Performance and Emission Characteristics of Direct Injection C.I Engine Retrofitted with Mono-CNG System

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Abstract. Diesel engines are widely used in logistics and haulage as vehicular prime movers. In the mechanized and fast-moving forward world of today, the consumption of petroleum products has become an important yardstick of a country's prosperity. This ever-increasing consumption has led the world to face the twin challenge of energy shortage and environmental deterioration. Natural gas has been one of the highly considered alternative fuels for both spark ignition (S.I) and compressed ignition (C.I.) engines. The advantages and benefits of CNG have made it the preferred choice as alternative fuel in the transportation sector. This present study focused on the effects of retrofitted direct injection C.I. engine with mono-CNG system to its performance and exhaust emissions. The engine speed was varied from 850 rpm to 2500 rpm, with load test conditions of 0Nm, 27.12Nm and 53.23Nm, using an engine dynamometer. Results indicated that CNG has the potential to provide better fuel consumption compared to diesel fuel. Meanwhile, the characteristics of exhaust gas emissions such as smoke opacity and CO2 gave promising results compared to CO, HC and NOX, for diesel combustion.

1. Introduction

The shortage in the hydrocarbon fuel sources and the stringent future emission regulations have been a formidable challenge to the most prominent worldwide automotive industries [1]. Therefore, the alternative sources of fuel are receiving a lot attention in the automotive industry. These are the main reasons for exploring alternatives, which are abundantly available and less polluted in nature. Natural gas or Compressed Natural Gas (CNG) has been one of the highly considered alternative fuels for both S.I and C.I. engines [2]. CNG is the favorite for fossil fuel substitution, which is made up primarily of methane (CH4). Its favorable chemical properties are high hydrogen to carbon ratio (H/C) and high research octane number (RON) than gasoline, which is approximately range from 120 to 130 compare to 93 to 97 for gasoline. CNG is colourless, odorless, non-toxic, and lighter than air and inflammable [3].

There are lots of previous studies [4],[5] on CNG as an alternative fuel, which led to economic fuel consumption for fleet operators. The benefits of using CNG include lower fuel cost and maintenance cost and cleaner exhausts emissions. The operational cost using CNG is one third of vehicle running on gasoline [6]. Therefore, CNG has been identified as a leading contender for transportation application especially for vehicle fleet operators: logistic and haulage companies.

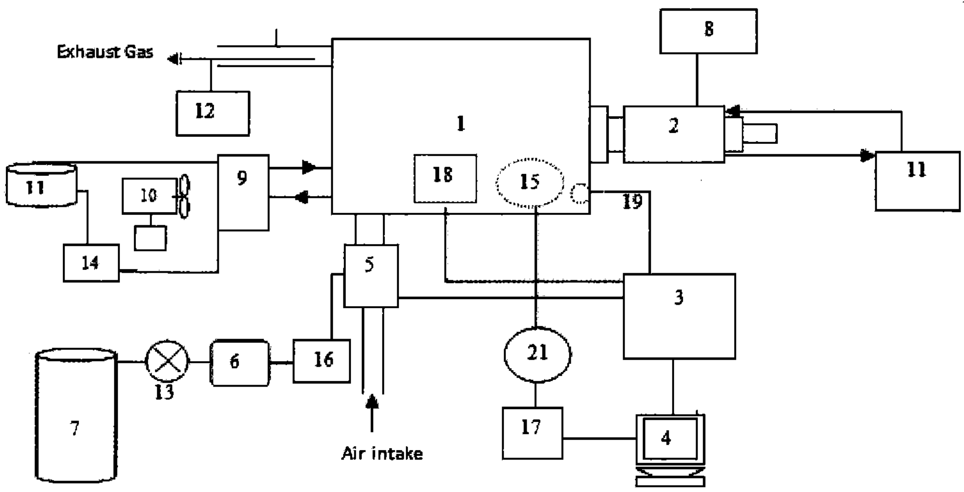
In Malaysia, most of the logistics and haulage companies are using diesel fuel and compression ignition (C.I.) engines to propel their small-duty until up to prime mover vehicles. Therefore, for those companies to gain additional economic benefits, retrofitting their fleets with mono-gas CNG system will be the best option to take. Through retrofitting, the C.I engines to run using CNG, fleet operators will still have beneficial option operating their existing C.I. engines fleet. Therefore, this research is to evaluate and advanced monitoring the CNG fuel, engine speed and test load conditions which is necessary in helps to understand the combustion process, exhaust emissions and engine performance in retrofitted direct injection C.I. engine equipped with mono-gas system.

2. Experimental setup and Procedures

The tests were performed in the Automotive Laboratory, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia. The experimental setup consists of a medium duty diesel engine that was selected as the base engine to be retrofitted for dedicated natural gas operation. The base engine is a non-turbocharger type and configured to meet the EURO II emission standard. The specifications of the test engine are given in **Table 1** while **Figure 1** shows the schematics views of the experimental setup.

Table 1: Engine specifications [7]

Type of Fuel	**Diesel**	**Mono-CNG**
Type of Engine	4-Stroke, natural aspirator, single overhead cam	
No. of Cylinders	4 Cylinders in-line	
Bore x Stroke (mm)	112 x 110	
Engine Displacement (cc)	4,330	
Compression Ratio	19:1	11:1
Combustion Chamber	Bowl in-shape	
Fuel System	Injection nozzle and pump	Regulator, Mixer, Throttle body
Ignition System	Compression Ignition	Spark Ignition



1. Engine
2. Dynamometer
3. ECU
4. Computer
5. Mixer
6. Regulator
7. CNG tank
8. Dyno Control pane
9. Radiator
10. Radiator fan
11. Water tank
12. Exhaust analyzer
13. Pressure gauge
14. Water pump
15. Pressure sensor
16.Gas flow meter
17. Dewetron
18. Ignition Coil
19.Camshaft sensor
20.Oxygen sensor
21. Charge amp

Figure 1: The schematics views of the experimental setup

The engine was attached with turbulent water-brakes engine dynamometer model D-316 by Go Power System Inc and operated on raw water principle. This system converts the rotating torque of the engine to stationary torque that can be exactly measured and calculated in terms of horsepower. This dynamometer can be operated continuously at any power level within its capacities. This system also equipped with control panel consists of electric tachometer, torque gauge and two levers for controlling the values of applied torque.

An electronic control unit (ECU) was used for this tests engine to ensure the characteristics of CNG are fully function in C.I. engines. This ECU's controls the injection timing, injection duration, spark timing, oxygen signal, and cam position signal. In addition, the ECU's setting was set as default setting provides by manufacturer. The experiments were conducted at steady-state condition, where the values of torque at 0Nm, 20Nm and 40Nm and engines speed at idle until up to 2500 rpm have defined.

3. Instrumentation and Data Measurement

This section will described the used of instruments in the experimental engine. A non-dispersive infrared (NDIR) type exhaust gas analyser (SPTC Auto-Check) was used for measurement of CO, CO2, HC and O2. Dräger MSI-200E gas analyser was used to measured the values of NO and NOX concentration emissions. Auto-Check 4/5 Smoke opacity meter was used to measure smoke intensity. The gas analyser was calibrated by passing a known amount of span gases and readings were recorded with variation in span gas concentration. The measurement of diesel fuel consumption, Ono-Sokki flow meter (FM2500) and detector (FZ2100) were used while Sure Gas Turbine flow meter will measured the flow rate of CNG. Airflow for air intake was determined accurately measuring the pressure drop and velocity by using anemometer hot-wires (brand TSI-Velocical). For temperature measurement, two units of K-type thermocouple couple with TESTO temperature logger was used at exhaust manifold and exhaust tail pipe.

4. Results and Discussion

The effects of retrofitted mono-gas system into direct injection C.I. engine on exhaust emissions and engine performance were investigated. These results of CNG fuel was compared to the diesel fuel to prove the facts of CNG advantages against base fuel for engine speed of 850 (idle condition), 1000 rpm, 1500 rpm, 2000 rpm and 2500 rpm. The tests condition was set to 0Nm, 27.12Nm and 53.23Nm on the engine dynamometer for all engine operations. **Figure 2** depicts the variation in the exhaust emissions such as smoke opacity, O2, CO, CO2, HC and NOX. As seem in **Figure 2**, the use of CNG as a fuel under all engine speed and engine loads depicts the reduction of smoke opacity. The emission of CO2 gas also indicates the reduction approximately up to 38% for all engine condition except in idle condition, where CNG contributes higher emission than base fuel. However, the others exhaust gas emissions; CO, HC and NOX increased monotonically with the increasing of engine variables. This correlation causes by the high amount of fuel supplied in chamber responsible for the rich combustion and increased the emissions. Therefore, the HC emission increase in magnitude associated with the poor combustible mixture preparation and fuel-air mixture causes by possible sources: crevices effect, a quench layer that containing unburned and partially burned fuel-air mixture is left at combustion chamber wall, and thin film of engine oil at cylinder wall, piston and cylinder head [8]. In addition, the emission of NOX and CO increased due to the oxygen concentration and mixing pattern, fuel vaporisation is slow, and combustion temperature.

The influences of engine tests conditions on the point of engine performance are investigated and depicted in **Figure 3**. It seems that the fuel consumption of retrofitted mono-gas engine promotes the better consumption at all engine speeds and loads condition. The utilization of CNG in tests engine can be saved approximately up 50% compared to base condition. Conversely, the reduction of engine performance is expected causes by the lower calorific value of CNG, improper air-fuel mixture, ignition timing and combustion variations.

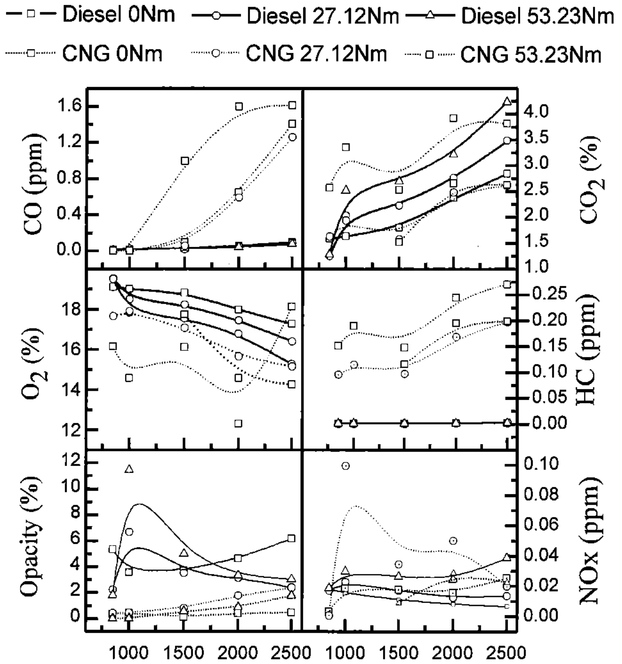


Figure 2: Effects of retrofitted mono-gas engine on emissions under various loads

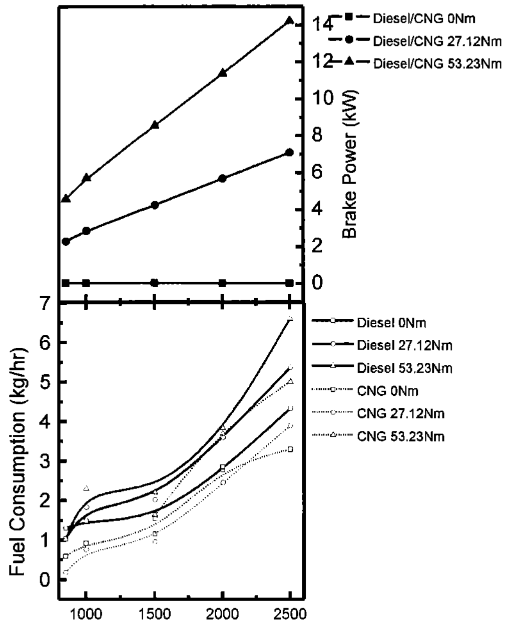


Figure 3: Effect of retrofitted mono-gas engine on engine performance under various loads

5. Summary

The studies on the performances and emission characteristics of mono-CNG engine under various engine speeds and loads were demonstrated. As comparison with base conditions, CNG engine was successfully produced the lowest fuel consumption up to 50% saving. However, the low calorific values of the CNG fuel was expected to be the strong influence on reduction engine performances. This reduction was expected and agreed by the previous literatures. In case of exhaust emissions, mono-CNG engine offers reduced smoke opacity, where it was almost invisible. While, the emission of CO2 gas indicated a reduction up to 38%, others emission such as CO, HC and NOX did not shows any significant changes due to the incomplete combustion and insufficient of air that influenced the carbon and hydrogen ratio. Moreover, it was also assumed that the results were due to the use of standard setting from the ECU.

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7. References

1. Amir Khalid, Shahrul Azmir Osman., M. Norrizam Mohamad Jaat, Norrizal Mustaffa, Siti Mariam Basharie, Bukhari Manshoor, *Performance and Emissions Characteristics of Diesel Engine Fuelled by Biodiesel Derived from Palm Oil.* Applied Mechanics and Materials 2013. 315(1): p. 517-522.

2. S. A. Osman, A. J. Alimin., V.S. Liong, *Optimum Combustion Chamber Geometry for a Compression Ignition Engine Retrofitted to Run Using Compressed Natural Gas (CNG).* Applied Mechanics and Materials, 2013. 315(1): p. 552-556.
3. Owen, k. and T. Coley, *Automotive fuels reference book.* 2nd Edition ed. 1995, Warrendale, USA: Society of Automotive Engineers, Inc.
4. Middleton, A., B. Neumann, and D.S. Khatri, *Natural Gas Injection System for Buses and Trucks - Potential to Achieve Future Performance and Emission Norms.* 2007, The Automotive Research Association of India.
5. D.S.Shin, et al. *Development of a Natural Gas Fueled Daewoo 11.1L Engine.* in *FISITA World Automotive Congress.* 2000. Seoul, Korea.
6. Semin, A. Idris, and R.A. Bakar, *An Overview of Compressed Natural Gas as an Alternative Fuel and Malaysian Scenario.* European Journal of Scientific Research, 2009. 34(1): p. 6-15.
7. Shanghai Client Diesel Engine Co., L. *Isuzu diesel engine 4HF1.* 2011 [cited 2012 December 2012]; Available from: http://www.isuzudieselengines.net/ISUZU_Diesel_Engine/ISUZU_ENGINE_Isuzu_4HF1_engine_isuzu_diesel_engines.html.
8. Heywood, J.B., *Internal combustion engine fundamentals.* McGraw-Hill series in mechanical engineering. 1988, New York McGraw-Hill.