EFFECTS OF OCTANE RATING OF COMMERCIALLY AVAILABLE GASOLINE FUEL ON ENGINE PERFORMANCE, EMISSIONS AND COMBUSTION CHARACTERISTIC IN SPARK IGNITION (SI) ENGINE

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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ABSTRAK

Petrol di antara bahan api yang paling banyak digunakan dalam sektor pengangkutan berbanding bahan api lain. Penyelidikan untuk menganalisis kesan bahan api bahan bakar yang berbeza atau penarafan oktana bahan api (RON) pada prestasi enjin di bawah kelajuan enjin yang berbeza telah dilakukan. Satu enjin tunggal silinder Mitsubishi GM131P aci mendatar digunakan untuk persediaan percubaan. Enjin itu didorong oleh tiga jenis bahan api yang berbeza iaitu RON 95, RON 97 dan RON 100 untuk menentukan prestasi enjin. Kajian ini juga menganalisis kesan penggabungan dua dan tiga jenis bahan api campuran bersama pada prestasi dan pelepasan enjin. Enjin ini dihubungkan dengan eddy dinamometer dan pengawal semasa untuk mengukur daya, tork dan kuasa yang dihasilkan oleh enjin. Bagi menganalisis pelepasan hasil gas, penganalisis Autocheck SPTC 5-gas digunakan untuk mengukur jumlah gas yang dikeluarkan oleh enjin di bawah keadaan yang berbeza dan sensor suhu gas ekzos (EGT) dipasang pada ekzos enjin bersama dengan probe penganalisis gas. Secara keseluruhannya, keputusan penyelidikan ini menunjukkan enjin yang beroperasi dengan RON 95 memberikan prestasi enjin yang lebih baik, tetapi dengan pelepasan ekzos karbon carbon dioksida (CO2), karbon monoksida (CO) dan nitrogen oksida (NOx) yang lebih banyak. Penggunaan campuran bahan api ternari meningkatkan prestasi enjin tetapi tidak mesra alam di mana ia menghasilkan pembentukan CO2 dan NOx yang tinggi.

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ABSTRACT

Gasoline among the most fuel used in transportation sector compares to other fuel. Research to analyze the effect of different gasoline fuel grade or fuel octane rating (RON) on engine performance under a different engine speed has been done. A single-cylinder engine Mitsubishi GM131P horizontal shaft is used for experimental setup. The engine was fueled by three different type of fuel which is RON 95, RON 97 and RON 100 to determine the performance of the engine. This research also analyzes the effect of blending two (binary blend) and three (ternary blend) type of fuel together on the engine performance and emissions. The engine is connected with eddy current dynamometer and controller to measure the force, torque, and power produced by the engine. As for analyzing the emission of gas produce, Autocheck SPTC 5-gas analyzer was used to measure the amount of gas produced by the engine under different condition and an exhaust gas temperature (EGT) sensor is attached at the exhaust of the engine alongside with the gas analyzer probe. Overall, the experimental result shows the engine operates with RON 95 provide a better engine performance, but with higher exhaust emissions of carbon dioxide (CO2), carbon monoxide (CO) and nitrogen oxide (NOx). The usage of ternary fuel blend improves the performance of the engine but not environment-friendly where it produces high formation of CO2, and NOx.

CHAPTER 1: INTRODUCTION

1.1 Brief Overview.

Gasoline or petrol fuel is the most popular fuel type use in world transportation. In 2016, about 55% of gasoline used in transportation sector energy consumption of total U.S. transportation energy consumption [1]. Gasoline is a fuel made from crude oil and other petroleum fuel produce by fractional distillation process. Gasoline fuel primarily used in spark-ignited internal combustion engine generally known as petrol engine or SI engine. The effect of burning the gasoline fuel in an internal combustion engine always associated with it emissions in the forms of nitrogen oxides (NOx), carbon dioxides (CO2), carbon monoxide (CO) and unburned hydrocarbons (UHC). These emissions have an effect on the environment both global and local.

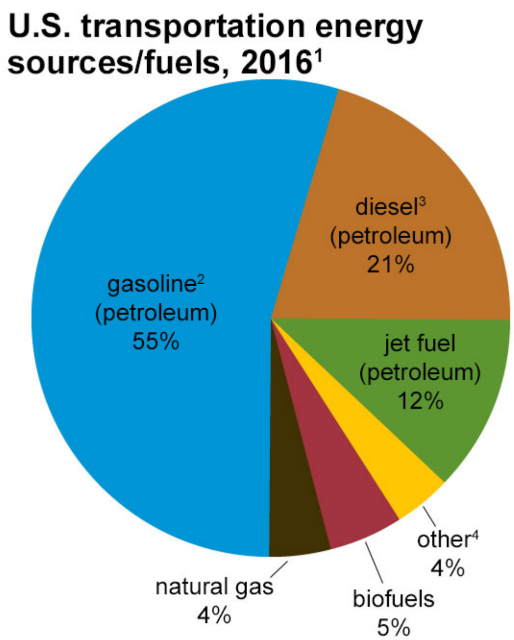

Figure 1. 1 Total of U.S. transportation energy in 2016 [2].

Basically, gasoline fuel can be categorized by several grades which are measured by its octane rating. Octane rating actually plays an important role where higher-octane rating fuel will produce better engine performance. As in SI engine, the knocking intensity also can be reduced by using a higher-octane rating fuel that more resistant to knock. The most common measurement method of determining the octane rating of fuel is Research Octane Number (RON). This method used by running the fuel in an engine with variable compression ratio under certain condition and the result compares with a mixture of iso-octane and n-heptane [3]. There is three main grade that can be found at the market namely regular, midgrade and premium fuel. In Malaysia, several grades of gasoline fuel can be found commercially at the fuel station known as RON 95, RON 97 and RON 100.

Figure 1. 2 Type of fuel available at gas station in Malaysia.

In past several years, RON 100 and RON 97 are practically being used more compared to RON 95 as people trying to maximize their vehicle engine performance. People believed that higher-octane rating makes the engine runs better in performance and it attracts people to use higher-octane gasoline fuel. Fuels with a higher-octane rating are used in high-performance gasoline engines that require higher compression ratios while fuels with lower octane numbers are ideal for diesel engines [4]. The compression ratio is directly related to power and to thermodynamic efficiency of an internal combustion engine. Every model of the engine has a different range of octane number requirements due to production tolerances and variations in engine and vehicle conditions. Table 1.1 below shows the differences in characteristic between RON 95 and RON 97.

Table 1. 1 Characteristic of RON 95 vs RON 97 fuel.

RON 95	RON 97
Less efficient combustion	More efficient combustion
Fast combustion	Slow combustion
Price cheaper	Expensive price
Low viscosity	High viscosity
Suitable for carburetor engine	Suitable for injection engine

In Malaysia, most of the vehicles available are operates by using a gasoline fuel. The vehicle that uses gasoline usually will produce emission of nitrogen oxide (NOx) and carbon dioxide (CO2). The emission of these two gases can give air pollution to the environment. Based on European emissions standard, the light commercial vehicle needs to only produce 175 g/km of CO2 emissions from burning of fuel. As known, CO2 and NOx gas are the greenhouse gas shown in Figure 1.3 where it can result in global warming and climate changes. Table 1.2 shows the European emission standards for passenger cars. The increase in a number of the vehicle in the recent years will increase the emissions of NOx and CO2 produce thus will increase the risk of pollution will occur.

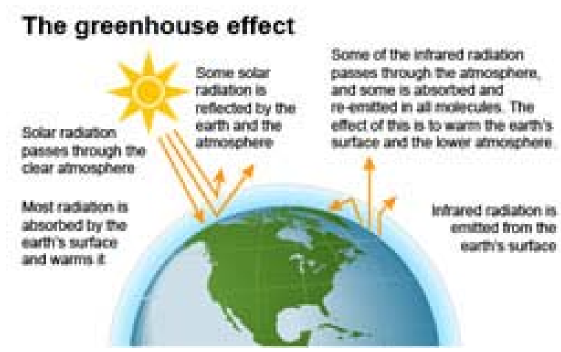

Figure 1. 3 Greenhouse effect [4].

Table 1. 2 European emission standards for passenger cars (Category M*), g/km [5].

Petrol (Gasoline)							
Tier	CO	THC	NMHC	NOx	HC+NOx	PM	PN [#/km]
Euro 1†	2.72 (3.16)	-	-	-	0.97 (1.13)	-	-
Euro 2	2.2	-	-	-	0.5	-	-
Euro 3	2.3	0.2	-	0.15	-	-	-
Euro 4	1	0.1	-	0.08	-	-	-
Euro 5	1	0.1	0.068	0.06	-	0.005**	-
Euro 6	1	0.1	0.068	0.06	-	0.005**	6×1011***

To reduce the pollution, the study of emission gas produced by commercially available gasoline fuel needs to be done for determined which fuel are the most environmental fuel available in the market.

1.2 Problem statement.

In recent years, we can see the price for fuel on the market are not consistent and being controlled by the government. Based on the past five years price, the lowest price for fuel RON 95 was RM1.60 per liter which is in March 2016 and highest price fuel sold since past five years is RM2.33 per liter for RON95, RM2.66 per liter for RON97 and RM2.15 per liter for diesel [6]. Due to uncertain of oil price shown in Figure 1.4, most of the people arguing about the quality of the oil available with the price in the market. As we know, RON 97 will provide higher quality on performance of the engine compare RON 95 but the price per liter of RON 97 are quite higher than the price of RON 95 available in the market. However, there is some people are purposely mixing different type of fuel in their vehicle which is the combination of RON 95 with RON 97 or etc. so that they can maximize the engine performance of their vehicle. So, to validate the problem experimental study on the effect of different fuel on engine performance will be carried out.

Figure 1. 4 Malaysia historical weekly petrol prices [6].

1.3 Objective

1. To investigate engine performance, emissions and combustion for engine fueled with gasoline fuel; with a different octane rating of RON 95, RON 97 and RON 100 on single cylinder SI engine.
2. To investigate engine performance, emissions and combustion for engine fuel with a binary blend of gasoline fuel of RON 95, RON 97 and RON 100 on single cylinder SI engine.

3. To investigate engine performance, emissions and combustion for engine fuel with a ternary blend of gasoline fuel of RON 95, RON 97 and RON 100 on single cylinder SI engine.

1.4 Scope of Project

1. Modification on the current engine (mounting exhaust gas temperature and extend exhaust pipe).
2. Fuel blending for two commercially available gasoline fuels (RON 95 + RON 97, RON 95 + RON 100, RON 97 + RON 100).
3. Fuel blending for three commercially available gasoline fuels (RON 95 + RON 97 + RON 100).
4. Experimental test of engine performance, emissions, and combustion analysis.
5. Collect and analyze the result data from the experiment.

CHAPTER 2: LITERATURE REVIEW

2.1. Engine Performance

Due to development of technology in this modern age, automobile industries need to produce the high-performance vehicle. To meet the requirement of the user, many of the company trying to build a car with high performance of the engine. Engine was a main part of the vehicle. Engine can be defined as a machine that converts some energy into mechanical energy that used to do work. Basically, automotive engine uses fuel to generate power. Gasoline or petrol is the most popular fuel used because of their wide availability. As known, the fuel used for operating the engine can affect the engine performance.

Performance of engine can be measured by determining the torque, engine speed, power and its efficiency. In 2014, a study by Taib Iskandar et. al [7] on engine performance has been carried out by using two different type of fuel; RON 95 and RON 97 operates on a 4-cylinder engine. Based on their study, the performance of the engine produces slightly higher torque and brake power when RON 95 is used compared to other fuel. Its efficiency of fuel consumption also seen to be better. Another study by Saud Binjuwair et. al with using two different fuel delivery system; port injection and direct injection [8] on SI engine. Results show that at higher engine speed performance of the engine was better for both systems.

In 2017, D. Ramasamy et. al [9] conducted an experimental investigation of engine by using dual fuel injection and gasoline fuel with the addition of compressed natural gas (CNG) use to operates the engine. Based on their result, it shows the torque, power, and efficiency of the engine was increased by 10% with the addition of CNG. Adnan Kadhim Rashid et. al studied the effect on engine performance by using three different type of fuel [10]. Fuel tested was RON 95, RON 97 and RON 102 on a 4-cylinder engine. High torque and power produce by RON 102 compared to other two fuel. The BSFC of RON 97 is higher compared to RON 95 and 102. Another study by Ali Alahmer et. al uses two different type of fuel quality. RON 90 and RON 95 operates in one-cylinder SI engine and been tested on variable engine speed. They propose that using the higher grade of fuel than engine requirement can give negative impact on the performance of the engine [11] [12].

Other than that, there some researchers are trying to optimize the performance of the engine by using a mixture of fuel with other substances. Say Ismail M.M. Elsemary et. al [13], the proper gasoline-hydrogen mixture can increase the cylinder pressure and improve the thermal efficiency but lowering the BSFC. In 2018, P. Iodice et. al studied on a characteristic of the engine with using gasoline and methanol mixture as fuel.[14]. Another study made by M. Yusoff et. al [15] on blending the alcohol with gasoline; butanol-isomer blend. The result shows that by adding the alcohol, the fuel will produce slightly higher brake power and torque compare to pure gasoline. A mixture of acetone-gasoline fuel used in Ashraf Elfasakhany [16] study on a characteristic of engine performance. It proves that addition of acetone in the blend can improve the performance of the engine such as brake power and engine torque increase with compare to neat gasoline.

Based on journal reviewed, we can see clearly many of the researchers tends to compare the performance of the engine by using a different type of fuel which is a lower grade of fuel compared with the higher grade of fuel. Other than that, some of the researcher using a blending of fuel with various alcohol to optimize the performance of the engine. The fuel was tested under a different condition and the results of their study have been discussed above. Unfortunately for most of the reviewed journal, there are not much of the researcher trying to blend together two or three different type of fuel grade which will be applied in my investigation.

2.2. Engine Emissions

In a car or other transportation vehicle, most of it use an engine that basically use the process of combustion. This combustion process of the engine will produce emissions of hydrocarbon, carbon monoxide, carbon dioxide, nitrogen oxide and many others harmful gas. The gas produce will affect the health of the people and it also not good for the environment. As we know that emissions of this gas are harmful and can be categorized as air pollution. To prevent this, many of the researchers conducted a study on the emission of the engine and validate its effect on the environment.

Saud Binjuwair [8] et. al study emission produce by two different grade of fuel which is RON 95 and RON 91. They noticed that lower grade of fuel which is RON 91 produce higher NOx, CO and HC compare to a higher grade of fuel. This pattern of result can be obtained by study of H.G. How et. al [17]. RON 95 produce lower NOx, but higher CO, CO2, and HC compare to

RON 97. So it shows that higher grade of fuel will produce lower emissions [7]. In 2016, Yanuandri Putrasari conducted a study on the emission of gasoline-biodiesel blend that operates on single-cylinder compress ignition engine [18]. It is shown that emission produce by addition of gasoline in the blend is much lower compare to pure diesel fuel.

A study by Cenk Sayin et. al and Ali Alahmer et. al show that when using a higher grade fuel than the requirement of the engine specification will increase the exhaust emission [12] [11]. In 2016, Rinu Thomas et. al study the emission produces of SI engine fueled with the gasoline-butanol blend. The engine tested at a different type of compression ratio in SI engine and it shows at higher compression ratio the emissions produce can be reduced [19]. Emission analysis of ternary fuel blend of bio-ethanol-iso-ethanol-gasoline blend in single cylinder SI engine was carried out by Ashraf Elfasakhany in 2016 [20]. Result show emissions of unburned hydrocarbon and carbon dioxide lower 15-20% than pure gasoline fuel and lower 10-15% that dual blend of fuel. Guven Gonca has conducted a study on how engine parameter can affect the emission of the gas [21].

Based on review journal, we can clearly see that the type of fuel used to operates engine will affect the exhaust gas emissions. A higher grade of fuel tends to produce a lower emission of gas compare to the lower grade of fuel. It also shows that with the addition of several amounts of alcohol in the fuel gasoline/diesel, it can improve the emissions of the exhaust and produce lower emissions of the harmful gases.

2.3. Engine Combustion

Combustion is processing to convert the energy which occurs in the most internal combustion engine and it almost used in most of all vehicle. This combustion process can be affected by the characteristic of the engine which is a number of the cylinder, the compression ratio of the engine and air-fuel ratio. It also can be determined by the characteristic of fuel used to operate the engine. According to Said Binjuwair et. al [8], a higher grade of fuel will burn faster than a lower grade of fuel hence increase the combustion efficiency. This statement also agreed by Ali Ghanaati et. al [22]. Osman Emiroğlu et. al [23] conducted study combustion of various alcohol (butanol, ethanol, and methanol) blend with a diesel fuel. With the addition of alcohol in diesel fuel shows that it need longer ignition delay and produce higher heat releases rate compare to pure diesel fuel. Other than that, on a study by I. Schifter et. al [24] shown that with increasing composition of alcohol mixed with a gasoline can improve the combustion compare to pure gasoline.

Selahaddin Orhan Akansu et. al also study on a characteristic of combustion by using gasoline-ethanol-hydrogen fuel blend in SI engine [25]. The result shows that in addition of hydrogen in the fuel blend can improve the combustion efficiency. In 2014, A. Irimescu et. al [26] conducted a study on combustion analysis from a different type of method used which is combination method of optical and thermodynamic approach to have more understanding on this process. Another method used by Hamid Reza Fajri et. al at 2016 [27] was by using a numerical investigation on compression ignition engine. A. Broatch et. al conducted study combustion characteristic by using a numerical computational fluid dynamic (CFD) method [28].

As stated by M. Ojapah et. al [29] by using controlled auto-ignition in the engine can lower the fuel consumption and produce better combustion. They also stated that by using an early intake valve closure (EVC) operation also can improve the fuel consumption efficiency. In 2016 T. Lanzanova et. al [30] experimental study on running gasoline with anhydrous ethanol and several wet ethanol compositions on single cylinder SI engine will affect the heat release rate. It also increased the combustion duration.

Y. Li et. al study combustion characteristic of methanol, ethanol, and butanol gasoline blend under different composition of the blend and engine load [31]. The result shows that by adding the alcohol in gasoline can improve the combustion of the fuel due to alcohol that has higher burning velocity. Another study by K.Liu et. al [32] to investigate the combustion characteristic of the butanol-gasoline blend on SI engine. The result show same pattern as the Y. Li et. al [31] result which is combustion of the fuel can be improved when the ratio of alcohol increases.

For overall reviewed journal above, we can clearly state that the combustion of an engine can be affected by the characteristic if fuel use to operates the engine. It shows that different type of fuel grade will produce different combustion characteristic due to their differences in fuel properties. Besides that, the addition of alcohol to the blend of fuel with gasoline/diesel can improve the combustion characteristic.

2.4. Engine Knocking

Knocking happen when the combustion in fuel chamber ignites without ignition of the spark plug. This happens due unevenly fuel burn in the cylinder, so it produces more than one pocket fuel burn in cylinder hence it will collide with each other and causes knocking to happen. Other than that, we also can say that using a lower grade of fuel also contributes the engine to knock itself out. Lower grade of fuel cannot withstand a high compression during the ignition and will lead to knocking. Remaining carbon deposits which left at the exhaust valve also can cause knocking to occur [33]. This happens when before the optimal combustion occurs the deposit of carbon drop to the fuel chamber. Due to high pressure, it will ignite itself then produce small pocket fuel burn inside the cylinder.

In 2016, Zhi Wang et. al [34] conducted a study on knocking combustion of SI engine. In this experimental study, they put a more focus to super-knock of engine compare to conventional knock. The study the effect on a characteristic of fuel between the pre-ignition and super knock [35]. They also stated that to have more understanding on knocking, fuel properties and engine design need to give more attention to prevent engine knocking. In 2013, Azher Razzak Witwit et. al conducted a study on the method used to detect knocking in internal combustion engine [36]. Another study made by S. Iqbal et. al [37] on the effect of ethanol and octane content in the ethanol-petrol mixture to knocking of the engine. It shows that higher number of octane can improve the engine to become more resistance to knocking.

H. Wei et. al investigate of knocking on an engine that fueled with gasoline-butanol blends in DISI single cylinder engine [38]. The result shows that gasoline fuel with the addition of butanol show better anti-knock ability compares to neat gasoline fuel. Besides that, H. Wei et. al [39] also investigate knocking characteristic by using a same gasoline-butanol blend with different exhaust gas recirculation (EGR) rate. The result shows that with the application of EGR, knocking of the engine can be decreased due to cooling and dilution effects. Another study conducted by H. Wei et. al with using of gasoline compression ignition engine [40]. The result shows that the knocking intensity increases as the BMEP increases due to injection timing. It also shows that knock in GCI engine low compare to SI engine because of auto-ignition occurs rapidly in SI engine. K. Liu et.

al stated that with the addition of alcohol in gasoline can improve the knocking intensity of the engine [32].

Based on current research, we can say that knocking tends to occur in the engine that operates using a lower octane number more rapidly compared to the engine that operates in higher octane number. This happen because of the higher-octane number of fuel will have the properties of fuel that a more resistance to knocking. Other than using a different grade of fuel, the addition of alcohol also can improve the engine to resist knocking to occur. It also has been discussed above with application of EGR and proper injection timing can help to reduce knocking in the engine.

2.5. Engine Noise

The engine produces noise when it operates. The noise produced by the engine can be a sign of engine failure or malfunction [41], [42] and maybe the noise produce could harm human hearing. As stated by the national institute of safety and health (NIOSH) the recommended exposure limit (REL) is not more than 85 decibels (dCB) and it can be acceptable if the person is exposed to higher than the limit of REL for not longer than 8 hours [43]. Exposure to more than REL can be hazardous and will affect the safety and health of a person. Basically, noise is the unwanted sound that is produced by vibration of the object. Vibration can occur by imbalanced of rotating parts in the engine or uneven friction of the piston movement in the cylinder. In 2015, M. Seifi [44] by using DI diesel engine fueled with water-diesel emulsion to investigate the noise produce. It supports that the engine speed, load, and type of fuel play an important role in noise emission. It also shows that with the addition of water in diesel fuel did not have much impact on noise emission compared to neat diesel fuel.

A study by A. Alahmer et. al [11] on noise emission of SI engine by using two different grade of fuel. Results show at high speed the sound pressure level (SPL) for both two types of fuel increased. This experiment also stated that noise produced by an engine that used high-grade fuel than the requirement of the engine is more disturbing. A study by Xiaokang Deng et. al [45] on SI engine show that engine fueled with neat gasoline produce high noise emission compare to gasoline which was added with hydrous ethanol. It also shows that higher engine speed will produce high noise emission neither for neat gasoline or with the addition of hydrous ethanol in gasoline.

Based on a study conducted by M. Seifi et. al [46] stated that type of fuel use in the engine can affect the engine noise emission. It shows that higher engine speed and the emulsions of water in diesel will produce high noise; which more than 90 decibels. We can see that the noise produces past over the REL stated by NOISH. Another study conducted by N. Siavash et. al [47] by using a biodiesel-diesel fuel blend show that in increasing of biodiesel volume on blend will increase the acoustic emissions but still produce a lower acoustic emission than neat diesel. D. Satsangi et. al [48] show that there is a relationship between combustion noise and pressure rise of fuel use.

Based on above discussion, we can see that the type of fuel used to operates the engine will affect the engine noise produced. Using higher grade of fuel than the requirement of the engine will produce a more disturbing noise. Most of the researcher found that the noise produced by the engine is more than the REL that been fixed by NIOSH and can be classified to be harmful if exposed for a long duration.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Experimental Design.

In this study, an experimental work will be conducted to determine the performance and gas emission of the engine. The engine will be fueled by a different type of research octane number (RON) under a different engine speed. Experimental setup as shown in Figure 3.1 to 3.3 will be used throughout the experiment to determine the performance and gas emissions of the gas in this project. A 126cc single-cylinder engine, Mitsubishi GM131P horizontal shaft connected with eddy current dynamometer and ECU are used to determine the engine power, torque, and force of the engine. The engine will be tested at a constant speed ranging from 1600 rpm to 3200 rpm with an increment of 400 rpm under different fuel composition. The fuel consumption of the engine will be measured by taking the time engine run at constant speed under certain time constant. Autocheck SPTC 5-gas analyzer will be used to determine the gas emissions such as hydrocarbon (HC), carbon monoxide (CO), carbon dioxide (CO2), oxygen (O2) and nitrogen oxide (NOx) produce by the engine. The probe of the gas analyzer and exhaust gas temperature (EGT) will be mount at the exhaust of the engine. Some modification on the engine and other instrumentation used in this experimental also will be described later.

Figure 3. 1 Fuel measurement system setup for the experiment.

Figure 3. 2 Engine and dynamometer setup used in the experiment.

Figure 3. 3 Exhaust ventilator and gas probe analyzer setup for the experiment.

In this study, all the experimental work was performed on a single-cylinder engine, Mitsubishi GM131P, horizontal shaft, 126cc, 4-stroke OHV tilt cylinder gasoline engine. This engine available at the Engine Lab of School of Mechanical Engineering, Universiti Sains Malaysia. The engine picture and specification are shown in Figure 3.4 and Table 3.1.

Figure 3. 4 Mitsubishi GM131P test engine.

Table 3. 1 Specification of engine Mitsubishi GM131P.

Name	Mitsubishi GM131-4.0HP gasoline engine
Type	Air-cooled 4-stroke OHV tilt cylinder gasoline engine
Bore and stroke	62 * 42
Row tolerance	126CC
Rated continuous output power (hp / rpm)	4.0/3600 (4.0/1800)
Fuel tank capacity	2.5 L
Maximum output power	4.0 hp
Air filter	Duplex filter
PTO shaft steering-oriented	Clockwise
Ignition system	Non-contact electromagnetic ignition, flywheel permanent magnet generator
Net Weight	13.7 kg
Dimensions L * W * H	306 * 345 * 320 (mm)

As mentions earlier, some modification work will need to be done to provide a better measuring and analyzing the data of the engine. One of the modification was being made on the old exhaust muffler of the engine shown in Figure 3.5. As shown the EGT was mounted to the exhaust where it more exposed to room temperature and the result obtained may vary with the room temperature. The engine exhaust muffler was mounted with 6-inch L-shape of cylinder pipe shown in Figure 3.6 to improve the measurement of the EGT sensor and also can provide much space for inserting the gas probe analyzer used to measure the emissions produced by the engine. Along the new exhaust muffler, there a hole drill at the curve of the cylinder to able the EGT to be mounted on it for better temperature measurement. The regular spark plug used also have been replaced with Kistler spark plug pressure sensor where it measures the pressure in the combustion chamber and analyzed the combustion characteristic of the engine. Other than that, a little modification of fuel delivery system is being made to easier the process of changing the fuel.

Figure 3. 5 Old exhaust muffler of the engine.

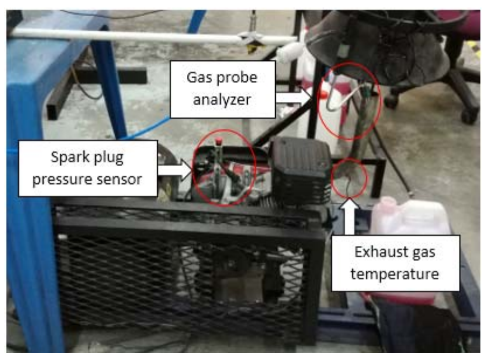

Figure 3. 6 New modification made on the engine.

For the combustion analysis, the engine was mounted with a pressure sensor at the top of the cylinder as shown in Figure 3.6. As know accurate measurements of crank angle and cylinder pressure, as well as intake and exhaust gas pressure, are important factors when analyzing the combustion of the engines. Along with the pressure sensor, at the flywheel of the engine was mounted with crank angle encoder to measure the crank angle position during the combustion occur inside the combustion chamber. All of this instrument was controlled by data acquisition system where all the data measured being analyzed by the computer.

Autocheck SPTC 5-gas analyzer as shown in Figure 3.7 was used to determine the emission of gas produced by the engine. This gas analyzer will be used to determine the percentage of gas emissions produce such as hydrocarbon (HC), carbon monoxide (CO), carbon dioxide (CO2), oxygen (O2) and nitrogen oxide (NOx). The instrument's probe was inserted into the exhaust flow as mentioned above where the data transfer into a computer software for interpreted the data. This analyzer uses a single beam, non-dispersive infrared (NDIR) to determine CO, CO2 and HC concentration, O2 and NOx are detected by electrochemical sensors. The probe inserted on the exhaust will draw a small amount of sample of the stack gas and a sensor in the gas analyzer will analyze the content of the gas, calculated and displayed the result. Table 3.2 shows the specification of the gas analyzer.

Figure 3. 7 Autocheck SPTC 5-gas analyzer.

Table 3. 2 Specification of exhaust gas analyzer.

Item	Range	Resolution
CO	0.00 - 15.00 %	0.01%
HC	0.00 - 30000 ppm	1 ppm
CO2	0.00 - 20.00%	0.01%
O2	0.00 - 25.00%	0.01%
NOx	0.00 - 5000 ppm	1 ppm
Lambda	0.50 - 3.00	-
AFR	5.00 - 25.00	-
Response time	Less than 10s	
Warm up time	Less than 60s	
Operating humidity	0.00 - 90.00% RH	
Operating Temperature	-10 – 50 °C	

3.2 Fuel blending.

In this study, three different type of fuel which is RON 95, RON 97 and RON 100 shown in Figure 3.8 are being used to determine the performance of single-cylinder engine and SI. As mention earlier, this study will be conducted to determine the effect of different type of fuel and fuel blend being used on the single-cylinder engine. At first, the engine will be tested by using original composition of fuel RON 95, RON 97 and RON 100. The engine will be tested by mixing/blending two different types of fuel with a 50% composition of each type of fuel. There are three different type of fuel blending produce which is RON 95 + RON 97, RON 95 + RON 100 and RON 97 + RON 100 and being called as a binary blend of fuel. For the blending fuel combination of the RON 95+RON 97+RON 100, the fuel composition is equally divided for each type of fuel which is 33.33% volume of fuel and known as ternary furl blend. Refers to Table 3.3 for the composition of fuel blending of the RON 95+RON 97+RON 100. For this experimental study total of 7 types of different fuel blend including the original compositions will be used to determine the performance of the engine and analyze the emissions produced by the fuel. This engine will be tested under different conditions.

Figure 3. 8 Type of fuel used in the experiment.

Table 3. 3 Composition of fuel for RON 95, RON 97 and RON 100.

NO	NAME	FUEL COMPOSITION %		
		RON 95	RON 97	RON 100
1	RON 95	100	0	0
2	RON 97	0	100	0
3	RON 100	0	0	100
4	RON 95 + RON 97	50	50	0
5	RON 95 + RON 100	0	50	50
6	RON 97 + RON 100	50	0	50
7	RON 95 + RON 97 + RON 100	33	33	33

3.3 Fuel Properties.

Petrol or gasoline fuel was one of the common types of fuel use SI engine. most of this fuel contains organic compound in it. As in this study, the fuel used to operates the engine was RON 95, RON 97 and RON 100 where all of this fuel have a different octane rating. Basically, petrol was produced in several grades of octane and have a different number of characteristics and properties. All of the petroleum has a common composition which is hydrogen molecule and some small amounts of additives. One of the properties that play an important role in the combustion of the engine was the calorific value of the fuel. As know, the calorific value can be defined as total energy released as heat by a substance when undergoes a complete combustion. This calorific value can be measured by using a conventional instrument or can be calculated by using a formula. In this study, the calorific value of fuel used is measured by using the conventional instrument where it is measured by using a bomb calorimeter. Figure 3.9 below shows the types of bomb calorimeter used in this process.

Figure 3. 9 Nenken-type adiabatic bomb calorimeter.

Another testing made in determining the properties of the fuel was RON and MON number testing. Octane rating was a standard measure of performance of an engine. As known, the fuel such as RON 95, RON 97 and RON 100 all are named based on their octane number. In this experiment, there are several types of fuel blend being used. As the fuel mix and blend together with other, so a proper testing need to conduct to determine the octane number of the blended fuel, so it can give a better understanding on the behavior of this fuel when operates the engine. In this testing process, Shatox SX-200 portable octane tester shown in Figure 3.10 was used to determine the RON and MON number of the fuel. This analyzer measures the octane level according to ASTM D 2699-86, ASTM D 2700-86.

Figure 3. 10 Shatox SX-200 portable octane tester.

3.4 Project flowchart.

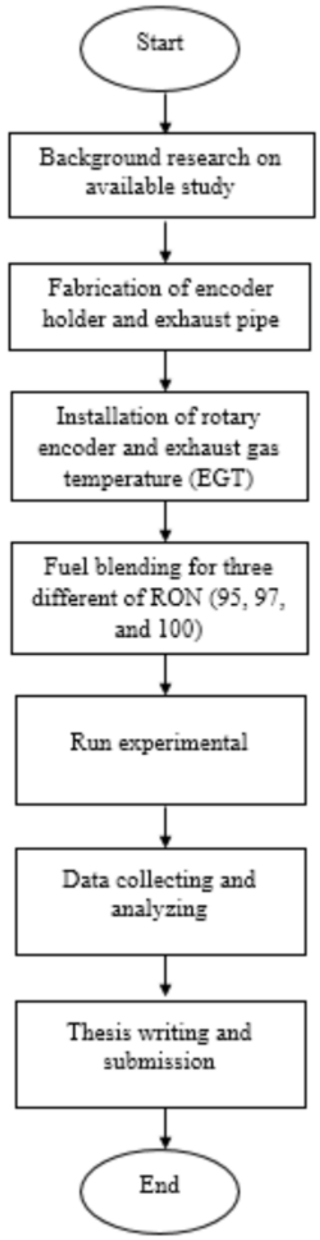

Figure 3. 11 Research flow chart.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Effect of RON on SI Engine.

This section discussed the result on the effect of using pure fuel of RON 95, RON 97 and RON 100 on SI engine and will be explained on three different type of analysis which is performance, emissions, and combustion analysis.

4.1.1 Performance Analysis.

Based on results obtained, torque output produces by the engine was shown in Figure 4.1. The engine was tested at variable engine condition from 1600 rpm to 3200 rpm with using three different type of fuel; RON 95, RON 97 and RON 100. The maximum torque produced by the engine was 6.9 Nm which is the engine fuel with RON 97 at 2400 rpm. As for the engine fuel with RON 95, the maximum torque produce was 6.8 Nm at 2000 and 2400 rpm respectively while for the engine fuel with RON 100, the maximum torque produce was 6.7 Nm at 2000 rpm. At 2800 rpm, the result shows the lowest torque produced by the engine. The higher the octane number of fuel use the lower the torque produced. The torque produced by the engine fuel with RON 95, RON 97 and RON 100 was 6.1, 6.0 and 5.9 Nm respectively. At higher engine speed, torque produce seems to be on same for all of the fuel except for RON 95 which produce 1.5% higher torque compare to others. For the average torque produced by the engine, can see that the higher-octane number will decrease the torque produced. Average torque produce by RON 95 is higher by 0.9% of RON 97 and higher by 1.2% of RON 100.

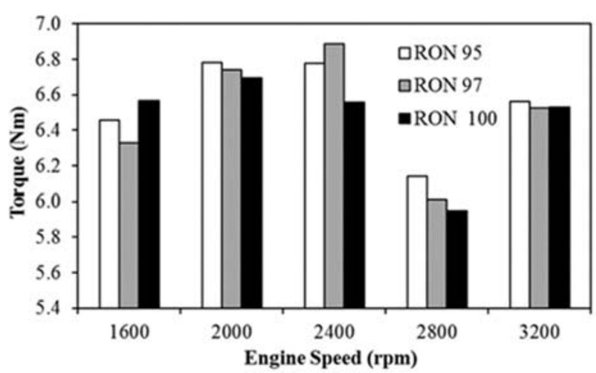

Figure 4. 1 Torque vs Engine speed.

Figure 4.2 shows the effect of using different types of fuel on the brake power engine produce. Based on the result, we can clearly see that with increasing the engine speed the brake power also increases through a different type of fuel being used. At the lower speed of the engine, can see that RON 100 produce slightly 1.8% higher brake power than RON 95 and 7.6% higher than RON 97. On the other side, at high speed the brake power produce by RON 95 is higher than RON 97 and RON 100. The brake power produce by RON 95 was 2.22 kW and RON 97 and RON 100 produce same value of brake power, 2.20 kW.

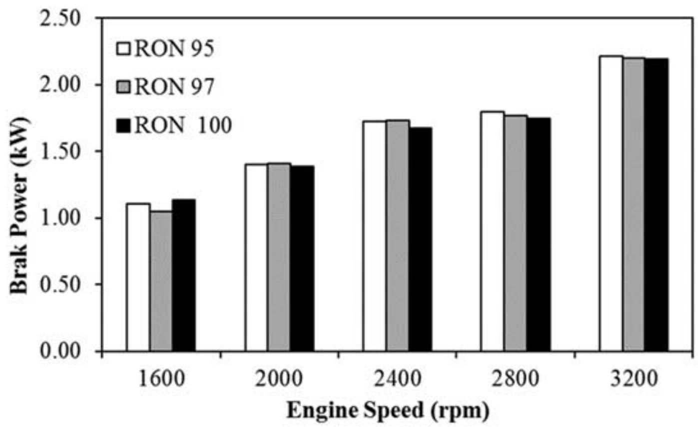

Figure 4. 2 Brake power vs Engine speed.

Other parameters that used to determine the engine performance was the brake mean effective pressure, BMEP produces by the engine as shown in Figure 4.3. Higher BMEP produce by RON 97 at 2400 rpm was 6.87 bar while the lowest BMEP produce by RON 100 at 2800 rpm was 5.93 bar. At higher engine speed, the higher BMEP was produced by RON 95 to be 6.54 bar which was lower 5% from the highest BMEP produce by RON 97 at 2400 rpm and lower 3.3% from highest BMEP produce by RON 95. The average lowest value of BMEP produce was RON 100 which was lower 1.2% from the highest average value produce was RON 95. At engine speed 2800 rpm, we can see the value of BMEP output produce was the lowest for all types of fuel.

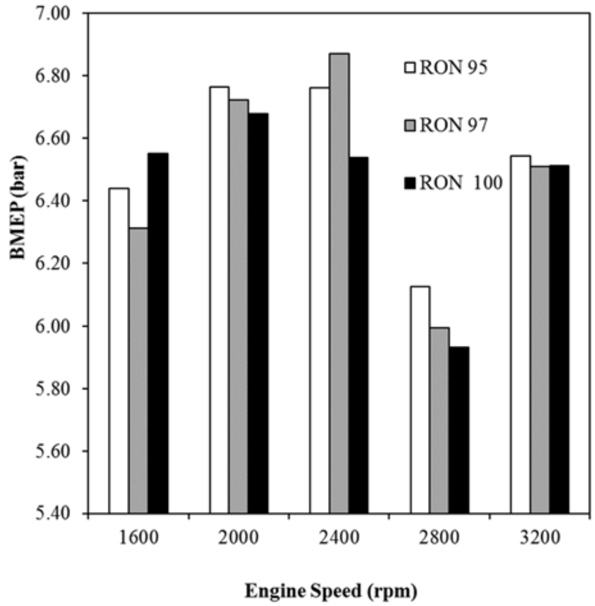

Figure 4. 3 BMEP vs Engine speed.

Figure 4.4 shows the results of BTE of fuel running with different types of fuel and engine speed. As general, we can see at lower engine speed BTE produce was the lowest and as the engine speed increase the should supposedly also increase. The highest BTE produce was 31.7% by engine operates with RON 95 at engine speed of 2400 rpm. Theoretically, BTE produce will increase with increasing engine speed until it reached a maximum value and later it will decrease as the engine speed increase. For average BTE produce, we can see that RON 95 produce higher 4.8% from RON 100 and 3% higher than RON 97. Based on the graph below, we can see that maximum BTE produce by all three types of fuel was at 2400 rpm. The BTE produce for RON 95, RON 97 and RON 100 was 31.7%, 28.6%, and 26.3% respectively.