Journal of Applied Sciences Research 5(8): 949-954, 2009

Torque and Power of CNGDI Engine with Two Different Piston Crown Shapes

[1]Mohd.Khair Hassan, [2]Ishak Aris, [3]Khairul Nizam Zainuddin and [4]Nik Anis Alina

[1]Advanced Automotive Technology Laboratory, Institute of Advanced Technology, Universiti Putra Malaysia, 43400, Serdang, Selangor. MALAYSIA
[2]Department of Electrical and Electronic Engineering, Universiti Putra Malaysia, 43400, Serdang, Selangor. MALAYSIA
[3]Advanced Automotive Technology Laboratory, Institute of Advanced Technology, Universiti Putra Malaysia, 43400, Serdang, Selangor. MALAYSIA
[4]Advanced Automotive Technology Laboratory, Institute of Advanced Technology, Universiti Putra Malaysia, 43400, Serdang, Selangor. MALAYSIA

Abstract: This paper presents the experimental test results of single cylinder high compression engine fuelled with compressed natural gas. The engine uses central direct injection with high pressure injector system which is known as Compressed Natural Gas Direct Injection (CNGDI) engine. This initial experiment on a single cylinder CNGDI engine is to investigate the feasibility of the CNGDI engine with different piston crown shape. The performance of two piston crown shapes for (i) homogeneous (ii) stratified combustion was investigated. The start of injection (SOI) timing for each piston was varied between 120^0 before top dead centre (bTDC) to 220^0 bTDC to study it combustion response at various engine speed. SOI laid between 120^0 bTDC to 180^0 bTDC, which produced a constant power and torque. The experimental results have shown; (i) ignition timing has to be advanced and (ii) the best injection timing is at 120^0 BTDC to 180^0 bTDC to achieve a good performance. For homogeneous charge combustion operation engine, the injection timing was set at early of compression stroke to ensure the better fuel/air mixing.

Key words: High compression engine, CNGDI engine, single cylinder CNGDI

INTRODUCTION

The search of alternative fuels is becoming a major concerned worldwide. This is due to few obvious reasons; an increased of oil price, a declining trend of oil production globally, health-issues due to pollution and an alarming global climate change. One of the most affected industries due this current situation is an automotive sector. Automotive sector is one of the highest contributions to pollution and global warming. Thus, the demand for alternative fuel is always a burning issue. Natural gas engine has been acknowledged for having an almost zero emission but lacked of power and torque as reported by many researchers worldwide [1,2,3]. However, to keep the output power and torque of natural gas engine comparable to gasoline or diesel counterparts, a high boost of pressure should be used [4]. In terms of exhaust emission reduction, high activity of catalyst for methane oxidation and lean NOx system or three-way catalyst with precise air-fuel ratio control strategies should be developed to meet future stringent emission standards.

Malaysia Energy Centre (PTM) has estimated that in year 2030, there major industries that contributes to CO_2 emission; (i) electricity 49%, (ii) transportation 28% and (iii) industry 20%, [5]. The percentage indicates the automotive industry will be the second biggest contributor towards global emission. A study conducted by World Energy Council, (WEC) on the energy demand and the availability of energy has shown that the trend of natural gas consumption estimated to increase in contrast to oil consumption during the period of 2005 to 2025, [6,7,8]. The ratio of natural gas reservation to production worldwide estimated to be 62 years, compared to oil ratio, 38 years as depicted in Figure 1 [9].

Natural gas is regarded as one of the most promising alternative fuels and probably the cleanest fuels. Natural gas vehicles (NGVs) typically offer

Corresponding Author: Mohd.Khair Hassan, Advanced Automotive Technology Laboratory, Institute of Advanced Technology, Universiti Putra Malaysia, 43400, Serdang, Selangor. MALAYSIA
Email: khair@eng.upm.edu.my
Tel: +06389464367 Fax: +06389466327

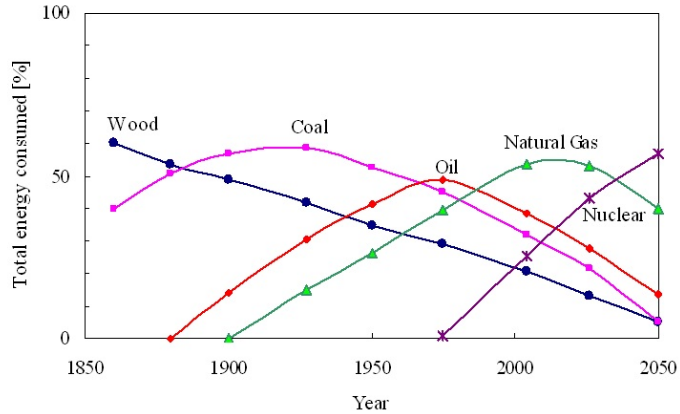

Fig. 1: Energy Consumed [9].

greenhouse gas reductions as much as 30%. With climate change now firmly on the agenda at all levels of society, NGVs offer an economic and environment advantage unmatched by any other fuel. It also has been noted that is has high-octane value, a good cold-starting characteristics that cause less wear on engine and the vehicle can be fueled at home, [10].

The objective of this study is to examine the potential of CNGDI with two shapes of piston crown (i) homogenous (ii) stratified. The outcome of this initial experiment will be used as a benchmark of multi-cylinder engine of CNGDI.

1.1 Spark Ignition CNG Fuelled Engine: Spark ignition engine, uses more volatile gasoline fuel, has compression ratios between 8 and 11 while the compression-ignition requires typically 18 to 21 to accomplish its combustion process. The compressed ignition engine uses heating air during compression stroke to vaporize a liquid fuel and heat the vapor to its self-ignition temperature. Such heating processes take time. A practical mechanism that can be used to speed the process up is to raise the heat transfer rate between the hot air and the cold fuel droplets by increasing the relative velocity between these two fluids. This presents two options (1) either have fuel droplets that move rapidly through the air, or (2) have slower-moving fuel whirled by faster-moving air. The first option gives rise to the direct-injection and the second to the indirect type. One significant characteristic of natural gas is the flammability limit as tabulated in Table 1. Natural gas has high flammability limit compares to gasoline and diesel, thus requires high energy of spark ignition for combustion.

Yusoff A and Muthana I, [12] were conducted a study on the potential of high-pressure injection by using flat piston crown. They have tested a single cylinder, 20-bar central direct injection system, high-energy spark plug with 14:1 compression ratio of CNG fuelled engine. The result shows that high-pressure injection system produced higher torque and power compared to low-pressure system. It also has an advantage of low fuel consumption.

A similar study was carried out to examine the influence of fuel spray angle of CNG into the cylinder, [13]. Wide spray angle (70^0) was produced good engine performance compared to narrow spray angle (30^0). The experiment was conducted with injection timing of 40°bTDC and ignition timing of 18° bTDC. The air-fuel ratio was controlled at stochiometric over a wide range of engine speed.

In conclusion, the results have shown a combination of high-pressure injector (20 bars) and 70 degrees spray angle has shown high torque and high power engine. Therefore, from outcome of these investigations, it is suggested in order to obtain a good CNGDI engine performance, two criteria of injector will be used;

1. Wide spray angle 70^0
2. High-pressure injector 20 bars.

2. 0 Experimental Setup: This experimental work was carried out at Universiti Teknologi Petronas, Tronoh, Perak. The experimental setup is shown in Figure 2. The laboratory consists of a control room to monitor the engine operation and one room for the engine under testing. A 20 bar pressure is applied to the injector, which is located at the centre of the cylinder head. The engine compression ratio is 14 and the engine specification as tabulated in Table 2.

The engine management system of CNGDI fuel system was configured to deliver controlled and accurate of CNG at specific pressure and timing. The pressure and timing were based on the required mapping of the engine demand. It also delivers characterized spray angle for rapid fuel mixing to ensure the engine operates properly without any shot circuit of the air intake. The system consists of a filler

Table 1: Selected common fuel property [11]

Property	*Natural gas*	*Gasoline*	*Diesel*
Flammability Limits (Volume % In Air)	5-15	1.4-7.6	0.6-5.5
Auto-Ignition Temperature (^{0}F)	842	572	446
Peak Flame Temperature (^{0}F)	3432	3591	3729

Table 2: Specification of the Engine Model

Engine parameters	Value
Bore × Stroke (mm)	78 × 84
Connecting rod length (mm)	131
Displacement (cm^3)	1596 (4 Cylinders – Inline)
Compression ratio	14:1
Engine speed (rpm)	2000
Intake valve open (° CA)	12° before TDC
Intake valve close (° CA)	48° after BDC
Exhaust valve open (° CA)	45° before BDC
Exhaust valve close (° CA)	10° after TDC

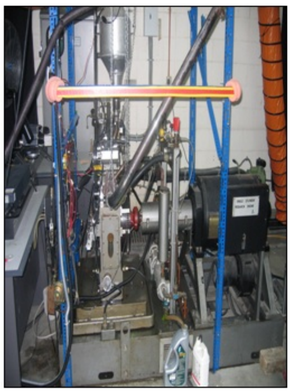

Fig. 2: Single Cylinder Engine Test bed

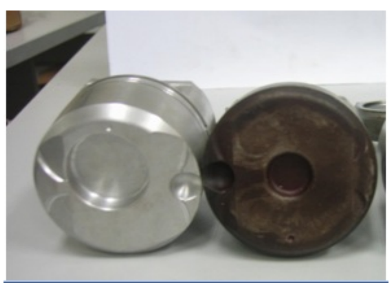

Fig. 3: From left: Stratified crown and Homogenous crown

valve, CNG tanks, a high pressure fuel line, a pressure gauge, a pressure regulator, a low pressure fuel line, a fuel rail and an injector. CNGDI injectors based on the Synerject Strata injector with modified spring preload for operation at 2000 kPa. The Strata family of air injectors is designed to minimize package size, while maximizing commonality and flexibility for use across a wide range of applications

Two different piston crowns namely stratified and homogenous were tested to realize the combustion in the cylinder as illustrated in Figures 7.

RESULTS AND DISCUSSION

Besides mechanical approaches used to enhance the engine performance, the engine management system and its calibration technique are other important factors need to be considered. By setting the ignition angle and injection timings properly, the improvement in the engine performance and emission level could be achieved [14,15]. The best suited injection timing, ignition timing, air-fuel ratio are few main parameter that contribute to the enhancement of engine performance [16,17].

A comparison of two different piston crowns as demonstrated in Figure 3 has been investigated to identify the potential of each piston crown. The homogeneous crown has produced high torque compared to the stratified piston crown as illustrated in Figure 4. The maximum torque is 31.8Nm at 3000 rpm, compared to 24.65Nm for stratified crown. Thus, the torque different is 7.15Nm for both piston. For stratified crown, the torque is drastically decreased after 3000 rpm. The reduction of torque for stratified piston crown is due to unstable combustion in the cylinder especially during high speed. Fundamentally, when stratified combustion is implemented the mixture around the spark plug is most important. Fumitaka Honjo *et al* [18] from Nissan Diesel Motor Co.Ltd, also reported the power reduction of stratified combustion when they developed stratified charged combustion CNG direct injection engine.

In terms of the brake power as illustrated in Figure 5, the maximum power is 12.29 KW at 4000 rpm for homogeneous but 6.5KW at 2500rpm for stratified crown. An overallthe homogeneous piston crown may provide good engine performance. Figures 6 and 7 are another example of engine performance characteristic for each piston crown. The start of injection timing was varied from 120^0 bTDC until 230^0 bTDC and ignition angle was set at 24^0 bTDC. The engine speed was kept constant at 2000 rpm. The homogeneous crown produces higher torque compared to stratified crown shape. It also shows the torque curve decrease as late injection is applied. The best start of injection is between 120^0 bTDC to 180^0 bTDC. However, for stratified piston crown, the variation of torque curve is not so obvious. It seemed that the injection timing might not influence the torque curve very much. The power curve also has shown a decrement of power when the late injection is implemented. The result has shown that if the start of injection is set too late i.e 200^0 bTDC thus, the torque and power curve decreased.

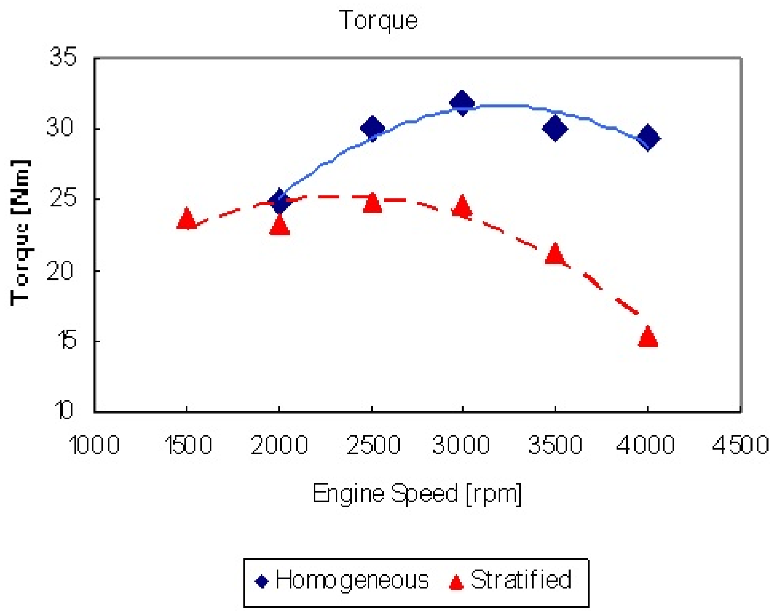

Fig. 4: Torque Comparison

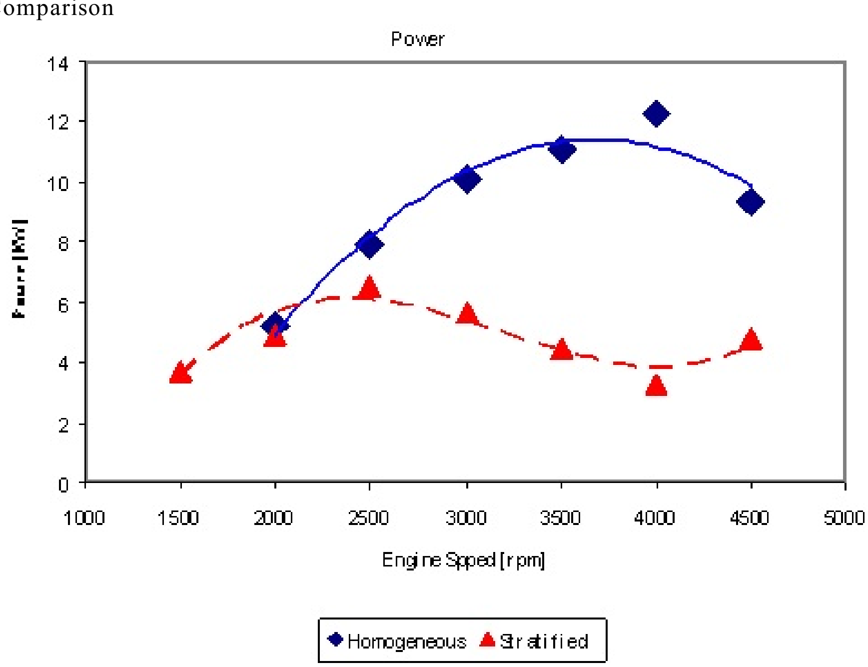

Fig. 5: Power Comparison

Conclusion: The CNGDI is best suited with high-pressure injection and has been proven by the experimental test results. The experimental results demonstrate that the homogenous crown performance higher than stratified crown. In terms of engine performance, the homogenous crown has shown higher torque and higher power. The main advantage of using high-pressure injector is less fuel consumption can be achieved where the fuel is to be injected directly into combustion chamber after both intake and exhaust valves are closed.

ACKNOWLEDGMENT

The author would like to thank the Ministry of Science, Technology and Innovation of Malaysia for the grant for this research under IRPA research grant. Special thank also goes to Universiti Teknologi Petronas, Perak for the assistance of engine dynamometer testing.

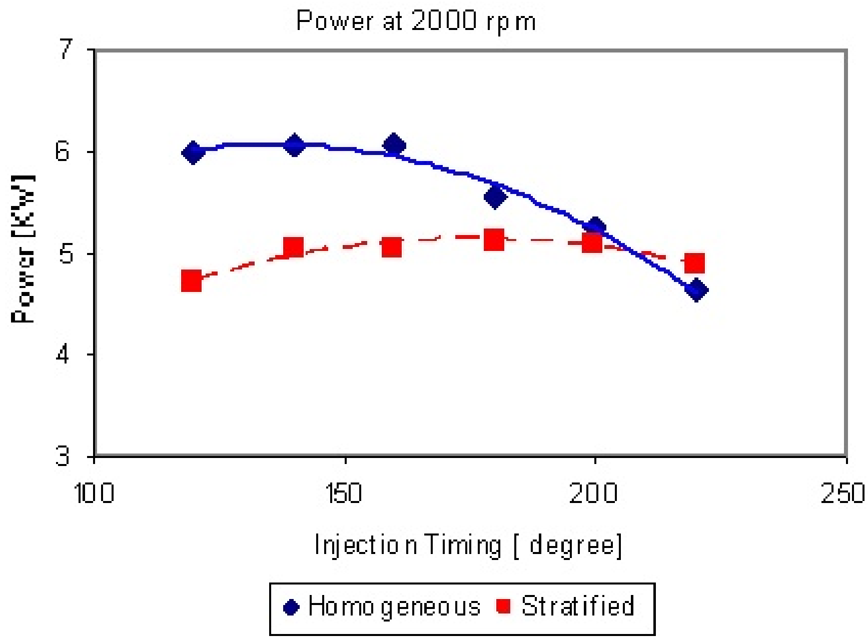

Fig. 7: Power Comparison at 2000 rpm

REFERENCES

1. Robert, W., Weeks, John J. Moskwa, 1994. Transient Air Flow Rate Estimation in a Natural Gas Engine Using a Nonlinear Observer, Society of Automotive Engineering, SAE 940759.
2. Nigel, N., Clark, Gregory E. Mott, Christopher M. Atkinson, Remco J. deJong, Richard J. Atkinson, Tim Latvakosky, Michael L. Traver, 1995. Effect of fuel composition on the operation of a lean-burn natural gas engine, SAE 952560.
3. Yuichi Goto, Yoshio Sato and Kazuyuki Narusawa, 1998. Combustion and emission characteristic in a direct injection natural gas engine using multiple stage injection. The Fourth International Symposium COMODIA, 98: 543-548.
4. Haeng Muk Cho and Bang-Quan He, 2007. Spark ignition natural gas engine- A review, Journal of Energy Conversion and Management, 48: 608-618.
5. Anuar Abdul Rahman, 2008. Renewal energy; Road to energy independence, CEO of PTM, (2nd session: Supply Security), Electricity Summit 2008, KLCC 17-18 June 2008, Kuala Lumpur, Malaysia.
6. World Energy Council, 1993. Energy for tomorrow's world, St. Martin's Press, USA, pp: 320.
7. World Energy Council, 1994. New renewable energy resources: A guide to the future, Kogan Page, London (UK), pp: 391.
8. Barkawi Sahari, Yusoff Ali, Fakhru`l-Razi Ahmadun, Shahrir Abdullah, Masjuki Hj Hassan, Ishak Aris, 2005. A compressed natural gas direct injection (CNGDI) passenger vehicle development- a Malaysian initiative, Proc. of ANGVA 2005, July 26-28, Kuala Lumpur, Malaysia. CD proceeding.
9. BP., 2001. Statistical review of world energy, June 2001. www.bp.com.
10. Deanna E. Wang and Harry C.Watson, Direct injection compressed natural gas combustion and visualization, SAE 2000-01-1838.
11. Keith Owen and Trevor Coley, 1995. Automotive fuels reference book. Society of Automotive Engieers, Inc Publication. Warrendale, U.S.A.
12. Yusoff, A., I. Muthana, 2005. Design Of High Pressure Fuel System For CNGDI, ATCi 2005, Conference on Automotive Technology, Dec 6-8, 2005, Putrajaya, Malaysia.
13. Yusoff Ali and Muthana, 2005. The Effect of Spray angle of Injectors on the Performance of CNGDI Engine, Conference of Automotive technology, Putrajaya 6-8 Dec. 2005 UPM, ATCi2005, COAT 2005, CD proceeding.
14. Aris, I. M.K. Hassan, I. Mat, Nizam, N.A. Alina, R.K. Zakiah, R. Sidek, S. Mahmood, 2005. Model-Driven Electronic Control Unit with Real-Time Embedded Target, Engineering Transactions, Mahanakorn University of Technology, Thailand., 8: 1(18),Jan-June 2005.

15. Mohd Khair Hassan, Ishak Aris, Roslina Sidek, Senan Mahmod, 2005. Model-Based Approach with Real Time Embedded Target for Rapid ECU Development: An Overview, JIEEEC 2005, 15-17 Nov, 2005. Amman, Jordan. CD Proceeding.
16. Huang, Z., S. Shiga, T. Ueda, N. Nakamura, T. Ishma, T. Obokata, M. Tsue and M. Kono, 2003. Effect of fuel injection timing relative to ignition timing on natural-gas direct injection combustion, J.Eng. Gas Turbines and Power, 125: 783-790.
17. Anupam Gangopadhya and Peter Meckl, 2001. Modeling and Validation of a Lean Burn Natural Gas Engine, Journal of Dynamic Systems, Measurement and Control September 2001, 123; 425-430.
18. Fumitaka Honjo, Akinori Miura, Akira Nakamura, Takayuki Tsuchiya, 2002. Development of Stratified Charged Combustion CNG Engine,Technical Report Nissan Diesel Motor Co., Ltd.