

Simulation Studies on the Performance of Small Engine Fuelled by Methane and the Effect of Various Valve Timings

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Abstract

Over the past few years, many researchers have conducted experimental and simulation studies using alternative fuels for Internal Combustion Engine (ICE). There are many types of existing alternative fuels can be used in Internal Combustion Engine, but the fundamental information about their combustion process is still limited due to difficulties in developing the experimental work. This study focus on the performance of methane fuelled engine and optimize it by varying the cam timing angle for both intake and exhaust valves. The engine performance was measured on the brake torque, brake power, Brake Mean Effective Pressure (BMEP) and in-cylinder peak pressure. The engine model was developed based on Modenas Kriss 110cc 4-stroke single cylinder gasoline engine. CATIA software was used in developing the 3D engine model and followed by utilization of GT-Suite software in analyzing the engine performance. The engine performance results for methane fuelled engine were found to be lower at about 20.1 % for engine torque, brake power and BMEP and 12.0 % for in-cylinder peak pressure when compared to gasoline engine. In the case of different valve timing, it was found that retarding the exhaust valve open timing at about 10° would produce the highest brake power in the range 5–10 %. From these results it can be concluded that the methane fuel produced lower engine performance compared to gasoline and different cam timing angle is required for methane fueled engine.

Keywords: Engine, GT-Suite, Methane, Performance

1. Introduction

Nowadays, the needs in finding renewable energy resources are growing to fulfill the energy demand that keeps increasing years after years. Fluctuating of oil price and environmental issue have increased the activities in finding alternatives fuel resources that will provide a sustainable energy and achieve greener environment. There are many previous researches have studied the performance of alternative fuels¹⁻³. However, the detail information and finding about pure methane fuelled engine is still limited. This study focused on the potential

of methane fuel usage in a small spark ignition engine. Methane is one of the largest components in natural gas. Additionally, Compressed Natural Gas (CNG) that available in market contains of about 75 – 98 % methane with small percentages of ethane, propane, butane⁴.

Previous research has shown that the usage of CNG as alternative fuel will degrade the power, torque and Bmep compared to gasoline engine⁵. However, the brake specific fuel consumption of natural gas is lower compared to gasoline⁶ The Carbon Monoxide (CO) and Carbon Dioxide (CO₂) are also lower than gasoline engine⁷. Other research work also found that the natural gas lack in term of power

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and torque compared to gasoline engine⁸. To increase the performance of natural gas fuelled engine, few investigations were carried by optimizing the engine parameters. There are several ways in optimizing the engine performance such as using various injection timing, fuel delivery pressure and flow rate⁹. Another method is by varying the inlet throat diameter¹⁰. The simplest method is by varying the cam angle timing for intake and exhaust valves¹¹.

The opening of the intake valve allows air-fuel mixture to enter the cylinder from the intake manifold. Opening the intake valve too early can result in exhaust gasses flowing into the intake manifold instead of leaving the cylinder through the exhaust valve. Retard the Intake Valve Openings (IVO) can restrict the entry of air-fuel from the manifold. The typical IVO timing for production engine is around 10 - 20° before Top Dead Centre (TDC). Meanwhile the function of Exhaust Valve Opens (EVO) will allow pressure inside the cylinder to escape into the exhaust system. A typical EVO timing is in the range of 50–60° before Bottom Dead Centre (BDC) for a production engine. By varying these parameters, it will affect the valve overlap. Therefore, the intake gas flow and the exhaust gas flow influence each other.

The purpose of this study is to understand the performance of methane fuelled engine such as brake torque, brake power, BMEP and in-cylinder peak pressure and compared it performance to gasoline engine. Furthermore, the effect of various valve timing for intake and exhaust are also been studied.

2. Methodology

The primary objectives of this paper are to evaluate the performance of methane fuel engine and to study the effect of various valves cam timing angle. The first step taken is determining the performance of gasoline engine by using experimental setup. Engine dynamometer was used simultaneously with gas analyzer to determine the gasoline engine performance and air-fuel ratio. The engine performance test is performed at Wide Open Throttle (WOT) condition. The experimental results are used for validation of the developed engine model. Table 1 indicates the technical specifications of the engine.

In this study, a single cylinder engine model is built using commercial software called GT-Suite. The technique in modelling the engine can be referred in GT-Suite manual¹². GT-Power, which is one of the modules under the GT-Suite, is a powerful tool that has been used by many

Table 1. Engine technical specifications

Type	4-stroke SOHC, single cylinder
Bore × Stroke	53 × 50.6 mm
Displacement	110cc
Maximum torque	9.3 N.m @ 4000 rpm
Intake Valve Open (IVO)	20°BTDC
Exhaust Valve Open (EVO)	55°BBDC
Duration time intake/exhaust	260°

researchers in internal combustion engine modeling^{13,14}. Some of the inputs in 1D engine modeling require detail geometry of engine components. Components like airbox, intake runner and exhaust system have been developed in 3D CAD model. The 3D model development process involve in taking the dimension of the engine such as runner length, diameter of pipe throat and radius of pipe bends. Here, the 3D model is performed using CATIA software. The 3D CAD model is then imported into one of the GT-Suite module called GEM-3D in order to convert it into 1-dimensional engine diagram. Then, GT-Power is used to run the simulation and obtained the performance of the engine. The validation of the engine model is performed by comparing the engine performance results between simulations of the gasoline engine with the experiment results¹³. After the engine model fuelled with gasoline has been validated, then the gasoline fuel is changed to methane fuel. The stoichiometry of air-fuel ratio between gasoline and methane are different. Therefore, the usage of equivalence ratio is applied to finds the new air-fuel ratio for methane fuel. In achieving the optimum methane fuel engine performance, it is very much depends on the configuration of the engine. Finally, both of intake and exhaust valves cam timing angle are simulated to identify which of the angle gives the optimum performance.

3. Experimental Setup

The experimental setup used in this work is shown in Figure 1, consist of engine dynamometer (Focus Applied Model G7.5LC) coupled with Modenas Kriss 110 cc engine. Wide open throttle mode experiment is performed to obtain the engine performance. Gas analyzer (SPTC 085241) is used in finding the air-fuel ratio at various engine speeds. This setup provides useful information such as Torque, Rpm and in-cylinder pressure trace. The in-cylinder trace is acquired using PCB Piezotronics (Model 112A05) pressure transducer and Dewetron



Figure 1. Experimental setup for gasoline engine performance measurement.

(Model DEWE-30-8) data acquisition (DAQ). For other parameters, they are calculated using formula such as for brake power (Equation 1) and BMEP (Equation 2).

$$bp = 2\pi NT \quad (1)$$

$$bmep = \frac{2bp}{ALnN} \quad (2)$$

Where N is engine speed in rpm, T is torque in Nm, A is area in m², L is length of stroke and n is number of cylinder.

4. Engine Modeling

The model development process starts with 3D engine part modeling using CATIA. It starts from building the internal volume of air box, intakes runner, inlet port, exhaust port, exhaust runner and tail pipe. The parts are created individually for easier discretized process in GEM-3D. By discretizing the part in GEM 3D, the 3D model is converted into 1D diagram that is used in GT-Power. The created 1D diagram for each part (Figure 2) is connected by string called junction in GT-Power. It simulates the flow path starting from air enters the air box until combustion process completed and exhaust gas leaving the tail pipe. The cylinder geometry is created in GT-Power and should be defined accordingly to engine technical specifications.

The intake and exhaust valve geometries are also defined in GT-Power. The intake and exhaust valve opening and closing timing are very crucial and should be defined according to real engine. The valve lift array is obtained by

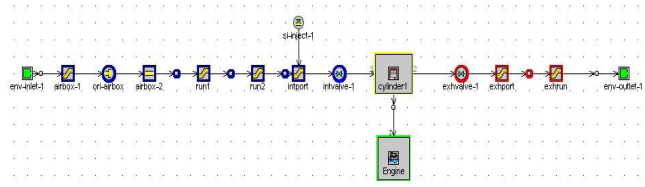


Figure 2. Constructed model for Modenass Kriss 110 engine.

setting the valve diameter, valve lift and flow coefficient inside the given table in GT-Power file so that it can be auto calculated¹². As for the simulation setup, the solver needs the information on the speed of the engine, as well as the air-fuel ratio. The same procedure is repeated for the next cases with different value of speed and air-fuel ratio. By doing this, the air-fuel ratio can be used at a different speeds according to experimental results. Finally the model is simulated and the results of the performance are plotted.

5. Results and Discussion

To investigate the performance of methane fuelled engine and the effect of various valve timing, three different studies were used;

- Case 1:** Verification of model with experimental results for gasoline engine.
- Case 2:** Modeling of methane fuelled engine. The performance of the methane fuel was analyzed and compared to gasoline.
- Case 3:** Investigate on the effect of various valve timing for intake and exhaust valve.

All of these findings will be discussed more in following subsection.

6. Model Verification

To assess the accuracy of the constructed model, verification to the experimental data is needed. The accuracy of the constructed model was verified by comparing the engine performance between model and experiment. Both of the results were correlated based on their trends and value. At the early stages of the verification, the simulation results shows quite significant different when compared to experimental results. It shows that the model needs to be calibrated so that the results will be close as the experimental results. In order to calibrate the model, lift angle multiplier was set to 0.83 thus the duration of

the IVO and EVO is the same as the engine specifications. The forward coefficient was set to 0.95 and the maximum lift was changed to 5 mm height which changes the flow array. A new setting of flow array was redefined at 5 mm lift to generate the new flow array and was used in the model valves flow array. The validation of model to experimental data is shown in Figure 3.

After the tuning and calibration process, the simulation was run with the aim to obtained less than 10 % differences which make the model reliable and ready to use for the next simulation. From the analysis, it was found that the average percentage of different between the model and experiment is at about 4.1 % for engine torque, brake power and bmep and 5.0 % for in-cylinder pressure. The trends also have shown similarity for both model and experimental data. It can be concluded that the Modenas Kriss 110cc engine model was successfully developed

into one dimensional model using GT-Suite software. It represents the real engine which the output of the model gives nearly same results as the experiment results.

6.1 Methane Fuel Engine Performance

In case of methane fuel, methane_vap type of fuel was selected from the GT-Suite library. In order to provide comparison to gasoline, the air-fuel ratio was setup based on the same equivalence ratio with gasoline engine. The detail of modelling condition is shown in Table 2. The stoichiometric air-fuel ratio (AFR) for gasoline was referred as 14.7:1. The equivalence ratio was found by dividing 14.7 to the air-fuel ratio obtained from the experiment. Hence, the obtained equivalence ratio was used to find the actual ratio of methane by dividing the stoichiometric ratio of methane which is 17.2¹⁵ to the equivalence ratio. This method was used for all rpm as well.

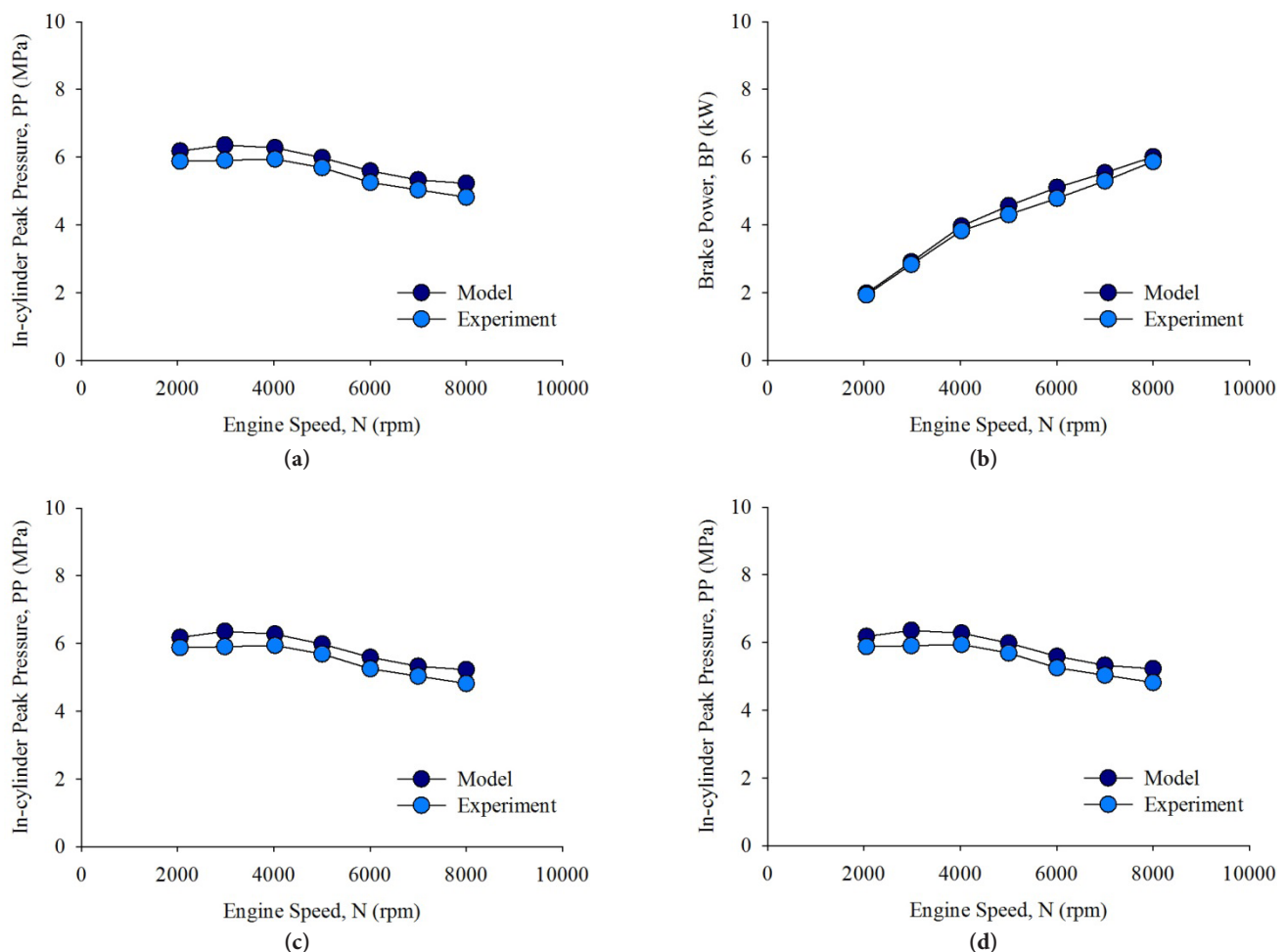
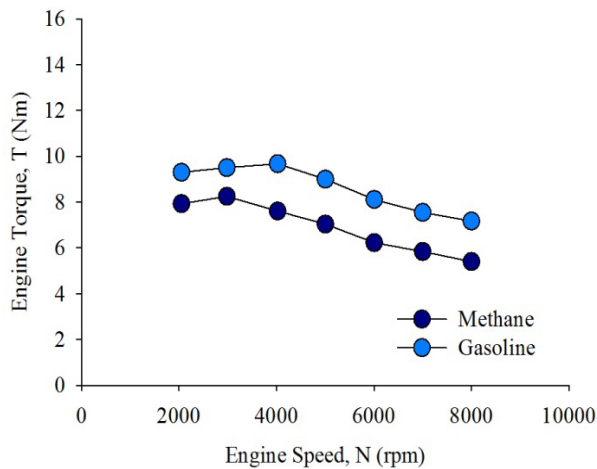


Figure 3. Validation of gasoline model according to (a) engine torque, (b) brake power, (c) BMEP and (d) in-cylinder peak pressure.

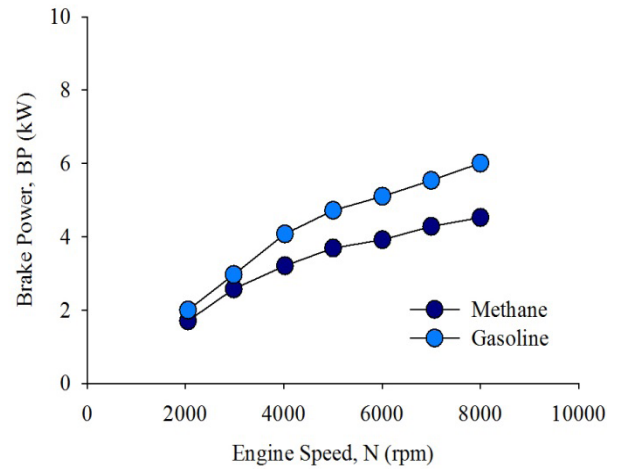
Table 2. Modeling AFR for gasoline and methane

Engine Speed (rpm)	Equivalence Ratio	AFR (Gasoline)	AFR (Methane)
2000	1.1	13.41	15.64
3000	1.13	13.05	15.22
4000	1.32	11.16	13.03
5000	1.38	10.66	12.46
6000	1.39	10.54	12.37
7000	1.3	11.74	13.23
8000	1.38	10.68	12.46

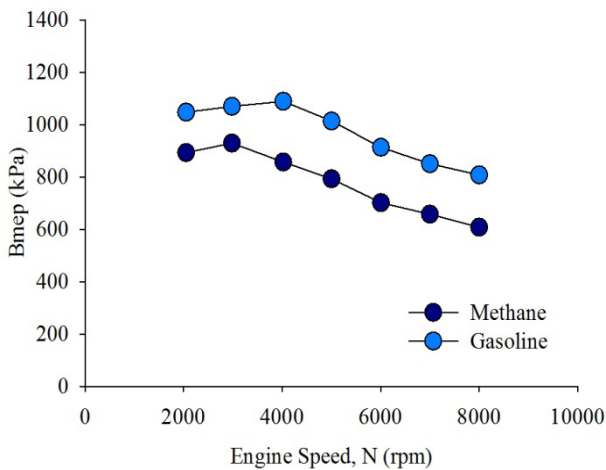
Figure 4 shows the performance of methane compared to gasoline. From the figures, it was found that methane fuelled engine experienced power degradation at about 20.1 % for engine torque, brake power and bmep and 12.0 % for in-cylinder peak pressure when compared to gasoline. At lower speed it can be observed that the methane engine performance is close to gasoline for brake power. However, when the speed increases to at about 3500 rpm the difference in engine performance increases mostly due to lower energy density for methane. Although there is a large different in engine performance, but when it comes to emission and brake specific fuel consumption (BSFC) methane produced better results compared to gasoline¹⁶. Moreover, in-cylinder peak pressure trace had exposed gasoline



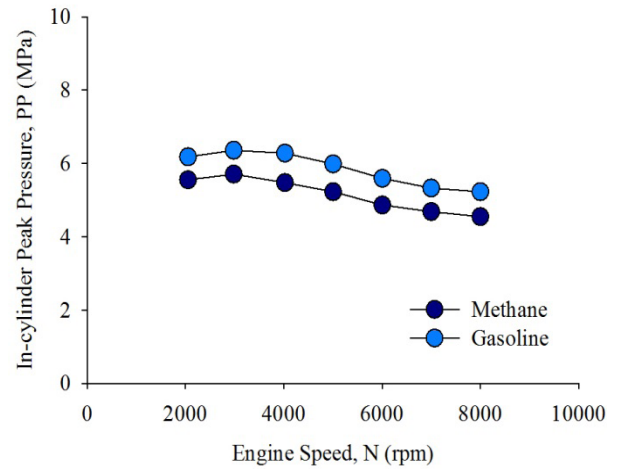
(a)



(b)



(c)



(d)

Figure 4. Comparison of (a) engine torque, (b) brake power, (c) BMEP and (d) in-cylinder peak pressure between methane and gasoline.

engine produced higher peak pressure than methane. With the high in-cylinder pressure, gasoline engine will produced higher torque, power and bmep compared to methane.

6.2 Effect of Various IVO and EVO Timings

To increase the performance of methane fuelled engine, various valve cam angles were investigated to find the optimum IVO and EVO timings for methane. This process was tested at two different engine speeds which are at 2000 rpm and 5000 rpm. These can be achieved by using optimization tool in GT-power and the configuration and output for the optimization is shown in Table 3.

Referring to Table 3, it was found that the maximum brake torque was achieved by using IVO at 10° BTDC that produced 6.32 Nm of brake torque. Same optimized IVO angle were found for both two different speeds. In the case of EVO, the maximum brake torque was obtained at 45° BBDC that produced brake torque at about of 8.02 Nm. The optimum setting for IVO and EVO then were used and compared to standard original equipment manufacturer (OEM) setting.

Figure 5 shows the optimized IVO and EVO for methane fuelled engine. For optimum valve timing, it was found that the maximum improvement for engine torque,

Table 3. Intake and exhaust valve open timings and maximum brake power

Intake Valve Open (IVO) Timing (degree BTDC)	Brake Torque (N.m)
0	6.22
10	6.32
20 – OEM Setting	6.23
30	6.02
40	5.75
Exhaust Cam Open (EVO) Timing (degree BBDC)	Brake Torque (N.m)
35	7.97
45	8.02
55 – OEM Setting	7.93
65	7.57
75	6.97

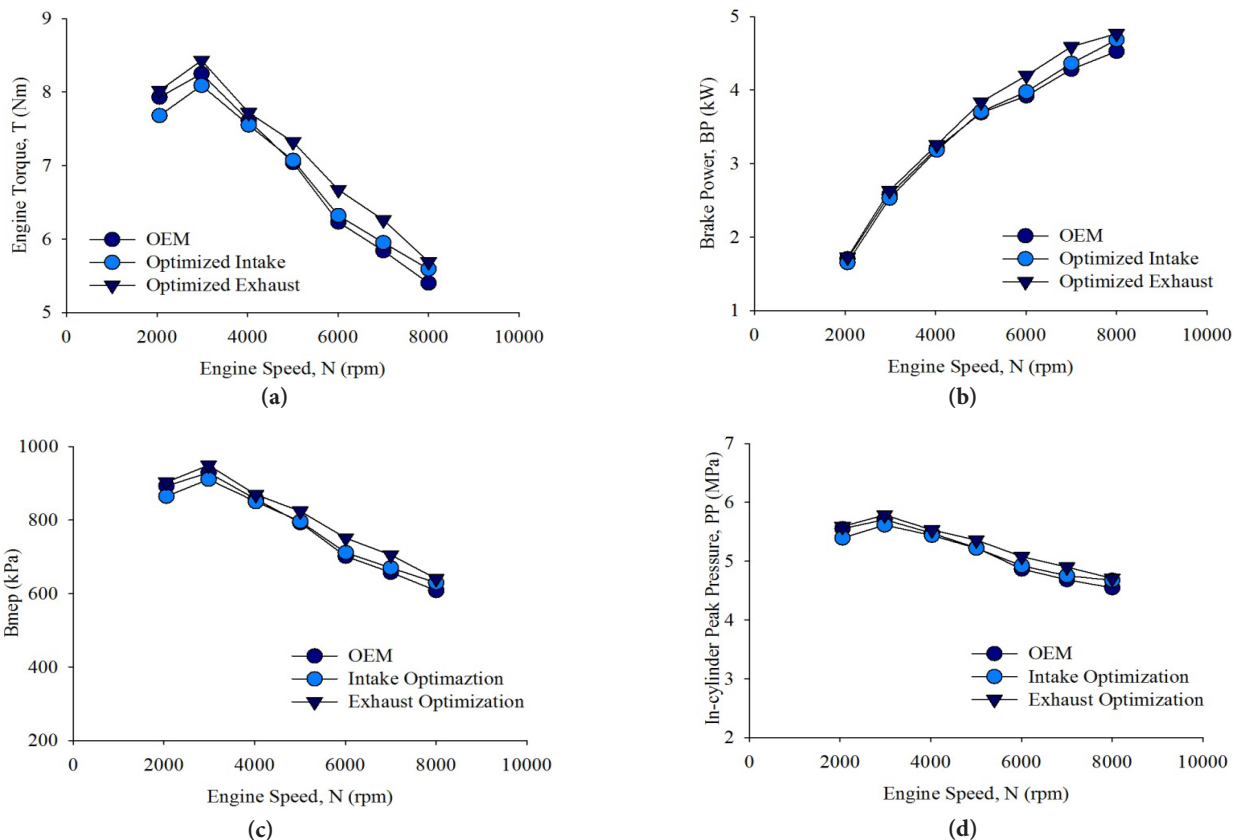


Figure 5. Optimized (a) engine torque, (b) brake power, (c) BMEP and (d) in-cylinder peak pressure for methane fuelled engine.

brake power and bmep is at about 10 % and for in-cylinder peak pressure is at about 5 %. Referring to intake timing angle optimization, the result is almost the same to OEM setting in which at initial rpm low torque, power, bmep and peak pressure were obtained. But at high engine speed the performance is gradually increasing but not as much as adjusting the exhaust valve timing angle. EVO produced better engine performance compared to optimized IVO for this research engine. Delaying the EVO would make the cylinder pressure is much closer to exhaust back pressure results in less time for exhaust gas to escape through valve. Low speed torque as well as part load efficiency also increases since EVO closer to BDC. Due to this setting, valve overlap also increases. If the valve overlap was decreases, lower torque value at lean-burn limit achieved. This is because the volumetric efficiency of the engine is reduced¹⁷. As a conclusion methane fuel produced lower engine performance compared to gasoline. Studies on the effect of different valve timings also had suggested, methane fueled engine required different cam timing angle to increase its performance.

7. Conclusion

The Modenas 110cc engine model was successfully developed into one dimensional model using GT-Suite software. It represents the real engine which the output of the model gives nearly same results as the experiment results. The behavior of the gasoline engine and methane fuelled engine were found to be same. From the experiment it was found that the methane fuelled engine experiences some degradation in performance when compared to gasoline engine. The optimization is made by varying the IVO and EVO timing angle. However, minor improvement was found with optimized cam angle timing. For optimized exhaust valve timing, as the timing was retard by 10° this will increase the valve overlap. Due to increasing in valve overlap the volumetric efficiency also increases which lead to increasing of torque, power, bmep and peak pressure. As a conclusion, methane fuel produced lower engine performance compared to gasoline and different cam timing angle is required for methane fueled engine.

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