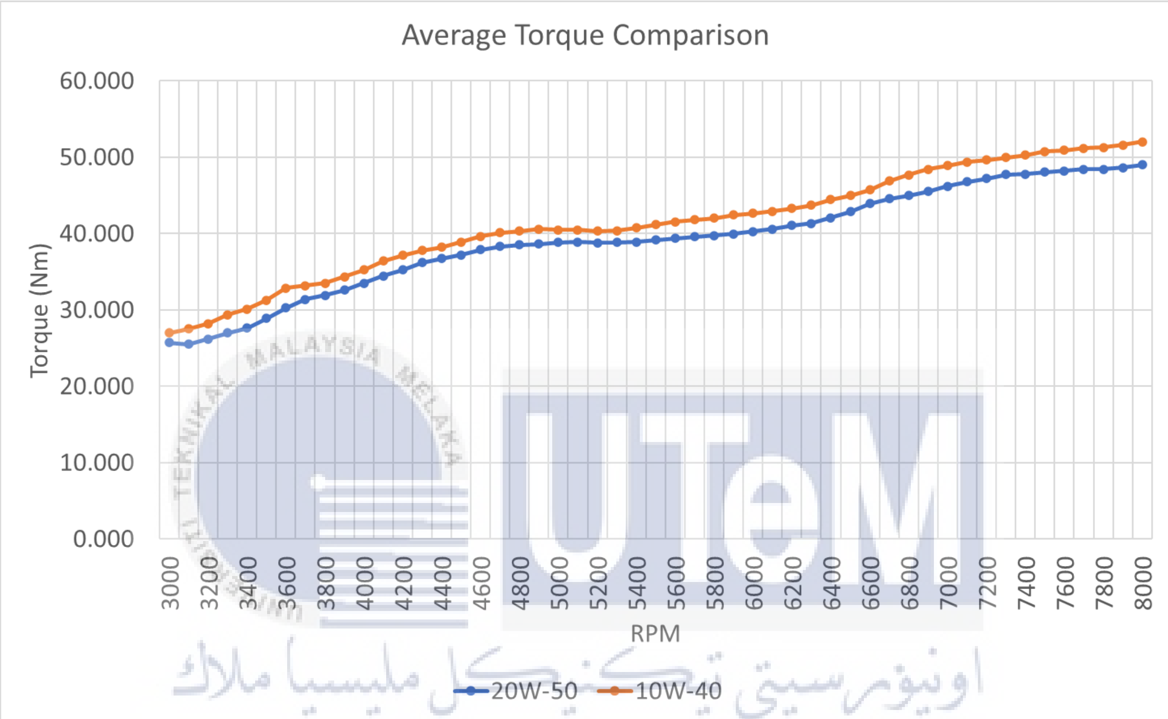

Figure 4.6: Average torque comparison graph

CHAPTER 5

DISCUSSION AND ANALYSIS

5.1 INTRODUCTION

The data and results will be discussed and analysed. The data and results will be focused on engine power, engine torque and engine RPM as stated in the objective. The impact of different engine oil towards the power performance of the engine will be investigated. The impact of different engine oil towards the torque performance of the engine will also be investigated.

5.2 POWER VS RPM ANALYSIS

From chapter 2 literature review, subchapter 2.3.3 Engine Performance Characteristic Related to Viscosity, it is stated that the kinematic viscosity of the engine oil will decrease when the operation temperature rise. (L.Severa, et al, 2009). The dynamics viscosity of the engine oil also shows an exponential decreasing curve when the temperature increase. (Hlaváč, et al, 2015).

On the other hand, the viscosity of the engine oil also influences the friction loss of the engine. Friction due to engine oil seal decrease when using a low viscosity oil. In conclusion, by ensuring the engine oil seal will not leak, low viscosity engine oil decrease the rate of fuel consumption, as the frictional loss caused by engine oil seal is reduced. (H.G. Kim, et al, 2007).

For the results, the difference between 2 sets of engine oil is obvious. The details will be shown and explained.

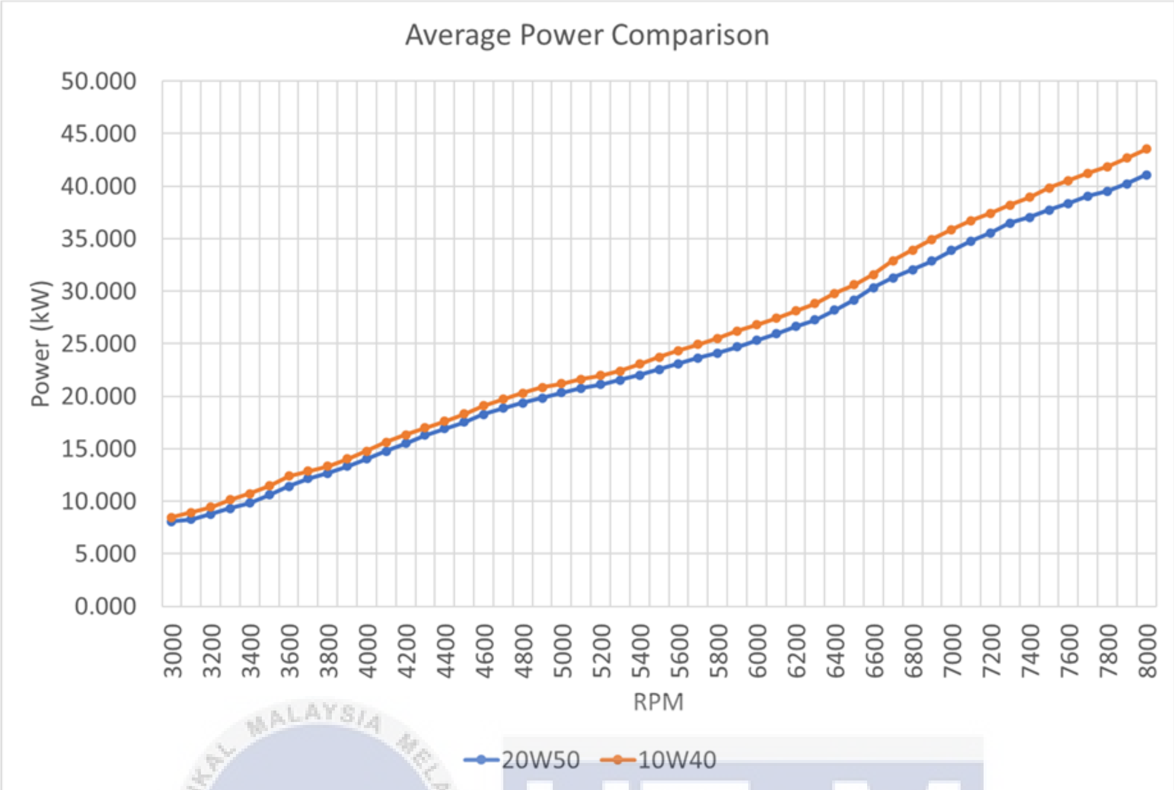

Figure 5.1: Average power comparison graph

Figure 5.1 is the average power comparison graph. From the graph, both SAE 20W-50 and 10W-40 engine showed a constant increasing pattern. Engine oil 20W-50 produced lower value of power compared to engine oil 10W-40 at all RPM. The difference in power is smaller at low RPM ang bigger at high RPM.

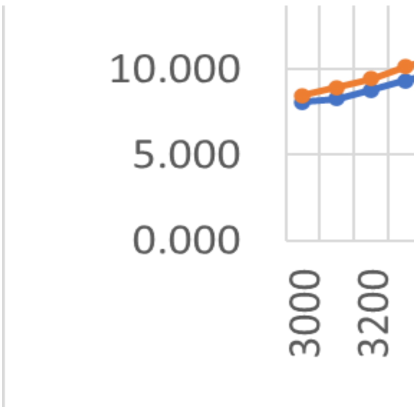

Figure 5.2: Power Vs RPM graph at 3000 RPM

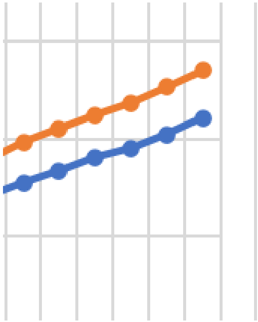

Figure 5.3: Power Vs RPM graph at 8000 RPM

Table 5.1: Power difference between 2 engine oils

RPM	Power (kW)		Power Difference (kW)	Percentage Different (%)
	10W-40	20W-50		
3000	8.476	8.090	0.386	4.554
4000	14.771	14.034	0.737	4.990
5000	21.190	20.336	0.854	4.030
6000	26.807	25.307	1.500	5.600
7000	35.862	33.870	1.992	5.555
8000	43.537	41.094	2.443	5.611

From the table, the power difference (kW) between two type of engine oil increase gradually as RPM increases. However, the percentage different (%) suggest that the portion of power loss due to higher viscosity only increase in a small scale, ranging from 4% to 5.6%. The percentage different (%) that represent the portion of power loss do not increase with increasing RPM. Further analysis is required.

RPM	Power Difference (kW)	Percentage Difference (%)
3000	0.386	4.559
3100	0.650	7.286
3200	0.678	7.177
3300	0.825	8.120
3400	0.888	8.281
3500	0.870	7.585
3600	0.956	7.717
3700	0.694	5.402
3800	0.642	4.814
3900	0.709	5.057
4000	0.736	4.984
4100	0.850	5.436
4200	0.837	5.124
4300	0.718	4.219
4400	0.677	3.848
4500	0.787	4.292
4600	0.818	4.287
4700	0.872	4.420
4800	0.911	4.492
4900	1.005	4.822
5000	0.854	4.029
5100	0.851	3.936
5200	0.854	3.891
5300	0.856	3.821
5400	1.031	4.473
5500	1.158	4.885
5600	1.257	5.163
5700	1.293	5.185
5800	1.382	5.417
5900	1.530	5.832
6000	1.500	5.594
6100	1.477	5.390
6200	1.448	5.152
6300	1.546	5.363
6400	1.585	5.319
6500	1.440	4.703
6600	1.240	3.925
6700	1.628	4.948
6800	1.881	5.544
6900	2.061	5.898
7000	1.992	5.554
7100	1.960	5.335
7200	1.872	5.000
7300	1.727	4.520
7400	1.912	4.910
7500	2.098	5.268
7600	2.166	5.345
7700	2.215	5.368
7800	2.316	5.533
7900	2.428	5.689
8000	2.443	5.611
Average	1.285	5.265

Figure 5.4: Power Difference (kW) and Power Percentage Difference (%) vs RPM data

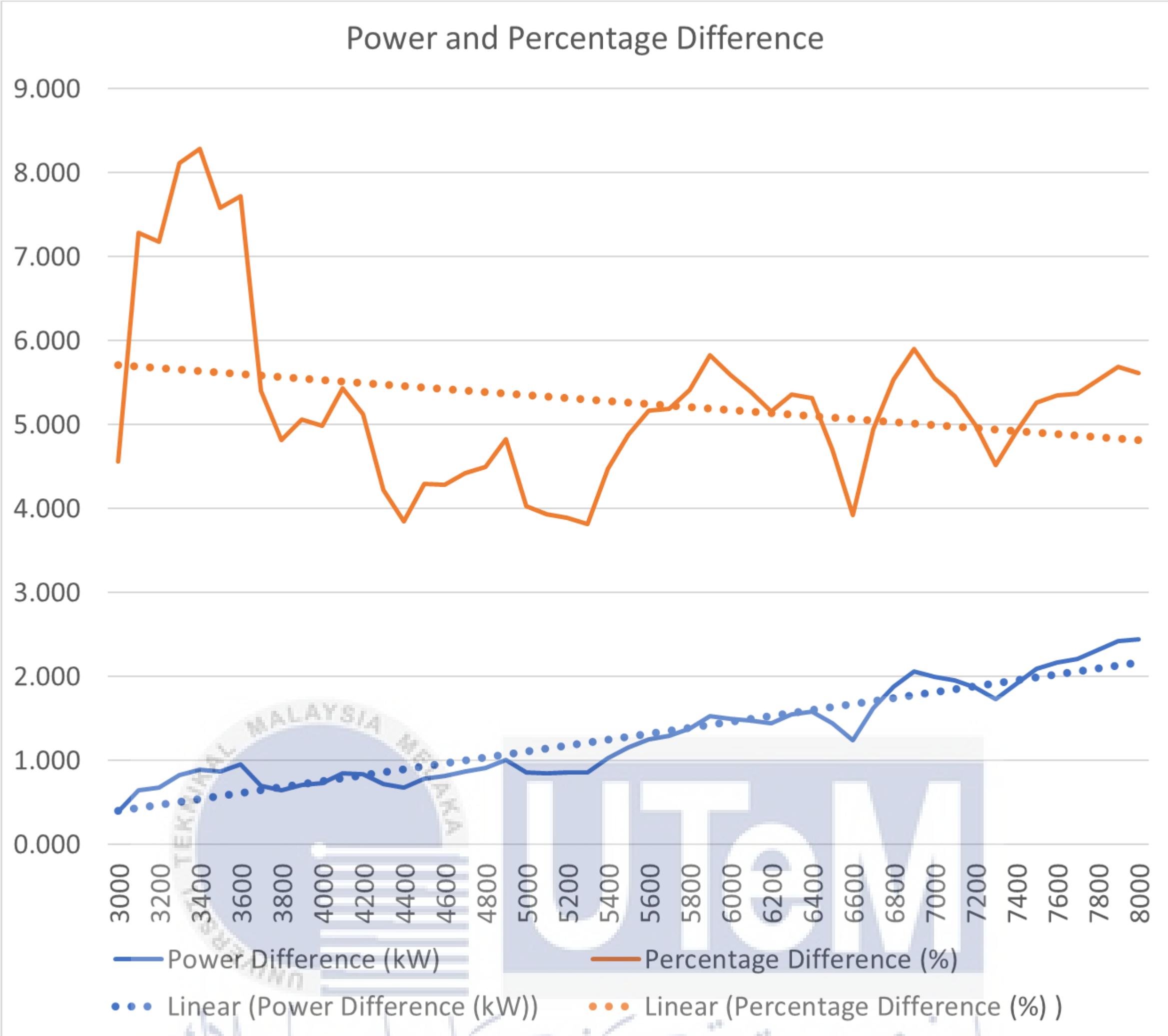

Figure 5.5: Power and Percentage Difference Graph

Table 5.2: Highest and lowest percentage difference for power (%)

RPM	Power Difference (kW)	Percentage Different (%)	Description
3400	0.888	8.281	Highest Percentage Different
5300	0.856	3.821	Lowest Percentage Different
Average	1.285	5.265	-

From figure 5.4, the pattern of power difference and percentage difference against RPM can be observed.

Although as RPM rise, the power difference (kW) showed a fluctuant pattern, an overall gradually increasing pattern can still be observed. The trendline also suggest that the power difference (kW) increase as engine speed (RPM) increase. It can be concluded that as engine speed (RPM) increase, the power difference due to engine oil with difference SAE grading will increase gradually.

As for the percentage difference (%), the graph proposed a random and unpredictable trend. The observed highest percentage difference (%) is 8.281% at 3400 RPM and the lowest percentage difference (%) is 3.821% at 5300 RPM. However, the trendline suggested that a slight declination pattern was observed. Hence, it can be concluded that the power percentage difference (%) will stay within a range, the power percentage difference (%) will decrease gradually as engine speed (RPM) increase.

5.3 TORQUE VS RPM ANALYSIS

The data and results of torque vs RPM were compared and analysed. The results will be presented and explained by using proper analysis.

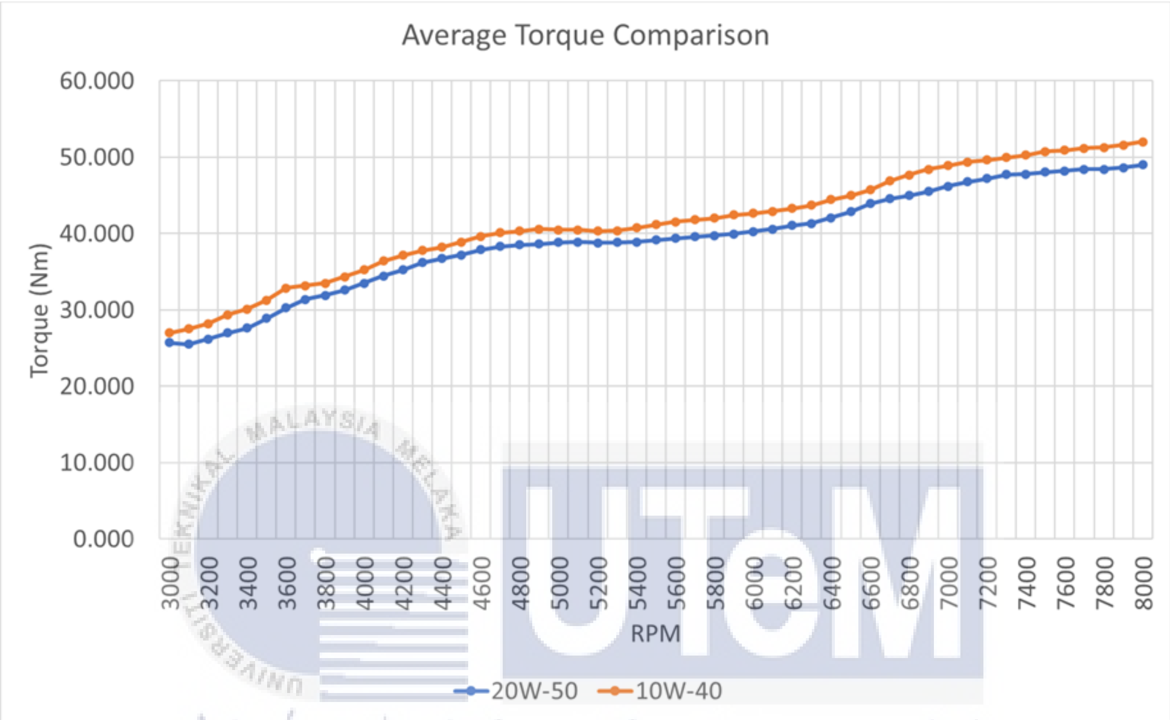

Figure 5.6: Average Torque comparison graph

From figure 5.5, the value of torque for both SAE 10W-40 and SAE 20W-50 engine oil showed an overall increasing pattern. SAE 10W-40 engine oil produced a higher torque at all RPM compared to SAE 20W-50 engine oil. From the graph, the torque different seems to be same throughout the graph. Further investigation is required.

Table 5.3: Torque difference between two engine oils

RPM	Torque (Nm)		Torque Difference (Nm)	Percentage Different (%)
	10W-40	20W-50		
3000	26.978	25.735	1.243	4.607
4000	35.247	33.497	1.750	4.964
5000	40.471	38.857	1.614	3.988
6000	42.651	40.258	2.393	5.612
7000	48.907	46.195	2.712	5.545
8000	51.998	49.024	2.974	5.720

From the table, the torque difference (Nm) between two type of engine oil shows a gradually increasing pattern as RPM increases. The percentage different (%) suggest that the portion of torque loss due to higher viscosity fluctuate within a specific range, ranging from 3.988% to 5.720%. The percentage different (%) that represent the portion of power loss do not depend on increasing RPM. Further analysis is required.

RPM	Torque Difference (Nm)	Percentage Difference (%)
3000	1.243	4.607
3100	2.025	7.360
3200	2.020	7.157
3300	2.362	8.040
3400	2.492	8.272
3500	2.358	7.542
3600	2.563	7.802
3700	1.777	5.356
3800	1.594	4.759
3900	1.723	5.018
4000	1.750	4.964
4100	1.945	5.343
4200	1.906	5.131
4300	1.584	4.194
4400	1.482	3.879
4500	1.672	4.299
4600	1.721	4.343
4700	1.763	4.397
4800	1.812	4.490
4900	1.953	4.812
5000	1.614	3.988
5100	1.586	3.919
5200	1.556	3.859
5300	1.526	3.782
5400	1.840	4.513
5500	2.003	4.868
5600	2.178	5.244
5700	2.177	5.210
5800	2.276	5.417
5900	2.477	5.833
6000	2.393	5.612
6100	2.328	5.425
6200	2.211	5.108
6300	2.350	5.379
6400	2.337	5.260
6500	2.132	4.737
6600	1.794	3.924
6700	2.322	4.950
6800	2.675	5.611
6900	2.884	5.959
7000	2.712	5.545
7100	2.644	5.352
7200	2.464	4.963
7300	2.237	4.477
7400	2.494	4.962
7500	2.697	5.316
7600	2.698	5.300
7700	2.725	5.328
7800	2.857	5.573
7900	2.965	5.747
8000	2.974	5.720

Figure 5.7: Torque Difference (Nm) and Torque Percentage Difference (%) vs RPM data

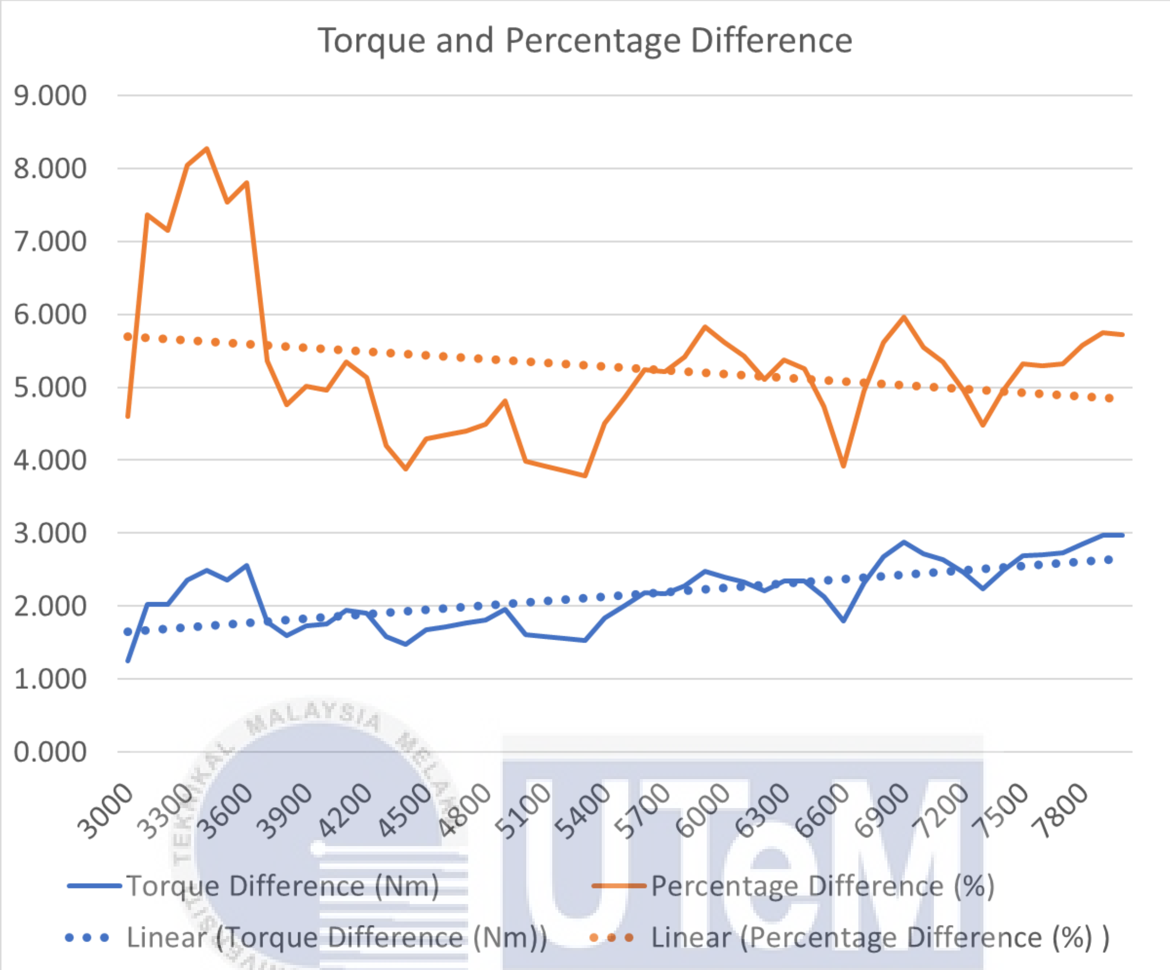

Figure 5.8: Torque and percentage difference graph

Table 5.4: Highest and lowest percentage difference for torque (%)

RPM	Torque Difference (Nm)	Percentage Difference (%)	Description
3400	2.492	8.272	Highest Percentage Different
5300	1.526	3.782	Lowest Percentage Different
Average	2.154	5.268	-

From figure 5.7, the pattern of torque difference and torque percentage difference against RPM can be observed.

Although as RPM rise, the torque difference (Nm) showed a fluctuant pattern, an overall gradually increasing pattern can still be observed. The trendline also suggested that as engine speed (RPM) increase, the torque difference (Nm) showed an increasing trend. Hence, it can be concluded that as engine speed (RPM) increase, the torque difference due to engine oil with difference SAE grading will increase in a small scale.

As for the percentage difference (%), a random and unpredictable pattern was observed from the graph. The observed highest torque percentage difference (%) is 8.272% at 3400 RPM and the lowest percentage difference (%) is 3.782% at 5300 RPM. The graph suggested that no obvious pattern can be observed. However, the trendline for torque percentage difference suggested that a minor decreasing pattern as engine speed (RPM) rise. Hence, it can be concluded that although the torque percentage difference (%) will stay within a range, the torque percentage difference (%) will decrease marginally as engine speed (RPM) increase.

5.4 LIMITATIONS

Various type of limitations faced in this study will be presented and explained. First of all, the title of this study is "A study of different types of engine oils on high compression ratio engine performance". In general, engine performance can be represented by many common specifications such as engine capacity, max power, max torque, and acceleration. However, indirect categories such as rate of emission, rate of fuel consumption, noise caused from internal friction and vibration, as well as mechanical and thermal loading can also consider as engine performance.

The first limitation of this study was lack of diversity in the results. The data and results of this study was focused on engine power (kW) and engine torque (Nm) against engine speed (RPM). As a consequence, the results lack the authoritativeness as many other parameters and specifications were not considered in this study.

Other than that, the engine model is also considered as a limitation. Car or motor engine with different design, arrangement, displacement as well as other specification behaved differently even in similar conditions. The engine used is Yamaha XJ6S/ XJ6SA Diversion engine. Hence, the results of this study were only applicable to engine with similar arrangement, and displacement.

Moreover, the lack of equipment and facilities were also one of the limitations in this study. The equipment allowed to use in this study was only the 800-Pro MC/ATV EC Dyno by DYNOmite DYNAMOMETER. Other equipment was unavailable due to maintenance. As a result, this study only focused on engine power and torque as the outcome.

In addition, financial limitation also exists in this study. Thus, only two different type of engine oil, YAMALUBE Semi-Synthetic 4 Stroke Oil 10W-40 and YAMALUBE Mineral 4 Stroke Oil 20W-50 were used to investigate the impact of engine oil with different viscosity towards the engine performance.

Finally, the major limitation for this study is the influence of COVID-19 pandemic. As a consequence, the time allowed for students to enter the lab had reduced significantly. Hence, experimental process and scope had to be reduced due to the lack of time.

In a nutshell, there were various limitations faced in this study. These limitations could be the possible future work that increase the credibility of this study.

5.5 SUMMARY

The data and results concluded that engine oil with higher SAE grading (higher viscosity) will give reduced power and torque compared to engine oil with lower SAE grading (lower viscosity). This statement is validified by one of the research journals in literature review. From the journal, it is stated that high viscosity of the lubricant will lead to unavoidable frictional loss. Low viscosity engine oil decreases the rate of fuel consumption, as the frictional loss caused by engine oil seal is reduced. (H.G. Kim, et al, 2007)

Figure 5.1 and figure 5.6 showed that as RPM increase, the power and torque produced by the engine will increase. Figure 5.5 showed that the power difference (kW) showed an overall gradually increasing pattern as RPM increase. The trendline also suggest that the power difference (kW) increase as engine speed (RPM) increase. Table 5.2 stated that the observed highest power percentage difference (%) is 8.281% at 3400 RPM and the lowest power percentage difference (%) is 3.821% at 5300 RPM. The trendline suggested that a slight declination pattern was observed.

Figure 5.8 showed that, the torque difference due to engine oil with difference SAE grading will increase in a small scale as RPM increase while torque percentage difference (%) will decrease marginally as RPM increase. Table 5.2 concludes that the highest torque percentage difference (%) is 8.272% at 3400 RPM and the lowest percentage difference (%) is 3.782% at 5300 RPM.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In this final year project with title “A study of different types of engine oils on high compression ratio engine performance”, the impact of different type of engine oil towards the high compression engine performance was investigated and analysed. In order to achieve this target, three objectives had been proposed. These objectives are studied and investigated throughout the project. The first objective and second objective are to investigate the impact of different engine oil towards the power performance and torque performance of the engine, respectively. These two objectives were achieved. The data were presented chapter 4 and the results were further investigated and discussed in chapter 5. The third objective is to investigate the impact of environmental factor towards the properties of the engine oil. This objective is achieved and presented in chapter 3.

In chapter 3, the methodology used in this project was presented and explained. The flow chart for methodology was presented in figure 3.1. Engine configuration and engine oil specification were presented. The engine was YAMAHA XJ6 Diversion, and the selected engine oil specimen is YAMALUBE Semi-Synthetic 4 Stroke Oil 10W-40 and YAMALUBE Mineral 4 Stroke Oil 20W-50. The dynamometer used was 800-Pro MC/ATV EC Dyno by DYNOmite DYNAMOMETER. The impact of different weather towards the results of the test is negligible. The overall process for changing engine oil was also presented.

In chapter 4, all data and results from the study and experiment was presented, including test results for SAE 20W-50 engine oil and test results for SAE 10W-40 engine oil. The raw data were simplified by using interpolation. The original raw data were presented in appendices.

In chapter 5, the data and results were further discussed and analysed. In short, engine oil with higher SAE grading (20w-50) will give reduced power and torque compared to engine oil with lower SAE grading (10w-40). The power loss ranged from 3.821% to 8.281% while the torque loss ranged from 3.782% to 8.272%

5.2 RECOMMENDATION

The limitations of this study were presented in previous chapter. Several recommendations were proposed for the future work of this study.

The main recommendation is to increase the diversity of the results in this study. Other than power and torque, many specifications such as rate of emission, rate of fuel consumption, noise caused from internal friction and vibration, mechanical and thermal loading and wear scar diameter can be used to study the impact of different engine oil towards engine performance.

Other than that, increasing the number of engine oil specimen can be consider as one recommendation for future work too. To further study the impact of engine oil viscosity towards engine performance, larger range of SAE grading such as 10W-30, 10W-50, 15W-40, and 20W-40 can be used for obtaining more data for comparison purpose. Engine oil with different additives can be used too.

Finally, a brand-new engine or a throughout maintenance and refurbish for the old engine is required for results with better accuracy. This is to minimize and eliminate all possible unseen factor that might affect the credibility the study.

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APPENDIX

SAE 20W-50 RAW DATA

Sec(Seconds)	RPM (RPM)	Power (kW)	Torque (N-m)
0	2875	9.778	32.5
0.1	2877	9.689	32.2
0.2	2882	9.523	31.6
0.3	2889	9.281	30.7
0.4	2900	8.979	29.6
0.5	2917	8.639	28.3
0.6	2939	8.337	27.1
0.7	2963	8.114	26.2
0.801	2989	7.991	25.5
0.901	3014	7.97	25.2
1.001	3039	8.018	25.2
1.101	3063	8.108	25.3
1.201	3086	8.217	25.4
1.301	3110	8.337	25.6
1.401	3132	8.464	25.8
1.501	3155	8.593	26
1.601	3177	8.73	26.2
1.701	3199	8.866	26.5
1.802	3222	9.008	26.7
1.902	3243	9.137	26.9
2.002	3264	9.247	27
2.102	3286	9.337	27.1
2.202	3307	9.407	27.2
2.302	3329	9.473	27.2
2.402	3354	9.561	27.2
2.502	3377	9.669	27.3
2.602	3401	9.815	27.6
2.702	3426	9.996	27.900
2.803	3450	10.2	28.2
2.903	3474	10.41	28.6
3.003	3497	10.61	29
3.103	3520	10.8	29.3
3.203	3543	10.98	29.6
3.303	3564	11.14	29.9
3.403	3586	11.32	30.1
3.503	3608	11.5	30.4
3.603	3630	11.67	30.7
3.703	3651	11.82	30.9
3.804	3672	11.94	31
3.904	3693	12.02	31.1
4.004	3715	12.1	31.1
4.104	3736	12.18	31.1
4.204	3759	12.28	31.2
4.304	3781	12.41	31.4
4.404	3803	12.57	31.6
4.504	3826	12.75	31.8
4.604	3848	12.92	32.1
4.704	3869	13.1	32.3
4.805	3892	13.27	32.6
4.905	3914	13.44	32.8
5.005	3936	13.6	33
5.105	3958	13.76	33.2
5.205	3980	13.91	33.4
5.305	4003	14.08	33.6
5.405	4026	14.24	33.8
5.505	4048	14.4	34
5.605	4071	14.56	34.2
5.705	4093	14.73	34.4
5.806	4115	14.92	34.6
5.906	4137	15.13	34.9
6.006	4157	15.33	35.2
6.106	4179	15.53	35.5
6.206	4199	15.72	35.7
6.306	4219	15.88	35.9
6.406	4240	16.04	36.1
6.506	4260	16.18	36.3
6.606	4281	16.32	36.4
6.706	4302	16.45	36.5
6.807	4322	16.58	36.6
6.907	4343	16.72	36.8
7.007	4363	16.84	36.9
7.107	4383	16.95	36.9
7.207	4404	17.07	37
7.307	4425	17.17	37.1
7.407	4446	17.29	37.1
7.507	4467	17.44	37.3
7.607	4488	17.59	37.4
7.707	4510	17.76	37.6
7.808	4530	17.92	37.8
7.908	4551	18.07	37.9
8.008	4572	18.21	38
8.108	4591	18.34	38.1
8.208	4612	18.46	38.2
8.308	4632	18.59	38.3
8.408	4651	18.7	38.4
8.508	4672	18.82	38.5
8.608	4692	18.93	38.5
8.708	4712	19.03	38.6
8.809	4733	19.13	38.6
8.909	4754	19.22	38.6
9.009	4774	19.32	38.6
9.109	4795	19.43	38.7
9.209	4815	19.53	38.7
9.309	4836	19.65	38.8
9.409	4856	19.75	38.8
9.509	4876	19.86	38.9
9.609	4897	19.96	38.9
9.709	4917	20.07	39
9.81	4937	20.17	39
9.91	4957	20.28	39.1
10.01	4977	20.38	39.1
10.11	4998	20.49	39.2
10.21	5018	20.6	39.2
10.31	5038	20.71	39.3
10.41	5058	20.83	39.3
10.51	5076	20.92	39.4
10.61	5095	21	39.4
10.71	5113	21.07	39.3
10.811	5130	21.12	39.3
10.911	5149	21.17	39.3
11.011	5167	21.24	39.3
11.111	5186	21.32	39.3
11.211	5205	21.41	39.3
11.311	5225	21.5	39.3
11.411	5246	21.6	39.3
11.511	5264	21.68	39.3
11.611	5284	21.76	39.3
11.711	5304	21.84	39.3
11.812	5324	21.91	39.3
11.912	5345	21.99	39.3
12.012	5366	22.08	39.3
12.112	5386	22.17	39.3
12.212	5406	22.27	39.3
12.312	5426	22.37	39.4
12.412	5446	22.47	39.4

Figure A.1: SAE 20W-50 Test 1 Part 1

12.512	5467	22.58	39.4	18.819	6766	32.23	45.5
12.612	5487	22.69	39.5	18.919	6787	32.42	45.6
12.712	5507	22.8	39.5	19.019	6805	32.6	45.7
12.813	5527	22.91	39.6	19.119	6825	32.79	45.9
12.913	5547	23	39.6	19.219	6844	32.99	46
13.013	5567	23.1	39.6	19.319	6863	33.19	46.2
13.113	5588	23.19	39.6	19.419	6883	33.4	46.3
13.213	5607	23.28	39.6	19.519	6902	33.58	46.5
13.313	5631	23.39	39.7	19.619	6921	33.76	46.6
13.413	5651	23.49	39.7	19.719	6940	33.93	46.7
13.513	5671	23.6	39.7	19.82	6960	34.09	46.8
13.613	5694	23.71	39.8	19.92	6979	34.25	46.9
13.713	5714	23.81	39.8	20.02	6999	34.41	46.9
13.814	5735	23.92	39.8	20.12	7017	34.56	47
13.914	5756	24.01	39.8	20.22	7038	34.73	47.1
14.014	5775	24.1	39.9	20.32	7057	34.88	47.2
14.114	5799	24.21	39.9	20.42	7076	35	47.2
14.214	5819	24.29	39.9	20.52	7096	35.11	47.2
14.314	5840	24.38	39.9	20.62	7115	35.18	47.2
14.414	5863	24.49	39.9	20.72	7135	35.27	47.2
14.514	5884	24.62	39.9	20.821	7156	35.39	47.2
14.614	5906	24.78	40.1	20.921	7175	35.56	47.3
14.714	5927	24.98	40.2	21.021	7197	35.8	47.5
14.815	5948	25.17	40.4	21.121	7216	36.04	47.7
14.915	5968	25.35	40.6	21.221	7234	36.27	47.9
15.015	5988	25.52	40.7	21.321	7254	36.45	48
15.115	6007	25.67	40.8	21.421	7272	36.58	48
15.215	6027	25.81	40.9	21.521	7291	36.68	48
15.315	6046	25.95	41	21.621	7310	36.76	48
15.415	6066	26.07	41	21.721	7329	36.84	48
15.515	6085	26.18	41.1	21.822	7349	36.94	48
15.615	6105	26.3	41.1	21.922	7369	37.04	48
15.715	6126	26.44	41.2	22.022	7388	37.15	48
15.816	6146	26.61	41.3	22.122	7408	37.27	48
15.916	6166	26.8	41.5	22.222	7428	37.41	48.1
16.016	6186	27.01	41.7	22.322	7449	37.59	48.2
16.116	6205	27.2	41.9	22.422	7469	37.77	48.3
16.216	6224	27.37	42	22.522	7488	37.96	48.4
16.316	6243	27.52	42.1	22.622	7508	38.16	48.5
16.416	6263	27.66	42.2	22.722	7527	38.31	48.6
16.516	6284	27.8	42.3	22.823	7545	38.43	48.6
16.616	6305	27.96	42.3	22.923	7564	38.51	48.6
16.716	6326	28.13	42.5	23.023	7582	38.57	48.6
16.817	6348	28.32	42.6	23.123	7602	38.65	48.5
16.917	6368	28.52	42.8	23.223	7622	38.75	48.6
17.017	6388	28.73	43	23.323	7642	38.9	48.6
17.117	6408	28.95	43.1	23.423	7663	39.09	48.7
17.217	6427	29.15	43.3	23.523	7682	39.26	48.8
17.317	6449	29.36	43.5	23.623	7701	39.42	48.9
17.417	6469	29.54	43.6	23.723	7720	39.55	48.9
17.517	6490	29.72	43.7	23.824	7739	39.67	48.9
17.617	6511	29.89	43.8	23.924	7759	39.79	49
17.717	6532	30.04	43.9	24.024	7778	39.89	49
17.818	6554	30.19	44	24.124	7798	40	49
17.918	6575	30.33	44	24.224	7819	40.09	49
18.018	6597	30.47	44.1	24.324	7840	40.19	49
18.118	6620	30.62	44.2	24.424	7861	40.32	49
18.218	6642	30.79	44.3	24.524	7883	40.47	49
18.318	6665	31.01	44.4	24.624	7903	40.63	49.1
18.418	6687	31.26	44.6	24.724	7926	40.81	49.2
18.518	6708	31.53	44.9	24.825	7946	40.98	49.2
18.618	6728	31.8	45.1	24.925	7966	41.12	49.3
18.718	6748	32.04	45.3	25.025	7984	41.24	49.3

Figure A.2: SAE 20W-50 Test 1 Part 2

Sec (Seconds)	RPM (RPM)	Power (kW)	Torque (N-m)
0	2617	8.271	30.2
0.1	2624	8.171	29.7
0.2	2634	8.005	29
0.301	2648	7.759	28
0.401	2665	7.481	26.8
0.501	2687	7.2	25.6
0.601	2714	6.956	24.5
0.701	2743	6.798	23.7
0.801	2773	6.745	23.2
0.901	2804	6.799	23.2
1.001	2832	6.936	23.4
1.101	2861	7.141	23.8
1.201	2886	7.35	24.3
1.302	2910	7.54	24.7
1.402	2933	7.697	25.1
1.502	2955	7.809	25.2
1.602	2978	7.895	25.3
1.702	3001	7.967	25.3
1.802	3025	8.027	25.3
1.902	3049	8.084	25.3
2.002	3072	8.131	25.3
2.102	3095	8.17	25.2
2.202	3119	8.212	25.1
2.303	3144	8.267	25.1
2.403	3169	8.349	25.2
2.503	3196	8.464	25.3
2.603	3222	8.603	25.5
2.703	3250	8.771	25.8
2.803	3276	8.943	26.1
2.903	3303	9.122	26.4
3.003	3330	9.307	26.7
3.103	3355	9.476	27
3.203	3380	9.649	27.3
3.304	3405	9.822	27.5
3.404	3429	9.989	27.8
3.504	3455	10.18	28.1
3.604	3480	10.37	28.4
3.704	3505	10.56	28.8
3.804	3532	10.77	29.1
3.904	3557	10.96	29.4
4.004	3582	11.16	29.7
4.104	3608	11.35	30
4.204	3633	11.54	30.3
4.305	3660	11.74	30.6
4.405	3684	11.94	31
4.505	3707	12.13	31.3
4.605	3730	12.32	31.5
4.705	3751	12.46	31.7
4.805	3773	12.57	31.8
4.905	3797	12.66	31.8
5.005	3820	12.75	31.9
5.105	3844	12.87	32
5.205	3868	13.01	32.1
5.306	3892	13.16	32.3
5.406	3917	13.33	32.5
5.506	3940	13.5	32.7
5.606	3963	13.67	32.9
5.706	3988	13.86	33.2
5.806	4010	14.04	33.4
5.906	4033	14.22	33.7
6.006	4056	14.39	33.9
6.106	4078	14.56	34.1
6.206	4102	14.72	34.3
6.307	4125	14.87	34.4
6.407	4148	15.01	34.6
6.507	4173	15.16	34.7
6.607	4197	15.31	34.8
6.707	4222	15.48	35
6.807	4246	15.64	35.2
6.907	4269	15.81	35.4
7.007	4293	15.99	35.6
7.107	4315	16.16	35.8
7.207	4337	16.33	35.9
7.308	4360	16.49	36.1
7.408	4381	16.63	36.3
7.508	4403	16.77	36.4
7.608	4425	16.9	36.5
7.708	4446	17.02	36.6
7.808	4470	17.16	36.7
7.908	4491	17.29	36.8
8.008	4513	17.45	36.9
8.108	4535	17.62	37.1
8.208	4556	17.78	37.3
8.309	4577	17.93	37.4
8.409	4598	18.06	37.5
8.509	4619	18.18	37.6
8.609	4641	18.31	37.7
8.709	4662	18.43	37.8
8.809	4683	18.57	37.9
8.909	4705	18.71	38
9.009	4725	18.85	38.1
9.109	4747	18.99	38.2
9.209	4768	19.12	38.3
9.31	4788	19.23	38.4
9.41	4810	19.34	38.4
9.51	4830	19.44	38.4
9.61	4851	19.52	38.4
9.71	4872	19.6	38.4
9.81	4892	19.68	38.4
9.91	4913	19.77	38.4
10.01	4935	19.86	38.4
10.11	4955	19.95	38.5
10.21	4977	20.05	38.5
10.311	4997	20.14	38.5
10.411	5018	20.22	38.5
10.511	5039	20.29	38.5
10.611	5058	20.36	38.4
10.711	5079	20.43	38.4
10.811	5099	20.51	38.4
10.911	5119	20.59	38.4
11.011	5139	20.66	38.4
11.111	5159	20.71	38.3
11.211	5178	20.74	38.3
11.312	5200	20.78	38.2
11.412	5220	20.83	38.1
11.512	5241	20.9	38.1
11.612	5262	21	38.1
11.712	5283	21.1	38.1
11.812	5304	21.2	38.2
11.912	5325	21.31	38.2
12.012	5345	21.43	38.3
12.112	5366	21.55	38.3
12.212	5387	21.67	38.4
12.313	5409	21.79	38.5
12.413	5429	21.92	38.5

Figure A.3: SAE 20W-50 Test 2 Part 1

12.513	5450	22.04	38.6	18.819	6750	31.52	44.6
12.613	5472	22.17	38.7	18.919	6770	31.67	44.7
12.713	5492	22.31	38.8	19.019	6791	31.84	44.8
12.813	5512	22.45	38.9	19.119	6811	32	44.9
12.913	5533	22.58	39	19.219	6831	32.16	45
13.013	5553	22.69	39	19.32	6852	32.33	45.1
13.113	5573	22.8	39.1	19.42	6872	32.51	45.2
13.213	5594	22.92	39.1	19.52	6894	32.72	45.3
13.314	5614	23.05	39.2	19.62	6914	32.93	45.5
13.414	5635	23.19	39.3	19.72	6934	33.13	45.6
13.514	5656	23.33	39.4	19.82	6955	33.31	45.7
13.614	5676	23.47	39.5	19.92	6976	33.48	45.8
13.714	5698	23.59	39.5	20.02	6997	33.63	45.9
13.814	5718	23.7	39.6	20.12	7018	33.78	46
13.914	5739	23.8	39.6	20.22	7040	33.92	46
14.014	5759	23.89	39.6	20.321	7062	34.08	46.1
14.114	5779	23.99	39.6	20.421	7083	34.23	46.1
14.214	5801	24.11	39.7	20.521	7104	34.38	46.2
14.315	5821	24.25	39.8	20.621	7126	34.56	46.3
14.415	5841	24.4	39.9	20.721	7147	34.76	46.4
14.515	5862	24.55	40	20.821	7168	35.01	46.6
14.615	5882	24.67	40	20.921	7189	35.28	46.9
14.715	5902	24.78	40.1	21.021	7207	35.55	47.1
14.815	5923	24.88	40.1	21.121	7227	35.8	47.3
14.915	5943	24.98	40.1	21.221	7245	35.99	47.4
15.015	5963	25.08	40.2	21.322	7263	36.12	47.5
15.115	5982	25.16	40.2	21.422	7282	36.22	47.5
15.215	6002	25.23	40.1	21.522	7300	36.28	47.5
15.316	6022	25.31	40.1	21.622	7320	36.35	47.4
15.416	6042	25.38	40.1	21.722	7338	36.42	47.4
15.516	6063	25.48	40.1	21.822	7357	36.51	47.4
15.616	6083	25.61	40.2	21.922	7377	36.63	47.4
15.716	6103	25.76	40.3	22.022	7396	36.76	47.5
15.816	6124	25.93	40.4	22.122	7415	36.9	47.5
15.916	6143	26.08	40.5	22.222	7435	37.04	47.6
16.016	6162	26.2	40.6	22.323	7454	37.15	47.6
16.116	6182	26.29	40.6	22.423	7473	37.27	47.6
16.216	6202	26.38	40.6	22.523	7492	37.39	47.6
16.317	6223	26.48	40.6	22.623	7511	37.52	47.7
16.417	6244	26.6	40.7	22.723	7531	37.67	47.8
16.517	6266	26.75	40.8	22.823	7550	37.82	47.8
16.617	6289	26.92	40.9	22.923	7569	37.98	47.9
16.717	6311	27.09	41	23.023	7589	38.11	48
16.817	6333	27.27	41.1	23.123	7608	38.23	48
16.917	6355	27.44	41.2	23.223	7628	38.35	48
17.017	6377	27.6	41.3	23.324	7647	38.47	48
17.117	6400	27.76	41.4	23.424	7666	38.59	48.1
17.217	6423	27.92	41.5	23.524	7686	38.72	48.1
17.318	6445	28.1	41.6	23.624	7704	38.83	48.1
17.418	6470	28.33	41.8	23.724	7723	38.93	48.1
17.518	6493	28.6	42.1	23.824	7742	39.01	48.1
17.618	6516	28.92	42.4	23.924	7761	39.07	48.1
17.718	6537	29.28	42.8	24.024	7781	39.15	48.1
17.818	6557	29.63	43.2	24.124	7801	39.25	48
17.918	6578	29.99	43.5	24.224	7822	39.39	48.1
18.018	6596	30.29	43.9	24.325	7843	39.56	48.2
18.118	6615	30.56	44.1	24.425	7862	39.74	48.3
18.218	6635	30.8	44.3	24.525	7883	39.92	48.4
18.319	6653	30.99	44.5	24.625	7902	40.08	48.4
18.419	6671	31.13	44.6	24.725	7922	40.23	48.5
18.519	6690	31.23	44.6	24.825	7942	40.39	48.6
18.619	6709	31.31	44.6	24.925	7961	40.54	48.6
18.719	6730	31.4	44.6	25.025	7978	40.69	48.7

Figure A.4: SAE 20W-50 Test 2 Part 2

Sec (Seconds)	RPM (RPM)	Power (kW)	Torque (N-m)	6.212	4215	15.58	35.3
0	2927	10.04	32.8	6.312	4237	15.79	35.6
0.101	2927	9.939	32.4	6.412	4259	16.01	35.9
0.201	2930	9.756	31.8	6.512	4279	16.2	36.2
0.301	2936	9.485	30.9	6.612	4298	16.38	36.4
0.401	2947	9.15	29.7	6.712	4318	16.51	36.5
0.501	2964	8.774	28.3	6.812	4337	16.63	36.6
0.606	2985	8.459	27.1	6.912	4357	16.74	36.7
0.706	3009	8.243	26.2	7.012	4377	16.84	36.7
0.806	3034	8.15	25.6	7.113	4397	16.96	36.8
0.906	3059	8.165	25.5	7.213	4418	17.09	36.9
1.006	3083	8.264	25.6	7.318	4439	17.22	37
1.107	3104	8.39	25.8	7.418	4460	17.35	37.1
1.207	3126	8.524	26	7.518	4482	17.47	37.2
1.307	3148	8.662	26.3	7.618	4503	17.6	37.3
1.407	3170	8.792	26.5	7.718	4525	17.76	37.5
1.507	3193	8.926	26.7	7.818	4545	17.91	37.6
1.607	3215	9.059	26.9	7.918	4565	18.07	37.8
1.707	3236	9.184	27.1	8.019	4586	18.24	38
1.807	3258	9.307	27.3	8.119	4605	18.37	38.1
1.907	3279	9.412	27.4	8.219	4625	18.5	38.2
2.007	3300	9.506	27.5	8.319	4644	18.62	38.3
2.108	3321	9.591	27.6	8.419	4663	18.73	38.4
2.208	3342	9.672	27.6	8.519	4684	18.85	38.4
2.308	3364	9.758	27.7	8.619	4703	18.95	38.5
2.408	3387	9.857	27.8	8.719	4722	19.05	38.5
2.508	3411	9.974	27.9	8.819	4742	19.14	38.5
2.608	3436	10.12	28.1	8.919	4762	19.22	38.5
2.708	3460	10.29	28.4	9.02	4782	19.3	38.5
2.808	3484	10.49	28.7	9.12	4802	19.38	38.5
2.908	3508	10.7	29.1	9.22	4823	19.46	38.5
3.008	3531	10.92	29.5	9.32	4843	19.55	38.5
3.109	3554	11.14	29.9	9.42	4864	19.63	38.5
3.209	3575	11.35	30.3	9.52	4884	19.72	38.6
3.309	3596	11.54	30.6	9.62	4905	19.83	38.6
3.409	3618	11.73	31	9.72	4926	19.93	38.6
3.509	3639	11.9	31.2	9.82	4947	20.05	38.7
3.609	3660	12.07	31.5	9.92	4967	20.17	38.8
3.709	3682	12.23	31.7	10.021	4986	20.28	38.8
3.809	3702	12.38	31.9	10.121	5006	20.39	38.9
3.909	3722	12.52	32.1	10.221	5025	20.49	38.9
4.009	3742	12.64	32.3	10.321	5044	20.58	39
4.11	3761	12.73	32.3	10.421	5065	20.66	39
4.21	3782	12.8	32.3	10.521	5083	20.72	38.9
4.31	3802	12.85	32.3	10.621	5103	20.78	38.9
4.41	3823	12.9	32.2	10.721	5121	20.83	38.8
4.51	3846	13	32.3	10.821	5140	20.9	38.8
4.61	3868	13.14	32.4	10.921	5159	20.97	38.8
4.71	3889	13.31	32.7	11.022	5178	21.05	38.8
4.81	3911	13.48	32.9	11.122	5197	21.13	38.8
4.91	3932	13.64	33.1	11.222	5216	21.22	38.9
5.01	3955	13.8	33.3	11.322	5235	21.31	38.9
5.111	3977	13.94	33.5	11.422	5252	21.4	38.9
5.211	3999	14.08	33.6	11.522	5271	21.49	38.9
5.311	4023	14.25	33.8	11.622	5290	21.58	39
5.411	4044	14.42	34.1	11.722	5309	21.67	39
5.511	4066	14.6	34.3	11.822	5328	21.76	39
5.611	4087	14.77	34.5	11.922	5347	21.83	39
5.711	4107	14.91	34.7	12.023	5367	21.92	39
5.811	4127	15.02	34.8	12.123	5386	22	39
5.911	4148	15.13	34.8	12.223	5406	22.08	39
6.011	4170	15.24	34.9	12.323	5427	22.17	39
6.112	4193	15.4	35.1	12.423	5447	22.27	39

Figure A.5: SAE 20W-50 Test 3 Part 1

12.523	5468	22.37	39.1	18.834	6750	31.42	44.4
12.623	5489	22.47	39.1	18.934	6772	31.54	44.5
12.723	5509	22.58	39.1	19.035	6793	31.65	44.5
12.823	5530	22.69	39.2	19.135	6814	31.77	44.5
12.923	5550	22.81	39.2	19.235	6836	31.89	44.5
13.024	5571	22.92	39.3	19.335	6857	32.01	44.6
13.124	5591	23.03	39.3	19.435	6880	32.16	44.6
13.224	5611	23.13	39.4	19.535	6902	32.33	44.7
13.324	5632	23.24	39.4	19.635	6924	32.52	44.9
13.424	5652	23.34	39.4	19.735	6946	32.77	45
13.524	5672	23.44	39.5	19.835	6967	33.04	45.3
13.624	5694	23.55	39.5	19.935	6989	33.36	45.6
13.724	5714	23.65	39.5	20.036	7009	33.69	45.9
13.824	5736	23.76	39.6	20.136	7029	34.02	46.2
13.924	5757	23.87	39.6	20.236	7049	34.34	46.5
14.025	5779	23.97	39.6	20.336	7067	34.58	46.7
14.125	5801	24.08	39.6	20.436	7085	34.75	46.8
14.225	5822	24.18	39.7	20.536	7104	34.86	46.9
14.325	5843	24.29	39.7	20.636	7123	34.95	46.9
14.425	5864	24.41	39.7	20.736	7142	35.04	46.9
14.525	5885	24.52	39.8	20.836	7162	35.15	46.9
14.625	5905	24.63	39.8	20.936	7181	35.28	46.9
14.725	5926	24.73	39.9	21.037	7201	35.44	47
14.825	5945	24.82	39.9	21.137	7221	35.62	47.1
14.925	5966	24.91	39.9	21.237	7241	35.82	47.2
15.026	5986	25.01	39.9	21.337	7261	36.04	47.4
15.126	6007	25.12	39.9	21.437	7279	36.24	47.5
15.226	6029	25.26	40	21.537	7298	36.42	47.7
15.326	6049	25.4	40.1	21.637	7317	36.57	47.7
15.426	6069	25.56	40.2	21.737	7335	36.7	47.8
15.526	6088	25.71	40.3	21.837	7355	36.83	47.8
15.626	6108	25.85	40.4	21.937	7373	36.94	47.8
15.726	6128	26	40.5	22.038	7393	37.03	47.8
15.826	6147	26.13	40.6	22.138	7412	37.14	47.8
15.926	6166	26.25	40.7	22.238	7431	37.24	47.9
16.027	6186	26.38	40.7	22.338	7452	37.37	47.9
16.132	6204	26.48	40.8	22.438	7471	37.49	47.9
16.232	6222	26.56	40.8	22.538	7490	37.61	48
16.332	6241	26.63	40.7	22.638	7511	37.74	48
16.432	6261	26.7	40.7	22.738	7529	37.87	48
16.532	6283	26.8	40.7	22.838	7549	37.99	48.1
16.632	6304	26.95	40.8	22.938	7568	38.1	48.1
16.732	6326	27.16	41	23.039	7587	38.19	48.1
16.832	6347	27.4	41.2	23.139	7608	38.28	48.1
16.932	6367	27.63	41.4	23.239	7627	38.4	48.1
17.033	6388	27.88	41.7	23.339	7647	38.55	48.1
17.133	6408	28.09	41.9	23.439	7667	38.71	48.2
17.233	6428	28.28	42	23.539	7685	38.84	48.3
17.333	6448	28.48	42.2	23.639	7704	38.93	48.3
17.433	6468	28.68	42.3	23.739	7723	38.98	48.2
17.533	6489	28.91	42.5	23.839	7742	39.03	48.1
17.633	6509	29.15	42.8	23.939	7762	39.11	48.1
17.733	6529	29.39	43	24.04	7782	39.23	48.1
17.833	6550	29.64	43.2	24.14	7801	39.39	48.2
17.933	6570	29.87	43.4	24.24	7822	39.56	48.3
18.034	6591	30.11	43.6	24.34	7841	39.71	48.4
18.134	6611	30.34	43.8	24.44	7860	39.84	48.4
18.234	6631	30.54	44	24.54	7880	39.94	48.4
18.334	6650	30.73	44.1	24.64	7899	40.05	48.4
18.434	6670	30.89	44.2	24.74	7921	40.2	48.5
18.534	6689	31.04	44.3	24.84	7940	40.37	48.6
18.634	6710	31.18	44.4	24.94	7959	40.57	48.7
18.734	6730	31.3	44.4	25.041	7976	40.77	48.8

Figure A.6: SAE 20W-50 Test 3 Part 2

SAE 10W-40 RAW DATA

Sec (Seco	RPM (RPM	kW (kW)	Torque (N-m
0	2867	9.965	33.2
0.1	2870	9.873	32.9
0.2	2875	9.699	32.2
0.301	2883	9.466	31.4
0.401	2896	9.18	30.3
0.501	2914	8.881	29.1
0.601	2934	8.64	28.1
0.701	2958	8.472	27.3
0.801	2984	8.403	26.9
0.901	3009	8.424	26.7
1.001	3036	8.526	26.8
1.101	3060	8.668	27.1
1.201	3084	8.834	27.4
1.302	3108	9.015	27.7
1.402	3132	9.191	28
1.502	3157	9.38	28.4
1.602	3181	9.581	28.8
1.702	3206	9.802	29.2
1.802	3232	10.05	29.7
1.902	3255	10.29	30.2
2.002	3278	10.53	30.7
2.102	3300	10.75	31.1
2.202	3320	10.93	31.4
2.303	3340	11.08	31.7
2.403	3361	11.19	31.8
2.503	3381	11.27	31.8
2.603	3404	11.36	31.9
2.703	3427	11.46	31.9
2.803	3450	11.57	32
2.903	3474	11.72	32.2
3.003	3496	11.88	32.4
3.103	3518	12.04	32.7
3.203	3540	12.21	32.9
3.304	3562	12.36	33.1
3.404	3586	12.53	33.4
3.504	3607	12.67	33.5
3.604	3629	12.81	33.7
3.704	3651	12.94	33.8
3.804	3671	13.05	33.9
3.904	3692	13.14	34
4.004	3712	13.21	34
4.104	3732	13.28	34
4.204	3753	13.35	34
4.305	3775	13.44	34
4.405	3797	13.55	34.1
4.505	3822	13.71	34.2
4.605	3845	13.89	34.5
4.705	3868	14.1	34.8
4.805	3891	14.33	35.2
4.905	3912	14.53	35.5
5.005	3934	14.72	35.7
5.105	3954	14.87	35.9
5.205	3975	15.01	36.1
5.306	3998	15.18	36.2
5.406	4019	15.34	36.5
5.506	4041	15.52	36.7
5.606	4062	15.69	36.9
5.706	4081	15.83	37
5.806	4103	15.95	37.1
5.906	4124	16.07	37.2
6.006	4145	16.19	37.3
6.106	4168	16.35	37.5
6.206	4189	16.51	37.6
6.307	4210	16.67	37.8
6.407	4230	16.82	38
6.512	4251	16.96	38.1
6.612	4272	17.08	38.2
6.712	4293	17.19	38.2
6.812	4314	17.3	38.3
6.912	4336	17.41	38.3
7.012	4357	17.51	38.4
7.112	4378	17.62	38.4
7.212	4401	17.75	38.5
7.313	4422	17.88	38.6
7.413	4445	18.01	38.7
7.513	4467	18.16	38.8
7.613	4488	18.33	39
7.713	4511	18.52	39.2
7.813	4532	18.73	39.5
7.913	4552	18.94	39.7
8.013	4573	19.14	40
8.113	4592	19.29	40.1
8.213	4612	19.41	40.2
8.314	4632	19.52	40.2
8.414	4651	19.63	40.3
8.514	4672	19.77	40.4
8.614	4691	19.9	40.5
8.714	4710	20.02	40.6
8.814	4730	20.12	40.6
8.914	4750	20.19	40.6
9.014	4770	20.26	40.6
9.114	4790	20.33	40.5
9.214	4809	20.41	40.5
9.315	4830	20.5	40.5
9.415	4851	20.6	40.6
9.515	4871	20.7	40.6
9.615	4892	20.82	40.6
9.715	4910	20.93	40.7
9.815	4929	21.02	40.7
9.915	4948	21.09	40.7
10.015	4966	21.13	40.6
10.115	4985	21.16	40.5
10.215	5004	21.18	40.4
10.316	5024	21.21	40.3
10.416	5046	21.26	40.2
10.521	5067	21.34	40.2
10.621	5087	21.41	40.2
10.721	5108	21.48	40.2
10.821	5128	21.56	40.1
10.921	5148	21.64	40.1
11.021	5168	21.73	40.1
11.121	5188	21.83	40.2
11.221	5208	21.93	40.2
11.322	5228	22.01	40.2
11.422	5249	22.09	40.2
11.522	5269	22.17	40.2
11.622	5289	22.27	40.2
11.722	5311	22.39	40.3
11.822	5332	22.55	40.4
11.922	5353	22.73	40.5
12.022	5374	22.94	40.8
12.122	5394	23.14	41
12.222	5414	23.33	41.1
12.323	5434	23.5	41.3
12.423	5454	23.64	41.4

Figure A.7: SAE 10W-40 Test 1 Part 1

12.523	5474	23.75	41.4
12.623	5493	23.84	41.4
12.723	5513	23.92	41.4
12.823	5534	24.02	41.4
12.923	5555	24.13	41.5
13.023	5575	24.27	41.6
13.123	5596	24.42	41.7
13.223	5616	24.58	41.8
13.324	5637	24.74	41.9
13.424	5657	24.88	42
13.524	5677	25.03	42.1
13.624	5697	25.18	42.2
13.724	5717	25.31	42.3
13.824	5736	25.45	42.4
13.924	5756	25.57	42.4
14.024	5775	25.66	42.4
14.124	5796	25.75	42.4
14.224	5817	25.84	42.4
14.325	5837	25.95	42.4
14.425	5859	26.1	42.5
14.525	5879	26.27	42.7
14.625	5899	26.44	42.8
14.725	5918	26.59	42.9
14.825	5937	26.7	42.9
14.925	5958	26.81	43
15.025	5977	26.93	43
15.125	5997	27.07	43.1
15.225	6017	27.21	43.2
15.326	6036	27.33	43.2
15.426	6055	27.42	43.2
15.526	6075	27.51	43.2
15.626	6094	27.6	43.2
15.726	6115	27.7	43.3
15.826	6135	27.8	43.3
15.926	6155	27.91	43.3
16.026	6175	28.03	43.3
16.126	6194	28.15	43.4
16.226	6213	28.28	43.5
16.327	6233	28.41	43.5
16.427	6252	28.54	43.6
16.527	6273	28.7	43.7
16.627	6294	28.88	43.8
16.727	6315	29.1	44
16.827	6336	29.32	44.2
16.927	6355	29.53	44.4
17.027	6377	29.74	44.5
17.127	6397	29.94	44.7
17.227	6418	30.13	44.8
17.328	6440	30.33	45
17.428	6462	30.51	45.1
17.528	6485	30.67	45.2
17.628	6508	30.84	45.2
17.728	6531	30.99	45.3
17.828	6556	31.19	45.4
17.928	6579	31.42	45.6
18.028	6602	31.7	45.9
18.128	6624	32.05	46.2
18.228	6645	32.39	46.5
18.329	6665	32.7	46.9
18.429	6685	32.97	47.1
18.529	6704	33.21	47.3
18.629	6725	33.45	47.5
18.729	6745	33.69	47.7
18.829	6764	33.93	47.9
18.929	6784	34.17	48.1
19.029	6803	34.38	48.3
19.129	6823	34.58	48.4
19.229	6842	34.77	48.5
19.33	6860	34.95	48.6
19.43	6880	35.13	48.8
19.53	6899	35.29	48.9
19.63	6918	35.45	48.9
19.73	6939	35.63	49
19.83	6958	35.79	49.1
19.93	6978	35.97	49.2
20.03	6998	36.15	49.3
20.13	7018	36.32	49.4
20.23	7039	36.5	49.5
20.331	7060	36.68	49.6
20.431	7080	36.85	49.7
20.531	7102	37.04	49.8
20.631	7122	37.2	49.9
20.731	7143	37.36	49.9
20.831	7163	37.51	50
20.931	7183	37.65	50.1
21.031	7204	37.79	50.1
21.131	7224	37.93	50.1
21.231	7244	38.08	50.2
21.332	7265	38.24	50.3
21.432	7285	38.4	50.3
21.532	7306	38.56	50.4
21.632	7326	38.73	50.5
21.732	7347	38.89	50.5
21.832	7368	39.07	50.6
21.932	7388	39.26	50.7
22.032	7408	39.48	50.9
22.132	7427	39.74	51.1
22.232	7446	39.98	51.3
22.333	7466	40.23	51.5
22.433	7484	40.41	51.6
22.533	7501	40.52	51.6
22.638	7523	40.61	51.6
22.738	7540	40.66	51.5
22.838	7559	40.73	51.5
22.938	7578	40.82	51.4
23.038	7597	40.93	51.4
23.138	7617	41.05	51.5
23.238	7637	41.17	51.5
23.339	7656	41.31	51.5
23.439	7676	41.5	51.6
23.539	7695	41.7	51.7
23.639	7713	41.89	51.9
23.739	7731	42.03	51.9
23.839	7748	42.13	51.9
23.939	7767	42.19	51.9
24.039	7786	42.24	51.8
24.139	7806	42.3	51.7
24.239	7827	42.41	51.7
24.34	7847	42.57	51.8
24.44	7868	42.8	51.9
24.54	7889	43.05	52.1
24.64	7909	43.29	52.3
24.74	7929	43.51	52.4
24.84	7948	43.67	52.5
24.94	7966	43.8	52.5
25.04	7983	43.91	52.5

Figure A.8: SAE 10W-40 Test 1 Part 2

Sec (Seco	RPM (RPN	kW (kW)	Torque (N-
0	2859	9.545	31.9
0.1	2867	9.464	31.5
0.2	2876	9.362	31.1
0.3	2888	9.227	30.5
0.4	2904	9.056	29.8
0.5	2921	8.885	29
0.601	2942	8.727	28.3
0.701	2964	8.616	27.8
0.801	2986	8.561	27.4
0.901	3012	8.557	27.1
1.001	3035	8.602	27.1
1.101	3059	8.686	27.1
1.201	3081	8.799	27.3
1.431	3130	9.111	27.8
1.531	3151	9.215	27.9
1.632	3171	9.284	28
1.732	3193	9.334	27.9
1.832	3216	9.387	27.9
1.932	3240	9.461	27.9
2.032	3264	9.562	28
2.132	3287	9.678	28.1
2.232	3309	9.791	28.3
2.332	3332	9.911	28.4
2.432	3356	10.03	28.5
2.532	3380	10.16	28.7
2.633	3406	10.32	28.9
2.733	3431	10.5	29.2
2.833	3457	10.72	29.6
2.933	3483	10.98	30.1
3.033	3506	11.24	30.6
3.133	3529	11.51	31.1
3.233	3551	11.76	31.6
3.333	3571	11.97	32
3.433	3592	12.15	32.3
3.533	3611	12.29	32.5
3.634	3632	12.4	32.6
3.734	3653	12.49	32.7
3.834	3674	12.58	32.7
3.934	3696	12.67	32.7
4.034	3717	12.76	32.8
4.134	3738	12.85	32.8
4.234	3759	12.94	32.9
4.334	3780	13.02	32.9
4.434	3801	13.1	32.9
4.534	3823	13.19	33
4.635	3844	13.29	33
4.735	3867	13.41	33.1
4.835	3889	13.54	33.2
4.935	3913	13.69	33.4
5.035	3938	13.86	33.6
5.135	3962	14.06	33.9
5.235	3986	14.3	34.3
5.335	4010	14.56	34.7
5.435	4032	14.8	35.1
5.535	4053	15.03	35.4
5.636	4074	15.23	35.7
5.736	4095	15.4	35.9
5.836	4117	15.57	36.1
5.936	4137	15.74	36.3
6.036	4157	15.9	36.5
6.136	4178	16.05	36.7
6.236	4199	16.19	36.8
6.336	4220	16.31	36.9
6.436	4242	16.44	37
6.536	4264	16.58	37.1
6.637	4287	16.74	37.3
6.737	4308	16.9	37.5
6.837	4330	17.06	37.6
6.937	4352	17.22	37.8
7.037	4373	17.36	37.9
7.137	4395	17.49	38
7.237	4417	17.63	38.1
7.337	4438	17.79	38.3
7.437	4461	17.98	38.5
7.537	4482	18.19	38.8
7.638	4502	18.39	39
7.738	4523	18.59	39.3
7.838	4542	18.76	39.4
7.938	4561	18.9	39.6
8.038	4581	19.02	39.6
8.138	4600	19.11	39.7
8.238	4621	19.2	39.7
8.338	4640	19.29	39.7
8.438	4660	19.39	39.7
8.538	4682	19.54	39.8
8.639	4702	19.69	40
8.739	4721	19.84	40.1
8.839	4741	19.98	40.3
8.939	4759	20.09	40.3
9.039	4780	20.19	40.3
9.139	4800	20.26	40.3
9.239	4820	20.35	40.3
9.339	4841	20.45	40.3
9.439	4861	20.57	40.4
9.539	4881	20.69	40.5
9.64	4900	20.79	40.5
9.74	4919	20.87	40.5
9.84	4940	20.93	40.5
9.94	4960	20.99	40.4
10.04	4980	21.07	40.4
10.14	5002	21.19	40.5
10.24	5022	21.33	40.6
10.34	5042	21.5	40.7
10.44	5061	21.64	40.8
10.54	5080	21.74	40.9
10.641	5099	21.8	40.8
10.741	5118	21.82	40.7
10.841	5137	21.84	40.6
10.941	5158	21.88	40.5
11.041	5177	21.92	40.4
11.141	5197	21.98	40.4
11.241	5217	22.04	40.3
11.341	5237	22.11	40.3
11.441	5257	22.18	40.3
11.541	5277	22.26	40.3
11.642	5298	22.36	40.3
11.742	5319	22.49	40.4
11.842	5339	22.62	40.5
11.942	5359	22.77	40.6
12.042	5378	22.89	40.6
12.142	5397	22.99	40.7
12.242	5418	23.09	40.7
12.342	5438	23.18	40.7
12.442	5459	23.3	40.8
12.542	5480	23.45	40.9

Figure A.9: SAE 10W-40 Test 2 Part 1

12.643	5500	23.62	41
12.743	5520	23.8	41.2
12.843	5540	23.97	41.3
12.943	5559	24.11	41.4
13.043	5579	24.22	41.5
13.143	5598	24.3	41.5
13.243	5617	24.38	41.4
13.343	5637	24.47	41.4
13.443	5657	24.57	41.5
13.543	5677	24.68	41.5
13.644	5697	24.79	41.6
13.744	5716	24.87	41.6
13.844	5737	24.96	41.6
13.944	5757	25.05	41.5
14.044	5778	25.15	41.6
14.144	5799	25.26	41.6
14.244	5819	25.38	41.6
14.344	5840	25.52	41.7
14.444	5860	25.66	41.8
14.544	5881	25.81	41.9
14.645	5901	25.97	42
14.745	5920	26.11	42.1
14.845	5940	26.24	42.2
14.945	5959	26.36	42.2
15.045	5979	26.48	42.3
15.145	5999	26.6	42.3
15.245	6019	26.71	42.4
15.345	6039	26.82	42.4
15.445	6060	26.93	42.4
15.545	6080	27.05	42.5
15.646	6100	27.16	42.5
15.746	6121	27.31	42.6
15.846	6141	27.47	42.7
15.946	6161	27.64	42.8
16.046	6181	27.82	43
16.146	6200	27.99	43.1
16.246	6218	28.13	43.2
16.346	6238	28.26	43.3
16.446	6260	28.39	43.3
16.546	6280	28.52	43.4
16.652	6301	28.66	43.4
16.752	6325	28.85	43.6
16.852	6345	29.03	43.7
16.952	6366	29.23	43.9
17.052	6388	29.44	44
17.152	6409	29.62	44.1
17.252	6431	29.79	44.2
17.352	6454	29.95	44.3
17.452	6475	30.09	44.4
17.552	6498	30.26	44.5
17.653	6521	30.45	44.6
17.753	6544	30.67	44.8
17.853	6567	30.97	45
17.953	6589	31.29	45.3
18.053	6611	31.64	45.7
18.153	6631	32	46.1
18.253	6650	32.34	46.4
18.353	6669	32.65	46.8
18.453	6687	32.9	47
18.553	6705	33.08	47.1
18.654	6723	33.2	47.2
18.754	6742	33.28	47.1
18.854	6762	33.36	47.1
18.954	6782	33.46	47.1
19.054	6803	33.6	47.2
19.154	6824	33.81	47.3
19.254	6844	34.04	47.5
19.354	6864	34.29	47.7
19.454	6885	34.55	47.9
19.554	6903	34.76	48.1
19.655	6923	34.95	48.2
19.755	6943	35.13	48.3
19.855	6962	35.29	48.4
19.955	6982	35.46	48.5
20.055	7002	35.64	48.6
20.155	7021	35.82	48.7
20.255	7041	36	48.8
20.355	7061	36.17	48.9
20.455	7080	36.32	49
20.555	7100	36.46	49
20.656	7120	36.58	49.1
20.756	7141	36.72	49.1
20.856	7161	36.85	49.1
20.956	7181	36.99	49.2
21.056	7202	37.14	49.2
21.156	7221	37.27	49.3
21.256	7241	37.41	49.3
21.356	7262	37.56	49.4
21.456	7282	37.7	49.4
21.556	7303	37.85	49.5
21.657	7324	37.99	49.5
21.757	7345	38.13	49.6
21.857	7367	38.29	49.6
21.957	7387	38.44	49.7
22.057	7408	38.61	49.8
22.157	7428	38.78	49.9
22.257	7448	38.97	50
22.357	7469	39.17	50.1
22.457	7488	39.38	50.2
22.557	7508	39.6	50.4
22.658	7528	39.81	50.5
22.758	7547	40	50.6
22.858	7567	40.17	50.7
22.958	7585	40.3	50.7
23.058	7603	40.42	50.8
23.158	7623	40.53	50.8
23.258	7641	40.63	50.8
23.358	7660	40.72	50.8
23.458	7679	40.84	50.8
23.558	7698	41	50.9
23.659	7717	41.21	51
23.759	7735	41.42	51.1
23.859	7752	41.59	51.2
23.959	7771	41.69	51.2
24.059	7788	41.73	51.2
24.159	7808	41.77	51.1
24.259	7828	41.85	51.1
24.359	7848	41.98	51.1
24.459	7869	42.18	51.2
24.559	7889	42.38	51.3
24.66	7909	42.56	51.4
24.76	7930	42.72	51.4
24.86	7949	42.86	51.5
24.96	7968	43	51.5
25.06	7984	43.13	51.6

Figure A.10: SAE 10W-40 Test 2 Part 2

Sec (Seco	RPM (RPM	kW (kW)	Torque (N-r
0	2858	9.848	32.9
0.1	2861	9.783	32.6
0.2	2867	9.655	32.2
0.3	2877	9.446	31.4
0.4	2889	9.204	30.4
0.5	2907	8.935	29.4
0.601	2928	8.693	28.4
0.701	2952	8.526	27.6
0.801	2978	8.443	27.1
0.901	3003	8.455	26.9
1.001	3028	8.534	26.9
1.101	3051	8.655	27.1
1.201	3072	8.773	27.3
1.301	3092	8.878	27.4
1.401	3113	8.958	27.5
1.501	3134	9.02	27.5
1.602	3158	9.087	27.5
1.702	3181	9.171	27.5
1.802	3205	9.286	27.7
1.902	3230	9.441	27.9
2.002	3254	9.617	28.2
2.102	3278	9.798	28.5
2.202	3300	9.971	28.8
2.302	3323	10.12	29.1
2.402	3345	10.26	29.3
2.502	3367	10.38	29.4
2.603	3390	10.5	29.6
2.703	3414	10.63	29.7
2.803	3439	10.78	29.9
2.903	3464	10.97	30.2
3.003	3489	11.2	30.7
3.108	3514	11.46	31.1
3.208	3537	11.72	31.6
3.308	3559	11.96	32.1
3.408	3578	12.16	32.5
3.508	3599	12.33	32.7
3.609	3618	12.46	32.9
3.709	3638	12.54	32.9
3.809	3659	12.6	32.9
3.909	3680	12.65	32.8
4.009	3703	12.72	32.8
4.109	3726	12.82	32.8
4.209	3748	12.94	33
4.309	3773	13.11	33.2
4.409	3796	13.29	33.4
4.509	3818	13.48	33.7
4.61	3841	13.67	34
4.71	3861	13.82	34.2
4.81	3882	13.95	34.3
4.91	3903	14.06	34.4
5.01	3924	14.16	34.4
5.11	3948	14.28	34.5
5.21	3971	14.43	34.7
5.31	3994	14.61	34.9
5.41	4017	14.82	35.2
5.51	4039	15.03	35.5
5.611	4061	15.23	35.8
5.711	4082	15.41	36
5.811	4102	15.55	36.2
5.911	4124	15.7	36.4
6.011	4145	15.84	36.5
6.111	4166	16	36.7
6.211	4189	16.16	36.8
6.311	4210	16.31	37
6.411	4231	16.46	37.2
6.511	4252	16.61	37.3
6.612	4272	16.76	37.5
6.712	4294	16.92	37.6
6.812	4314	17.06	37.8
6.912	4334	17.19	37.9
7.012	4356	17.31	38
7.112	4376	17.42	38
7.212	4398	17.53	38.1
7.312	4419	17.66	38.2
7.412	4441	17.79	38.3
7.512	4464	17.94	38.4
7.613	4486	18.08	38.5
7.713	4507	18.23	38.6
7.813	4529	18.37	38.7
7.913	4549	18.49	38.8
8.013	4570	18.61	38.9
8.113	4590	18.74	39
8.213	4610	18.87	39.1
8.313	4632	19.02	39.2
8.413	4652	19.19	39.4
8.513	4672	19.35	39.6
8.614	4694	19.52	39.7
8.714	4713	19.67	39.9
8.814	4733	19.81	40
8.914	4753	19.94	40.1
9.014	4772	20.06	40.1
9.114	4793	20.18	40.2
9.214	4813	20.29	40.3
9.314	4834	20.41	40.3
9.414	4855	20.56	40.4
9.514	4874	20.69	40.5
9.615	4894	20.82	40.6
9.715	4914	20.92	40.7
9.815	4933	21.01	40.7
9.915	4954	21.09	40.7
10.015	4973	21.15	40.6
10.115	4992	21.2	40.5
10.215	5012	21.24	40.5
10.315	5032	21.3	40.4
10.415	5053	21.38	40.4
10.515	5073	21.47	40.4
10.616	5093	21.57	40.4
10.716	5112	21.66	40.5
10.816	5131	21.74	40.5
10.916	5150	21.8	40.4
11.016	5171	21.88	40.4
11.116	5190	21.95	40.4
11.216	5210	22.04	40.4
11.316	5230	22.15	40.4
11.416	5250	22.25	40.5
11.516	5270	22.36	40.5
11.617	5290	22.45	40.5
11.717	5309	22.54	40.5
11.817	5330	22.63	40.5
11.917	5350	22.71	40.5
12.017	5370	22.8	40.5
12.117	5390	22.88	40.5
12.217	5411	22.98	40.6
12.317	5432	23.09	40.6
12.417	5453	23.23	40.7

Figure A.11: SAE 10W-40 Test 3 Part 1

12.517	5474	23.4	40.8
12.618	5495	23.6	41
12.718	5515	23.78	41.2
12.818	5535	23.95	41.3
12.918	5554	24.09	41.4
13.018	5573	24.19	41.5
13.118	5593	24.27	41.4
13.218	5612	24.33	41.4
13.318	5632	24.41	41.4
13.418	5654	24.5	41.4
13.518	5674	24.62	41.4
13.619	5695	24.76	41.5
13.719	5715	24.91	41.6
13.819	5735	25.06	41.7
13.919	5755	25.21	41.8
14.019	5775	25.34	41.9
14.119	5795	25.47	42
14.219	5817	25.63	42.1
14.319	5836	25.79	42.2
14.419	5856	25.98	42.4
14.519	5875	26.14	42.5
14.62	5893	26.26	42.6
14.72	5913	26.34	42.5
14.82	5932	26.39	42.5
14.92	5952	26.44	42.4
15.02	5973	26.54	42.4
15.12	5993	26.67	42.5
15.22	6014	26.83	42.6
15.32	6035	27	42.7
15.42	6055	27.16	42.8
15.52	6075	27.3	42.9
15.621	6095	27.42	43
15.721	6115	27.52	43
15.821	6137	27.65	43
15.921	6156	27.79	43.1
16.021	6176	27.95	43.2
16.121	6195	28.1	43.3
16.221	6214	28.26	43.4
16.321	6234	28.41	43.5
16.421	6254	28.55	43.6
16.521	6274	28.7	43.7
16.622	6295	28.85	43.8
16.722	6315	29.01	43.9
16.822	6336	29.19	44
16.922	6357	29.39	44.2
17.022	6377	29.61	44.3
17.122	6398	29.85	44.5
17.222	6418	30.07	44.7
17.322	6439	30.27	44.9
17.422	6459	30.46	45
17.522	6480	30.63	45.1
17.623	6502	30.82	45.3
17.723	6523	31	45.4
17.823	6544	31.18	45.5
17.923	6567	31.37	45.6
18.023	6588	31.54	45.7
18.123	6611	31.71	45.8
18.223	6634	31.88	45.9
18.323	6656	32.06	46
18.423	6680	32.27	46.1
18.523	6702	32.53	46.4
18.624	6723	32.82	46.6
18.724	6744	33.15	46.9

18.824	6763	33.42	47.2
18.924	6782	33.67	47.4
19.024	6801	33.88	47.6
19.124	6820	34.07	47.7
19.224	6840	34.26	47.8
19.324	6859	34.44	47.9
19.424	6878	34.61	48.1
19.524	6898	34.8	48.2
19.625	6918	34.99	48.3
19.725	6937	35.19	48.4
19.825	6957	35.39	48.6
19.925	6976	35.57	48.7
20.025	6996	35.76	48.8
20.125	7016	35.95	48.9
20.225	7035	36.14	49.1
20.325	7055	36.34	49.2
20.425	7074	36.51	49.3
20.525	7094	36.67	49.4
20.626	7114	36.8	49.4
20.726	7133	36.92	49.4
20.826	7154	37.05	49.5
20.926	7173	37.2	49.5
21.026	7192	37.37	49.6
21.126	7212	37.55	49.7
21.226	7231	37.73	49.8
21.326	7251	37.91	49.9
21.426	7270	38.06	50
21.526	7289	38.2	50
21.627	7309	38.33	50.1
21.727	7328	38.44	50.1
21.827	7347	38.55	50.1
21.927	7367	38.67	50.1
22.027	7385	38.79	50.2
22.127	7405	38.91	50.2
22.227	7424	39.01	50.2
22.327	7444	39.09	50.1
22.427	7464	39.18	50.1
22.527	7484	39.32	50.2
22.628	7506	39.52	50.3
22.728	7525	39.71	50.4
22.828	7543	39.9	50.5
22.928	7563	40.06	50.6
23.028	7582	40.15	50.6
23.128	7601	40.22	50.5
23.228	7622	40.32	50.5
23.328	7641	40.45	50.6
23.428	7661	40.63	50.6
23.528	7681	40.82	50.8
23.629	7699	40.99	50.8
23.729	7719	41.13	50.9
23.829	7737	41.24	50.9
23.929	7756	41.33	50.9
24.029	7776	41.42	50.9
24.129	7796	41.52	50.9
24.229	7816	41.66	50.9
24.329	7836	41.81	51
24.429	7856	41.97	51
24.529	7876	42.14	51.1
24.63	7896	42.31	51.2
24.73	7916	42.5	51.3
24.83	7937	42.73	51.4
24.93	7956	42.92	51.5
25.03	7973	43.1	51.6
25.13	7987	43.22	51.7

Figure A.12: SAE 10W-40 Test 3 Part 2

20W-50		(use interpolation)		
	Power (kW)			
RPM	Test 1	Test 2	Test 3	Average
3000	7.982	7.964	8.324	8.090
3100	8.287	8.179	8.366	8.277
3200	8.872	8.485	8.968	8.775
3300	9.384	9.102	9.506	9.331
3400	9.809	9.787	9.920	9.839
3500	10.635	10.522	10.630	10.596
3600	11.435	11.292	11.575	11.434
3700	12.046	12.072	12.365	12.161
3800	12.548	12.672	12.845	12.688
3900	13.332	13.214	13.395	13.314
4000	14.058	13.958	14.087	14.034
4100	14.790	14.707	14.861	14.786
4200	15.728	15.330	15.457	15.505
4300	16.438	16.044	16.393	16.292
4400	17.047	16.751	16.979	16.926
4500	17.683	17.355	17.581	17.540
4600	18.391	18.071	18.336	18.266
4700	18.970	18.678	18.934	18.861
4800	19.455	19.290	19.372	19.372
4900	19.977	19.714	19.804	19.832
5000	20.501	20.151	20.357	20.336
5100	21.019	20.514	20.771	20.768
5200	21.386	20.780	21.144	21.104
5300	21.824	21.181	21.627	21.544
5400	22.240	21.741	22.056	22.012
5500	22.762	22.366	22.531	22.553
5600	23.247	22.959	23.075	23.094
5700	23.740	23.601	23.580	23.640
5800	24.214	24.105	24.075	24.131
5900	24.736	24.769	24.603	24.703
6000	25.615	25.223	25.083	25.307
6100	26.270	25.738	25.794	25.934
6200	27.150	26.371	26.458	26.660
6300	27.922	27.005	26.921	27.283
6400	28.862	27.760	28.006	28.209
6500	29.801	28.697	29.042	29.180
6600	30.490	30.347	30.214	30.350
6700	31.427	31.272	31.113	31.271
6800	32.550	31.912	31.690	32.051
6900	33.561	32.783	32.315	32.886
7000	34.418	33.651	33.542	33.870
7100	35.125	34.351	34.837	34.771
7200	35.838	35.445	35.432	35.572
7300	36.718	36.280	36.436	36.478
7400	37.222	36.789	37.071	37.027
7500	38.080	37.445	37.672	37.732
7600	38.642	38.179	38.246	38.356
7700	39.412	38.806	38.911	39.043
7800	40.009	39.245	39.382	39.545
7900	40.606	40.063	40.057	40.242
8000	41.347	40.884	41.052	41.094

Figure A.13: Average Power for 20W-50 by using interpolation.

20W-50	Using Interpolation			
	Torque (N-m)			
RPM	Test 1	Test 2	Test 3	Average
3000	25.368	25.300	26.538	25.735
3100	25.517	25.179	25.762	25.486
3200	26.509	25.331	26.764	26.201
3300	27.167	26.367	27.500	27.011
3400	27.588	27.460	27.854	27.634
3500	29.039	28.720	28.967	28.909
3600	30.291	29.908	30.673	30.290
3700	31.100	31.209	31.880	31.396
3800	31.573	31.813	32.300	31.895
3900	32.673	32.364	32.800	32.612
4000	33.574	33.309	33.608	33.497
4100	34.464	34.283	34.630	34.459
4200	35.710	34.824	35.164	35.233
4300	36.490	35.664	36.410	36.188
4400	36.981	36.386	36.814	36.727
4500	37.509	36.841	37.286	37.212
4600	38.143	37.510	38.074	37.909
4700	38.540	37.977	38.484	38.334
4800	38.700	38.400	38.500	38.533
4900	38.915	38.400	38.600	38.638
5000	39.200	38.500	38.870	38.857
5100	39.372	38.400	38.900	38.891
5200	39.300	38.200	38.816	38.772
5300	39.300	38.181	39.000	38.827
5400	39.300	38.459	39.000	38.920
5500	39.500	38.840	39.100	39.147
5600	39.600	39.130	39.345	39.358
5700	39.800	39.510	39.500	39.603
5800	39.900	39.695	39.600	39.732
5900	40.045	40.090	39.800	39.978
6000	40.763	40.110	39.900	40.258
6100	41.100	40.285	40.360	40.582
6200	41.847	40.600	40.778	41.075
6300	42.300	40.950	40.781	41.344
6400	43.060	41.400	41.820	42.093
6500	43.748	42.191	42.665	42.868
6600	44.113	43.942	43.690	43.915
6700	44.786	44.600	44.352	44.579
6800	45.672	44.845	44.500	45.006
6900	46.479	45.360	44.691	45.510
7000	46.906	45.914	45.765	46.195
7100	47.200	46.181	46.879	46.753
7200	47.532	47.022	46.995	47.183
7300	48.000	47.500	47.700	47.733
7400	48.000	47.500	47.800	47.767
7500	48.460	47.642	48.000	48.034
7600	48.510	48.000	48.100	48.203
7700	48.895	48.100	48.300	48.432
7800	49.000	48.005	48.195	48.400
7900	49.085	48.400	48.405	48.630
8000	49.300	48.829	48.941	49.024

Figure A.14: Average Torque for 20W-50 by using interpolation.

10W-40	Using Interpolation			
	Power (kW)			
RPM	Test 1	Test 2	Test 3	Average
3000	8.416	8.559	8.454	8.476
3100	8.955	8.920	8.908	8.928
3200	9.749	9.350	9.262	9.454
3300	10.750	9.745	9.971	10.155
3400	11.344	10.283	10.554	10.727
3500	11.909	11.172	11.314	11.465
3600	12.623	12.209	12.337	12.390
3700	13.168	12.687	12.711	12.855
3800	13.569	13.096	13.325	13.330
3900	14.416	13.609	14.044	14.023
4000	15.195	14.452	14.665	14.771
4100	15.934	15.439	15.536	15.636
4200	16.594	16.196	16.239	16.343
4300	17.227	16.839	16.962	17.009
4400	17.744	17.522	17.542	17.603
4500	18.429	18.370	18.180	18.326
4600	19.338	19.110	18.805	19.084
4700	19.957	19.675	19.567	19.733
4800	20.372	20.260	20.219	20.284
4900	20.869	20.790	20.850	20.836
5000	21.176	21.179	21.216	21.190
5100	21.453	21.801	21.603	21.619
5200	21.890	21.989	21.995	21.958
5300	22.330	22.372	22.497	22.400
5400	23.197	23.004	22.928	23.043
5500	23.868	23.620	23.645	23.711
5600	24.452	24.308	24.292	24.351
5700	25.200	24.803	24.798	24.933
5800	25.767	25.266	25.506	25.513
5900	26.448	25.962	26.288	26.233
6000	27.091	26.606	26.723	26.807
6100	27.629	27.160	27.445	27.411
6200	28.191	27.990	28.142	28.108
6300	28.943	28.653	28.890	28.829
6400	29.967	29.543	29.872	29.794
6500	30.781	30.277	30.803	30.620
6600	31.676	31.465	31.629	31.590
6700	33.159	33.030	32.506	32.899
6800	34.347	33.580	33.869	33.932
6900	35.299	34.725	34.819	34.948
7000	36.167	35.622	35.798	35.862
7100	37.023	36.460	36.709	36.731
7200	37.763	37.126	37.442	37.444
7300	38.514	37.829	38.272	38.205
7400	39.392	38.545	38.880	38.939
7500	40.514	39.512	39.465	39.830
7600	40.948	40.400	40.216	40.521
7700	41.753	41.022	40.997	41.257
7800	42.282	41.754	41.548	41.861
7900	43.182	42.479	42.348	42.670
8000	44.020	43.260	43.331	43.537

Figure A.15: Average Power for 10W-40 by using interpolation.

10W-40		Using Interpolation		
	Torque (N-m)			
RPM	Test 1	Test 2	Test 3	Average
3000	26.772	27.238	26.924	26.978
3100	27.600	27.494	27.438	27.511
3200	29.104	27.900	27.658	28.221
3300	31.100	28.218	28.800	29.373
3400	31.883	28.854	29.642	30.126
3500	32.455	30.470	30.876	31.267
3600	33.467	32.384	32.711	32.854
3700	34.000	32.719	32.800	33.173
3800	34.112	32.900	33.455	33.489
3900	35.329	33.292	34.386	34.335
4000	36.229	34.533	34.978	35.247
4100	37.086	35.945	36.180	36.404
4200	37.705	36.805	36.905	37.138
4300	38.233	37.424	37.660	37.772
4400	38.496	38.023	38.110	38.209
4500	39.104	38.980	38.567	38.884
4600	40.140	39.700	39.050	39.630
4700	40.547	39.980	39.763	40.097
4800	40.500	40.300	40.235	40.345
4900	40.644	40.500	40.630	40.591
5000	40.421	40.491	40.500	40.471
5100	40.200	40.795	40.437	40.477
5200	40.200	40.385	40.400	40.328
5300	40.250	40.310	40.500	40.353
5400	41.030	40.700	40.548	40.759
5500	41.400	41.000	41.050	41.150
5600	41.720	41.489	41.400	41.536
5700	42.215	41.600	41.525	41.780
5800	42.400	41.600	42.023	42.008
5900	42.805	41.995	42.565	42.455
6000	43.115	42.305	42.533	42.651
6100	43.229	42.500	43.000	42.910
6200	43.432	43.100	43.326	43.286
6300	43.857	43.400	43.825	43.694
6400	44.714	44.057	44.520	44.430
6500	45.200	44.509	45.290	45.000
6600	45.874	45.500	45.752	45.709
6700	47.258	47.072	46.373	46.901
6800	48.268	47.186	47.589	47.681
6900	48.904	48.067	48.210	48.393
7000	49.310	48.590	48.820	48.907
7100	49.791	49.000	49.400	49.397
7200	50.100	49.200	49.640	49.647
7300	50.371	49.486	50.055	49.971
7400	50.820	49.762	50.200	50.261
7500	51.600	50.320	50.273	50.731
7600	51.415	50.783	50.505	50.901
7700	51.756	50.911	50.805	51.157
7800	51.730	51.140	50.900	51.257
7900	52.210	51.355	51.220	51.595
8000	52.500	51.700	51.793	51.998

Figure A.14: Average Torque for 10W-40 by using interpolation.

Average Power Comparison		
	Engine Oil	
RPM	20W-50	10W-40
3000	8.090	8.476
3100	8.277	8.928
3200	8.775	9.454
3300	9.331	10.155
3400	9.839	10.727
3500	10.596	11.465
3600	11.434	12.390
3700	12.161	12.855
3800	12.688	13.330
3900	13.314	14.023
4000	14.034	14.771
4100	14.786	15.636
4200	15.505	16.343
4300	16.292	17.009
4400	16.926	17.603
4500	17.540	18.326
4600	18.266	19.084
4700	18.861	19.733
4800	19.372	20.284
4900	19.832	20.836
5000	20.336	21.190
5100	20.768	21.619
5200	21.104	21.958
5300	21.544	22.400
5400	22.012	23.043
5500	22.553	23.711
5600	23.094	24.351
5700	23.640	24.933
5800	24.131	25.513
5900	24.703	26.233
6000	25.307	26.807
6100	25.934	27.411
6200	26.660	28.108
6300	27.283	28.829
6400	28.209	29.794
6500	29.180	30.620
6600	30.350	31.590
6700	31.271	32.899
6800	32.051	33.932
6900	32.886	34.948
7000	33.870	35.862
7100	34.771	36.731
7200	35.572	37.444
7300	36.478	38.205
7400	37.027	38.939
7500	37.732	39.830
7600	38.356	40.521
7700	39.043	41.257
7800	39.545	41.861
7900	40.242	42.670
8000	41.094	43.537

Figure A.15: Average power comparison data

Average Torque Comparison		
	Engine oil	
RPM	20W-50	10W-40
3000	25.735	26.978
3100	25.486	27.511
3200	26.201	28.221
3300	27.011	29.373
3400	27.634	30.126
3500	28.909	31.267
3600	30.290	32.854
3700	31.396	33.173
3800	31.895	33.489
3900	32.612	34.335
4000	33.497	35.247
4100	34.459	36.404
4200	35.233	37.138
4300	36.188	37.772
4400	36.727	38.209
4500	37.212	38.884
4600	37.909	39.630
4700	38.334	40.097
4800	38.533	40.345
4900	38.638	40.591
5000	38.857	40.471
5100	38.891	40.477
5200	38.772	40.328
5300	38.827	40.353
5400	38.920	40.759
5500	39.147	41.150
5600	39.358	41.536
5700	39.603	41.780
5800	39.732	42.008
5900	39.978	42.455
6000	40.258	42.651
6100	40.582	42.910
6200	41.075	43.286
6300	41.344	43.694
6400	42.093	44.430
6500	42.868	45.000
6600	43.915	45.709
6700	44.579	46.901
6800	45.006	47.681
6900	45.510	48.393
7000	46.195	48.907
7100	46.753	49.397
7200	47.183	49.647
7300	47.733	49.971
7400	47.767	50.261
7500	48.034	50.731
7600	48.203	50.901
7700	48.432	51.157
7800	48.400	51.257
7900	48.630	51.595
8000	49.024	51.998

Figure A.16: Average torque comparison data