THE SIMULATION OF PERFORMANCE CHARACTERISTICS OF PORT INJECTION DEDICATED COMPRESSED NATURAL GAS SPARK IGNITION ENGINE

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Abstract

This paper presents the computational modelling simulation results of port/sequential injection dedicated compressed natural gas (CNG) spark ignition engine to investigate and evaluate the engine performance while base engine converted by using compressed natural gas as an alternative fuel. The baseline engine in this research is four stroke direct injection diesel engine. The computational modelling design and development has performed using GT-Power software at Automotive Excellent Centre Laboratory, Faculty of Mechanical Engineering, University Malaysia Pahang, Malaysia. To investigate the engine performance, the engine computational model is operated between 500-4000 rpm, under steady state condition. In this research, the sequential injection dedicated compressed natural gas spark ignition engine performance investigation results such as torque, power, fuel consumption pressure and exhaust gas emissions were investigated and compared to base diesel engine performance. From the CNG engine computational modelling simulation results are shown that by development of sequential injection dedicated compressed natural gas spark ignition engine has a potential to reduce the engine emissions. Unfortunately, the development of sequential injection dedicated compressed natural gas spark ignition engine can be reducing the engine performance. However, the study of required to improve the performance of sequential injection dedicated compressed natural gas spark ignition engine has a potential of reducing engine.

Keywords: *CNG engine, computational modelling, engine performance, port/sequential injection*

1. Introduction

Compressed Natural Gas (CNG) is the most favourite for fossil fuel substitution [1]. CNG is a gaseous form of natural gas were compressed, it have been recognized as one of the promising alternative fuel due to its substantial benefits compared to gasoline and diesel fuel. These include lower fuel cost, cleaner exhaust gas emissions, higher octane number and most certainly. Therefore, the numbers of engine vehicles powered by CNG engines were growing rapidly [2, 3]. Natural gas is safer than gasoline in many respects [4]. The ignition temperature for natural gas is higher than gasoline and diesel fuel. Additionally, natural gas is lighter than air and will dissipate upward rapidly if a rupture occurs. Gasoline and diesel fuel will pool on the ground, increasing the danger of fire. Natural gas is non-toxic and will not contaminate groundwater if spilled. Advanced CNG guarantee considerable advantages over conventional gasoline and diesel engines [5].

However, the CNG as an alternative fuel for engines has some disadvantages, either in dual-fuel, bi-fuel or in dedicated forms has lower performance compared to gasoline and diesel engines [6]. The lower performance of CNG as an alternative fuel for engines are caused by low energy density [7], low engine volumetric efficiency because it is a gaseous fuel, low flame speed and absence of fuel evaporation, the set point for the best compromise between emissions and fuel economy is not clear, the optimum air-fuel mixing and air-fuel ratio are changes with both operating conditions [8]. Hence, systematic studies have been carried out to improve optimum CNG engines. The objective of this research is to investigate the performance effect of diesel engine convert to port injection dedicated CNG engine spark ignition based on computational simulation using GT-Power software.

2. Engine Computational Simulation Development

The development of port injection dedicated compressed natural gas (CNG) engine spark ignition computational simulation is using GT-Power software. All of the components data from the base diesel engine is input to the GT-Power engine model window libraries of the computational modeling menu. The parameters of the engine are shown in Tab. 1.

Tab. 1. Specification the engine

Engine and Intake Parameter	Diesel Engine	CNG Engine
Bore (mm)	86.0	86.0
Stroke (mm)	70.0	70.0
Displacement (cc)	407.0	407.0
Compression ratio	20.28	14.5
Intake Valve Close (CA)	496	496
Exhaust Valve Open (CA)	191	191
Intake Valve Open (CA)	361	361
Exhaust Valve Close (CA)	325	325
Ignition system	Compression	Spark
Fuel system	Direct Injection	Port Injection
Fuel	Diesel	Natural Gas
Intake port diameter in (mm)	40.69	40.69
Intake port diameter out (mm)	32.78	32.78
Intake port length (mm)	55.2	55.2
Discreatization length (mm)	34.4	34.4

The model is start from intake environment and finish in exhaust environment. There are three sub-system in the computational model of the sequential injection dedicated compressed natural gas (CNG) engine spark ignition. The first is design and development of intake system, the second is design and development of engine cylinder and engine crank train and the third is design and development of exhaust system of sequential injection compressed natural gas (CNG) engine spark ignition. Then input all of the diesel engine components for all of the three sub-system CNG engine and connect all of the engine components to develop the sequential injection compressed natural gas (CNG) engine spark ignition. After the sequential injection compressed natural gas (CNG) engine spark ignition computational modelling is completed, then running the model to simulate the engine model performance and exhaust gas emissions. The performance investigation of port injection compressed natural gas (CNG) engine spark ignition computational modelling is running in engine speeds variations.

The sequential injection CNG engine model based from diesel engine convert to CNG engine data is shown in Fig. 1. In the sequential injection CNG engine model is added intake pipe and throttle, then fuel is injected using injector in intake manifold. Where, 1 is intake environment, 2 is intake pipe1, 3 is air cleaner, 4 is intake pipe2, 5 is throttle, 6 is intake pipe3, 7 is intake runner, 8 is fuel injector, 9 is intake port, 10 is intake valve, 11 is engine cylinder, 12 is engine crank train, 13 is exhaust valve, 14 is exhaust port, 15 is exhaust runner, 16 is muffler, 17 is exhaust pipe and 18 is exhaust environment.

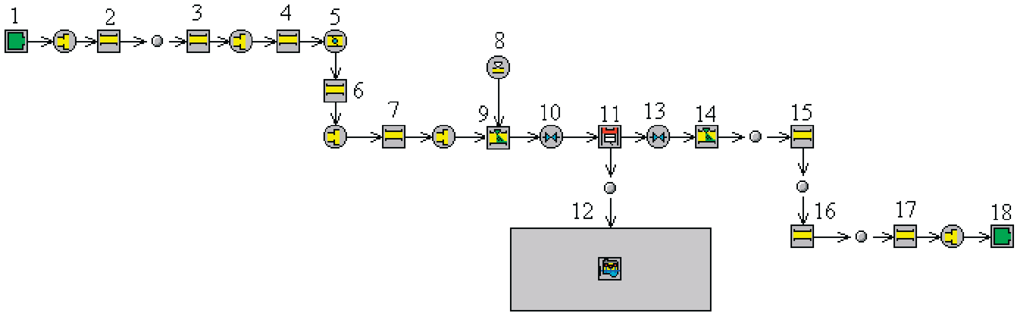

Fig. 1. Sequential injection CNG engine model using GT-POWER

Solver of GT-Power determines the performance of an engine model simulation based on engine speed mode in the EngineCrankTrain object [9]. Speed mode is the most commonly used mode of engine simulation, especially for steady states cases [9, 10]. In the research imposes the engine speed as either constant or by a dependency reference object. This method typically provides steady-state results very quickly because the speed of the engine is imposed from the start of the simulation, thus eliminating the relatively long period of time that a loaded engine requires for the crankshaft speed to reach steady-state.

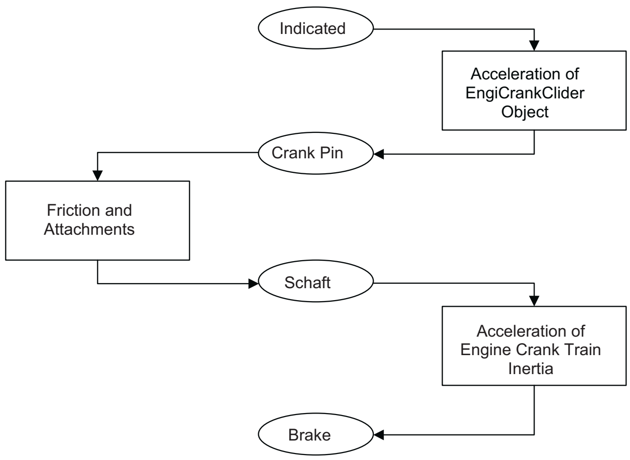

Fig. 2.The relationship indicated, crank pin, shaft, and brake performance

The engine performance parameters are studied using direct injection diesel fuel and port injection CNG engine spark ignition. When an „EngineCrankTrain" part is present in the model, there are four different instantaneous power, torque and mean effective pressure quantities available both as plots and as sensed quantities. The designations given to these four instantaneous power, torque and mean effective pressure values are indicated, crank pin, friction, attachment, shaft, and brake. The relationship between these values is explained graphically in the Fig. 2.

3. Results and Discussion

The simulation results for comparison between diesel and CNG fuel are shown in Fig. 3-5. Fig. 3 shows that when diesel fuel is being used, the brake power changes from 0.222 kW at 250 rpm to 6.370 kW at 4000 rpm.

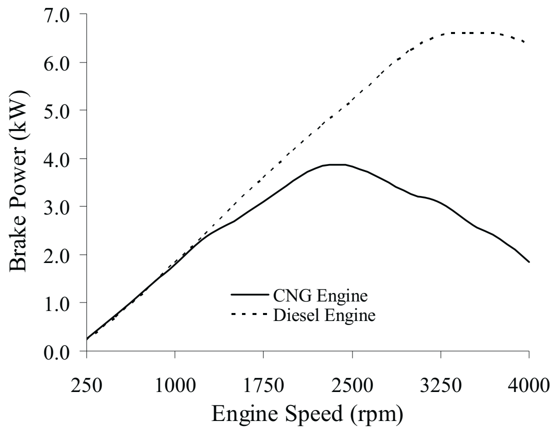

Fig. 3. Brake power of engine

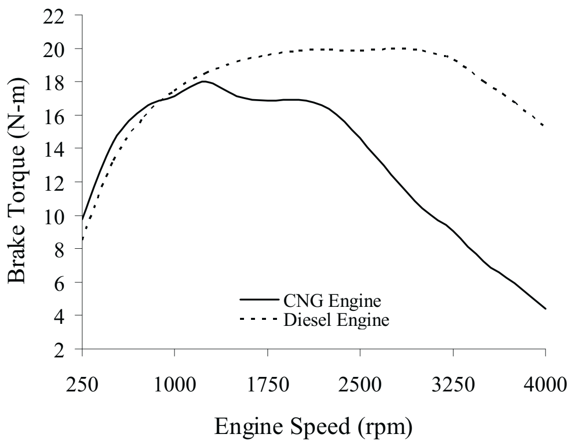

Fig. 4. Brake torque of engine

The peak value is 6.60 kW at 3500 rpm which is the maximum brake power for diesel fuel. Meanwhile when the engine is converted to port injection dedicated CNG engine spark ignition, the brake power changes from 0.255 kW at 250 rpm to 1.849 kW at 4000 rpm. The maximum brake power for CNG engine is 3.857 kW at 2250 rpm. By comparison, the maximum brake power will reduce 41.56% when converted to CNG engine.

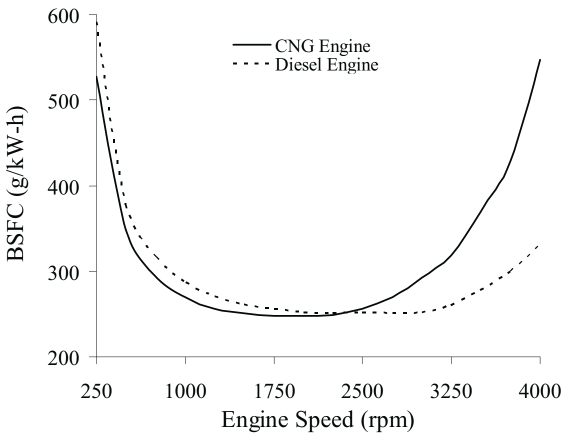

Fig. 5. Brake specific fuel consumption

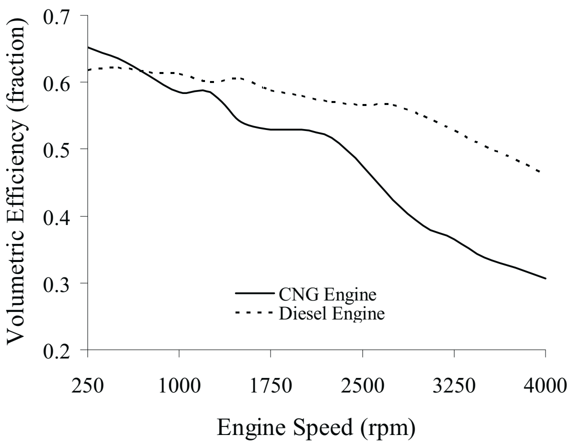

Fig. 6. Volumetric efficiency

Brake torque versus rpm graph is shown in Fig. 4. For diesel engine, the brake torque changes from 8.48 Nm at 250 rpm to 15.207 Nm at 4000 rpm. The maximum brake torque is 19.941 Nm at 2250 rpm. Meanwhile, for CNG engine, the brake torque changes from 9.764 Nm at 250 rpm 4.413 Nm at 4000 rpm. The maximum brake torque for this fuel is 18.016 Nm at 1250 rpm. By comparison, the maximum brake torque will reduce by 9.65% when the diesel engine converted to port injection dedicated CNG engine. The comparison of brake specific fuel consumption for diesel and CNG is shown in Fig. 5. For diesel engine, the brake specific fuel consumption changes from 591.184 g/kWh at 250 rpm to 329 g/kWh at 4000 rpm. The minimum brake specific fuel for diesel engine is 250.841 g/kWh at 2750 rpm. Meanwhile, for CNG engine, the brake specific fuel consumption changes from 527.521 g/kWh at 250 rpm to 546 g/kWh at 4000 rpm. The minimum value for this fuel is 247.488 g/kWh at 2000 rpm. By the comparison, the brake specific fuel consumption will decrease when engine operated in low speed and will be increased if the engine operated in high speed. In the high speed operation the CNG engine will be increase the BSFC in 66.04%. The usage of CNG in the small diesel engine will increase brake specific fuel consumption and reduction in terms of brake power and brake torque. This is because of gas fuel will reduce 33.59% volumetric efficiency compared to liquid fuel as shown in Fig. 6.

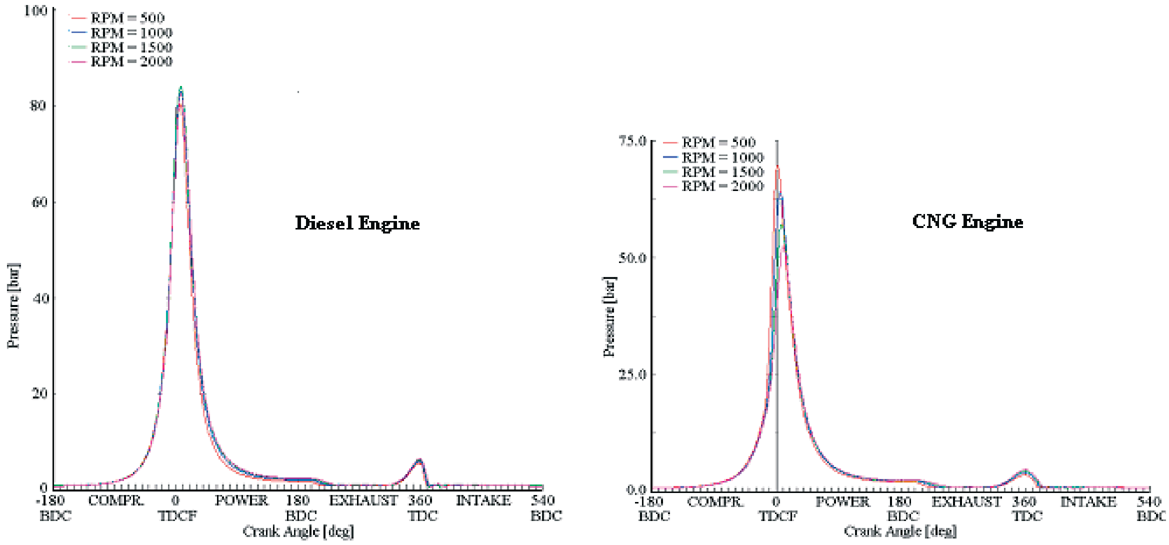

Fig. 7. In-cylinder pressure vs crank angle of engine on 500 – 2000 rpm

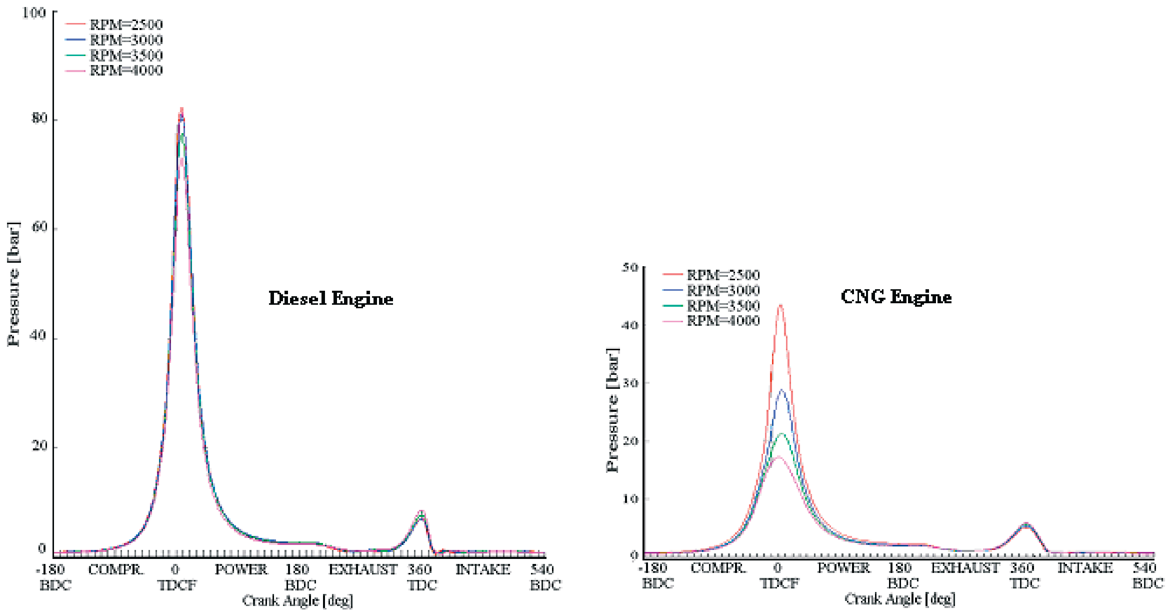

Fig. 8. In-cylinder pressure vs crank angle of engine on 500-2000 rpm

Another factor that must be considered is composition of hydrocarbon for each fuel. Diesel which has higher hydrocarbon compares to CNG will give more energy to the engine as shown in Fig. 7 and Fig. 8. At 1000 rpm the effect from this combustion will cause diesel fuel generates pressure 5.4 bar compare to CNG fuel that will generates 5.296 bar. The pressure reduction of CNG fuel is 2% from diesel fuel pressure. At 2000 rpm, the pressure will be generated are 6.14 bar and 5.225 bar for diesel and CNG respectively as shown in Fig. 9. The pressure reduction is

14.9 % from diesel fuel pressure. Meanwhile at 3000 rpm, the pressures that will be generated are 6.14 bar for diesel engine and 3.215 bar as shown in Fig. 9. The pressure reduction CNG engine is 47.6% from diesel fuel pressure. At 4000 rpm, the pressure that will be generated is 4.699 bar for diesel fuel and CNG engine is 1.364 bar.

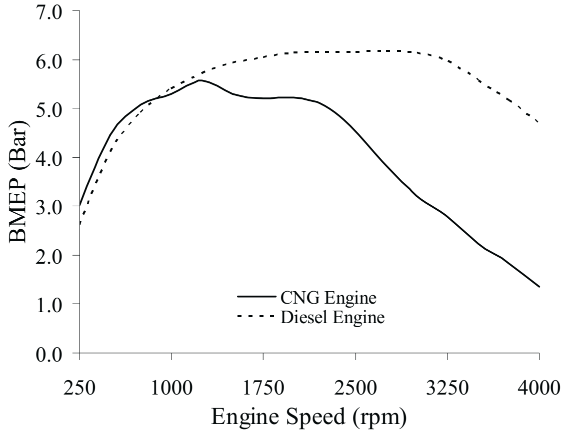

Fig. 9. Brake mean effective pressure (BMEP)

4. Conclusion

The results from these simulation investigations, it is observed that the diesel engine can be converted to port injection dedicated CNG engine. The studied parameters show that there are reduction by 41.56 % in brake power, 9.65 % in brake torque and addition of 66.04% in brake specific fuel consumption in high speed, but in low speed the CNG is reduced the BSFC in. To ensure that the percentage can be reduced, the engine needs some modification. For further research, experimental study will be conducted to validate the simulation results and to reduce the percentages for the mentioned parameters.

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