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Intake Port Gas Flow Pressure Profile Investigation of Port Injection Compressed Natural Gas (CNG) Engine Based on Engine Speed

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Abstract

The objective of this paper is to presents the gas flow pressure profile in the intake port of port injection compressed natural gas (CNG) engine spark ignition using GT-Power software for steady-state and transient simulation. The port injection CNG engine spark ignition computational model is developed from the real diesel engine data, where these data input to software window libraries. In this research, the simulation of engine computational model is running in variations engine speeds from 500, 1000, 1500, 2000, 2500, 3000, 3500 and 4000 rpm. The simulation output data is collected from the GT-Post post processing plots for static pressure versus crank angle and GT-Post post processing casesRLT for pressure in variations engine speeds. The simulation results are shown the characters in intake port pressure profile of port injection CNG engine in variations engine speeds. The detail of intake port gas flow pressure profile performance of port injection CNG engine is shown in graphs in this paper.

Key words: Engine speed, intake port, port injection CNG engine, pressure profile

INTRODUCTION

The great problems of the world in the internal combustion engines usage until today are focuses in environment protection and economically fuel consumption. In the internal combustion engines, there are some gasoline engines and diesel engines were used to generate the power in industries and transportations [1-5]. The problems are needs the new design, research and technology to find the new design of the new engine or its components, so its can using the alternative fuels another gasoline and diesel, can be protect and friendly with the environment, have high power and efficient in fuel consumption. So, some engine researcher and designers did the any new design, new concepts and new ideas to find the new engines better and better and have a high power and friendly with the environment and efficient in fuel consumption.

The internal combustion engines performance theory to link together with computer modeling of the engine thermodynamics in engine simulations are great challenge, as the latter make the most complete use of the former and the use models is becoming widespread. Engine modeling is a very large subject, in part because of the range of engine configurations possible and the variety of alternative analytical techniques or sub-models, which can be applied in overall engine models [1]. Engine modeling is a fruitful research area, and as a result many universities have produced their own engine thermodynamics models, of varying degrees of complexity, scope and ease to use. There are also now available a number of fairly comprehensive models which have a wider, more general purpose use with refined inputs and outputs to facilities their use by engineers other than their developers, most of these models had their origins in university-developed models [6]. They include WAVE from USA, PROMO from Germany, TRANSEG/ICENG/MERLIN from UK, among others [1]. A new code covering completes engine systems have emerged recently, GT-Suite [1].

The steady-state and transient of gas flow in intake port of compressed natural gas (CNG) engine simulation is using GT-Power in this research paper. This research is focuses in single cylinder four stroke port injection CNG engine spark ignition. The aim is to give an insight into intake port gas flow thermodynamics performance of the engine using GT-Power simulation model, how the engine model developed and how the components interaction.

Port injection CNG engine is internal combustion engines, where fuel is injected by the fuel injection system via intake port into the engine cylinder toward the end of the compression stroke, just before the desired start of combustion [7-12]. The gas fuel, usually injected at high velocity as one or more jets through small orifices or nozzles in injector tip, via intake port into the combustion chamber. The gas fuel mixes with high temperature and high pressure air in cylinder. The air is supplied from intake port of engine too. Since the air and gas temperature and pressure are near the ignition point, spark ignition of portions of the already-mixed gas fuel and after air a delay period of a few crank angle degrees. The cylinder pressure increases as combustion of the gas fuel-air mixture occurs [1, 12, 13].

Major problem in spark ignition CNG engine combustion chamber design is achieving sufficiently rapid mixing between the injected gas fuel and the air from intake port in the cylinder to complete combustion in the appropriate crank angle interval close to top-center [8, 12, 14-17]. Horsepower output of an engine can be dramatically improved through the good intake port design and manufacture [18].

To determine gas flow conditions right through the engine is the essence of modeling at small intervals time. Appropriate summation of these gas conditions over an engine cycle then leads to an estimate engine performance. Gas flow condition through the engine is basically meant pressures, temperatures, gas composition and mass or energy flows. The core of any model is the energy equation for each control volume in the engine [1]. The first essential the engine performance model is the energy for a control volume, which is derived from First Law Thermodynamics and the Perfect Gas Law. The first law states that the rate of change of internal energy of the volume from connected gas flows, less any net heat transfer out through the volume walls and less any work done by the control volume gas against its surroundings is shown in equation (1).

$$\frac{d(uM)}{dt} = \sum_{l} h_i \dot{m}_i - \frac{dQ}{dt} - P\left(\frac{dV}{dt}\right) \quad (1)$$

where *u* is the specific internal energy per unit mass of gas in the control volume and there are *l* pipes connecting to the control volume, the flow in the *i* pipe having specific enthalpy h_i and mass flow rate m_i (negative for outflow). Net heat transfer out of the control volume is *dQ/dt*, *M* is the mass of gas in the control volume at pressure *P* and this gas carrier out net work on its surroundings of *PdV/dt*, where *dV/dt* is the control volume's current rate of change of volume (zero for manifold control volume and not for cylinder control volume).

In the internal combustion engine, to determine flow through a pipe and constriction are needed the orifice equation [1]. The stagnation or total temperature T_t at any point in a flow is given by equation (2).

$$c_p T_t = c_p T + \frac{v^2}{2} \quad (2)$$

where, T_t is the temperature that the gas flowing at velocity *v* with static temperature *T* would reach if it were brought to rest adiabatically, the equation is simply an energy balance, $c_p T$ being a measure of the static energy, $v^2/2$ the kinetic energy and $c_p T_t$ the total energy (enthalpy). And to determine the mach number *Ma* is using equation (3), where *c* is velocity of sound, γ is equal with *cp/cv* and *cp-cv=R*.

$$M_a = \frac{v}{c} = \frac{v}{\sqrt{(\gamma RT)}} \quad (3)$$

Relationship of total to static temperature is obtained using equation (4) and (5). Then the total to static pressure equation is shown in equation (6).

$$\frac{T_t}{T} = 1 + \frac{v^2}{2c_p} = 1 + \frac{\gamma RTM_a^{\ 2}}{2c_p} \quad (4)$$

$$\frac{T_t}{T} = 1 + (\gamma - 1)\frac{M_a^{\ 2}}{2} \quad (5)$$

$$\frac{P_t}{P} = \left(\frac{T_t}{T}\right)^{\frac{\gamma}{\gamma-1}} = \left[1 + \left(\frac{\gamma-1}{2}\right)M_a^{\ 2}\right]^{\frac{\gamma}{\gamma-1}} \quad (6)$$

MATERIALS AND METHODS

In this research, the real diesel engine data is used for engine computational model design and development. The computational model of four stroke port injection CNG engine spark ignition has developed using GT-POWER software based from real diesel engine data [6, 7, 15, 19-23]. The specification of engines and the intake port are shown in Table 1. In the GT-POWER engine computational model development, component objects of a typical intake port is modeled using Import, engine is modeled using EngCylinder and EngineCrankTrain and connection objects are Valve*Conn and EngCylConn [24].

The diesel engines convert to run on dedicated compressed natural gas (CNG) engines are optimized for the natural gas fuel. They can be derived from petrol engines or may be designed for the purpose. Until original equipment manufacturer (OEM) engines are more readily available, however, the practice of converting diesel engines to spark ignition CNG engine will continue, which involves the replacement of diesel fuelling equipment by a gas port injection system and the addition of an ignition system and spark plugs. The specification of based diesel engine, intake port size and port injection CNG engine are shown in Table 1.

Table 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
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

For compression ignition engines convert to spark ignition CNG engines, the pistons must be redesign or modified to reduce the original compression ratio and a high energy ignition system must be fitted. The system is suitable for compressed natural gas and is ideally suited to port injection system and low pressure in-cylinder injection. Gas production provides greater precision to the timing and quantity of fuel provided, and to be further developed and become increasingly used to provide better fuel emissions performance [25, 26]. Before develop the physically engine conversion, the computational model has been did in this research. The computational model of port injection CNG engine development is using GT-POWER software based from real diesel engine data.

The new development of port injection CNG engine computational model based from diesel engine data is shown in Fig. 1. In the port injection CNG engine model is added intake pipe and throttle, then fuel is injected in intake port. A typical intake port is modeled using 9, engine cylinder is modeled using 11 and engine is modeled using 12, Valve*Conn and EngCylConn are connection objects. 9 used to define the basic geometry and characteristics of intake port, 11 and 12 are used to define the basic geometry and characteristics of engine. These objects further refer to some references objects for more detail modeling information on such attributes as gas flow temperature. Intake port must be connected to the engine cylinder using Valve*Conn, Engine cylinder must be connected to the engine using EngCylConn part, were the connectors are made from the predefined object which available in the template library. While Pipe, EngCylConn parts have number user to define the attributes, the global cylinder number for cylinder is assigned by the port number, where the EngCylConn connection is attached to the engine. Cylinder are connected to intake and exhaust ports using Valve*Conn connections. Many Valve*Conn connection templates are available to define the different types of valve, port and their characteristics.

Solver of GT-POWER determines the performance of an engine model simulation based on engine speed mode in the EngineCrankTrain object [6]. Speed mode is the most commonly used mode of engine simulation, especially for steady states cases [13, 24]. 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.

plot and 8 cases engine speeds for GT-Post post processing casesRLT. For post processing plot, case 1 is engine running in 1000 rpm, case 2 is engine running in 2000 rpm, case 3 is engine running in 3000 rpm and case 4 is engine running in 4000 rpm. GT-Post post processing plot results are intake port static pressure versus crank angle degree based on variations engine speeds. GT-Post post processing casesRLT results are intake port pressure versus engine speed based on 8 cases engine speeds variation from 500 rpm – 4000 rpm.

The static pressures characteristics in intake port profile of four stroke direct injection compression ignition engine and port injection CNG engine simulations results from GT-Post post processing plots are shown in Figure 2 - Figure 5. The results from the GT-Post post processing plots investigation are focuses in inlet port static pressure. Figure 2 and Figure 4 are shows the intake port static pressure of diesel engine. Figure 3 and Figure 5 are shows the intake port static pressure of port injection CNG engine. Figure 2 shows the base diesel engine intake port static pressure versus crank angle profile on 1000 - 2000 rpm engine speeds, Figure 3 shows the port injection CNG engine intake port static pressure versus crank angle profile on 1000 - 2000 rpm engine speeds, Figure 4 shows the base diesel engine intake port static pressure versus crank angle profile on 3000 - 4000 rpm engine speeds and Figure 5 shows the port injection CNG engine intake port static pressure versus crank angle profile on 3000 - 4000 rpm engine speeds.

The pressures characteristics in intake port of four stroke direct injection compression ignition engine and port injection CNG engine simulations results from GT-Post post processing casesRLT are shown in Figure 6 – Figure 15. The results of investigation are focuses on any cases in intake port pressure of CNG engine and original diesel engine. Figure 6 and Figure 7 shows the average pressure inlet and outlet in intake port on 1000 - 4000 rpm engine speed. Figure 8 and Figure 9 shows the maximum pressure inlet and outlet in intake port on 1000 - 4000 rpm engine speed. Figure 10 and Figure 11 shows the minimum pressure inlet and outlet in intake port on 1000 - 4000 rpm engine speed. Figure 12 and Figure 13 shows the pressure amplitude inlet and outlet in intake port on 1000 - 4000 rpm engine speed. Figure 14 and Figure 15 shows the average total pressure inlet and outlet in intake port on 1000 - 4000 rpm engine speed.

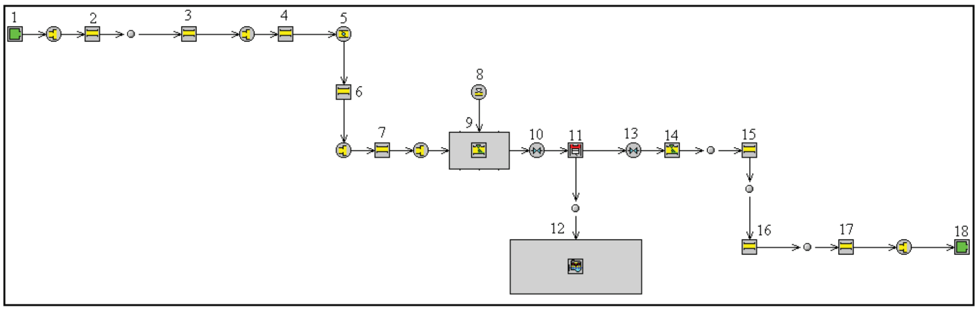

Figure 1. Port injection CNG engine model using GT-POWER

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. Components 1 to 10 are intake system, components 11 to 12 are engine, and components 13 to 18 are exhaust system.

RESULTS

The gas flow pressure profile investigation in intake port of the four stroke port injection CNG engine spark ignition model is running in 4 cases engine speeds for GT-Post post processing

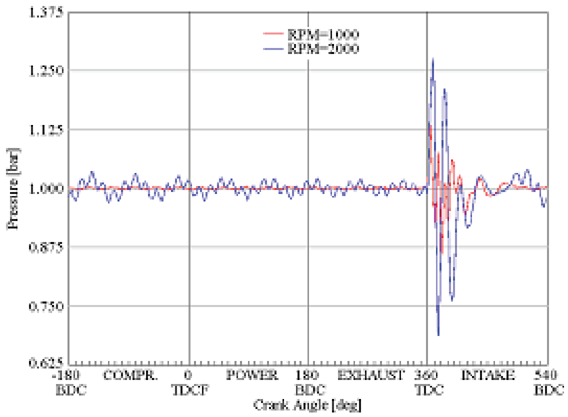

Figure 2. Diesel engine static pressure on 1000-2000 rpm

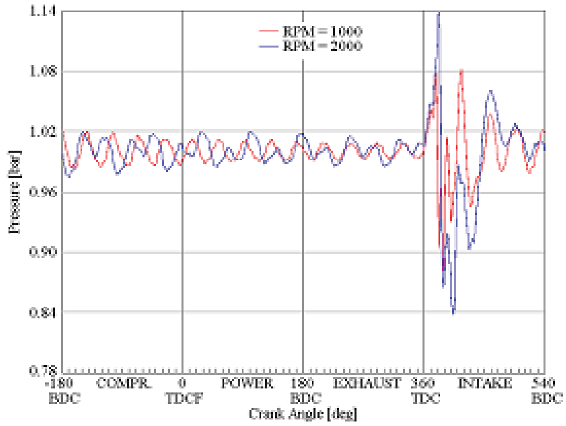

Figure 3. CNG engine static pressure on 1000-2000 rpm

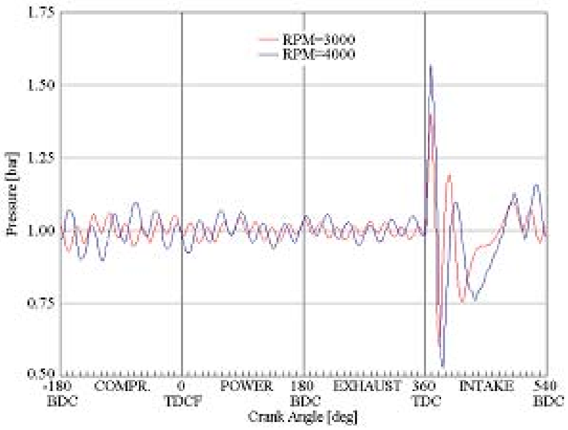

Figure 4. Diesel engine static pressure on 3000-4000 rpm

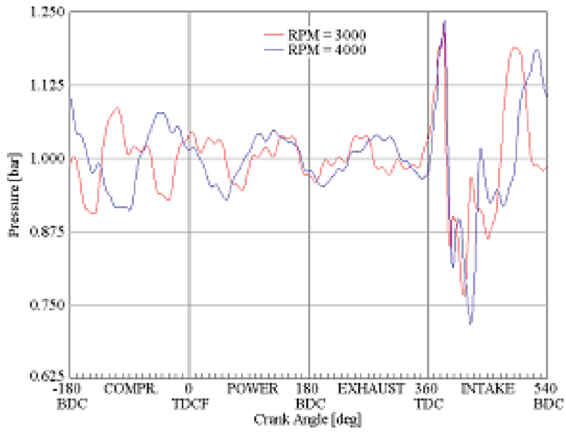

Figure 5. CNG engine static pressure on 3000-4000 rpm

DISCUSSION

The intake port static pressure results are plotted from simulation result output of GT-Post plots. Fig. 2 – Fig. 5 shows the minimum and the maximum intake port static pressure profile versus crank angle profile at 1000 - 4000 rpm engine speeds in compression stroke, power stroke, exhaust stroke and intake stroke of diesel engine and CNG engine. In this engine speed for both of the engine, nominal static pressure in the intake stroke is most extreme then in the compression stroke compared with power stroke and exhaust stroke. In the intake stroke is started from static pressure when the intake valve is just start opened, so the pressure not extreme different compared with another stroke. In the intake valve opened the static pressure is increase extremely because in the stroke the cylinder is needed suction air into the engine cylinder to mixture with fuel for engine combustion to product the power. In the intake valve close processing until the intake valve is closed the pressure static is very low because in this process the gas flow in the intake port is crass with back static pressure from intake valve closed. Then the static pressure is become to lower and lower in compression stroke, power stroke and in the exhaust stroke is the lowest.

In the intake stroke of diesel engine, the highest static pressure in intake port is 1.335 bar, declared in 4000 rpm engine speed and shown in Figure 4. In this engine speed condition, the combustion is excellent dramatically so need most of air to combustion process. The minimum static pressure is 0.624 bar and declared in 4000 rpm engine speed and shown in Figure 4 too. In this engine speed investigation the combustion, the intake valve lift and intake valve close is move most quickly, so the static pressure of air flow back from the intake valve closing is highest than the other engine speed.

In the intake stroke of port injection CNG engine, the highest static pressure in intake port is 1.172 bar, declared in 4000 rpm engine speed and shown in Figure 5. In this engine speed, the combustion is excellent dramatically so need most of air to combustion process. The minimum static pressure is 0.85 bar, declared in 4000 rpm engine speed and shown in Figure 5 too. In this engine speed investigation, the combustion, the intake valve lift and intake valve close moving is most quickly, so the static pressure of air flow back from the intake valve closing is highest than the other lower engine speed.

Gas flow pressure performance characteristics in intake port of port injection CNG engine in any cases engine speed shown in Figure 6 – Figure 15. Figure 6 shows the inlet average pressure to the intake port from the intake runner the highest is in 500 rpm engine speed both of CNG engine and diesel engine. The trend of the average pressure inlet in intake port both of CNG engine and diesel engine, increasing engine speed will be decrease the average pressure inlet. The average pressure inlet in intake port of CNG engine is higher than diesel engine. The average pressure outlet from intake port to the engine cylinder

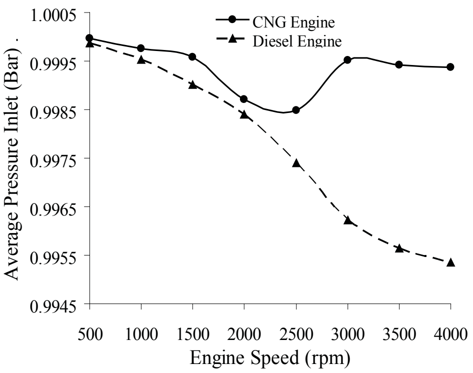

Figure 6. Average pressure inlet intake port

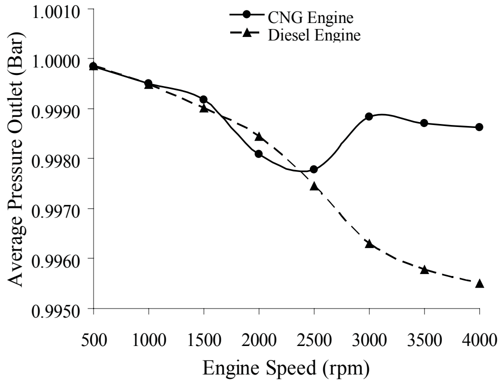

Figure 7. Average pressure outlet intake port

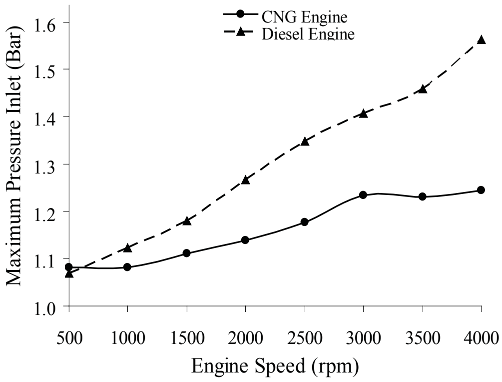

Figure 8. Max. pressure inlet intake port

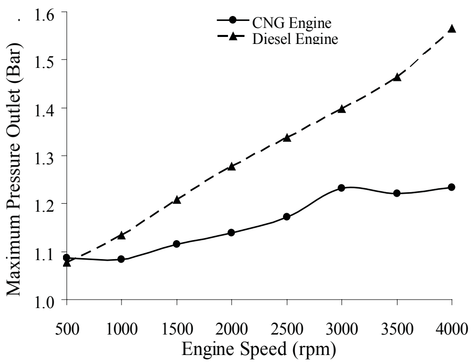

Figure 9. Max. pressure outlet intake port

is shown in Figure 7. The lowest of average pressure outlet is in 4000 rpm engine speed for diesel engine and in 2500 rpm for CNG engine. Average pressure outlet at intake port of CNG engine is higher than the diesel engine.

The maximum pressure inlet to the intake port from the intake runner is shown in Figure 8. The highest of maximum pressure inlet is in 4000 rpm engine speed both of CNG engine and diesel engine, likely the static pressure in 4000 rpm the combustion is most excellently so the engine cylinder is needed most air volume for in cylinder combustion process. Maximum pressure inlet of CNG engine is lower than diesel engine. Maximum pressure outlet from the intake port to the engine cylinder is shown in Figure 9. The highest maximum outlet pressure is in 4000 rpm engine speed both of CNG engine and diesel engine, because in 4000 rpm engine speed the combustion is most excellently so the engine cylinder is needed most air volume for in cylinder combustion process, so the engine need most pressure and volume compare the other speed. Maximum pressure outlet CNG engine is lower than diesel engine.

The minimum inlet pressure to intake port is shown in Figure 10. The lowest is in 4000 rpm engine speed and highest is in 500 rpm both of CNG engine and diesel engine, because in the engine speed the combustion and the intake valve opened and closed is most quickly. It can be the back flow of air from cylinder and intake valve closed is very high. The air back flow pressure can be reduced the intake pressure inlet to intake port. Figure 11 shows that the minimum pressure outlet from intake port to engine cylinder the highest is in 500 rpm and lowest is in 4000 rpm engine speed likely in minimum inlet pressure, because in the engine speed the combustion and the intake valve opened and closed is most quickly. It can be the back flow of air from cylinder and intake valve closed is very high. The air back flow pressure can be reduced the intake pressure outlet from intake port to the engine cylinder. Minimum pressure inlet and outlet of CNG engine is higher than diesel engine.

The highest nominal for amplitude maximum inlet and out are shown in 4000 rpm engine speed and the lowest is in 500 rpm engine speed. Figure 12 and Figure 13 are shows the pressure amplitude for the inlet to intake port and outlet from intake port. The gap of CNG engine and diesel engine pressure amplitude for inlet and outlet are zero in 500 rpm engine speed and increasing engine speed will be increase pressure amplitude inlet and outlet.

Average total pressure is mean of the minimum pressure and maximum pressure. Average of total pressure in inlet process to intake port and outlet process from intake port to engine cylinder is shown in Figure 14 and Figure 15. The average pressure inlet to intake port the highest is on 4000 rpm engine speed both for CNG engine and diesel engine. The lowest of average total pressure inlet is on 3000 rpm engine speed for diesel engine and on 2000 rpm engine speed for CNG engine. The average total pressure inlet in intake port of CNG engine is higher than

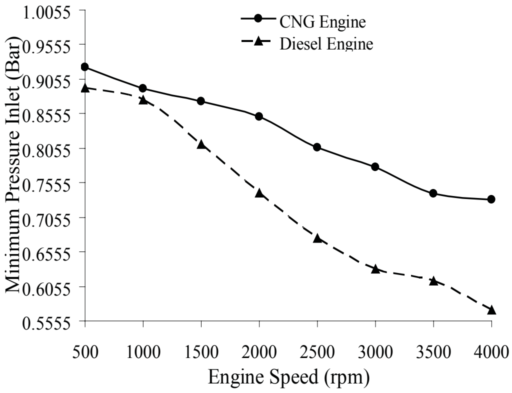

Figure 10. Min. pressure inlet intake port

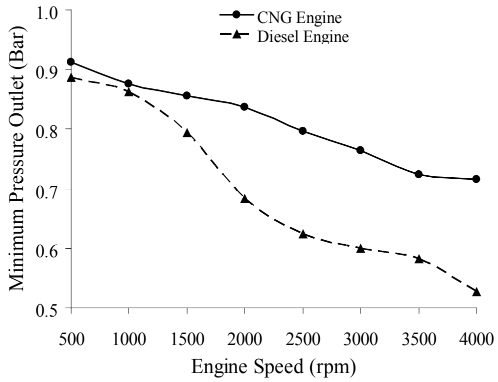

Figure 11. Min. pressure outlet intake port

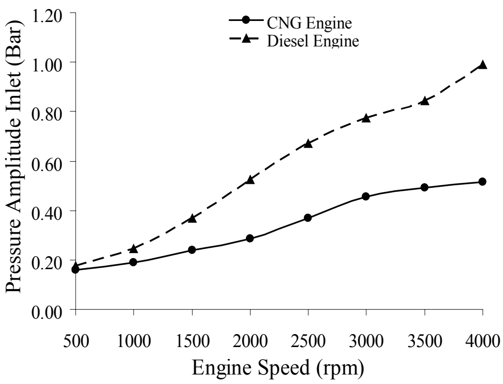

Figure 12. Pressure amplitude in intake port

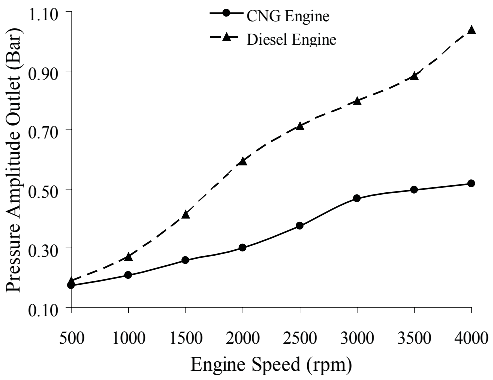

Figure 13. Pressure amplitude out intake port

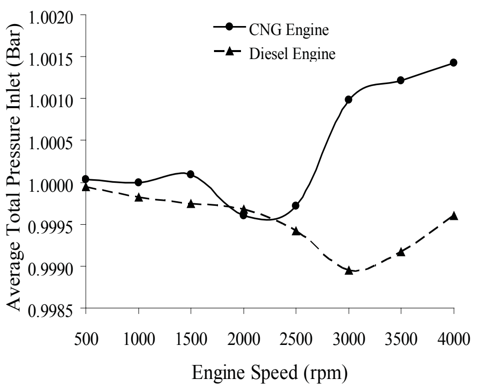

Figure 14. Average total pressure inlet intake port

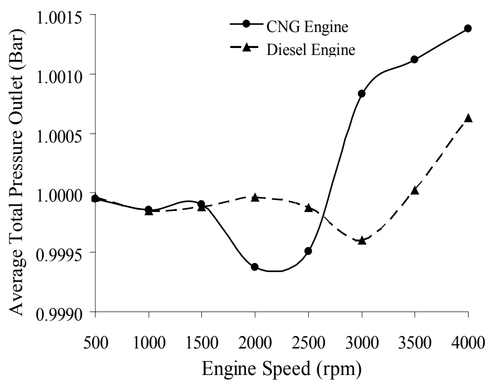

Figure 15. Average total pressure outlet intake port

diesel engine. The highest of average of total pressure outlet from intake port to engine cylinder is on 4000 rpm engine speed both of CNG engine and diesel engine and the lowest of the average total pressure outlet from intake port to engine cylinder is on 3000 rpm engine speed for diesel engine and on 2000 rpm engine speed for CNG engine.

Finally, the average total pressure inlet and outlet are as a measured pressure or as a pressure in intake port of engine. Intake port pressure of port injection CNG engine model is higher than the diesel engine, so the conversion of direct injection diesel engine to port injection CNG engine will be increase the intake pressure in intake port of the engine. The port injection CNG engine model intake port pressure performance is higher than the other, because in computational model the ambient effect is zero, but the real have nominal point. The increasing of gas flow pressure in intake manifold is caused by the development of gas fuel sequential injector in the intake manifold of port injection CNG engine, where in the diesel engine is using direct injection.

Other that, the combustion of diesel engine is quickly after injection start, but the port injection CNG engine combustion is later because the injection duration of port injection CNG fuel is more long time compared with direct injection fuel.

CONCLUSSION

The gas flow pressure in intake port versus crank angle and engine speed data can be used to obtain quantitative information to predict the characteristics of the intake port gas flow pressure were needed on the progress of combustion of CNG engine performance effect compared with base engine. The performance results are shown that the static pressure versus crank angle for CNG engine is lower than base diesel engine. The highest intake port static pressure versus crank angle is in 4000 rpm, both of CNG engine and diesel engine. The maximum pressure inlet and outlet in intake port for CNG engine is lower than diesel engine, minimum pressure inlet and minimum pressure outlet in intake port of CNG engine is lower than diesel engine. The average total pressure inlet and average total pressure outlet in intake port of CNG engine is higher than the diesel engine, so by convert the diesel engine to port injection CNG engine will be increase the intake pressure in intake port of the engine.

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