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Performance analysis of a spark ignition engine using compressed natural gas (CNG) as fuel

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Abstract

Compress natural gas (CNG) is also considered as alternative fuel to produce better emission in a vehicle, but the main disadvantage of CNG in comparison to liquid fuel (gasoline) is the lack of power produced for the same capacity of engine. In this study, the single cylinder spark ignition (SI) engine was selected in order to study the effect CNG into the spark ignition engine. The hydraulic dynamometer was used to study the performance of CNG and liquid fuel. The usage of sensor also applies to the test to extract the data during the ignition stage for liquid fuel and CNG. The heat generated by both types of fuel also had been extracted from the tested engine in order to define which usage of fuel would cause a higher heat transfer to the engine. From this study, the result showed that pressure inside cylinder for CNG is 20% less than gasoline. CNG fuel also produced 23% less heat transfer rate compared to gasoline. The results explained why CNG produced 18.5% lower power compared to liquid fuel (gasoline).So, some improvement needs to be done in order to use CNG as fuel.

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Keywords: CNG; singel cylinder engine; engine speed; engine power; pressure inside cylinder;heat transfer rate;crank angle

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1. Introduction

Liquid fuel is one of the energy sources, especially for internal combustion engine after the Stirling engine and the steam engine were abundant. However, the consumption of this energy source has been increased with the amount of population increase in this world. The demand of this energy source leads to the supply becoming critical. Besides that, internal combustion engine also one of the factors that caused the pollution to the environment.

The emission from internal combustion engine is very harmful and so with the emission from the fuel itself. The main harmful emission from liquid fuel are CO and NOx emission[1]. Therefore, the automotive experts had introduced alternative fuel and this alternative fuel is now being implemented in internal combustion engine. The alternative fuels currently introduced today are natural gas, bio-diesel, hydrogen gas, etc. The reason to introduce these alternative fuels is due to reduce the global warming that caused by the emission and to overcome the liquid fuel storage and supply problems.

The focus alternative fuel in this study is natural gas. Natural gas is also gained from fossil fuel, which is similar to liquid fuel and diesel. However, natural gas can be considered as renewable energy due to the recycle of methane gas [2]. But the power obtained from natural gas is not as high as liquid fuel. The more detail properties of natural gas can be observed in Table 1 [3]:

From Table 1, it is know that the main substance inside natural gas is methane. As mentioned before, methane can be considered as renewable fuel and apply in internal combustion engine. The implementation of natural gas in internal combustion engine produces low emission but at the main problems is that it produced lower performance[4, 5]. This study focused on the performance of (CNG) in a single cylinder engine. The performance of CNG in the spark ignition engine compares to liquid fuel is different due to the different properties of natural gas. Table 2 below shows the different properties between natural gas and liquid fuel[2]:

Engine power had been known to be decreased by using CNG but the detail of the problem had not been studied. This study focuses on each engine performance when using CNG as fuel, in order to improve or to increase the engine power.

Table 1.Natural gas properties.

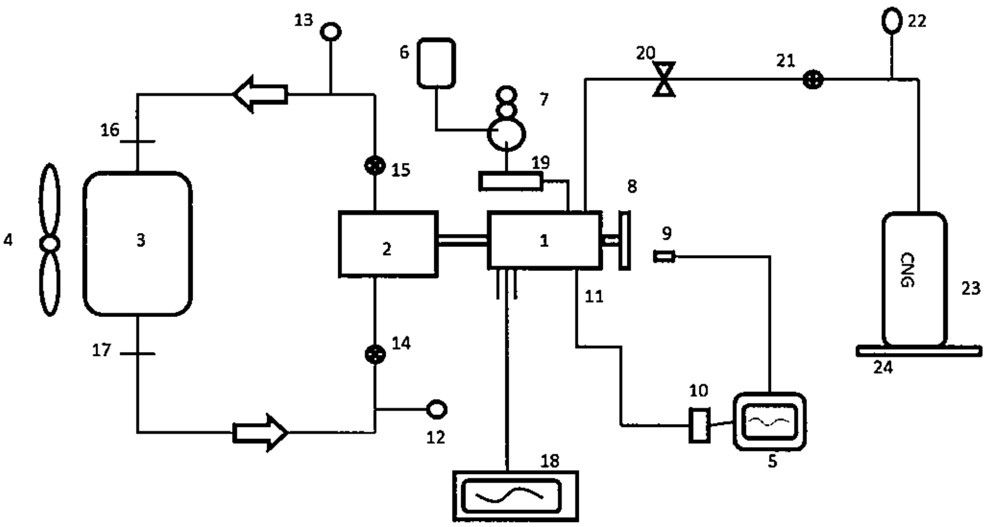
Constituent	Volume (%)
Methane	95.3
Ethane	2.16
Propane	0.19
N-Butane	0.02
Iso-Butane	0.02
N-Pentane	0.00
Iso-Pentane	0.01
Hexanes plus	0.00
Nitrogen	1.86
Carbon Dioxide	0.44
Oxygen	0.00
Hydrogen	0.00

Table 2. Properties of natural gas and liquid fuel.

Properties	Liquid fuel	Natural gas
Density(kg/cm3)	750	0.725
Lower heating value (Mj/kg)	44	45
Octane number	95	120
Auto ignition temp. (oC)	280	650

2. Research methodology

This study focused on the performance of CNG when used in a single cylinder SI engine. The tested engine was equipped with CNG kit, which represent as the CNG system in the vehicle. The system was tested using a hydraulic dynamometer, which operates in two different fuel sources. The fuels are CNG and liquid fuel. The data from these two different types of fuel were compared and analysed. Fig. 1 shows the schematic diagram of the dynamometer with tested engine and the CNG kits.



1	Engine	7	Fuel burret	13	Pressure gauges	19	Fuel pump
2	Hydraulic pump	8	Crank angle disc	14	Control valve	20	Flow rate gauges
3	Hydraulic tank	9	Crank angle decoder	15	Control valve	21	Pressure regulator
4	Cooling fan	10	Amplifier	16	Thermocouple	22	Pressure gauges
5	Combustion analyse	11	Pressure sensor	17	Thermocouple	23	CNG tank
6	Fuel tank	12	Pressure gauges	18	Gas analyzer	24	Weight scale

Fig. 1. Schematic diagram of experimental setup.

The fix variable during this experiment is backpressure from the hydraulic pump. The back pressure is only applied about 50% of certain engine speed in revolution per minute (rpm). When 100% back pressure applies to the engine, it will cause the engine to stop and it indicates that the pressure is too high. Manipulated variable is the engine speed (rpm).

For the overall average heat transfer from the gas to the cylinder coolant, convection type heat transfer equations are used.

$$Q/A = h(T_{gas} - T_{cool}) \tag{1}$$

where Q is overall heat transfer (W/m^2), A is reference cylinder area (m^2), T_{gas} is effective gas temperature typically 800°C, T_{cool} is coolant temperature typically 80°C, h: heat transfer coefficient (W/m^2 K)

The different engine speed will represent the performance of the tested engine with different types of fuel where in this case is liquid fuel (gasoline) and natural gas. Table 3 shows the tested engine specification that was used in this study. The result of this experiment indicates the performance of CNG in SI engine compared to the liquid fuel.

Table 3. Engine Specification.

Item	Specification
Bore x stroke (mm)	67 x52
Piston displacement	183 cm3
Power (max/ rpm)	2.6 kW/3,600 rpm
Type	Single cylinder
Stroke	4-stroke
Connecting rod length	91 mm

3. Results and discussion

From the experiments conducted, the data for CNG in SI engine were analysed. Then the data were compared with the liquid fuel data. The experiment results focus on the power, cylinder pressure, and volumetric efficiency. The experiment was conducted by applying the pressure from the hydraulic pump to the tested engine. Table 4 shows the pressure indicated from pressure gauge of the hydraulic pump.

Table 4. Experimental data.

Engine Speed (rpm)	Liquid Fuel Pressure (bar)	CNG Pressure (bar)
2,000	6	2
2,500	9	4
3,000	8	5
3,600	10	6
4,000	12	8

From the results shown in Fig. 2, the performance of liquid fuel is higher than CNG. During at low engine speed, such as 2,000 rpm, the liquid fuel shows higher power output compare with the CNG. This behavior is almost the same until at the end of engine speed which 4,000 rpm. Based on the engine specification in Table 4, the maximum power for this tested engine is 2.6 kW at 3,600 rpm. Therefore, from Fig. 2, in this experiment liquid fuel as power source at 3,600 rpm give the power output about 2.7 kW.

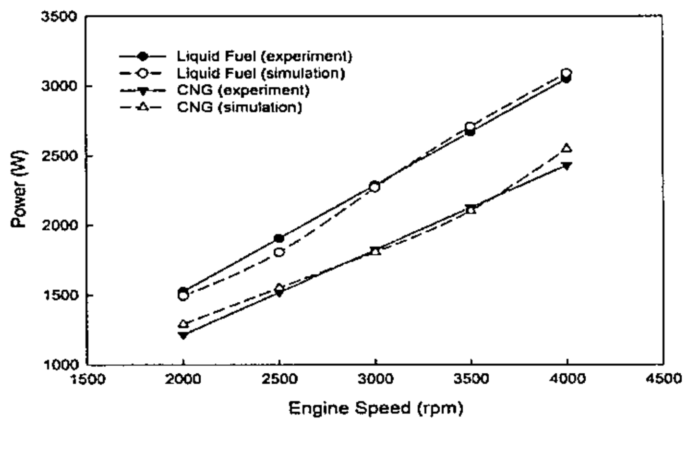


Fig. 2. Performance of tested engine with different types of fuel.

When CNG were used as a power source, the power output for this test engine at 3600 rpm is only 2.2 kW. This power drop by CNG engine is 18.5 %. Simulation model also have been done in order to validate the result for the power. In Fig. 2 shows the dash line which indicated the simulation result. The simulation was run based on the engine parameter.

The simulation result also shows the same behavior where the power created by CNG is lower than liquid fuel. The lower power for CNG is due to several factors. One of the main factors is volumetric efficiency. The volumetric efficiency of CNG is lower than liquid fuel[2]. Figure 3 shows the volumetric efficiency for liquid fuel and CNG.

According to the figure, the volumetric efficiency for this test engine is high when liquid fuel was used as the power source. However, when CNG was applied to this engine, it results low volumetric efficiency compare to liquid fuel. The lower volumetric efficiency is due to CNG physical properties, which is gas. During intake, CNG which consist of methane as the main particle does not produce a cooling effect during this condition. This result is due to the CNG is in the gas phase and it is vapour at ambient temperature.

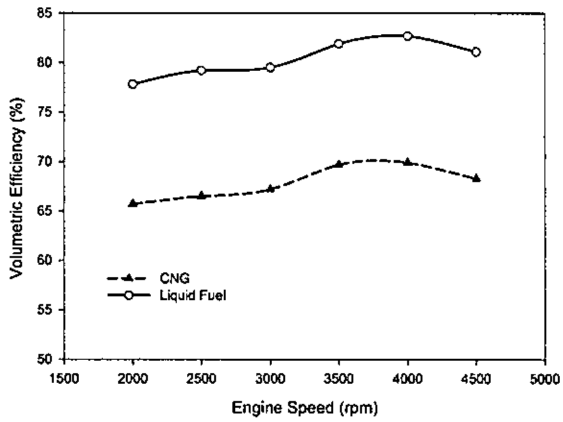


Fig. 3. Result of volumetric efficiency for both fuel.

Therefore, without cooling effect, it become low in volumetric efficiency compare to the gasoline fuel [6]. Fig. 3 also showed that the highest peak in volumetric efficiency for each type of fuel is at 3,600 rpm. This indicates that the highest is also achieved when the maximum power of the engine, referring to the engine specification in Table 3, also state that the maximum power obtained at 3,600 rpm. Therefore, from this experiment, the highest peak of volumetric efficiency will be obtained at maximum power output of the engine.

Other than the volumetric efficiency effect, the pressure inside cylinder also gives the different result between liquid fuel and CNG. The pressure inside the cylinder which also observed at all the stages of the engine, but the main focus is the ignition stage. According to previous studies, when the engine used CNG as a power source, during ignition stage the pressure inside the cylinder is lower than liquid fuel [3, 7, 8, 9].

Fig. 4 shows the effect of CNG into the pressure inside engine cylinder. Based on the graph comparison between Fig. 3 and Fig. 4, it showed that the pressure inside the cylinder of CNG fuel is lower than liquid fuel at various engine speeds. This pressure difference also shows the same behaviour with the power output of the tested engine where the pressure inside the cylinder of CNG fuel usually lower than liquid fuel.

The pressure inside cylinder for liquid fuel is shown in Fig.4and for CNG in Fig. 5.The results indicate that the pressure inside the cylinder increased as the engine speed increased. The different internal pressure produced during ignition stage between these types of fuel is due to the different density and volumetric efficiency as mentioned before. Based on Table 2, the density of liquid fuel is higher than the CNG. The density indicates the amount or mass of fuel fraction inside the combustion chamber.

Higher density will produce high amount of burned fuel and also will create more temperature during the ignition stage. This condition explained why the heat transfer rate of liquid fuel is higher than CNG. The effects of CNG to the heat transfer rate for the tested engine as shown in Fig. 7. Based on the results in Fig. 6 and Fig. 7 both types of fuel (liquid fuel and CNG) showed the rate of heat transfer increased as the engine speed increased. The graphs indicate that, the usage of liquid fuel causes the engine to suffer the high temperature at the main engine (in the combustion chamber or cylinder).

When CNG is used as fuel, the heat transfer rate reduced about 5 kW compared to liquid fuel. From Fig. 6 and Fig. 7, the highest heat transfer rate for liquid fuel is 27 kW at the engine speed of 4500 rpm. Where else, the rate of heat transfer at the same engine speed is only 20 kW for the CNG.

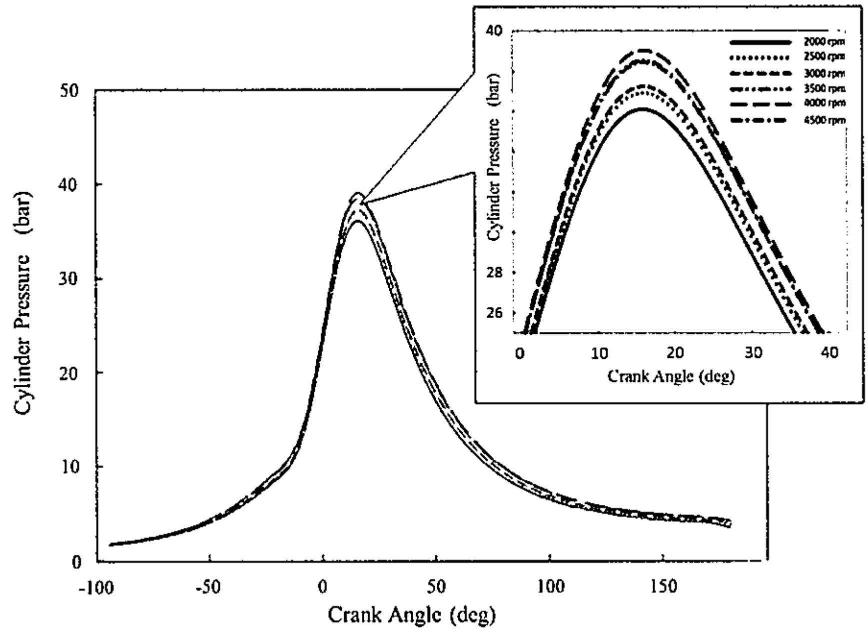


Fig. 4. Effect of cylinder pressure for liquid fuel at different engine speed

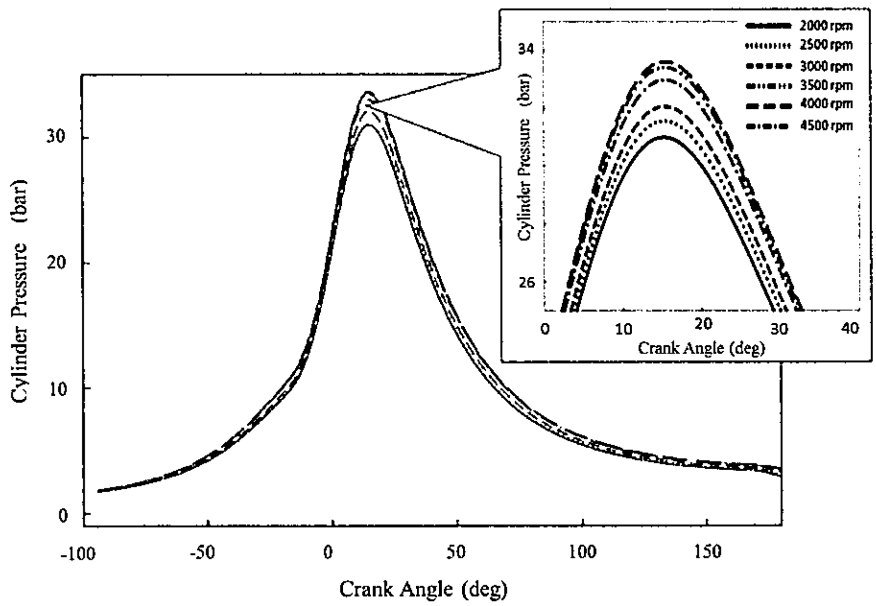


Fig. 5. Effect of cylinder pressure for CNG at different engine speed.

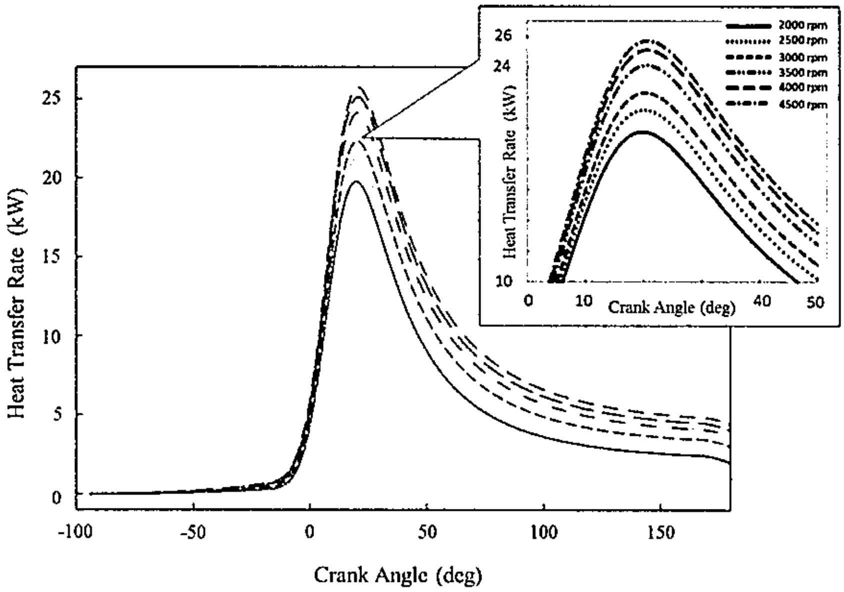


Fig. 6.Effect of heat transfer rate for liquid fuel at different engine speed.

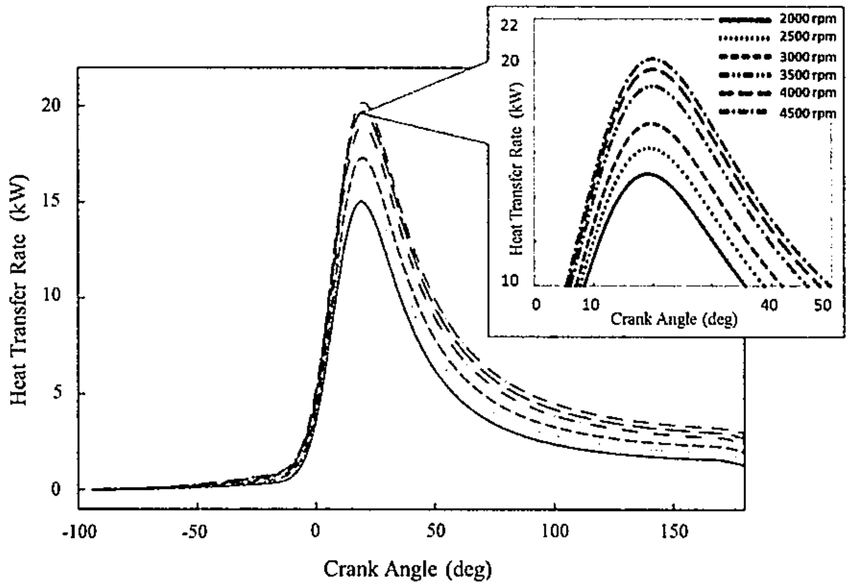


Fig. 7.Effect of heat transfer rate for CNG at different engine speed.

4. Conclusion

Based from the experiment in this study, compressed natural gas (CNG) produced low performance compared to liquid fuel. The power of CNG when compared to liquid fuel is reduced to about 18.5 %. The main reason for the lack of power when using CNG is because of the volumetric efficiency. CNG's volumetric efficiency is lower than liquid fuel, due to its physical properties which is gas. When the experiment result of pressure inside the cylinder is compared, the CNG have lower pressure than the liquid fuel at ignition stage. The pressure inside cylinder for liquid fuel at highest engine speed (4500 rpm) is nearly40 bar. However, for CNG at the same engine speed, the pressure inside engine cylinder is only 32 bar. The lower pressure obtained by CNG is due to the low density of CNG itself compared to liquid fuel. The density is also resulting the low heat generated by CNG. The low heat generated is based on the temperature during combustion. The heat transfer rate to the wall by CNG is also lower compared to the liquid fuel. In the experiment, heat transfer rate for CNG at4500 rpm is 20 kW at. However, the heat transfer rate by liquid fuel is higher (26 kW) at the same engine speed. Therefore, the performance of CNG is lower than liquid fuel, but in term of heat generated CNG give a better life span of the engine because of the low heat transfer rate to the wall. A new method to improve the CNG combustion is now being studied to continue this research. The possibility of using pre-combustion chamber and direct injection system to enhance the power produce is under development.

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