STUDY OF ENGINE PERFORMANCE AND EMISSIONS CHARACTERISTICS OF A SI ENGINE FUELED WITH DIFFERENT OCTANE RATING GASOLINE

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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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STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated.

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Abstrak

Sejak era-20, penggunaan kenderaan semakin popular dan bilangan kenderaan meningkat secara berterusan di seluruh dunia. Kebanyakan pembakaran enjin kereta bergantung kepada minyak petrol. Terdapat tiga jenis RON dalam pasaran Malaysia yang menjadi pilihan untuk pengguna kerata. Jenis RON yang berbeza sudah dinyatakan oleh banyak kajian dalam bidang RON yang berbeza. RON akan menentukan keberkesanan pemindahan haba dan pelepasan ekzos gas secara tidak langsung. Projek ini adalah untuk mengkaji tentang perkaitan antara keberkesanan pembakaran enjin dan pelepasan gas ekzos dengan kelajuan enjin dan beban enjin berubah. Enjin Myvi (Daihatsu K3-VE) yang terdapat 4 silinder dan nisbah mampatan 10:1 telah berjalan dengan penggunaan RON 95, RON 97 dan RON100 sebagai sumber tenaga enjin. Burette telah digunakan untuk mengukur isi padu petrol yang telah digunakan apabila engin dijalankan dalam keadaan stabil yang telah ditentukan.Enjin telah berjalan dengan kelajuan yang konsisten antara 1000rpm ke 4000rpm dengan setiap penambahan 1000rpm dalam keadaan beban separuh dan beban penuh. Keadaan tersebut akan ditetapkan dengan kawalan input tork engine WOT dan separuh nilai tork semasa jalan dalam keadaan WOT. Enjin penyalaan api (SI) telah bersambung dengan dynamometer elektrik eddy dengan unit kawalan elektrik dan penganalis gas ekzos untuk nendapat data prestasi enjin, pelepasan ekzoz dan ciri-ciri pembakaran enjin. Hasilan eksperimen telah menunjukkan penggunaan petrol oktana gred lebih tinggi dari keperluan dan reka bentuk enjin akan merendahkan prestasi enjin. Secara purata, kuasa brek dan keberkesaanan termo bagi SI enjin dengan penggunaan RON 95 lebih tinggi berbanding dengan RON 97 and RON 100 sebanyak 0.74% dan 0.61% masing-masing. Penambahbaikan BSFC ialah 4.1% dan 2.6%. Secara umum, pelepasan ekzos bagi NOx dan CO bagi enjin telah memberi penambahbaikan sebanyak 9% dan 4.37% bagi oktana 100 jika berbanding dengan oktana 95 dan oktana 97. Pada masa yang sama, kepekatan pelepasan gas HC bagi petrol RON 95 adalah lebih tinggi berbanding dengan petrol RON 97 dan RON 100 sebanyak 4.2% dan 26.5% masing-masing. Walaupun petrol RON yang lebih tinggi dapat memberi kelebihan dalam keberkesanan mengurangkan pelepasan gas ekzos terutamnya bagi gas CO dan gas HC, tetapi dari sudut pemikiran awam yang lebih mementingkan keberkesanan pembakaran enjin, RON 95 ialah petrol yang lebih sesuai untuk enjin K3-VE ini. Hal ini demikian, kerana nisbah mampatan 10:1 yand dikira sederhana tidak dapat merangsang penukaran tenaga nilai kalori dalam RON yang tinggi dengan sepenuhnya , ini menjadi kemerosotan dalam keberkesanan termo .

Abstract

Due to world crude oil price hike in the recent years, many countries have experienced increase in gasoline price. In Malaysia, where gasoline is sold in three grades; RON95 and RON97 and RON100 fuel price are regulated by the government, gasoline price has been gradually increased since 2009. The effect of gasoline RON95, RON97 and RON100 on performance and exhaust emissions in spark ignition engine was investigated on a representative engine: 1.298L, 4-cylinder K3-VE engine with CR 10:1. The engine was run at constant speed between 1000 and 4000 rpm with 1000 rpm increment at various loading conditions. The SI engine was connected to eddy current dynamometer and controller system with the exhaust gas analyser to determine engine performance and exhaust emissions characteristic. The experimental results showed that the using gasoline with octane grades higher than the requirement of an engine will decrease the engine performance. On average, the brake power and thermal efficiency for the SI engine fuelled with RON 95 is higher than that of gasoline RON 97 and RON 100 by 0.74% and 0.61% respectively, and improvement of BSFC by 4.1% and 2.6%. In general, the exhaust emission profiles for NOx and CO of the engine improved for RON 100 by 9% and 4.37% respectively. On the other side, the HC and CO_2 emissions concentration of gasoline RON 100 is lower than that of RON octane 95 by 26.5% and 1.9% respectively. RON 95 can deliver high performance and efficiency in both loading conditions whereas RON 100 fuel produced the lowest in compared to RON 95 and RON 97 fuels. Therefore, from economically view point, it is recommended that RON 95 be used in maintain the good performance with this type of engine. Besides, from this study, it proofs that higher RON gasoline not necessarily beneficial on engine power and fuel economy especially when the higher RON fuel was run with the moderate compression ratio engine. One of the reason that higher RON gasoline is suggest to be use is because of the advantage of RON 97 and RON 100 shown in the aspect of effectively reduction on the emissions of polluting gases CO and HC.

CHAPTER 1

INTRODUCTION

1.1 Brief Overview

It is evident that road transport dominates Malaysia's transportation sector, whereby the road network covers 96% of the economic activities. (Judin Abdul Karim 2008). On top of that, the share of the passenger sector is further divided into private cars and public transports. The former has the biggest share with 65%, while the later takes up the remaining 30% (Judin Abdul Karim 2008). A public survey conducted by Abdalla et al. (2007) has found out that local road users have high preference for the use of their personal vehicles rather than public transportation due to the convenience factor. This factor could be one of the reasons that contribute to the fact that vehicle ownership has considerably increased over the last decade (Radin Umar 2007). A high demand of private vehicles may also explain the encouraging scenarios in domestic automotive industry. The domestic motor vehicle market represents approximately 30% of the total demand in the five largest ASEAN economies— Indonesia, Malaysia, the Philippines, Singapore and Thailand (Li Wei et al. 2008). The production of vehicles, as observed in the last 10 years, achieved an average of 400,000 vehicles per year with approximately 75% from that figure being passenger vehicles (Lily Amelia et al. 2009).

At the same instant, the increment of the number of vehicles on the road, has given rise to the issue and many discussions on the fuels economy and the emissions from the transportation sector. Transportation in Malaysia is still using traditional fossil fuel types such as gasoline, diesel and electricity. These activities generate millions of tons of pollution gases each year. The pattern of emission production by the transportation sector in Malaysia has not been analyzed accurately yet (Malaysia Initial 2000). Suitable energy research on the formulation or alternative sources of fuels in the transportation sector can reduce demand for fossil fuel consumption and hence decrease the production of carbon and unburned gases and other emissions. The fuel consumption and emission are mainly depending on the engine architecture and the fuels properties. In Malaysia the vehicle sales and used by the public are dominated by local car manufacturers by assist of government policies that protect the local automotive industry i.e. via tariff and non-tariff barriers

(Mohd Rosli 2006). For instance, major local car manufacturers in Malaysia—Proton and Perodua. -had grabbed around 60% of the market share in 2007 (Lily Amelia et al. 2009). The Proton and Local's car user are having the several gasoline fuel brands selection, which offer different octane ratings are sold at a fixed price which is regulated by a managed float system that was implemented on 1st of December 2014 to cut out all the fuel subsidies. As of 1st April of 2018, the fuel prices for both RON95 and RON97 were set at RM2.20/L and RM2.47/L respectively. Hence, this research examines RON95, RON97 and RON100 fuel with one of the most common brands available in Malaysia and discuss the differences between all three tested gasolines.

Fuel sales have increased during the period 1985-2005. Gasoline use has increased by 72%. Gasoline is still as the most reliable and common fuel for the Malaysia passenger car user. Gasoline is a type of chemical mixture that consists of numerous hydrocarbons. It varies from one refinery to another. In this study, octane rating defines characteristics of the gasoline. Most of the public that consider higher RON fuel's as the premium fuel due to it is more expensive than standard- it is claimed by the gasoline seller on the increased octane rating can get the beneficial of lower fuel consumption as well as better engine protection and performance. Ultimately, the consumers are paying extra for higher-octane gas if they purchase higher-rated gas than what is recommended by the auto manufacturer. Nevertheless, using gasoline with lower octane ratings than manufacturer recommendations will cause decreased fuel efficiency.

Despite of the fuel economy and engine performance efficiency, another topic about the transportation is about the tightening vehicles emission standard in line with international developments. Air pollution by automotive emissions is one of the potential environmental problems. In recent years the internal combustion engine powered vehicles have a great concern due to pollution problems. The main pollutants by internal combustion engines due to incomplete combustion of hydrocarbon fuels during the combustion process are oxides of nitrogen, carbon monoxide, and unburned hydrocarbons. Automotive emissions are contributing to global atmospheric changes and are likely being hazardous to all kinds of lives. The temperature of spark ignition engine exhaust is typically between 400°C and 600°C. It is lower during idle (300-400°C) and may be higher (about 900°C) under high-load conditions (Heywood, 1988). The levels of CO, NO_x and unburned hydrocarbon concentrations are mainly dependent on the type of fuel and its octane number in addition to the fuel/air ratio.

Although the gasoline fuel with RON 95, RON97 and Ron 100 had been supplied in the Malaysia market since the year of 2015. The lack of the awareness of public in the outcome from technical engine testing that can bring for comprehensive understanding on the most famous local manufacturing car's engine. For that reason, the research studies on spark ignition (SI) engine fuels to improve the fuel properties, to decrease the engine fuel consumption, to augment engine power and to diminish the unwanted exhaust emissions become important especially for the typical large group of cars which affordable by most Malaysian. The discussion on the results from the different octane fuels are becomes the main aspect in this experiment and it can use as one of the sources of reference for the typical car user to help them on the selective of the most suitable RON fuel for their car engine.

1.2 Problem Statement

The growing concerns about the fuel economy and stringency of emission standards on the internal combustion engine are driving the need of study for the improvement in engine performance and reduction in the exhaust emission gaseous. Gasoline engines has high efficiency, which are widely used in vehicles especially for passenger car. Many finding show that use of the higher RON gasoline that with the higher-octane rating can produces better engine performance and emissions. However, using RON higher than engine design rating required not only reduces brake thermal efficiency but also increased brake specific fuel consumption, CO and HC emission.

Therefore, the continue study and finding on the effect of difference fuel formulation to the energy conversion and the consequent emission of exhaust gases from the engine. Although the RON 97 and RON 100 has already being available in the Malaysia market for some period, but there are very few research on engines running for these two different octane gasoline products in the laboratory testing especially in the aspect of the multi-cylinder 4-stroke engine that are more representative and the finding can provide some info for the user of passenger car. The detail study on the effectiveness of the different octane rating and concentration of pollutant gas emitted from exhaust will bring good awareness and better judgement for the car driver to select the most suitable octane gasoline that fulfil the engine requirement. Besides, the analysis in engine performance, exhaust emission and characteristic of combustion will be obvious importance to further refinement in the formulation of advance gasoline that match with the development of the engine specification and combustion system.

1.3 Objectives

1. To study the engine power, thermal efficiency and brake specific fuel consumption base on different octane rating fuel with the part load and full load condition.
2. To study on the concentration of exhaust gas emission from the internal combustion engine, - HC, CO, CO_2 and NO_X when run with the different octane fuel sample.

1.4 Scope of Project

In this research, the gasoline fuel in Malaysia market (RON95, RON97 and RON100) were be test and compare in the performance, combustion and emissions data generate when the engine was running in the part load and full load.

Firstly, the engine test bed is being modification with the connection with all of the gas emission analyser and the data acquisition system that control with the pre-set lab view interface to obtain the more accurate data in the shorter respond time. Then, build on the volumetric fuel measuring burette and the fuel sample RON 95, RON 97 and RON 100 is being prepared. The fuel density and heating value are measure in the laboratory with the technician to obtained basic physiochemistry properties of the fuels sample.

Test run the engine with the engine throttling and the effective loading with the eddy current dynamometer to ensure all the data from the experiment phase can be collection smoothly. At the last and most critical phase is throughout the session of experiment running process, all engine equipment and parameters need to work wisely when the engine performance. Exhaust emission and combustion are being test.

All the data from the experiment are being analyse in detail and the graphs generate being use as the general interpret and evaluation on the engine performance, the relationship in between the data and it corresponding reasoning or effect are being study with the aid of other similar research that done previously. Analyse, discuss and compare the significant outcome from engine performance, exhaust emission and combustion characteristic when the engine being test with the difference octane fuel.

CHAPTER TWO

LITERATURE REVIEW

Malaysia is a rapidly developing country in Asia, where the demand for passenger cars increases every year. The average car production in Malaysia is recorded with 56, 745 units in April 2015[1]. Perodua Myvi remained the best-selling car in Malaysia for eleven consecutive years, between 2006 and 2016[2]. Thus, it is important to study in decrease the engine fuel consumption and to diminish the unwanted exhaust emissions. Gasoline is the most widely used fuel for on-road vehicles worldwide and it has the more than 100-years history as the main fuel for the SI internal combustion engines. Increasing fuel efficiency, changing its attributes and progressing features are the major research areas. The octane number of gasoline is one of the most important parameter that determines the fuel quality. The octane number of the gasoline, which is indicated by the Research octane number (RON), is one of the most important parameters describing the anti-knock quality of fuel that allows higher compression ratio which has a significant impact on the engine efficiency and emissions [3]. The influence of octane number on engine performance has been investigated by several researchers [4-6]. Celikten and Korkmaz [6] investigated the effect of gasoline octane number on the engine performance and emissions. In that work, two different octane ratings (95 and 97 RON) were investigated in a SI engine which requires 95-RON gasoline. The results show that the minimum BSFC was obtained with 95-RON. In addition to this CO and HC emissions were increased, nitrogen oxide (NOx) emissions were decreased with higher RON gasoline. The optimal octane number of an engine is identified according to the engine design and compression ratio. Effect of engine compression ratio on different RON fuels were also have been investigated. For the study on a moderate compression ratio (11:1) engine with RON95 and RON97 gasoline has been done by [5]. Under the same operating conditions, the results showed that RON95 gasoline produced approximately 4.4% higher brake torque, brake power and brake mean effective pressure (BMEP) compared to RON97 gasoline. RON95 gasoline results showed it is 2.3% more fuel efficient when the operations of engine at high speeds and load. In terms of exhaust emissions, the emissions of CO_2, CO and HC were significant lower with RON97 gasoline with the average 7.9%, 36.9% and 20.3% respectively [5]. Another experimental study on a higher compression ratio of 13:1 on Spark ignition direct injection (SIDI) engine has been investigated by [13]. The results showed that a higher RON fuel produced significant torque improvement under high load with this relatively high compression ratio engine. The results showed that the higher RON fuel increased engine torque and efficiency by 13% and 21% respectively compared to the low compression ratio (9.8:1) engine.

Another performance evaluation has conducted by Sudsanguan and Chanchaowna [7] investigated the influence of gasoline octane number on effective power and BSFC. In that research, the engine which requires 91-RON was tested with 91-RON and 95-RON. Results confirmed that the BSFC using 95-RON is higher than that of 91-RON. Additionally, it has been seen in this study that using octane number gasoline higher than the engine requirement did not augment the effective power. Sudsanguan and Chanchaowna further studied with the three different octane ratings of RON91, RON 95 and RON 97 in the engine models that required RON95. Test runs was conducted at two throttle settings of 50% wide open throttle (WOT) and 100% WOT and with a range of engine speeds. It was noticed that an insignificantly changes of the engine power with a slightly higher RON97 or slightly lower RON91 at both of the given throttle position for tested engine. A study, by Sayin and Kilicastan, was reported that octane number plays an important role in exhaust emissions. They tested two different octane gasoline fuels, which are RON91 and RON93; these were conducted in a four-cylinder and four stroke SI engine. The results confirmed that as the octane number was increased from RON91 to RON93, CO emissions increased nearly 5% [8]. Sayin et al. [9] performed the energy and exergy analysis for four cylinders, four stroke gasoline engines. The test engine was fuelled with gasoline fuels of 91, 93 and 95.3 RONs. The results showed the engine will be operated in less energy and exergetic efficiencies when it is powered with a fuel with an octane rating higher than the design rating required. Khalifa et al. [10] carried out the experimental and theoretical investigations to compare the effect of using two gasoline blends octane 91 and octane 95 on the performance and exhaust emissions for SI fuel injection engine. The results proofed the using of octane 91 resulted in small improvements in terms of brake power and lower in brake specific fuel consumption compared to octane 95, and the same trends for exhaust emission for HC and CO. Binjuwair et al. [11] compared experimentally two rates of gasoline RON91 and RON95 from Saudi Arabian with respect to port injection and direct injection engines. The results showed that the engine brake power is higher for RON91 regardless of type of fuel systems. The exhaust emission of NOx of RON91 is higher than gasoline RON95 in most cases. Using RON higher than engine requirement with the original spark timing setting not only reduces brake thermal efficiency but also increased brake specific fuel consumption, CO and HC emission [12].

From the literature review, using the right gasoline requirement by the engine is more beneficial than using a higher or lower-gasoline for different type of engines. Many studies have been conducted to investigate the effects of RON number to engine performance and emissions. Even though many results have been published, the studies are far from exhausted since fuel-engine relation is complex and sensitive to fuel formulations and engine architecture. Each new engine model requires different range of octane number for optimal performance due to tolerances in production and variations in design and the expected driving conditions. At the market end, users are attracted to use higher RON gasoline due to the belief that the higher-octane rating produces better engine performance.

In this thesis, three available gasoline grades from the Malaysia market; RON95, RON 97 and RON 100 were evaluated using a four-cylinder research engine. This will give a good overview on the effects of local RON grade on engine performance and emission of the current domestic car user. Investigating the effects of RON grade on the resulting combustion behaviour and formation of exhaust emission of the engines will be obvious importance to further refinement in the formulation of gasoline to match the development of the engine architecture technology.

<u>Vehicle and gasoline perspective in Malaysia</u>

By the end 2013, there were nearly 23 million on-road vehicles in Malaysia. According to the statistic produced by Malaysia Institute of Road Safety Research (MIROS), vehicle ownership has doubled since 1997 from 2.8 to 1.3 person per vehicle in 2012. Growth of passenger car in Malaysia between 1980 and 2014, nearly 5.5 million of new passenger cars were registered. The total new car increased significantly between this period with high annual growth. Vast majority of passenger cars are fuels with gasoline while the remaining minority, mainly taxis, are powered with diesel.

Since 2015 the gasoline was sold in Malaysia in three grades; RON95, RON97 and RON100. Gasoline price is controlled by the government. In the recent years, the government increased the gasoline price as a result of global oil price hike. price since mid-2009 when the significant price increase started to take place. Since 2009 until May 2018 RON97 price are being increased from MYR1.80/liter to MYR2.47/liter, while price for RON95 only increased from MYR1.75/liter to MYR2.20/liter. The trend of price difference between the gasoline grades where at time this difference went up to 40%. There have been major complain responding to this. People argued that they were denied from using higher grade (thus more power and better fuel economy) gasoline. This has ignited an interest to look into this matter from technical point of view. From historical data, the K3-VI engine represents the biggest fraction of engines used in passenger cars of the studied vehicle owner group to this date. The ownership of the cars using these engines falls mainly to the M40 medium income people, whose main concerns are running and maintenance cost. The Myvi model is the middle of the range and selected for the experimental investigation. The outcomes of this experimental investigation can be used to verify people view about RON number related to fuel economy, performance and emission.

2.1 Combustion and Energy analysis

The energy balance, brake power, thermal efficiency and BSFC are the parameters that measure the engine performance. The energy balance relations for a reacting system can be developed after writing the equations of chemical reactions at equilibrium operations. To simplified this situation, the following assumptions were taken; namely: (i) no water vapor in the combustion; (ii) the air contains 21% oxygen and 79% nitrogen on a molar basis; (iii) only dissociation combustion of hydrocarbon fuel to form NOx; (iv) steady state process; and finally; (v) the changes in kinetic and potential energies are negligible. Therefore, the general form of the equation of chemical reaction is:

$$\text{Stoichiometric}: \quad C_xH_yO_z + \left(x + \frac{y}{4} - z\right)(O_2 + 3.76N_2) \rightarrow xCO_2 + \frac{y}{2}H_2O + 3.76 * \left(x + \frac{y}{4} - z\right)N_2 \quad (1)$$

$$\text{Actual}: \quad C_xH_yO_z + \frac{1}{\phi}\left(x + \frac{y}{4} - z\right)(O_2 + 3.76N_2) \rightarrow bCO_2 + cCO + dH_2O + eC_xH_y + fN_2 + gO_2 + hNO \quad (2)$$

$$\overline{(A/F)}_{Stoichiometric} = 4.76 * \left(x + \frac{y}{4} - z\right) \quad (3)$$

$$\overline{(A/F)}_{actual} = 4.76 * \frac{1}{\phi} * \left(x + \frac{y}{4} - z\right) \quad (4)$$

$$\phi = \frac{\overline{(A/F)}_{Stoichiomertic}}{\overline{(A/F)}_{Actual}} \quad (5)$$

where $\overline{A/F}$ is air fuel ratio on mole basis; ϕ is equivalence ratio.

In all test operations, the following parameters must be known: fuel chemical formulas, fuel and air flow rates and the flow rates of the exhausted emissions as CO2, CO, NO and unburned HC. Consequently, by applying conservation of mass to the carbon, hydrogen, oxygen and nitrogen, the unknown coefficients in Eq. (2) can be determined.

The engine brake power BP (kW) can be computed by:

$$BP = \frac{2 \times \pi \times N \times T}{60,000} \quad (6)$$

where N: is the engine speed (rpm); T: engine torque (N m).

The brake thermal efficiency (η_{th}) is defined as the ratio of the power output to the fuel energy input

$$\eta_{th} = \frac{\dot{W}}{\dot{n}_{fuel}\overline{LHV}} \quad (7)$$

where $\dot{W}$ is power output or brake power (kW); η_{fuel} is fuel mole flow rates; $\overline{LHV}$ is lower heating value on mole basis (kJ/kmole).

In engine tests, the fuel consumption is measured as a flow rate – mass flow per unit time. A more useful parameter is the *specific fuel consumption* (BSFC)- the measurement of fuel flow rate consumes per unit power output. It measures how efficiently an engine is using the fuel supplied to produce work:

$$BSFC(kg/kW.h) = \frac{\dot{m}_f(kg/h)}{BP\ (kW)} \quad (8)$$

Low values of BSFC are obviously desirable. For SI engine typical best value of brake specific fuel consumption are about 270g/ kW.h).

CHAPTER 3

METHODOLOGY

3.1 Test Procedure

In this research, experimental engine testing were used to study the intake valve and fuel consumption of a 4 stroke SI engine. The gasoline engine was powered using by commercial grades with 95, 97 and 100 RON's. The engine specifications details are displayed in Table and the fuel properties of gasoline were obtained from the manufacturer data sheet listed in Table. All fuel tests were performed without any modification on the test engine.

To measure the gasoline engine performance, the engine was coupled to dynamometer. The dynamometer is called eddy current dynamometer, water-cooled which is an electromagnetic load devices using a varying magnetic field in a coil to generate eddy current in the faces of the cooling chambers. The engine being tested spins a disk in the dynamometer. Electrical current passes through coils surrounding the disk, and induces a torque which opposes the rotor direction of rotation. Varying the current varies the load on the engine. It has two types of controllers: speed controlled operation and load controlled operation. The experimental work is set according to the following steps: The engine was warmed up until reaches steady state conditions. The engine reaches the desired torque and speed by controlling the engine throttle angle, and the dynamometer controller simultaneously. The engine speeds are varied from 1000RPM to 4000RPM, at increaments of 1000RPM. At every speed, the torque values are set to be 50% WOT- medium load and the 100% WOT respectively. Once the desired torque and speed are obtained, the fuel consumption value is collected, where difference in the fuel level is recorded.The difference of 40ml of fuel is then divided by the time taken to obtained the volume flow rate of fuel consumed for every second (in ml/sec). The experiment is run twice, and the average of the two fuel consumption values, is used. In this study, the fuel consumption data are collected of the 8 set points (2 division of load and 4 engine speed) for each typical of the octane fuel.

The engine was connected to ECU to provide the controlling for engine operation. After that, the data of engine brake torque, rotational speed, temperatures were collected subsequently and recorded. To change the engine speed from 4000rpm to much more lower desired amount, the load is adjusted. Before any experiment, the engine was regulated to its catalogue values, And the data were recorded after the engine had been stabilized.

The exhaust emissions such as CO, CO_2, unburned HC and NO_X were collected from the engine exhaust pipe and they were measured by KANE gas analyzer. The calibration of each test was done before taking the measurements. Table 3.3 shows the specifications of the exhaust emission equipment.

3.2 Engine Specification

The engine used in this experiment was the K3-VE engine. The engine is a 16-valve double overhead cam engine (DOHC) with dynamic variable valve timing (DVVT). This engine was chosen for this experiment because high number of production on many vehicle types such as Toyota Passo, Daihatsu Sirion and Perodua Myvi. The specification of the engine is shown in below-

Engine specification		
Engine type	4 stroke ; SI engine	
Valve Mechanism	DOHC with DVVT	
Valves	16	Valves
Bore	72.0	mm
Stroke	79.7	mm
Displacement volume	1298	CC
No. of Cylinders	4	
Compression Ratio	10:1	
Maximum Power	63	kW at 6000rpm
Maximum Torque	117	Nm at 3200rpm
Fuel System	Electronic Fuel Injection	

Table 3.1 K3-VE engine technical specifications

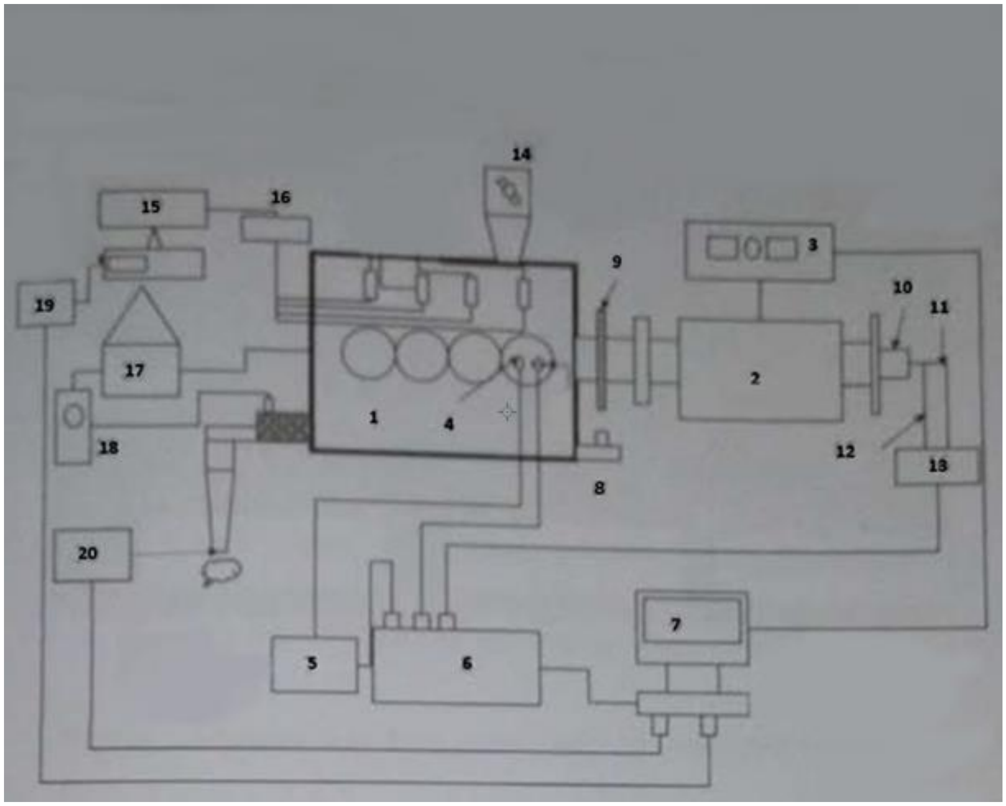

Figure 3.1 Schematic diagram of engine test bed.

1. Test Engine	11. Crank Angle Sensor
2. Dynamometer	12. TDC Sensor
3. Dynamometer Controller	13. Signal Conditioner
4. Pressure Transducer	14. TPS Sensor
5.Charge Amplifier	15. Gasoline Fuel Tank
6.Data Acquisition System	16. Gasoline Filter
7. Computer	17. Cooling Tower
8. Crank Speed pickup	18. Digital Thermocouple
9. Crank 36 tooth gear	19. RS232 Connector
10. Crank Encoder	20. Emissions Analyzer

3.3 Test Fuel

In this project, the experiment study was performed using three (3) fuel samples which involves baseline gasoline RON 95, RON 97 and RON 100. As tabulated in Table ? is the physical chemistry properties of the fuels. The density measurement for all fuels were performed in an engine laboratory and were tested according to the ASTM procedure D1217. The heating value for all fuels were cited from "Comparative analysis of different engine operating parameters for fuel octane number classification" [14]. Obviously, the heating value for RON 100 fuel was higher than that of RON 97 and then followed by the RON 95 fuel[12].

Research Octane Number (RON)			
			
Colour	**yellow**	**Pigment-red**	**Red**
Density (kg/m^3)	**740.0**	**737.7**	**770.6**
***Lower Heating Value (kJ/kg)**	**43,304**	**43,961**	**43,989**

Table.3.2 Properties of the gasoline fuels with different RONs used in test

***Refer from Journal of Advanced Research in Fluid Mechanics and Thermal Sciences- "Influence of Octane Number Rating on Performance, Emission and Combustion Characteristics in Spark Ignition Engine";2018; pg25**

3.4 Emissions Gas Analyser Specification

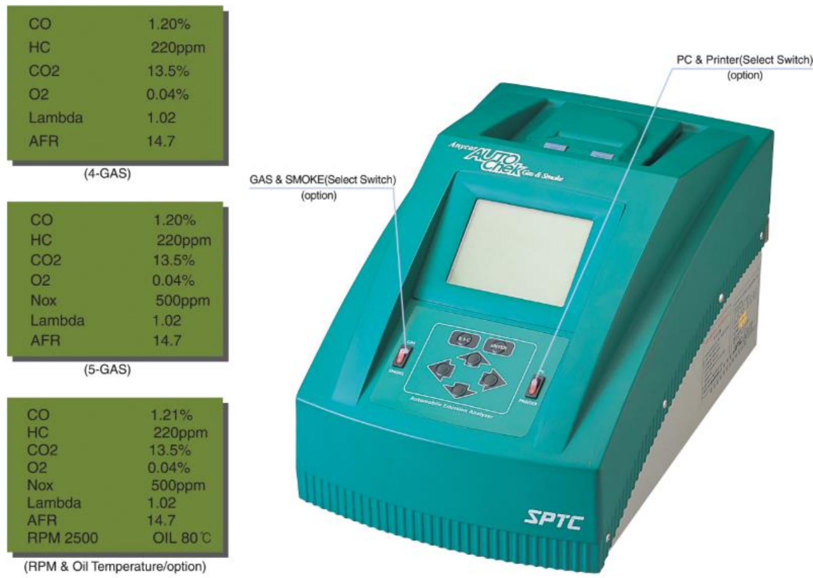

Figure 3.2. Autocheck SPTC 5- Gas Analyzer

	Item	Range	Resolution	Accuracy
Measuring	CO	15.00%	0.01%	±0.02%
	HC	0.00-2000ppm	1ppm	± 4ppm
	CO2	0.00-16.00%	0.01%	± 0.3%
	O2	0.00-25.00%	0.01%	± 0.01%
	NOx	0.00-4000ppm	1ppm	± 20ppm
	LAMBDA (λ)	0.50-3.00	-	-
	AFR	5.00-25.00	-	-
Response Time		Less than 10 seconds		

Table 3.3. Specification of SPTC 5- Gas Analyzer

3.5 Project Flow Chart

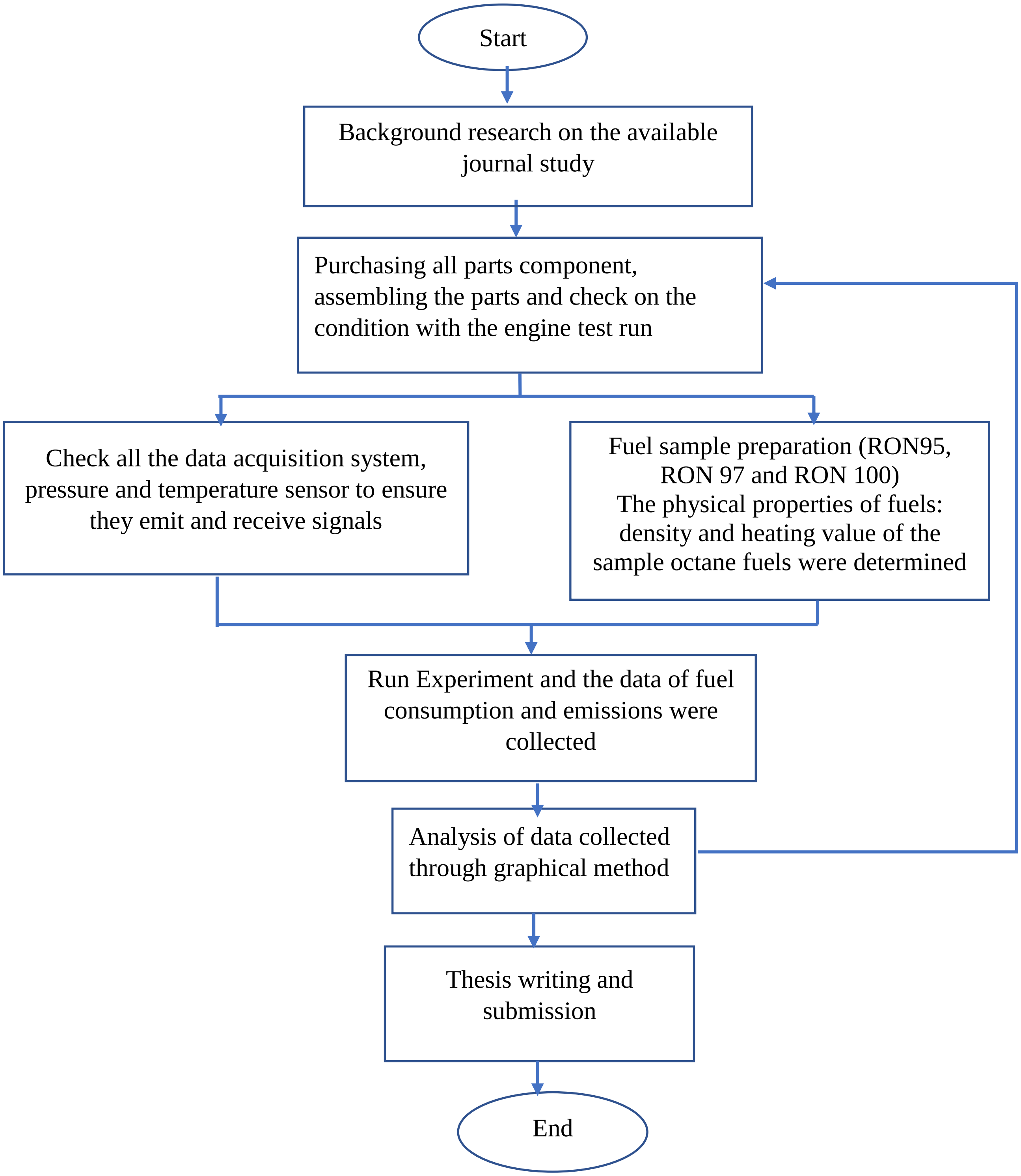

Fig. 3.3. Research flow chart

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Engine performance

4.1.1 Brake Power

The engine performance for the gasoline fuels RON 95, RON 97 and RON 100 were analysed in the form of the maximum brake power output (WOT), brake thermal efficiency and BSFC. **Fig.4.1.** shows the variation of maximum brake power with RON 95, RON 97 & RON 100 versus engine speed at different engine loads. At high torque condition, the brake power reached its peak value at the speed of 4000rpm as the SI engine brake power increases with the engine speed.

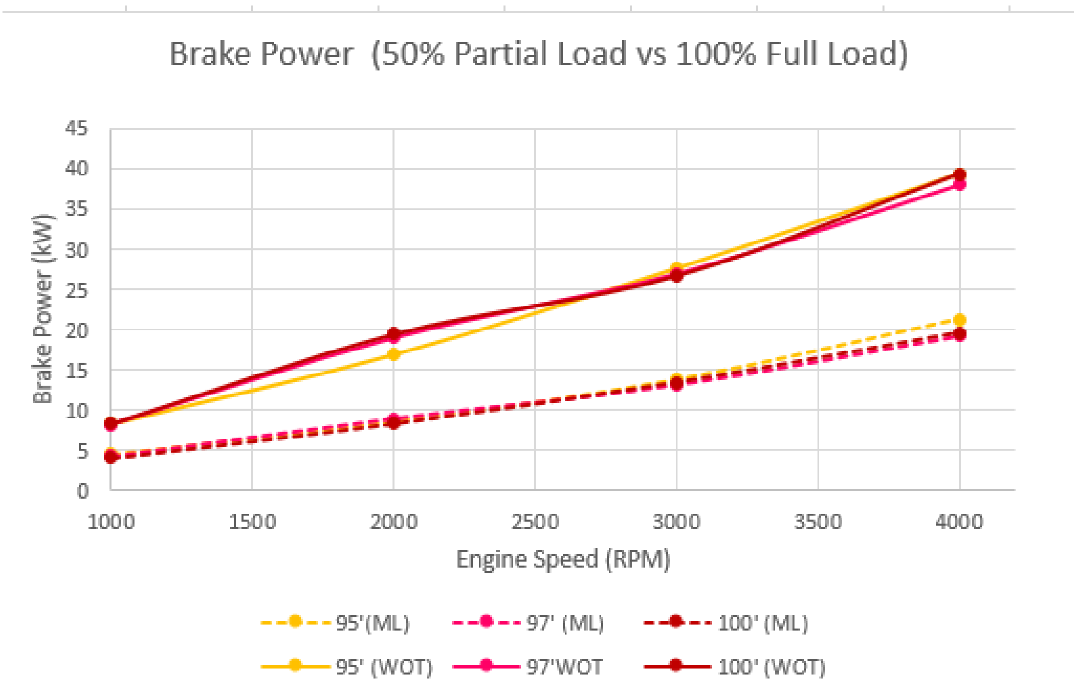

Fig.4. Brake Power of part load and full load against engine speed.

Table 4.1 The maximum power of the K3-VE engine when run with wide open throttle fuelled with different octane rating gasoline

Maximum Power (kW)			
Engine Speed (RPM)	RON 95	RON 97	RON 100
1000	**8.38 (80Nm)**	**8.27 (79Nm)**	**8.38 (80Nm)**
2000	**16.95 (81Nm)**	**19.06 (91Nm)**	**19.48 (93Nm)**
3000	**27.65 (88Nm)**	**27.02 (86Nm)**	**26.70 (85Nm)**
4000	**39.37 (94 Nm)**	**38.12 (91Nm)**	**39.37 (94 Nm)**

In this experiment, the RON 100 shows that it enables for the engine to operate with the relatively higher in torque, this was expected due to the higher heating value of RON 100. The average maximum torque of the engine fuelled with RON 100 increased by 2.6% and 1.5% compared to the RON95 and RON 97 fuels when the engine was run with the full load. However, the generated brake power within the constant engine speed does not vary with the RON's, the maximum brake power that is generated by RON95 and RON 97 is the same, both recorded 39.4 (kW) at 4000rpm. The brake power produces can increase up to the 470% of initial's when changes the engine speed from 1000rpm to 4000rpm.The engine can generate much more higher brake power in the much higher engine speed that claimed by the engine manufacturer. At higher load the engine brake power are increases more significantly. The average of the brake power can further increase by 100.6% when the engine operate change from the part load to the full load operation condition.

Fig.4.1 Brake power against engine speed

4.1.2 General Comparison on Brake Thermal Efficiency and BSFC in part load and full load condition

Fig.4.2 shows the variation of thermal efficiency and BSFC for RON 95, RON 97 and RON 100 versus engine speed with part and full engine loads. Brake thermal efficiency takes a increasing trend when the engine speed increases from 1000RPM to 3000RPM, however the brake thermal efficiency start to decreasing when engine speed increases further to 4000RPM. As known, at lower engine speeds, that will be part of heat to be transferred to the cylinder walls and at the higher engine speed, rapidly increasing of the friction power. As shown in figure, the brake specific fuel consumption BSFC is minima in 3000rpm for this 3 typical RON's. This is because at low engine speeds; the heat loss to the combustion chamber walls is proportionately greater than that at high speed, resulting in poorer combustion efficiency. Therefore, higher fuel consumption is required per unit power produced. At high engine speeds, the friction power will increase at a rapid rate, resulting in a slower increasing in the brake power than the increment of it fuel consumption rate. Hence, this can be state that the selected K3-VI engine are preferable to be operate within the medium engine speed that range between 2000RPM to 3000RPM which can give the better brake thermal efficiency and BSFC within this condition.

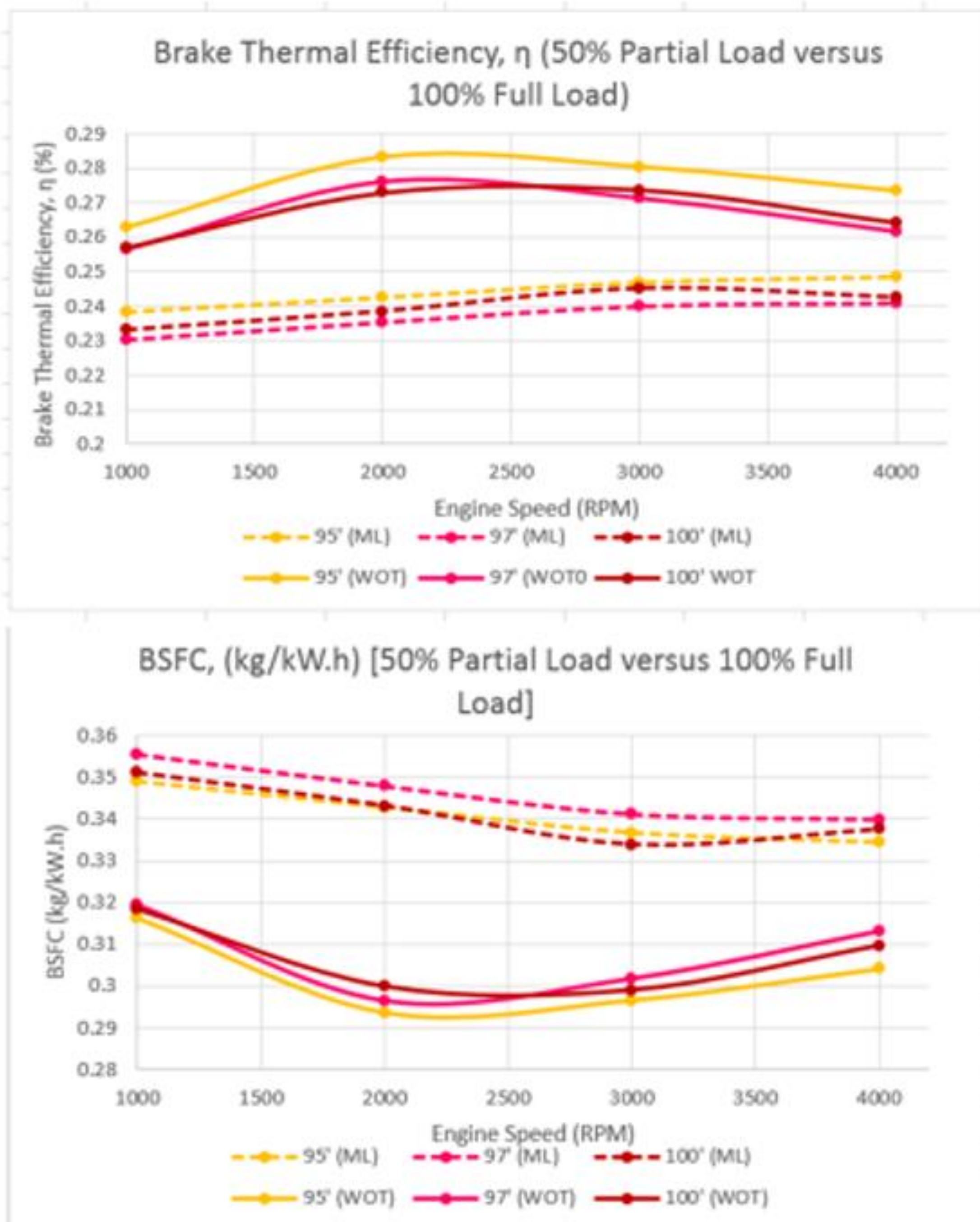

Fig. 4.2 The BTE and BSFC against engine speed(comparison between part load and full load)

Table 4.1. Engine Performance during the part load operation

Part load operation (42N.m~49N.m)						
Octane Rating	Engine Speed (RPM)	Mass flow rate, $\dot{m}_f(\times 10^{-3})$ kg/s	Thermal Power by fuel's (kW)	Engine Brake Power (kW)	Brake Thermal Efficiency, η	Brake Specific Fuel Consumption BSFC (kg/kW.h)
RON 95	1000	0.437	18.91	4.50	23.82%	0.349
	2000	0.818	35.41	8.59	24.25%	0.343
	3000	1.293	55.97	13.82	24.70%	0.337
	4000	1.984	85.92	21.36	24.87%	0.334
RON 97	1000	0.424	18.65	4.29	23.03%	0.356
	2000	0.870	38.27	9.01	23.54%	0.348
	3000	1.250	54.97	13.19	24.01%	0.341
	4000	1.819	79.97	19.27	24.10%	0.340
RON 100	1000	0.398	17.52	4.08	23.31%	0.351
	2000	0.799	35.13	8.38	23.85%	0.343
	3000	1.253	55.12	13.51	24.51%	0.339
	4000	1.846	81.19	19.69	24.25%	0.338

Table 4.2. Engine Performance during the full load operation

Wide Open Throttle, Full load (80N.m~94N.m)						
Octane Rating	Engine Speed (RPM)	Mass flow rate, $\dot{m}_f(\times 10^{-3})$ kg/s	Thermal Power by fuel's (kW)	Engine Brake Power (kW)	Brake Thermal Efficiency, η	Brake Specific Fuel Consumption BSFC (kg/kW.h)
RON 95	1000	0.995	31.88	8.38	26.27%	0.316
	2000	1.869	59.90	16.96	28.32%	0.294
	3000	3.077	98.60	27.65	28.04%	0.296
	4000	4.494	144.02	39.37	27.34%	0.304
RON 97	1000	0.734	32.27	8.27	25.64%	0.319
	2000	1.570	69.00	19.06	27.62%	0.296
	3000	2.265	99.56	27.02	27.14%	0.302
	4000	3.315	145.74	38.18	26.15%	0.313
RON 100	1000	0.741	32.59	8.38	25.70%	0.318
	2000	1.622	71.36	19.48	27.29%	0.300
	3000	2.218	97.55	26.70	27.37%	0.299
	4000	3.387	149.01	39.37	26.43%	0.310

Analysis of Engine Performance Fueled with different RON

Brake Thermal Efficiency

Figure 4.3, show the dependence of thermal efficiency on the engine speed from two different loading condition. The obtained maximum thermal efficiency while using RON 95, RON 97 and RON 100 were 28.32%, 27.62% and 27.37% respectively, whereas the obtained lower brake thermal efficiency was 23.82%, 23.03% and 23.31% respectively. It was shown that the brake thermal efficiency of octane 95 is higher than that of octane 97 and octane 100 at all speeds, because RON 95 possesses lower heating value but produces similar amount of power on average, this indicate the higher efficiency. Besides from RON 95, the break thermal efficiency for RON 100 was found to be higher than for RON97. This was because RON 100 can generate with the higher torque and hence with the slightly larger in brake power with the almost same fuel consumption as RON 97.
When the engine load increased for the full load, the break thermal efficiency of RON 95 shows the higher increment compare to RON 97 and RON 100. This may be as the supportive show that the engine currently specification more compatible to run with the RON 95 fuel, that can give better performance with the combustion of this fuel properties. The further validate need base on the analysis work from the combustion characteristic. The required to the adjustment on the ignition timing due to the increase of octane number, higher efficiency could be obtained.

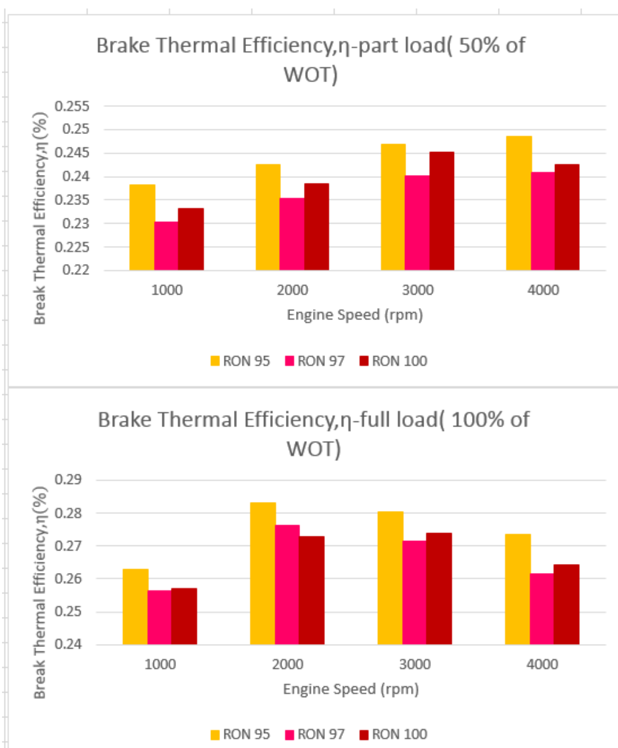

Fig. 4.3 BTE against engine speed