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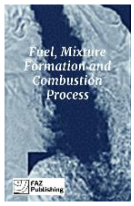

Analysis of the Exhaust Emission from Vehicle Fueled with Variance Research Octane Number Fuel

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Abstract: Transportation sector is one of the main and global sources of pollutants in the atmospheric environment. Vehicle emission control system has found to degrade with the resulting in the increased of emission rates as the vehicles ages. In this research, we present the study on the emission standard for passenger vehicle fuelled with gasoline in global market and analyzing the empirical data for the emission based on Malaysia standard. This research will be conducted with a laboratory setup to analyze the emission production from the passenger vehicle using Mustang Chassis Dynamometer and Bosch Emission Analyzer. The test is conducted using 1.3L engine of Perodua Myvi with RON 95, RON 97 and RON 100 fuel. The emission is acquired during the NEDC drive cycle with different engine speed throughout the drive cycle. Emission of CO, CO_2 and HC produced during the experiment was studied. Generally the result indicated that a higher octane fuel produces lower emission of CO and HC while lower octane fuel produces lower emission of CO_2. The overall result suggested that higher RON number fuel resulting in better emission compared to the lower RON. RON 100 produces the least total amount of CO emission which is 0.06 % followed by RON 95 with 0.142 % and the highest amount of CO is produced by RON 97 with 0.454 % throughout the experiment. RON 100 has the best combustion efficiency which is lead to higher formation of CO_2 for the environment and reduces the production of harmful gas of CO and HC. The result of the experiment that was conducted will be a helpful source of references for those who wish to continue the study on the related subject.

Keywords: Emission, research octane number, gasoline engine

Introduction

Emission of motor vehicle is one of the most significant sources of air pollution in many places and countries. The knowledge on the quantity of air pollution produces by the vehicle fleet is very important and high priorities in many researches, the authorities who are responsible to maintain of the states and the country. In internal combustion engines processes, the actual process is far away from perfect due to many factors. Therefore it is important to have a standardize emission inventories. The age of the vehicle will also lead to the different emission concentrations of pollutants due to many causes and factors of the vehicle.

Malaysia will expect in the increased number of registered vehicle in years to come and this will certainly increases the released of pollution into the atmosphere. According to the Malaysia Department of Environment (MDOE), the emission from the vehicle contributes 97.1% of carbon dioxide (CO_2) and 47% of NO_X release into the atmosphere [1-5]. Vehicle emission testing is important to prevent excessive pollution caused by a vehicle. Testing is important to ensure that the vehicle is not producing excess

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pollution. This can happen for a number of reasons, including a deteriorating exhaust system, problems with engine components, and more. A tailpipe test is usually performed to determine the amount of specific gases vented in the vehicle's exhaust. An on-board diagnostics (OBD) test will be performed to determine the condition of emissions system components. The feature is the gasoline engine is that it uses an external ignition source, normally an electrode spark plug. The spark plug gives a high voltage electrical discharge which ignites the air fuel mixture in the combustion chamber surrounding the spark plug. This can be achieved by the internal mixture formation (gasoline direct injection) and external mixture formation (manifold injection). Figure 1 shows an ideal Otto cycle of gasoline engine.

In internal combustion engine the engine combustion process converts the chemical energy from the fuel in the thermal energy in the combustion chamber. The thermal energy is converted into mechanical energy through piston rod crankshaft system.the combustion reaction between the air and fuel in the chamber is composed by the mixture of different hydrocarbons molecules **[2].** The chemical reaction is simplified as in equation 2.0:

$$\mathbf{C_xH_y + O_2 + N_2 \rightarrow CO_2 + H_2O + CO +} \qquad \textbf{(2.0)}$$

The ideal combustion process should only produce Carbon Dioxide(CO_2) and water vapour (H_2O). A real combustion process produces some other exhaust gases which is the result of incomplete combustion that produces Carbon Monoxide (CO), Unburned Hydrocarbons (HC), and Nitrogen Oxides (NO_X).

Addition to the unavoidable combustion products of CO_2 and water (H_2O), there are also the concentration of combustion products that is very dependant in the composition of the fuel, NO_X, HC, CO are also the main emission from gasoline engine [2]. Formation of soot and sulfur oxides are lesser important in gasoline engine. NO_X require four factors in order to be created, which is oxygen, nitrogen, high temperature and time. The oxygen and nitrogen is determine by the composition in gasoline engine and the available time is defined by the way of engine speed, nitrogen oxides in gasoline engines can only be reduces by low maximum combustion temperature such as ignition retardation or exhaust gas recirculation (EGR) [6].

The results of incomplete combustion will lead to the formation of HC and CO. In rich mixture, enough fuel is provided but in account of lack of oxygen that will lead into the increase in formation of HC and CO [7]. In lean mixture operation with accordingly reduces flame temperature a more intensive extinguishing flame is encountered, above all the area close to the wall, with a resulting increase in HC emission because of the excess oxygen is slightly oxidize, CO emission are nevertheless reduced. The soot formations in the engines are produces in extreme rich condition burn operation only. The sulfur content in the fuel indicates the amount of sulfur oxides formation.

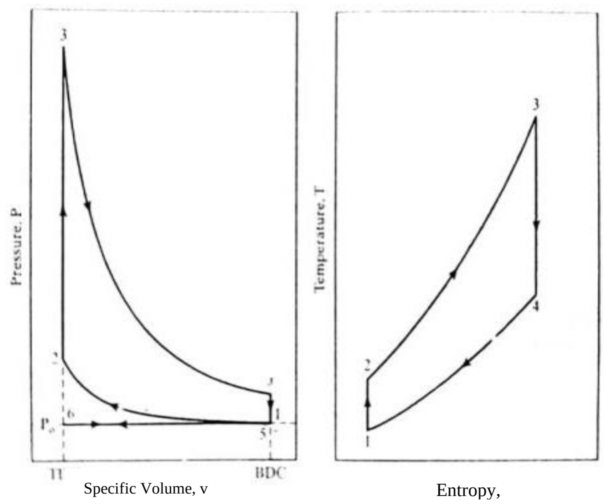

Fig. 1: Ideal Otto Cycle [3]

Air-fuel ratio (AFR) is the mass of air to fuel present in a combustion process such as in an internal combustion engine. The AFR is an important measure for anti-pollution and performance-tuning reasons. If exactly enough air is provided to completely burn all the fuel, the ratio is known as stoichiometric mixture or often abbreviated as stoich [6-8]. In practice this is never quite achieved, due to primarily to the very short time available in internal combustion engine for each combustion cycle. AFR numbers lower than stoichiometric are considered 'rich'.

Rich mixtures are less efficient, but may produce more power and burn cooler, which is kinder on the engine. AFR numbers higher than stoichiometric are considered 'lean'. Lean mixtures are more efficient but may cause engine damage or premature wear and produce higher levels of NO_X.

Octane number is the ability for the gasoline fuel to resist knock. It is define by numerical value of 0 to 100 that describe the behavior of the fuel during the combustion in engine [9]. In determining the octane number, the research octane number and the motor octane number is the primary factor. The octane number is the one of the most important parameter in determining the fuel quality [10].

The exhaust emission of CO, CO_2, and HC for RON 95, RON 97 and RON 100 fuels with respect to various engine speeds varies for each fuel type. The rate of emissions are primarily depend on the octane number of gasoline and engine operating condition such as ignition timing, load, speed and air-fuel ratio [8]. An experimental study on RON 91 and RON 95 produced a result of the emission of CO in RON 91 at higher load are higher than RON 95 while the production of HC produced the same pattern with CO [11-14]. The result of the experiment is shown in Figure 2.

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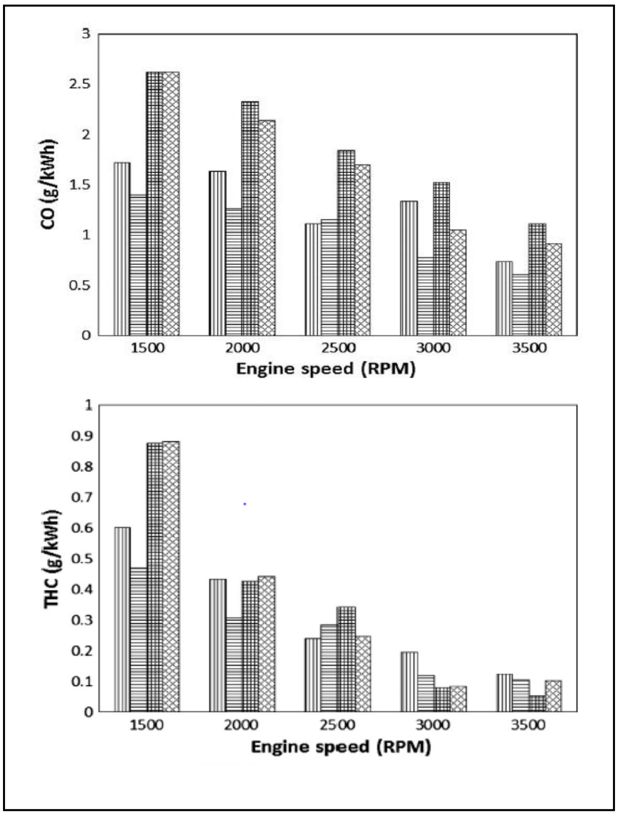

Fig. 2 - The concentrations of CO and THC emissions with engine speed for RON91 and RON 95 [12]

It is possible to categorize fuel sold in Malaysia into three grades RON 95, RON 97 and RON 100 and the fuel prices are regulated by the government, gasoline prices have gradually increased over time. The fuel quality upon grading of the same grade fuels also depending on the branding of the fuel stations. The results of this study produce a good review of the effect of the octane number to the emission of the gasoline engine [15-19]. Experimental parameters were set based on the literature reviews, the objective and the scope. It is followed by the testing method that is compatible to be used for the exhaust gas emission analysis. The data collected is then tabulated as the result based on the conducted experiment.

Experimental set up

The exhaust emission analysis is conducted by using Mustang Dynamometer and Bosch Emission Analyzer (BEA 060) equipment.

Test Fuel

The fuel property is called the octane number or just octane, which describes how well a fuel will or will not self-ignite. This is the numerical scale created by comparing the fuel's self-ignition characteristics to those of the standard fuels in a specific test engine under similar operating conditions [20-23]. The higher a fuel's octane level, the less likely it will self-ignite. Low-compression engines can use fuels with lower octane numbers, but high-compression engines need to use high-octane fuel to avoid self-ignition and knock. Table 1 shows the test condition for octane number measurement.

Table 1: Test Condition for Octane Number Measurement [6]

	RON	MON
Engine Speed (RPM)	600	900
Inlet Air Temperature (°C)	52 (125°F)	149 (300°F)
Coolant Temperature (°C)	100 (212°F)	100
Oil Temperature (°C)	57 (135°C)	57
Ignition Timing	13° bTDC	19°-26° bTDC
Spark Plug Gap (mm)	0.508 (0.020 in.)	0.508
Inlet Air Pressure	Atmospheric Pressure	
Air- Fuel Ratio	Adjusted for maximum knock	
Compression Ratio	Adjusted to get standard knock	

Table 2- Fuel Characteristics

Fuel Type	RON 95	RON 97	RON 100
Color	Yellow	Red	Red
Density at 15°C, kg/m^3	748.4	740.3	770.1
Research Octane Number	95	97	100
N-heptane %	5	3	0
Distillation, °C			
Initial Boiling Point	34.0	38.0	32.0
10% Evaporated	51.0	54.0	52.0
50% Evaporated	84.0	79.0	98.0
90% Evaporated	142.0	163.0	148.0
Final Boiling Point	178.0	195.0	181.0
Vapor Pressure, kPa	64.0	57.5	64.8

The fuel octane number is determined in a test engine and is calculated by comparing it witha mixture of iso-cotane and standard heptane which would have the same anti-knocking capacity as the fuel being tested: the proportion, by volume of iso-octane in that mixture is the fuel octane number. The characteristics of each fuel is shown in Table 2.

For example gasoline with the same kncocking characteristic as mixtuer of 90% iso-octane and 10% heptane combination would have an octane rating of 90 (RON 95). RON 95 means 95% of the contents are octane and the rest are pentane. On the other hand for RON 97, only 3% pentane and the rest is octane and RON 100 is a fully content of 100% octane. Since some fuels are more knock resistant than iso-octane, the definition has been extended to allow for octane numbers higher than 100.

Bosch Emission Analyzer

A tailpipe test is performed to determine the amount of specific gases vented in the vehicle's exhaust. An on-board diagnostics (OBD) test will be performed to determine the condition of emissions system components. Bosch Emission Analyzer consists of different parts used for various testing such as gasoline exhaust probe, diesel exhaust probe for cars and engine temperature sensor. This set of emission analysis equipment is combined with KTS 515 Anthracite. For this emission test that we carry out, we only use the gasoline exhaust probe as our test cars uses gasoline engines and also the KTS 515 anthracite. Bosch Emission Analyzer 060 was used in this emission study [13-18].

Fig. 2 - Bosch Emission Analyzer & KTS 515

The exhaust gas analyzer BEA 060 in Figure 3 permits the user friendly performance of exhaust gas measurement on gasoline vehicle. The range of the test specimens includes the entire spectrum of gasoline road vehicles on which emission measurement have to be taken during workshop inspections, both to comply with legal requirements and the purpose of localizing and rectifying the fault. The BEA 060 can be used as a stand-alone unit and with BEA 550.

Mustang Chassis Dynamometer

Mustang Chassis Dynamometer is robust equipment which is application is to apply load on the test vehicle. The Mustang Chassis Dynamometer is consolidated assembly of electrical/electronic, mechanical and electromechanical sub systems which operates together for the purpose of providing the ability to simulate actual road conditions while the vehicle is tested in a safe and confined space of the test centre.

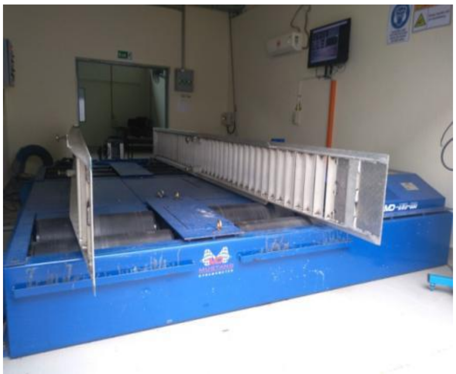

Fig. 3 - Mustang Chassis Dynamometer

Additionally, the Mustang Chassis Dynamometer which is shown in Figure 4 provides the vehicle performance information during the test, this ability of the equipment will also enable the user to install test instruments and diagnostic equipment to the test vehicle's engine to monitor the engine performance.

The Chassis Dynamometer has become a significant asset in the areas of Emissions Testing, Fault Diagnosis, Performance Engineering and Test Engineering all over the world. Chassis Dynamometer can perform a wide variety of vehicle testing as follows:

- Vehicle Heating & Cooling Systems
- Engine Performance and Evaluation
- Drive Train Component Evaluation
- Transmission Components
- Tire Testing
- Fuel Efficiency
- Failure Analysis
- Auxiliary Components

NEDC Drive Cycle

The entire test is run from the driving cycle based on the New European Driving Cycle (NEDC) for standardize testing procedures to provide instantaneous driving conditions required to overcome the aerodynamic, rolling, grade and inertia resistance [14-18]. This driving cycle is used for the evaluation of fuel consumption and pollutant emission from light vehicles with internal combustion engine. The drive cycle consist of three combinations of drive cycles. It is the combination of two different driving cycles: Urban Driving

Cycle (UDC) and Extra-Urban Driving Cycle (EUDC) and the whole dive cycle is the combination of both cycles of 4x UDC and 1x EUDC as in Figure 5.

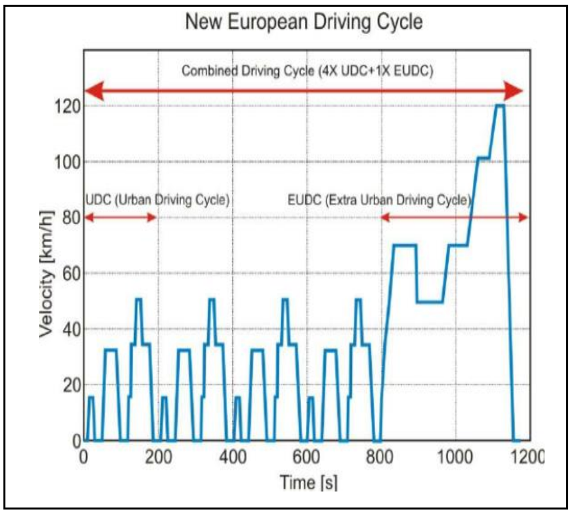

Figure 4: New European Driving Cycle [12]

The entire driving cycle total time is 1180 seconds including urban driving cycles (UDCs) and extra-urban driving cycles (EUDCs). The first 780 seconds was the UDC with the maximum speed of 50 km/h, and the next 400 seconds was the EUDC with the maximum speed of 120 km/h [15-19].

Test Vehicle

The test vehicle is run by spark ignition engine fuelled with gasoline. This car has four piston movements over two engine revolutions for each cycle. The Perodua Myvi as shown in Figure 6 is a B-segment car produced by Malaysian manufacturer Perodua since 2005. Table 3 shows the specifications of the test vehicle.

Fig. 6 - Perodua Myvi 1.3L

Table 3: Vehicle Specifications

Items	Specifications
Overall Length / width/ height	3895/1735/1515
Kerb weight (kg)	930
Engine Type	1NR-VE, 4 cylinders, DOHC with Dual VVT-i
Total displacement	1298 cm^3
Fuel Tank Capacity (L)	36
Fuel Consumption (km/l)	20.5
Maximum Torque	64 kW at 6000 rpm
Minimum Torque	116 Nm at 3200 rpm
Mileage at start (km)	862
Transmission	Manual

Test Procedures

The experimental procedures are run using Mustang Chassis Dynamometer and the gas emission is acquired by using the BEA 060. The vehicle in run on the Mustang Chassis Dynamometer to acquired the drivers trace from the dynamometer which is NEDC drive trace. The emission is acquired during the NEDC drive cycle with different engine speed throughout the drive cycle. During the test all the data is taken after the engine temperature has reach between 90°C to 93°C. Figure 7 shows the experimental setup.

Figure 7: Experimental Setup

The procedures for the experiment were conducted starting with turning on the isolators to power up the dyne panel and computer system. Launch PowerDynePC software. From the menu bar of the software, click on the ‘lift’ menu and select the ‘up’ option to raise the platform and restrain the roller as shown in Figure 8.

Fig. 8 - PowerDynePC's software homepage

Prepared the experimental setup by driving the test vehicle onto the dynamometer and ensure the drive wheels are appropriately placed in between the rollers. As the vehicle completely on the dynamometer, again from the software select the 'lift' menu and click on the 'down' option to release the restrain platform. Put together the four sets of restraining belt given. Engage two of the belt at the front side of the test vehicle (cross with each other) and another two at the rear side of the vehicle (can be crossed or parallel).

Figure 9: Vehicle Setup on dynamometer

Slightly tighten the belt after engaging them in the car. Rotate the roller by pressing the throttle at a minimum speed. The car should align itself into a balanced position. Then tighten the restraining belts and properly secure them by using the locks. As the vehicle fixed on the dynamometer as in Figure 9, go to the PowerDynePC's menu bar, click on the 'test' menu. Select the emission option and go to 'Driver's Trace (IM-240/FTP/etc)' option. The desired emission driving profile should be selected from the 'File > Load Trace' menu option (refer Figure 10). Select the desired drive cycle from the existing file (NEDC Drive Cycle).

Fig. 10 - Emission testing menu selection

The Bosch Emission Analyzer 550 (BEA) was set up in the workshop by connecting with the plug. The adapter cables supplied connect for speed measurement and the oil temperature sensor to the BEA 550 with the laptop to acquire the parameters during testing. After that, System Soft BEA-AU-OBD was opened and checked to make sure the device can interface with the BEA 550 to be set and a leak test will be initiated as the software of BEA was started as in Figure 12. The On-Board Diagnostics (OBD) was plugged in to the Myvi car before the ignition of the car was started. Finally, the BEA 550 and OBD were connected to the Myvi car via Bluetooth. The required data will be displayed if the KTS 515 and the Bosch Emission Analyzer is correctly connected. The diagnosis option is selected from the BEA software and Engine/gas value select menu is used to collect the result.

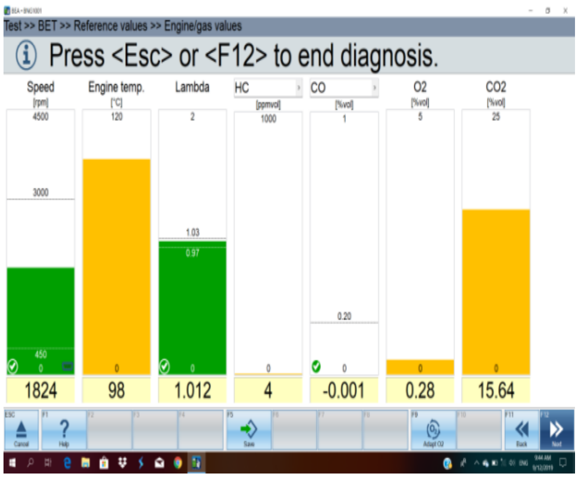

Fig. 11- Reading of engine values from BEA software

Click on the 'Start Test' to run the emission test from the PowerDynePC software. Drive the vehicle so that the speed indicating arrow stays between the two red lines, or very near the green line. As in Figure 11, the test displays the speed profile that is required for the driver to follow in order to perform the emissions test. Figure 12 shows NEDC drive cycle in the PowerDynePC software.

Fig. 12 - NEDC driver's trace

Emission result from the BEA is collected manually by saving the desired result at different engine speed. The main priority is the value of RPM which is near every 500 rpm started from 1000 rpm until 4000 rpm [16]. As the desired data collected the from the emission analyzer and saved the test was run again with same fuel for 2 more times to acquired the average reading of emission. For different RON fuel the vehicle was run until the fuel used completely and then the fuel is filled with RON 97 and followed by RON 100. The vehicle is run on the dynamometer for a while to make sure the residue fuel in fuel line is completely used. The steps of collecting data were repeated from step 14 until step 18 with RON 97 and RON 100 fuel.

4. **Results and Discussions**

The result of exhaust emission of CO_2, CO and HC for RON 95, RON 97 and RON 100 fuels to various engine speeds are shown in the Figures 14 to 16. Formation of CO occur when there is not enough oxygen to convert all the carbon into CO_2 and the unburned fuel will end up as CO. Formation of CO is resulted from incomplete oxidation of fuel carbon when insufficient oxygen is available to completely oxidize the fuel. CO rises significantly as the AFR ratio decreases below stoichiometric air-fuel ratio [11].

CO emission tends to decrease as the engine speed increases [11]. As the engine speed increase, it increases the volumetric efficiency and boosting turbulence flow in the combustion chamber, therefore the combustion improved.

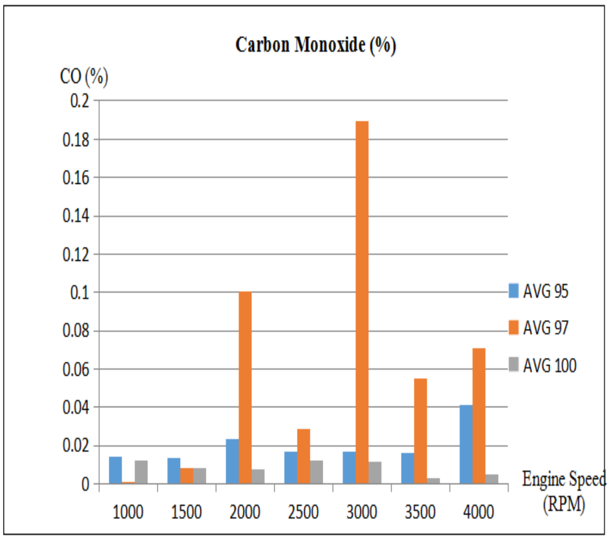

Fig. 13 - CO emission against engine speed

The increases in RON number shows that the least amount of CO emission produced. RON 100 produces the least total amount of CO emission which is 0.06 % followed by RON 95 with 0.142 % and the highest amount of CO is produced by RON 97 with 0.454 % throughout the experiment. Emission of CO in different RON fuel proves that RON 100 undergoing better combustion process as it produces the least amount of CO. Combustion process in RON95 and RON97 is less efficient compared to RON100.

Production of CO_2 in engine combustion is related to the improving in the combustion efficiency that leads to higher CO_2 production. Production of CO_2 and CO is related to each other. Figure 13 it show the production of CO decrease as the combustion efficiency increase as the fuel burned better and the combustion converts the fuel into CO_2 thus it decreases the production of CO.

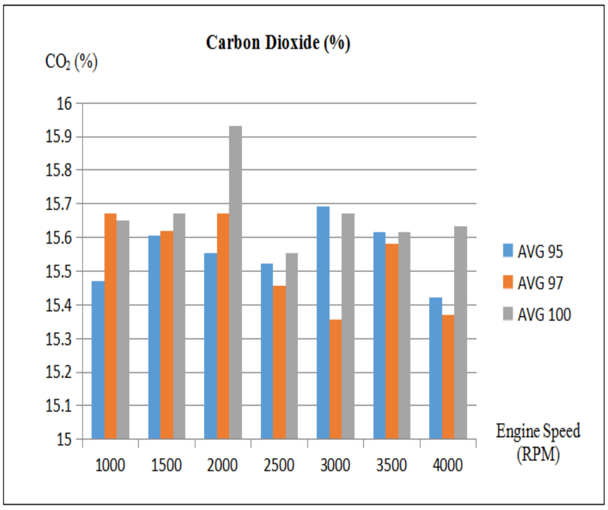

Fig. 14 - CO_2 emission against engine speed

The trend form in the CO_2 formation increases with the greater RON fuel as in Figure 14. This is related to the

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improved in the combustion efficiency that helps the oxidation of the carbon particles to form CO_2. RON 100 is again proven that it has a better fuel combustion efficiency compared to RON 95 and RON 97. The inconsistent reading of CO_2 in RON 95 and RON 97 is mainly due to the condition AFR during the combustion. The fuel-rich combustion produces less CO_2 as the fuel or carbon particles do not completely react with the oxygen to produce CO_2 as there is a low concentration of oxygen in fuel-rich combustion process. The formation of CO_2 in RON 100 during 2000 rpm engine speed is the highest as at the condition the AFR in the combustion chamber is nearly stoichiometric that helps a better oxidation of carbon particles. The formation of HC in the exhaust emission is mainly resulted from the unburned fuels, incomplete combustion and the presence of lubricating engine oil in fuel or combustion chamber. It is originated when fuel escapes combustion due to several processes such as flame quenching in narrow passages present in the combustion chamber and incomplete oxidation fuel that is trapped or absorbed in oil film or deposits. The reading of HC of each RON at 3000 rpm to 3500 rpm is observed to be higher compared to other engine speed throughout the experiment. The causes of the higher reading in the formation of HC at 3000 rpm to 3500 rpm are mainly due to very lean mixture. The incomplete mixing of air and fuel causes some fuel particles does not mix with the oxygen to react with which is then lead to the HC formation. The incomplete or imperfect combustion in the combustion chamber is the main reason in the formation of HC even if the fuel and air entering the chamber in ideal stoichiometric mixture, perfect combustion does not occur and some HC will end up in the exhaust

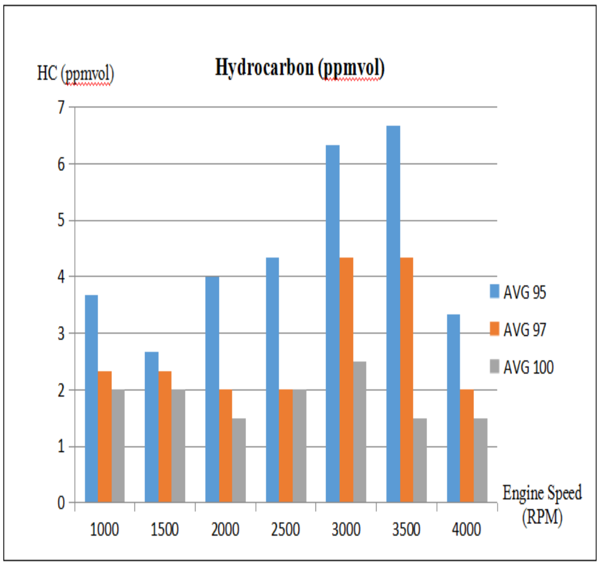

Fig. 15 - HC emission against engine speed

During fuel-rich mixture the concentration of fuel is higher compared to oxygen that causes not enough oxygen to react with the all the carbon, resulting in the higher levels of formation of HC. The formation of HC in each fuel is improved with greater RON number as shown in the Figure 15. Formation of HC in RON 100 shows the lowest value at each engine speed throughout the experiment. The improvement in volumetric efficiency promote more homogeneous mixture in the combustion chamber, therefore it can be observed that the HC emission is reduced.

5. Conclusions

This research is achieved to study the emission of passenger vehicle fueled with gasoline. The experiment is conducted by using a Perodua Myvi vehicle which is a gasoline fueled passenger vehicle. Different number of RON is proven to affect the rate of emission produced by the engine. The engine is tested using different RON number fuel which is RON 95, RON 97 and RON 100. Emission of CO, CO_2 and HC produced during the experiment was studied.

The increases in RON number shows that the least amount of CO emission produced. RON 100 produces the least total amount of CO emission which is 0.06 % followed by RON 95 with 0.142 % and the highest amount of CO is produced by RON 97 with 0.454 % throughout the experiment. The trend form in the CO2 formation increases with the greater RON fuel. This is related to the improved in the combustion efficiency that helps the oxidation of the carbon particles to form CO2. RON 100 is again proven that it has a better fuel combustion efficiency compared to RON 95 and RON 97. The formation of HC in each fuel is improved with greater RON number. Formation of HC in RON 100 shows the lowest value at each engine speed throughout the experiment and lowest compared to RON 95 and RON 97.

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