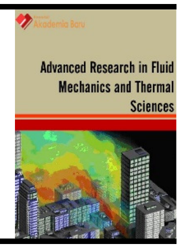
Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 45, Issue 1 (2018) 22-34

Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Influence of Octane Number Rating on Performance, Emission and Combustion Characteristics in Spark Ignition Engine

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ARTICLE INFO

Article history:
Received 12 March 2018
Received in revised form 27 April 2018
Accepted 30 April 2018
Available online 17 May 2018

ABSTRACT

Recently, the world crude oil price grows continuously and the increase in gasoline price is affected the gasoline consumer. In Malaysia, the gasoline fuel price per litre for RON 97 and RON 100 are higher than RON 95 at all times. In general, the influence of different research octane number (RON) fuels on engine performance remains unknown to the public. This research aimed to experimentally study the effect of RON of the commercially available gasoline fuels on the performance, emission and combustion characteristic of a spark ignition (SI) engine. Gasoline fuels with RON 97 and RON 100 were tested and benchmarked with RON 95 as baseline on a single-cylinder, air cooled, four-stroke spark-ignition gasoline engine. The engine speed was varied from 1600 to 3200 rpm with 400 rpm increment under full throttle conditions. Generally, the results indicated that higher octane fuel reduced the emission of CO and HC, while lower octane fuels caused a lower emission of CO_2 and NO_x. Besides, a higher cylinder pressure and heat release rate were achieved with lower octane fuel of RON95. Overall, the experimental results suggested that a moderate octane number fuel of RON 97 is a good candidate for operating on this engine with consideration is being focused on the balance between performance, emissions and combustion characteristics.

Keywords:
RON, combustion, NO_x, SI engine

1. Introduction

In the heat of the fuel issues, consumers are concerned about the difference in the quality of fuel, affecting the performance of the cars in the long run. While most would shy away from using premium fuel to save a few cents from their pockets, some cannot get rid of the nagging fear that lower quality fuel could bring damage to their car's engine [1]. Research Octane Number (RON), is the standard measure of the performance of fuel. Higher octane number shows that the fuel can withstand higher compression without knocking or detonation prematurely. However, with different companies producing different kinds of fuels with different type of additives, added with different kinds of cars on the road with their own personal configuration by the manufacturer, these RON values seems very uncertain [2]. A lot of unofficial experiments conducted to test the best fuel to be

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used on common cars, yet showing inconsistent result due to different driving styles, different engine configurations, etc. Even the same model of car might be producing different results due to different driving style.

The formulation of gasoline is mainly indexed with respect to octane number. Octane number of gasoline is the important parameters in determining the fuel quality. Besides, engine performance and exhaust emission are also affected by the octane number [3]. Essentially, RON scale is based on two paraffinic hydrocarbons which is define the two end of the scale; iso-octane is assigned the value of 100 and n- heptane the value of zero. The two components from the blend are referred to primary reference (PRF) which is define the intermediate points in the RON scale [4]. Thus theoretically, RON 95, RON 97 and RON 100 are blend of 95%, 97% and 100% iso-octane with 5%, 3% and 0% n-heptane by volume, respectively. In addition, the design of engine and compression ratio are the main factors determining the octane number of gasoline required by an engine. Besides, the other factors can also influence the required RON, such as weather, driving condition and mechanical conditions of the engine [5, 6]. Generally, a high quality of gasoline has the following properties; rapid warm up, clean-burning characteristic, anti-rust, oxidation, carburetor icing and engine knock. In addition, the ability of gasoline resistance to detonation is measured by its octane number. Therefore, the higher octane number of gasoline will eliminate knocking. Besides, nowadays, gasoline fuel with lead additives is no longer used in most of the country due to their hazardous effect to the environment [7]. On the exhaust emissions aspects, the formation of emissions from internal combustion engine are mainly consist of carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbon (HC) and nitrogen oxides (NO_x). In fact, the CO and HC are the main pollutants by the internal combustion (IC) engine due to the incomplete combustion of hydrocarbon fuels during the combustion process. The level of emissions are mainly depend on the octane number of gasoline and engine operating condition such as ignition timing, load, speed and the air-fuel ratio. The influence of octane number of gasoline on performance and emission in response to SI engine have been investigated and published by many researchers. For the parametric study on the effect of engine compression ratio on different RON fuels, a few researchers have been investigated. An experimental study on a low compression ratio (8:1) engine with fuelled with RON 91 and RON 95 gasoline fuels has been carried out by [8]. The results indicated that RON 91 gasoline produced approximately 4.2%-4.8% more power and 5.6% less brake specific fuel consumption (BSFC) compared to RON 95 gasoline while 3.4% and 5.7% lower HC and CO respectively. It can be concluded that the octane number of gasoline used higher than the engine requirement, it will cause a reduction of the engine performance and increased in exhaust emissions. Another similar experimental investigation on a moderate compression ratio (11:1) engine with RON 95 and RON 97 gasoline has been done by [9]. Under the same operating conditions, the results showed that RON 95 gasoline produced approximately 4.4% higher brake torque, brake power and brake mean effective pressure (BMEP) compared to RON 97 gasoline. For BSFC with RON 95 gasoline, the results showed that RON 95 gasoline is 2.3% higher than RON 97 gasoline but RON 95 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 higher with RON 95 gasoline with the average 7.9%, 36.9% and 20.3% respectively but RON 95 gasoline produced 7.7% lower NO_x emissions compared to RON 97 gasoline. Another experimental study on a higher compression ratio of 13:1 on Spark ignition direct injection (SIDI) engine has been investigated by [10]. The results showed that a higher RON fuel produced significant torque improvement under high load. The higher RON fuel increased engine torque and efficiency by 13% and 21% respectively compared to the low compression ratio (9.8:1) engine. In another research, RON 91 and RON 95 gasoline fuels have been studied on a compression ratio (10:1) engine. The experimental results showed that the brake power of the engine is higher with RON 91 which is due to higher heating value. The brake thermal efficiency was higher with RON 91 gasoline. With higher engine load, the brake specific fuel consumption decreases and it increases with the increasing of engine speed. At high speed and load condition, the BSFC of RON 91 gasoline is higher than RON 95 gasoline. In terms of exhaust emissions, RON 91 gasoline produced higher NOx emissions compared to RON 95 except with direct injection (DI) system. Besides, the CO emissions with RON 91 are higher at higher load compared to RON 95 gasoline. Moreover, the RON 91 gasoline produced higher HC emission compared to RON 95 gasoline [11].

Recently, another experiment study on a compression ratio (11:1) engine with RON 95, RON 97 and RON 102 has been studied by [12]. The engine was operated at a constant throttle position of 18% and with constant speed between 1000 rpm to 3500 rpm with 500 rpm increment. The results with RON 102 gasoline showed that the average torque of the engine increased by 13% and 6% compared to the RON 95 and RON 97, respectively. The highest output brake power produced by using RON 102 gasoline, followed by RON 97 and RON 95. The brake thermal efficiency for RON 97 and RON 102 gasoline improved at an average of 12% compared to RON 95 gasoline. RON 102 fuel produced the highest CO emission compared to RON 97 and RON 95 fuel at an average of 12.4% and 17% respectively. For the emission of NO_x, RON 102 fuel reduced an average of 34% and 40% compared to the RON 95 and RON 97 fuel respectively. Moreover, the RON 102 fuel produced the highest HC emission, followed by RON 97 and RON 95. Another study by Ali Alahmer *et al.*, [13] use 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 performance of the engine. An experimental study on engine response to lower octane number of gasoline than an engine requirement. The results showed that decrease in CO emissions and increase in unburned HC emissions with higher octane number (RON 95) compared to lower octane number (RON 91) [14].

Gasoline fuel sold in Malaysia can be categorized into three grades; RON95, RON97, and RON 100, and fuel price are regulated by the government, gasoline price has been gradually increased over time. Besides, for the same grade of fuel, there are also issues of fuel quality depending upon the branding of the gas station. This has resulted in escalated dissatisfaction among the mass. Through the present study, the performance, emissions and combustion characteristics of three different RON level of commercially available gasoline fuels were evaluated in a single cylinder engine. The outcome of this research study will provide a good overview on the effects gasoline octane number on engine performance, formation of exhaust emission and combustion behaviour.

2. Experimental Methodology

2.1 Apparatus Setup

In this investigation, the experiments were performed on a MITSUBISHI-GM131P single cylinder, air cooled and four-stroke spark-ignition gasoline engine. The engine specification is presented in Table 1. Figure 1 shows the schematic diagram of the experimental setup. A ST-3 Model A.C. Synchronous type engine dynamometer with the maximum absorbing mechanical power of 5 kW were employed to hold the speed and load of the engine. Fuel consumption was measured using a 25ml capacity burette and the rate of consumption was recorded with a stop watch. To perform of the analysis of combustion, a Kistler spark plug adapter type piezoelectric pressure sensor was employed. The output current signal was connected to a charge amplifier and the signal input to the Dewe-43 DEWESOFT data acquisition system is precisely recorded by synchronizing the signal with the 60 pulses per revolution gear tooth angle sensor. Besides, an index pick up sensor is used to supply the zero pulse to reset the measurement when a Z pulse is recognized. For each run, a total of 100 consecutive combustion cycles were stored and processed with DEWEsoft combustion analyser software. Besides, the gas analyser of AUTOCHEK was employed to detect CO, HC, CO_2, O_2 and NO_x level in exhaust.

Table 1
Specifications of the MITSUBUSHI-GM131P engine

Descriptions	Parameter
Type	Air-cooled, 4 stroke, OHV (overhead valve) engine
Number of cylinder	1
Number of cycles	4
Engine displacement (cm^3)	126
Bore (mm)	62
Stroke (mm)	42
Max rated power (kW/rpm)	3.9/4000

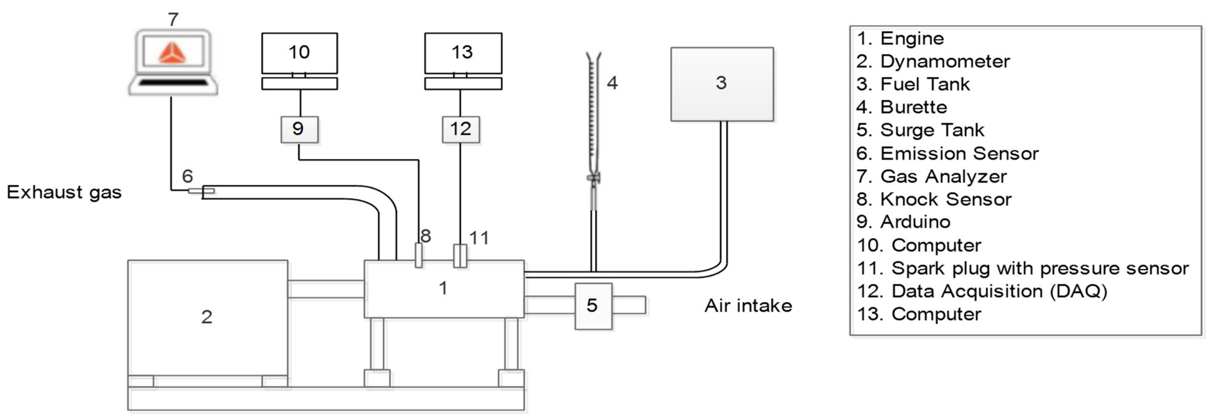


Fig. 1. Schematic diagram of the experimental set up.

2.2 Test Fuel

In this paper, the experimental study was performed using three (3) fuel samples which includes baseline gasoline RON 95, RON 97 and RON 100. As tabulated in Table 2 is the primary physicochemical properties of the fuels. The density analysis for all fuels were performed in an accredited laboratory and were tested according to the ASTM procedure D1217. Besides, the octane level was measured with a SHATOX SX-200 portable octane meter. The result of octane level was tested according to ASTM D2699-86 method and it can be seen that the RON 100 fuel has a greater octane level than RON 97 and RON 95 fuels. In addition, the heating value for all fuels were cited from [15]. Clearly, the heating value for RON 100 fuel was greater than that of RON 97 and followed by RON 95 fuel.

Table 2
Fuel properties

Fuel type	Octane level	Density @ 25°C, g/ml	Heating value (MJ/kg)
RON 95	95.3	0.7400	43.304
RON 97	98.6	0.7377	43.961
RON 100	100.1	0.7706	43.989

2.3 Test Procedure

The test fuels were prepared in the laboratory prior to the engine test. The initial step is to switch on all the devices (i.e. computer, data acquisition system, gas emission analyser and exhaust ventilation system). This was followed by filling the fuel tank with the test fuel. After that, the in-line valve was opened to allow gasoline flow to the burette and test engine. No modifications were made to the test engine for all tests and the tests were performed under steady-state condition with sufficiently warmed up exhaust gas temperature. For improved accuracy, each test point was repeated twice to obtain the average reading. The repeatability is matched over 95% for each test. This indicates that effects on performance, emissions and combustion characteristics can be reliably analysed from this test system. Besides, for performance test, the engine is set to operate under full load with engine speed vary in between 1600 to 3200 rpm and with 400 rpm increments. Besides, a volumetric type fuel flow meter was used to determine the quantity of fuel supply to the engine. Besides, a *K*-type thermocouple was employed to measure the temperature of exhaust gas.

3. Results and Discussions

3.1 Engine Performance

For engine performance analysis, the engine was operated at full load condition with five levels of engine speeds from 1,600 to 3,200 rpm with 400 rpm step. Figure 2 shows the variations in engine torque with response to different test fuels. The general trend indicated that the maximum engine torque was happened at 2,400 rpm for all fuel blends. With greater RON of the gasoline fuel, the common trend shows that the engine torque is always higher than that of baseline RON 95 across all tested speeds. This increment was expected because of the higher heating value of the RON 100 and RON 97 fuels compared to that of RON 95 fuel, as shown in Table 2. Furthermore, the engine power for various fuels at full load conditions as indicated in Fig. 3. As can be observed, maximum brake power of 2.2 kW was generated with baseline RON 95 fuel at 3,200 rpm. Besides, it was discovered that the brake power of RON 97 and RON 100 are higher than RON 95 fuel across all engine speeds.

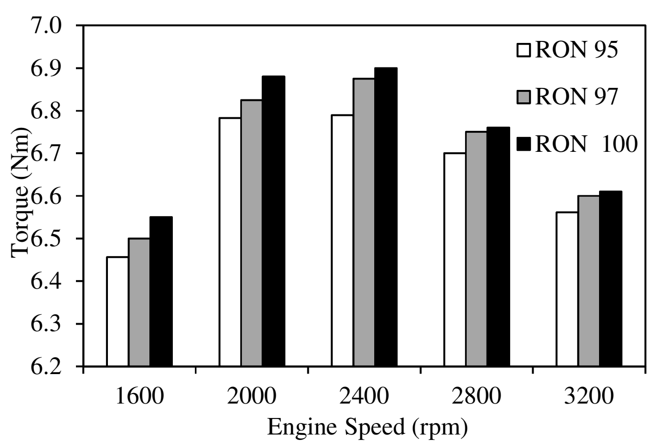


Fig. 2. Torque against engine speed

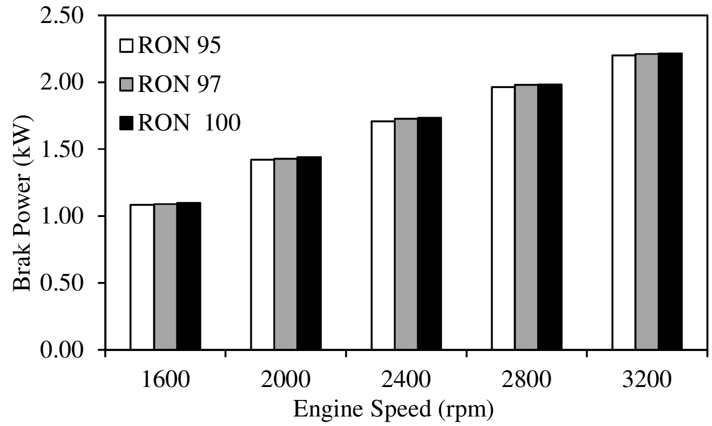


Fig. 3. Brake power against engine speed

Figure 4 reveals the changes in brake specific fuel consumption (BSFC) with response to engine speeds for all fuels. With respect to RON 97, the results indicated that the BSFC of RON 95 and RON 100 is always higher across all engine speeds. This can be related with the combination effects of relatively higher heating value and lower density of RON 97 fuel, which were the main culprits behind this issue. Thus, the RON 97 resulted in lower BSFC compared to RON 95 and RON 100.

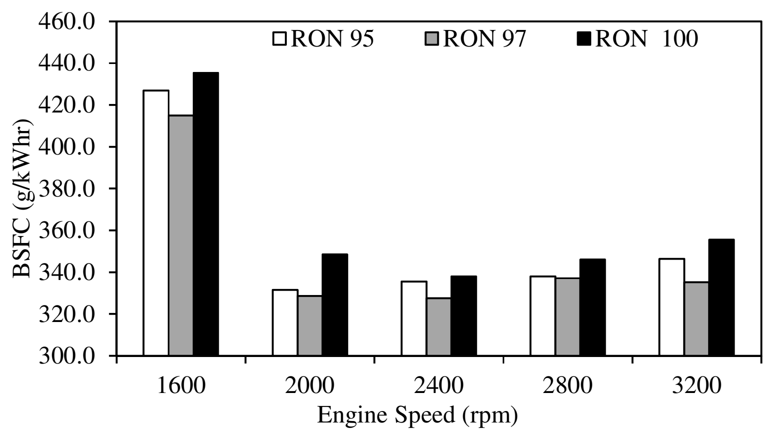


Fig. 4. BSFC against engine speed

Besides, the brake thermal efficiency (BTE) for RON 100 fuel is smaller with respect to those of RON 95 and RON 97 across all speed conditions as shown in Fig. 5. The lower BTE across all engine speeds for engine operation with RON 100 can be explained with the aforementioned phenomenon of increased in BSFC. In fact, Banapurmath stated that the gasoline fuel with higher viscosity and density may resulted in lower BTE [15]. Therefore, the results acquired from the present study revealed that RON 100 has lower BTE than RON 97 and RON 95 fuels.

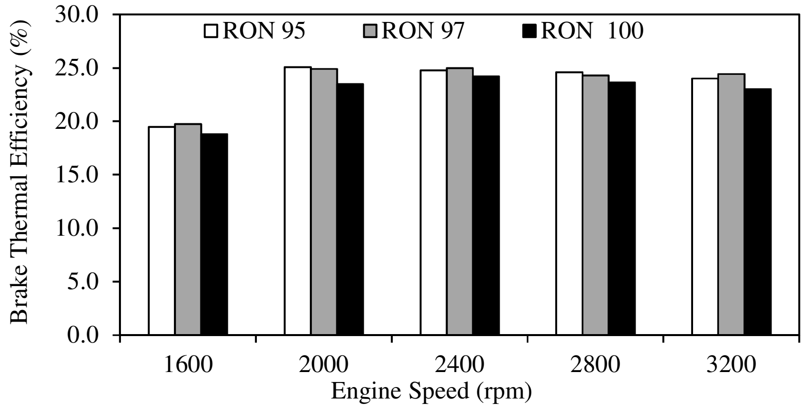


Fig. 5. BTE against engine speed.

3.2 Emission Analysis

The exhaust emissions of CO_2, CO, HC and NO_x for RON 95, RON 97 and RON 100 fuels with respect to various engine speed at full load condition are shown in Fig. 6 to Fig. 9. During the combustion process, the unburned carbon monoxide and hydrocarbon is oxidized to CO_2. Fig. 6 shows the trend that CO_2 increased with increasing engine speed for all fuels. Besides, the CO_2 level is increased with greater RON fuel. This can be related to the improving in combustion efficiency, thus caused higher CO_2 production. Besides, the results also indicated that RON 95 produced lower CO_2 compared to RON 97 and RON 100 across all engine speeds. On average, RON 95 fuel released lower CO_2 emission compared to RON 97 and RON 100 by 2.1% and 8.2%, respectively.

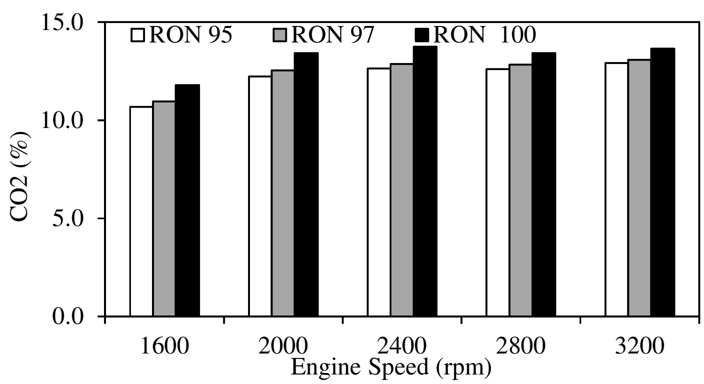


Fig. 6. CO_2 emissions against engine speed

Carbon monoxide (CO) from exhaust tailpipe is mainly associated with the partial oxidation of the fuels. This gas is highly dangerous and harmful because it destructs the ability of blood to function properly and results in fatal poisoning. In SI engine, the CO emission is greatly dependent on the operating condition of engine and air-fuel equivalence ratio. A fuel-rich combustion produces higher CO concentration and it increased with increasing equivalence ratio. Fig. 7 shows the changes in exhaust CO emissions at various engine speed for all tested fuels. Generally, the result suggested that higher RON fuels will lower the emissions of CO. In fact, the CO emissions tend to decrease with increasing engine speed. As the engine speed increased, the volumetric efficiency increases and boosting turbulence flow in combustion chamber, therefore combustion improved. On average, RON 100 produces lower CO emissions then RON 95 and RON 97 by 10.55% and 9.95% respectively.

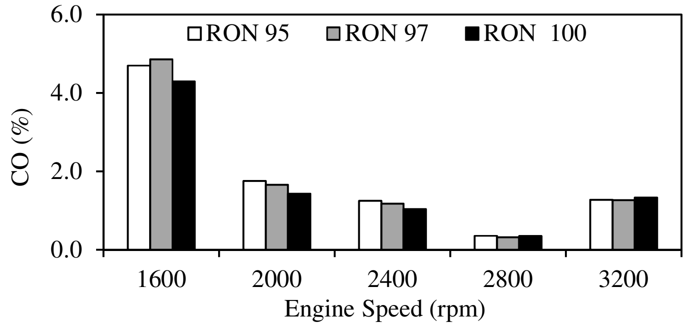


Fig. 7. CO emissions against engine speed.

Unburned hydrocarbon (UHC) emissions in the exhaust gas is mainly resulted from the unburned fuels, incomplete combustion and the presence of lubricating engine oil in the fuel or combustion chamber [16]. In SI engine, the volumetric efficiency improved with increasing engine speed. The improvement of volumetric efficiency promote more homogeneous mixture in the combustion chamber, therefore it can be observed that the HC emissions reduced for all type of fuels, as shown in Fig. 8 [17]. The results show that RON 100 produces lower HC emissions compared to RON 95 and RON 97 by an average of 28.1% and 39.9%, respectively. This indicated that higher RON fuel produced lower HC emissions.

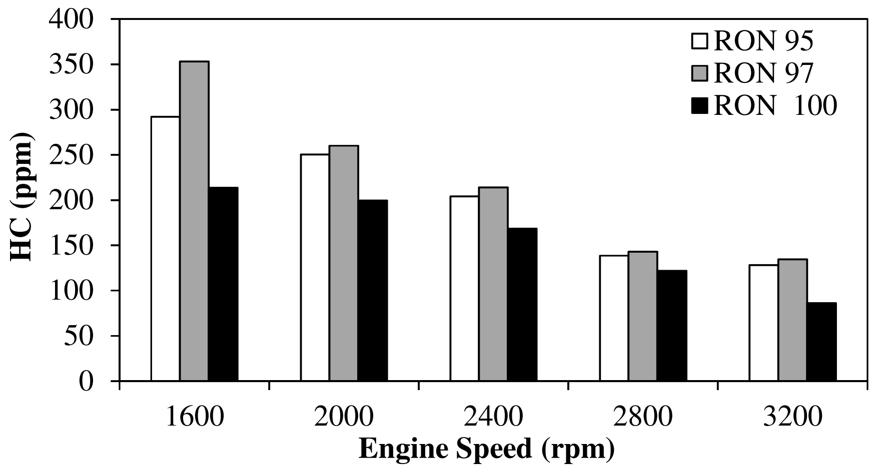


Fig. 8. HC emissions against engine speed.

NOx is classified as harmful and undesirable emission product which produced under elevated temperatures during combustion process. The NOx emissions in exhaust gas is primary made up of nitric oxide (NO) and nitrogen dioxide (NO2) in minor amount. The production of NOx dependence on engine operating conditions, fuel type and qualities. In fact, the rate of NO_x emission formation is directly dependent to oxygen concentration, cylinder temperature and retention time. From Fig. 9, it can be observed that the NOx emission is drastically increased with higher engine speed because of the higher cylinder combustion temperature. The higher NO_x emission is more apparent at 2000 to 2400 rpm and slightly reduced at 2800 to 3200 rpm. Besides, the NO_x emission from RON 100 is higher compared to RON 95 and RON 100 across all engine speeds. On average, RON 95 produces lower NO_x emissions compared to RON 97 and RON 100 by 3.4% and 12.6% respectively. This indicated that lower RON fuel tend to produce lower NO_x emissions.

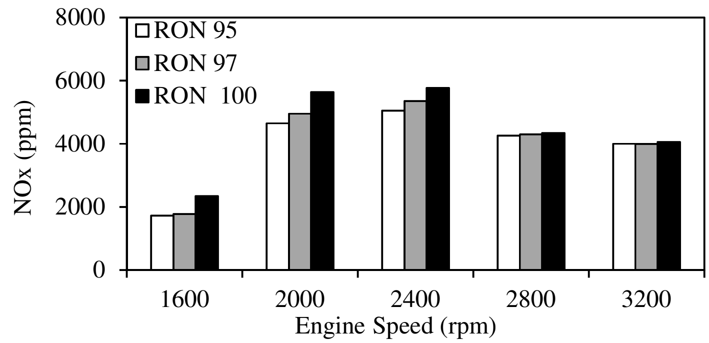


Fig. 9. NO_x emissions against engine speed.

Fig. 10 shows the exhaust gas temperature (EGT) for all fuels with respect to various engine speeds. In a natural aspirated SI engine, a higher EGT is unfavourable caused this will deteriorate engine fuel economy. The discharging waste exhaust thermal energy caused thermal damage to piston components. From the result, it can be observed that the EGT is increased with increasing engine speed. At higher engine speed of 3200 rpm, the EGT reached the highest level of 358.1 °C with RON 95 and follow by RON 100 and RON 97 with 355.2 °C and 347.2°C, respectively. The variation in EGT can be affected by the octane number and chemical structure of the fuels [18].

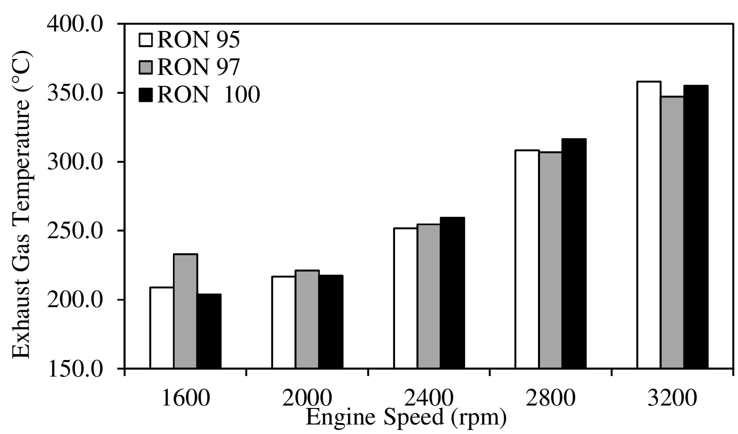


Fig. 10. EGT against engine speed.

3.3 Combustion Analysis

Figure 11 shows the cylinder combustion pressure and heat release rate (HRR) for all tested fuels with respect to crank angle at various engine speeds. Generally, it can be observed that the peak cylinder pressure decreased with increasing engine speed. This can be associated to the shorter combustion durations and constant ignition timing of the engine. Besides, the trend also shows that the peak cylinder pressure is almost similar regardless of the RON of the fuels. At 1600 rpm, the peak pressure of RON 95 is marginally higher than both of the RON97 and RON 100 fuels. This indicated that with higher RON of the fuel, the higher the resistance to detonation. In an SI engine, a negative work is produced when the fuel mixture is detonated rapidly and this will lead to the poor fuel economy. Generally, lower octane fuel contains higher percentage of n-heptane and will prompt to detonation under compression before the spark is triggered. Thus, lower octane fuel (i.e. RON 95) tend to increase the cylinder combustion pressure and the crank angle position of peak pressure was advanced towards the compression stroke. At 1600 rpm, the peak pressure of RON 95 is relatively higher than RON97 and RON 100 fuels.

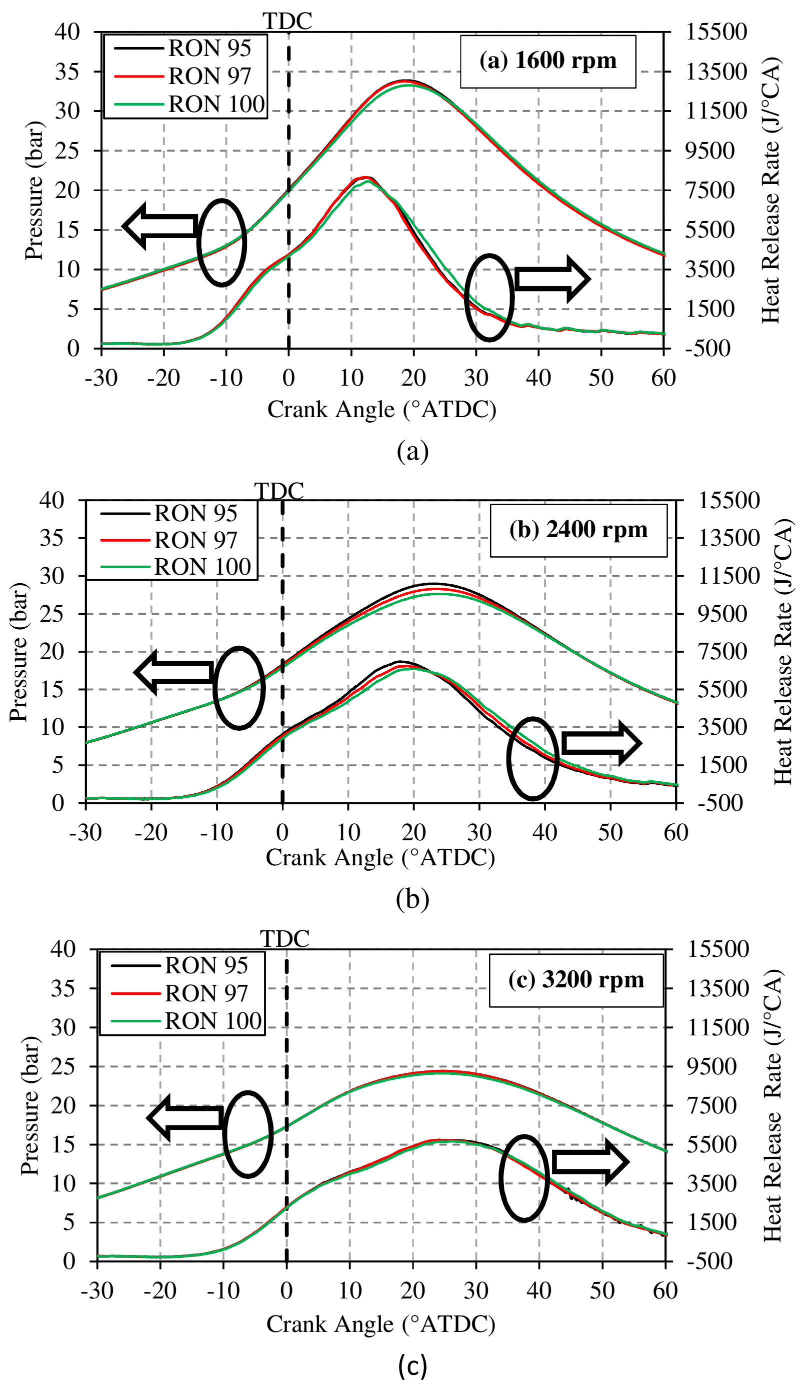
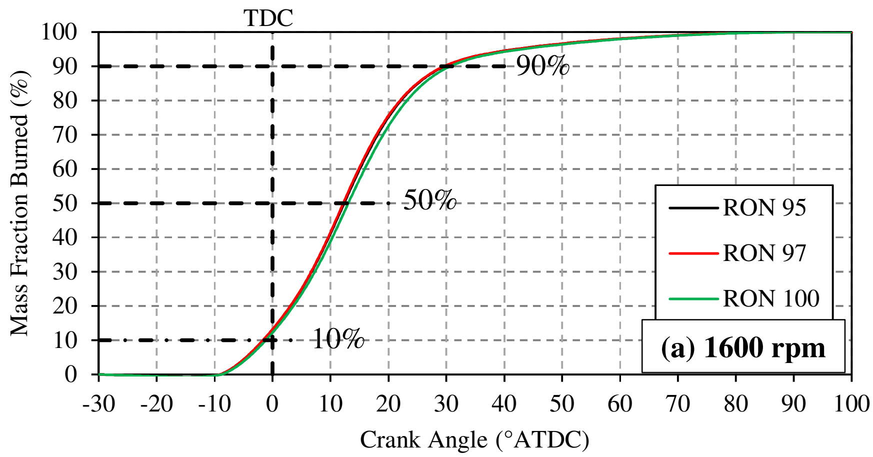
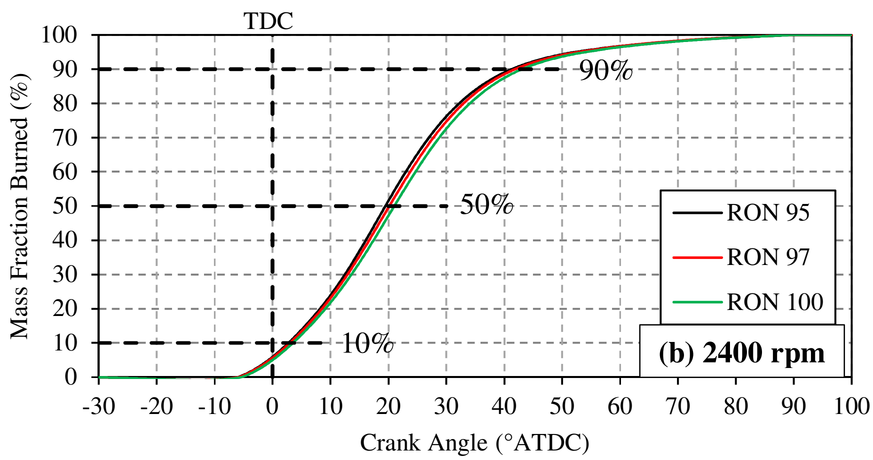


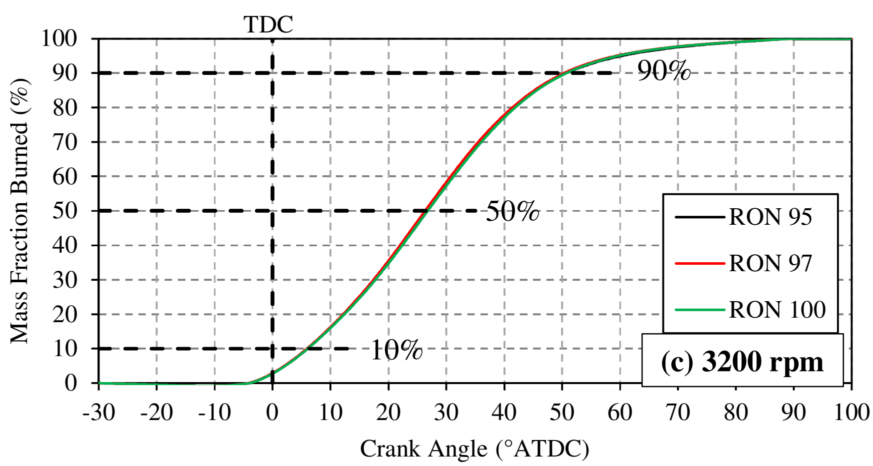
Fig. 11. Cylinder pressure and heat release rate curve as a function of crank angle at (a) 1600 rpm, (b) 2400 rpm and (c) 3200 rpm.



(a)



(b)



(c)

Fig. 12. Mass fraction burned as a function of crank angle at (a) 1600 rpm, (b) 2400 rpm and (c) 3200 rpm.

The magnitude and location of occurrence of peak pressure for RON 95, 97 and 100 are 33.89 bar at 18.8° ATDC, 33.78 bar at 18.6° ATDC and 33.27 bar at 19.2° ATDC, respectively. With increasing engine speed to 2400 rpm, the similar trend of peak pressure of RON 95 is higher than RON 97 and RON 100. The magnitude and location of occurrence of peak pressure for RON 95, 97 and 100 are 28.98 bar at 23.0° ATDC, 28.29 bar at 23.4° ATDC and 27.64 bar at 24.0° ATDC, respectively. However, with the highest tested speed of 3200 rpm, RON 97 shows a slightly higher peak cylinder pressure of 24.42 bar at 24.8° ATDC compared to RON 95 and RON 100 with 24.41 bar at 24.6° ATDC and 24.42 bar at 24.8° ATDC, respectively. For heat release rate analysis, the results showed that the trend of peak HRR is similar to peak cylinder pressure. In SI engine, the HRR can be affected by the air-fuel ratio, heating value and oxygen content of the fuel [19]. Similarly, the crank angle position of peak HRR was advanced towards the compression stroke with lower RON fuel. In fact, the peak location is shifted late toward expansion stroke with increasing engine speed. Among all the tested RON fuels, the maximum HRR value was achieved with RON 97 at all engine speeds, except at 2400 rpm. The higher peak HRR across all engine speeds for engine operation with RON 97 can be explained with the aforementioned phenomenon of decreased in BSFC.

Fig. 12 shows the mass fraction burned (MFB) for all fuels with respect to crank angle at various engine speeds. As shown in this figure, lines indicating mass fraction burned of 10% (CA10), 50% (CA50) and 90% (CA90) were marked. Empirically, 10% and 90% lines marked the start and end of main combustion duration, respectively. The period between CA10 and CA90 was defined as combustion duration and typically measured in the unit of crank angle. The results show that RON 97 promoted the faster combustion duration than RON 95 and RON 100 at all engine speeds, except at 2400 rpm. This can be confirmed by the aforementioned highest heat release rate. Essentially, it is worthy to note that the earlier complete combustion of RON 97 fuel than that of RON 95 and RON 100 is mainly due to the fastest combustion flame speed. Thus, this phenomenon suggested that a moderate RON fuel is a good candidate to operate on this engine.

4. Conclusions

The influence of RON on performance, emissions and combustion characteristic on spark ignition engine have been experimentally investigated under full load conditions. The main conclusion from the results can be summarized as below.

1. Brake torque and brake power for RON 100 fuel is consistently higher than that of RON 95 and RON 97 fuels across all engine speeds.
2. RON 100 has a lower BSFC compared to RON 95 and RON 97 fuels across all engine speeds.
3. RON 97 has a lower BTE compared to RON 95 and RON 100 fuels across all engine speeds.
4. CO_2 and NO_x were lower with RON 95.
5. RON 95 discharging the highest EGT at 3200 rpm compared to RON 97 and RON 100.
6. RON 97 fuel has resulted in early complete combustion than that of RON 95 and RON 100.

Overall, the experimental results suggested that a moderate octane number fuel of RON 97 is a good candidate to operate on this engine with consideration is being focused on the balance between performance, emissions and combustion characteristics.

Acknowledgements

The authors would like to acknowledge the Ministry of Higher Education (MOHE) of Malaysia, Universiti Malaya, KDU Penang University College Internal Research Grant and Universiti Sains

Malaysia (BRIDGING research grant scheme-304/PMEKANIK/6316119) for financial support toward this research project.

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