IN – CYLINDER PRESSURE MEASUREMENT AND COMBUSTION ANALYSIS OF A CNG FUELLED SI ENGINE TESTING

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Keywords :

Abstract :

Numerous attempts to use natural gas in engine have succeeded, but further development is still needed. Many applications to date have been based on retrofitting spark ignition or diesel engines and have failed to maintain the brake specific fuel (bsfc), or power density (kW/litre of engine displacement) of the base engine used. However, even thought these attempts have not captured the optimum advantages of natural gas, they still are an improvement over the base engine in fuel costs and emissions. The UTM CNG Engine Research Group has already performed research in this alternative fuel in SI engine, either in single cylinder research engine or within four cylinders commercial based engine. To have a clear understanding of the CNG fuelled engine characteristics, a pressure transducer has installed on one of the modified cylinder heads. Along with this, the crank angle encoder was also fit to measure the angle of the crankshaft and top dead centre (TDC) position. A Data Acquisition System (DAS) consist of charge and voltage module, signal conditioner and DAQ plug-in card, was also set up and was supported by the software to enable data processing. The results show that in term of pressure rise and burn rate, the CNG operation produced a slightly differences compared to that of gasoline. The results also confirmed the lower flame speed CNG characteristic's with longer combustion period needed. Although, produced lower pressure rise compared to gasoline operation, the CNG fuelled engine generated less emission.

INTRODUCTION

Conventionally fuelled engines have a significant market advantage over natural gas engines due to the fact that they are an established for over 100 years of development. However, up to date facts show that the supremacy this fuel should be re-evaluated. Estimation on the crude oil deposits and the emissions problem are among the reason why new or alternative fuels are essential. At the present consumption of petroleum energy deposit will last more or less in seventy-five years from year 2000 (Nakamura, *et al.*, 1991). In the later cause, emission products of these conventional fuel have formed the pollution problem, that turns into the centre of the interest in 1960's and became more urgent in the late 20th century. Therefore, over the past decade, alternative fuel had been studied for the possibility of lower emission, lower fuel cost, better (more secure) fuel availability and lower dependence on petroleum.

The characteristics of natural gas make it an attractive and desirable long term solution for the power of this country. Natural gas is abundant domestic fuel. It has an octane rating of up to 130, which allows the use of engines with higher compression ratios thus higher thermal efficiencies. Natural gas's main constituent is methane. Methane having the highest hydrogen to carbon ratio of all the organic compounds. It also the least producer of carbon dioxide and potentially one of the least producers of regulated emissions. Rosli et.al. (2001) list the advantages of compressed natural gas (CNG) that comprise cheaper fuel and maintenance costs, cleaner emission products, higher flammability that make it appropriate to run on lean burn technology and safer compared to those of conventional fuels.

However, CNG fuel has some disadvantages that limited its potential to achieve the optimum engine performance Beside the gaseous form than lowered the volumetric efficiency, CNG has also a low flame speed. Its burns slower than conventional fuels, such as gasoline and diesel. Values as much as 60% decrease in lower burning velocity for natural gas has been measured (Duan, 1996). These effects the total combustion duration prolonged compared with diesel and gasoline. Due to this attribute, the CNG operation usually advanced the ignition timing. These two causes drop the CNG fuelled engine performance for up to 20% to 40% less than conventional fuels.

The UTM CNG Engine Research Group concentrate on producing comparable CNG SI fuelled engine to that of gasoline through investigation on intake system and combustion process. This paper mainly illustrated the investigation method and procedures in mapping the CNG fuelled engine characteristics, especially in in-cylinder pressure profile and burn rate trend through

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the use of pressure transducer in the common engine testing facilities.

ENGINE TEST RIG

The 1.6 litre electronic fuel injection (EFI) gasoline based engine has been modified to run in the bi-fuel engine. A CNG conversion kit is used in order the engine can easily run in gasoline and CNG fuel. The kit was composed of a gas-air mixer unit, two electrically operated solenoid valves for gasoline and CNG cut-off, a timing advance processor to adjust the CNG and gasoline ignition timing, gas pressure regulator and storage cylinder. To dissipate the engine power, the engine was coupled to the hydraulic dynamometer. The specifications of the test engine used and CNG properties in this work are shown in Table 1 and Table 2 and 3. Detail descriptions of the engine testing facilities is presented in Figure 1.

Table 1. Engine specification

Name of Parts	Size/type
Type	4G92 EFI
Valve/No. of Cylinder	16V-DOCH/4
Bore x Stroke (mm)	81 x 77.5
Capacity (cc)	1597
Compression Ratio	11
Horsepower (kW/rpm)	131/7700*
Torque (Nm/rpm)	167/7500

Note: * the power rating is on premium fuel

Table 2. Petronas CNG properties

Items	Value
Real density (kg/m^3)	0.81
Gross Calorific Value (MJ/m^3)	40.03
Molecular Weight	19.19
Real Specific Gravity	0.66

Table 3. Petronas CNG compositions

Components	Average value (%)
Methane, CH_4	83.44
Ethane, C_2H_6	10.55
Propane, C_3H_8	1.13
Iso Butane, C_4H_{10}	0.13
Normal Butane, C_4H_{10}	0.07
Iso Pentane, C_5H_{12}	0.01
Normal Pentane, C_5H_{12}	-
Hexane, C_6H_{14}	0.01
Carbon Dioxide, CO_2	4.17
Nitrogen, N_2	0.31
Miscellaneous	0.18
Total	100

Figure 1. Experimental set-up photograph

Simultaneously with the engine performance test, the emission results were also recorded. The exhaust gas analyser was installed at the end of exhaust muffler. The hydrocarbon (HC), carbon monoxide (CO), carbon dioxide (CO_2), oxygen and nitrogen oxide (NO_x) are among the gas emissions that normally recorded in the emission test. Due to device limitation, in this study the Horiba exhaust gas analyser only measured HC, O_2, CO and CO_2. All the data were taken for CNG and gasoline fuelled engine operations.

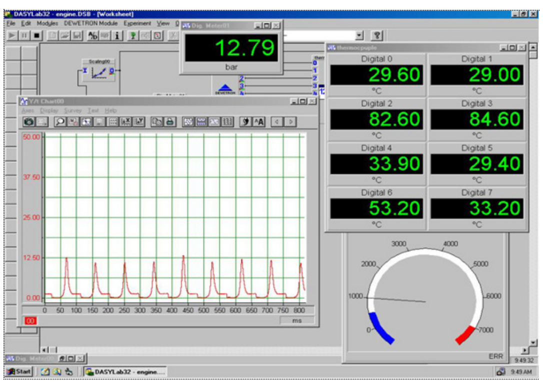
MEASUREMENT SYSTEM

In-cylinder pressure measurement and combustion analysis is one of the important stages in characterise the combustion profile inside combustion chamber. Since the purpose of internal combustion engine is to convert chemical energy into mechanical work through the action of gas pressure, the in-cylinder gas pressure directly affects the power output and performance of the engine.

To characterise the inside combustion chamber processes through pressure transducer is a complicated method. This is due to the nature of combustion process itself is very complex. It occurred at a very short duration, as much as 50 cycles per second at 3000 rpm operating conditions. Each cycle can be divided at least to 360 degree crank angles. In addition, it also take place at very high temperature, up to 2000 ^{0}C at the centre of flame propagation and at high pressure condition.

Since the pressure transducer produced a small electrical charge, a charge amplifier is needed to convert a charge into a proportional voltage signal. At this phase, calibration is necessary to determine the relationship between the pressure input and voltage output for this system. A dead weight tester is used to calibrate the pressure that connected to a computer based data acquisition (DAQ) system. This DAQ consists of a National Instrument DAQ plug in card that converted analog to digital signal. The charge module was also used to amplifie and convert the charge signal from pressure transducer to voltage. The voltage module conditions signals from the encoder. All these components were connected to a signal conditioner before connected to the personal computer. All the data was logged and managed using an experiment software called, DasyLab as shown in Figure 2 and 3.

Given that cylinder pressure in an SI engine varies from cycle to cycle due to variations in mixture strength and distribution and flow field, a statistical method is required to make sure the accuracy. Tunestal (2001) reported the decrease on standard deviation of 0.05 with the increased of data from 50 to 400 measurements. In this experiments engine cycle data were collected over 350 cycles at each point and average for analysis. The engine was run at the specific speeds and loads for a minimum of 6 minutes and data were collected during the last 2 minutes of operation. Pressure data were collected for all speeds and loada combinations, but for the purpose of this paper, only data taken The measurement start at steady state condition. The engine was started with 1000 revolution per minute (rpm), at which stage the torque, fuel (gas and gasoline) and air consumption, pressure and exhaust emission were measured. The test was held at three circumstances: no load, half and full loads. The same procedures were repeated for different speeds in the range of 1500 to 3500 rpm.



(a)

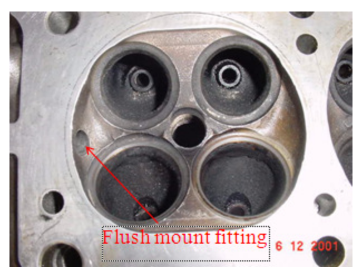
(b)
Figure 2. (a) Preview of DAS monitoring on PC
(b) Pressure and engine speed data

PRESSURE TRANSDUCER

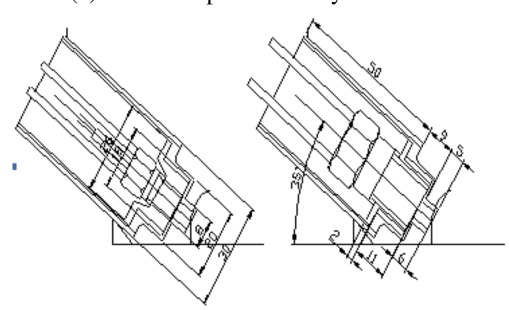
Engine cylinder-pressure data is generally acquired using piezoelectric pressure transducer due to it has a high frequency response, small size, light weight, low power consumption and is relatively insensitive to environmental conditions. Two type of transducer mounting is known; flush (direct) mounting and use of connecting passage. The flush mount type is preferable since it directly measure the pressure rise inside combustion chamber. However, this method maximizes the severity of thermal shock. The second method was proven to avoid the thermal shock effect but this add resonance of the gas in the connector passage as well as increased the chamber crevice volume.

In this experiment the flush mount method was implemented. The Kistler 6041A pressure transducer with measuring range from 0 to 250 bars and sensitivity of –25.6 pikocolumn/bar was used. This pressure transducer was attached in the first cylinder head due to it space available. Pressure transducer position is put in the head cylinder as shown in Figure 2 and Figure 3. Pressure transducer calibration was done using pressure calibrator before instalment.

The challenging process was occurred when installing the pressure transducer into the cylinder head. Since the engine used four valves (two intake and two exhaust valves), the space available to put the pressure transducers is not sizeable enough. At the same time, the combination of M10 and M14 type of pressure transducers caused the outside diameter of sleeve should be around 34 mm. At the early process the leakage usually take places. By using the 'brass' ring the leakage can be prevented.



(a) Hole drill position in cylinder head



(b) Pressure transducer hole position
Figure 3. The pressure transducer instalment position

RESULTS AND DISCUSSIONS

The pressure rise profile for CNG and gasoline is shown on Figure 4. Data is taken at operating condition of WOT at 3000 rpm. All data has been compiled to average value from as much as 400 cycles of data. The results demonstrated that the CNG mode data on cylinder pressure were lower compared to gasoline operation. At the same condition, the gasoline operation produced up to 45.8 bars compared to CNG at 40.1 bars. This approximately 10% dropped is mainly because of low volumetric efficiency and advanced ignition timing (Mardani and Rosli, 2001). From the data, the peak pressure for gasoline was around 14 to 16 deg. of crank angle, while the CNG type its occurred at 8 deg. This result may represent that due to lower flame speed of CNG. Another factor is due to lower volumetric efficiency of CNG compared to gasoline.

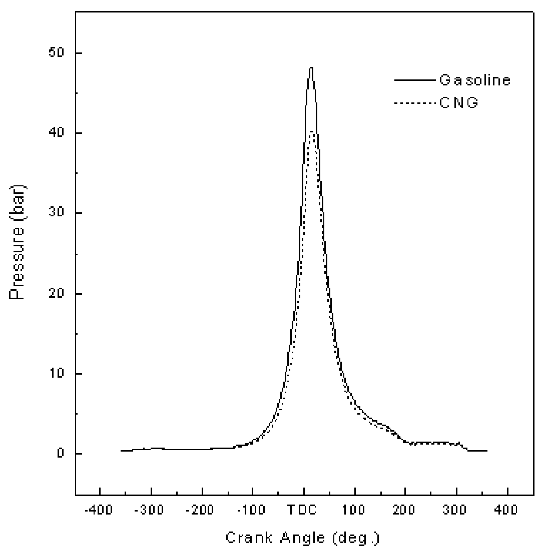


Figure 4. Pressure rise profile

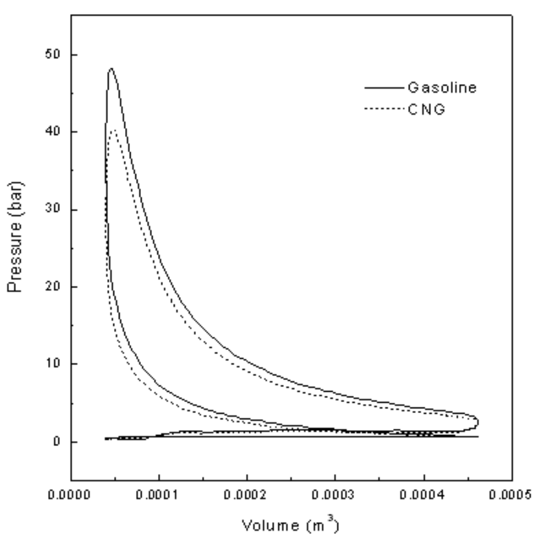


Figure 5. Pressure-volume profile

This condition also shown on the P-V profile at Figure 5, where the gasoline produced higher curve area compared to CNG operation. This means that gasoline generated higher power compared to CNG. Again the problem occurred due to the CNG characteristic. Since the implementation CNG fuel does not follow by major modification, the CNG performance as a lower outcome compared to gasoline mode.

The same condition also occurred with the Rate of Heat Release (ROHR) profile as shown in Figure 6 that demonstrated gasoline produced higher ROHR compared to CNG mode. This is appropriate with the trend that occurred in pressure rise profile, the P-V profile and the ROHR profile.

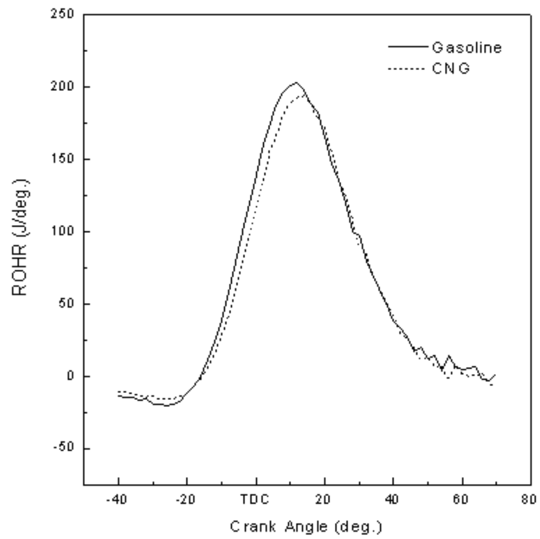


Figure 6. ROHR profile

CONCLUSION

The CNG fuel operation has already proven to be workable. The implementation of the CNG fuelled engine performance however produced lower power compared to gasoline mode. This lower performance widely die to the CNG characteristic which are lower flame speed and lower volumetric efficiency. In the overall, the CNG fuelled engine performance produced lower performance compared to gasoline fuelled engine in average 10% drop.

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