

# Predicting the performances of a CAMPRO engine retrofitted with liquefied petroleum gas (LPG) system using 1-dimensional software

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**Abstract.** Recently, the depletion of petroleum resources and the impact of exhaust emission caused by combustion towards environmental has been forced to all researchers to come out with an alternative ways to prevent this situation become worse. Liquefied petroleum gas (LPG) is the most compatible and have a potential to become a source of energy for internal combustion engine. Unfortunately, the investigation of LPG in internal combustion engine among researcher still have a gap in research. Thus, in this study a 1-Dimensional simulation CAMPRO 1.6L engine model using GT-Power is developed to predict the performances of engines that using LPG as a fuel for internal combustion engine. The constructed model simulation will throughout the validation process with the experimental data to make sure the precision of this model. The validation process shows that the results have a good agreement between the simulation model and the experimental data. As a result, the performance of LPG simulation model shows that a Brake Torque (BT), Brake Power (BP) and Brake Mean Effective Pressure (BMEP) were significantly improved in average of 7% in comparison with gasoline model. In addition, Brake Specific Fuel Consumption (BSFC) also shows an improvement by 5%, which is become more economic. Therefore, the developed GT-Power model offer a successful fuel conversion to LPG systems via retrofit technology to provide comprehensive support for implementation of energy efficient and environmental friendly vehicles.

## 1 Introduction

The depletion in petroleum resources have been a popular issue among others country recently. Excessive use of fossil based fuels exhausts the reserves and also increases the air pollution [1]. The researchers and automotive manufacturer are forced to concentrate on finding alternatives to conventional petroleum fuels. An alternative fuel must be technically feasible, economically competitive, environmentally acceptable, and readily available [2]. Various potential alternative fuels have been as expected, such as, natural gas, biodiesel,

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methanol, ethanol, hydrogen, and liquefied petroleum gas (LPG) [3]. Among of alternative fuel, as an environmentally friendly and economic fuel, LPG can help keep planetary citizens moving while minimizing the impact of road transport on climate, weather, natural resources, and the human health [4].

LPG (also known as “Autogas”) is a gas product of petroleum refining primarily consisting of Propane, some propylene, Butane and other light hydrocarbons [5]. Around 60% of total amount of LPG produced is recovered directly from oil and gas fields in which case no actual refining is needed. The remaining 40% is formed as a by-product in crude oil processing either in distillation phase or after treatment processes [6]. LPG is suitable and convenient as a fuel for internal combustion engine due to the higher Octane number but a low Cetane number which is close to 105 and also it has high calorific value compared to other gaseous fuels [7], [8]. LPG can be liquefied at low pressures, in the range 0.7–0.8 MPa, and low atmospheric temperatures. It has higher auto ignition temperature, greater flame velocity and wider flammability limits make LPG a better spark-ignition (S.I) engine fuel than gasoline [9].

Based on the established literatures, Z. Salhab et. al. [10] revealed that the use of LPG instead of conventional gasoline will mean a reduction in low engine BP with loss of power 7%, also a reduction in BSFC about 20% - 30%, where the engine was converted to operate either on gasoline or on LPG using fuel injection in spark-ignition four stroke outboard engine.

According Tasic et al. [11], they found that the LPG fuel had potential reduced the emissions in comparison with gasoline; CO (-30%), CO<sub>2</sub> (-10%) HC (-30%) and NO<sub>x</sub> (-41%) for urban test cycle (ECE 15) method. Meanwhile for the extra urban cycle (EUDC) method, the LPG fuel also the improvement in promoting a lower emission vehicles; CO (-10%), CO<sub>2</sub> (-11%) HC (-51%) and NO<sub>x</sub> (-77%). The comparison were made by using Opel Zafira with four cylinder 1800cc Ecotec engine as the test vehicle which is equipped with Landi Renzo retrofit kit.

Mistry et. al. [12] have been conducted an experimental works and they found that the brake power developed is higher in case of LPG engine whereas heat carried by jacket water is covered by exhaust gases and unaccountable losses are higher in case of petrol engine. They also observed that, LPG has higher fuel consumption compared to petrol. The works by Shankar K. S. et. al. [13], they was investigated the effect of variation in ignition timing on the performance of a four cylinder multipoint port fuel injection gasoline engine which is retrofitted to run with LPG injection. When using LPG as a fuel, better performance has been observed when ignition timing is set at 6° BTDC. Advancing the idle ignition timing has also resulted in reduced CO (-1%) and HC (-50ppm) emissions. But the advanced ignition timing shows an increase (+1400ppm) in NO<sub>x</sub> emissions.

In terms of numerical analysis, Ali M. Pourkhesalian et. al. [14], the environment coding using Matlab has been developed and its results are validated with experimental data. The author’s mentioned that this simulated engine model could be used as a powerful tool to investigate the performance and emission of a given S.I engine fuel by alternative fuels including hydrogen, propane, methane, ethanol and methanol. Eventually, it is concluded that gasoline produce more power than the all being tested alternative fuels. The BP produced by propane is less of gasoline by 10%, respectively. The BSFC of propane fueled engine is approximately 9% less than gasoline.

The works by Hakan Bayraktar et. al. [15], a mathematical cycle model has been arranged for both gasoline and propane, and a numerical analysis code for this model has been developed. Comparison shows that if LPG fueled S.I engines are operated at the same conditions with those of gasoline fueled S.I engines, significant improvements in exhaust emissions can be achieved. LPG decreased volumetric efficiency, thus reduces the engine effective efficiency and consequently increases specific fuel consumption.

In Malaysia scenario, the use of LPG as an alternative fuel via retrofit system are still questionable and tremendous potential of filling the gap in research. Therefore In this present paper, a 1-dimensional GT-Power engine simulation program is applied to investigate the engine performances such as BP, BT, BMEP and BSFC for S.I. engine.

## 2 Methodology

This study is focused on the investigation of engine performances by using LPG as an alternative fuel for S.I engine. This investigation also focused on constructing an engine simulation model based on a 1-dimensional GT-Power software. The input data that are required is based on the CAMPRO engine specifications; cylinder geometry, intake and exhaust system geometries, valve dimension, and engine operating conditions were measured accordingly. However, the undefined data and parameters were taken by using manual procedure of measurements and default data from the developer of GT-Power, Gamma Technologies LLC, since that information is not provided in the outsources database [16].

The experimental works was performed by using chassis dynamometer (Dynapack) to evaluate the engine performances such as BP, BT, BMEP and BSFC. The engine operating condition which is running at various engine speed 1500 rpm to 7000 rpm at wide open throttle (WOT) conditions. The engine system parameter that was used in the engine crank train is based on Table. 1. The details of model simulation was discussed in next section: engine modelling. In terms of data measurements, Kistler Pressure Sensor (6118B) coupled with Kistler Charge Amplifier (5018A) were used to capture the behavior of in-cylinder conditions. Meanwhile, Ono-Sokki flow meter (FM2500) and detector (FZ2100) were used to measure gasoline fuel consumption and LPG mass flow meter (M250SLPM).

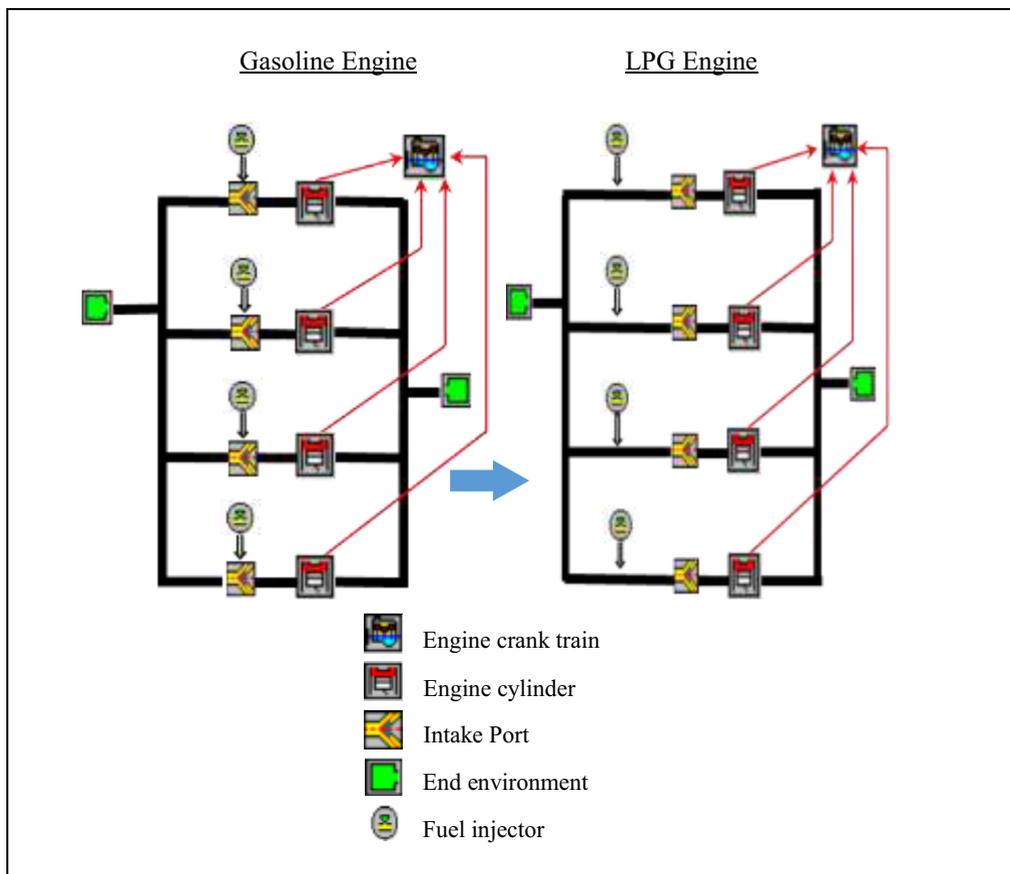
**Table 1.** Engine system parameter.

	Gasoline engine	LPG engine
<b>Engine type</b>	4 stroke	
<b>Number of cylinders</b>	4 cylinders	
<b>Bore</b>	76 mm	76 mm
<b>Stroke</b>	88 mm	88 mm
<b>Fuel injection</b>	Multipoint fuel injection	Liquid sequential injection
<b>Fuel type</b>	Gasoline	LPG
<b>Compression ratio</b>	10:1	10:1

## 3 Engine modelling

### 3.1 Model simulation

The simulation model that consists of three basic parts that built begin from the intake system, engine system and until exhaust system. Features in GT-Power software are consist of object component from flow and mechanical library. **Fig. 1.** shows a constructed simulation model based on LPG and gasoline. There are several specific values of input parameters including the air-fuel ratio (AFR), engine speed, and injection timing were defined in the both models. The AFR for gasoline and LPG engine are based on experimental database, where normally, the experimental AFR is in the range of 14.7 and 15.7 respectively [17].



**Fig. 1.** Engine model in GT-Power simulation.

The intake system consists of air cleaner parts, throttle body, intake manifold and fuel injector. The intake manifold was created from a series of intake runner by using pipe-round object and flowsplitTRight object. The difference part between both models is a position of the fuel injector. The object used is InjAF-RatioConn which required AFR as input data. In gasoline model, the injector is located at the intake port of the manifold. Meanwhile, LPG model is on the intake runner pipe.

Second part of the engine model is the Powertrain where generally consist of engine geometry, cylinder geometry and valve dimension. Non-predictive combustion model known as EngCylCombSI-Wiebe is chosen as a combustion model in an engine cylinder object which is preferred according to the condition of (S.I) engine. Furthermore, this combustion model simply imposes a burn rate as a function of crank angle. The burn rate is represented by crank angle where 50% fuel burned and the duration of fuel burned. Here, the burn rate is calculated from measured in-cylinder combustion pressure at various engine speeds with full load conditions [18], [19], [20]. Each cylinder consists of 2 ValveCammConn object on intake and exhaust system.

The exhaust system is the last part of engine modelling which is exhaust manifold that used bend-pipe-round object, catalytic converter, muffler and tailpipe object. It is to consider that the simulation model will represent as actual engine condition. Lastly, once the model was completed, the engine operating conditions of simulation models are defined as engine speed 1500 to 7000 rpm and at wide open throttle (WOT). The results that obtained are used to match up the model to the experimental data.

### 3.2 Model validation

To achieve the accuracy of the simulation model, the model has been correlated to the experimental data based on fuel type. Refer to Fig. 2. The correlated model of gasoline engine simulation by refer to in-cylinder condition (pressure) using gasoline as fuel for combustion, are very close to the experimental data, with the average differences of less than 4%. Moreover, the simulation results for LPG as Fig. 3. has also been verified, whereas the BT and BP predicts difference less than 7.42%. Last but not least, based on the validation process, the results between simulation models and experimental data has been well confirmed that represents as similar as actual engine condition.

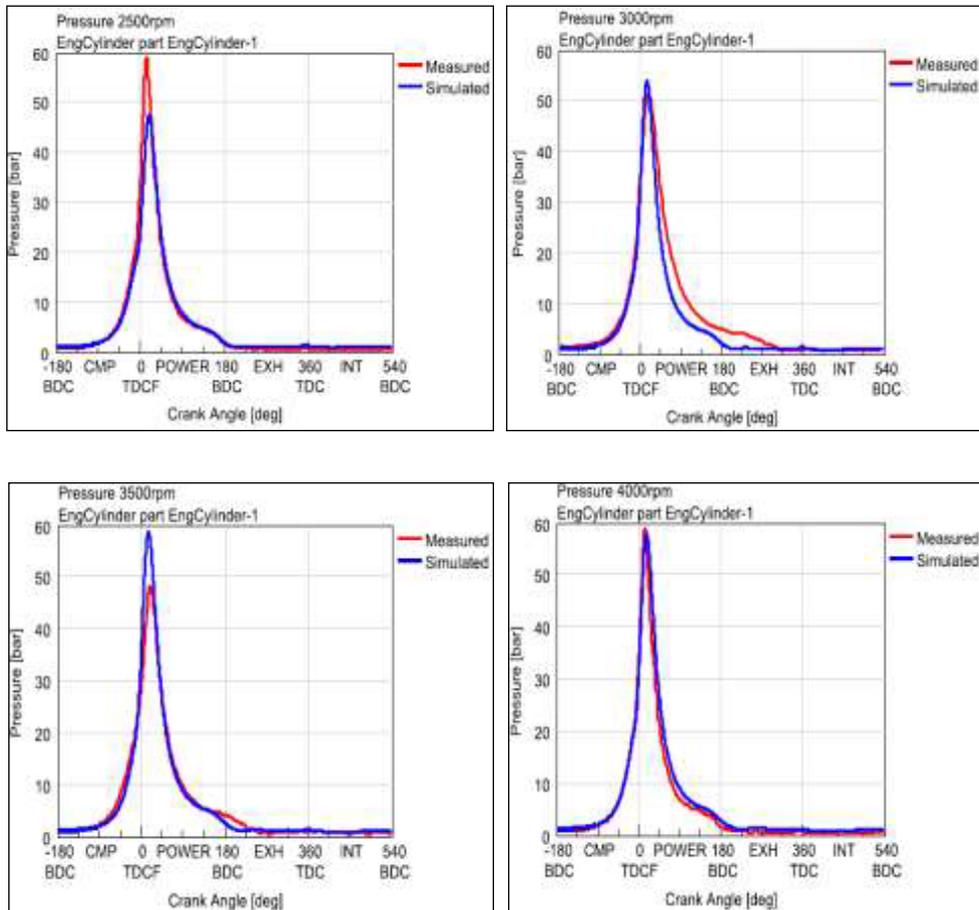
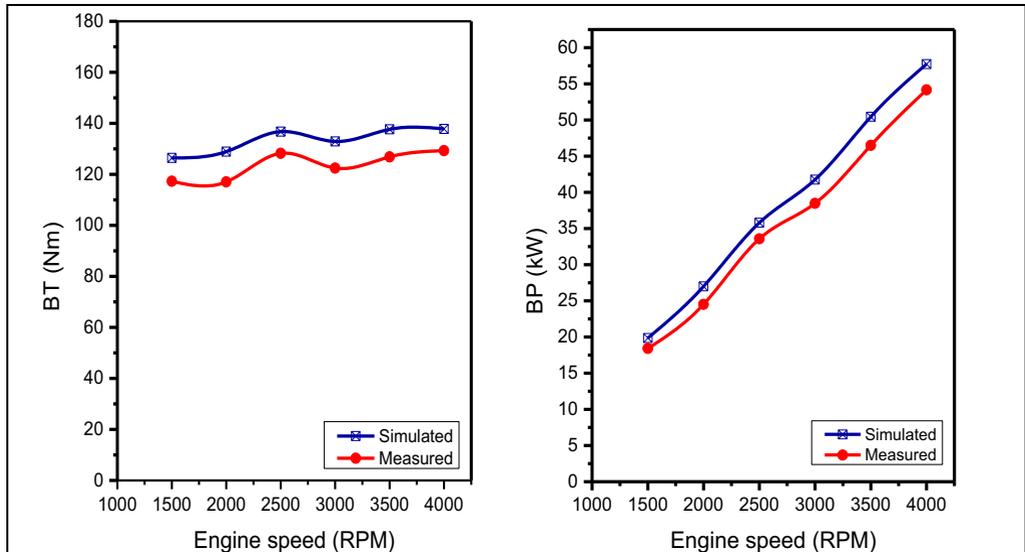


Fig. 2. Gasoline engine model correlation.

## 4 Results and discussion

Based on Fig. 4(a), shows that the BT at various engine speeds. The model simulation predicts that BT for LPG is higher compared to gasoline. At low engine speeds, LPG has been increased gradually from 1500 rpm until reach 2000 rpm at point maximum is 132.92 Nm. The engine experiences performance downfall due to a phenomenon known as torque loss at 2500 rpm until 3000 rpm. The torque dip phenomenon is caused by the pressure wave that is not coherent with the valve opening [21]. However, the BT a slowly recovered

to the highest point of 144.33 Nm at engine speeds 3000 rpm until 4500 rpm. Meanwhile, at higher engine speed, the performance reduced as engine speed increase.



**Fig. 3.** LPG engine model correlation.

Refer to the Fig. 4(b), shows differences of BP at various engine speeds. It is predicted that LPG have an improvement as an average difference is 6.55%, where the highest noticed at 7000 rpm with 86.63 kW. This is because of LPG contain a higher heating value (46.4 MJ/kg) compared to gasoline (44.0 MJ/kg). Moreover, LPG contained a higher octane number than gasoline.

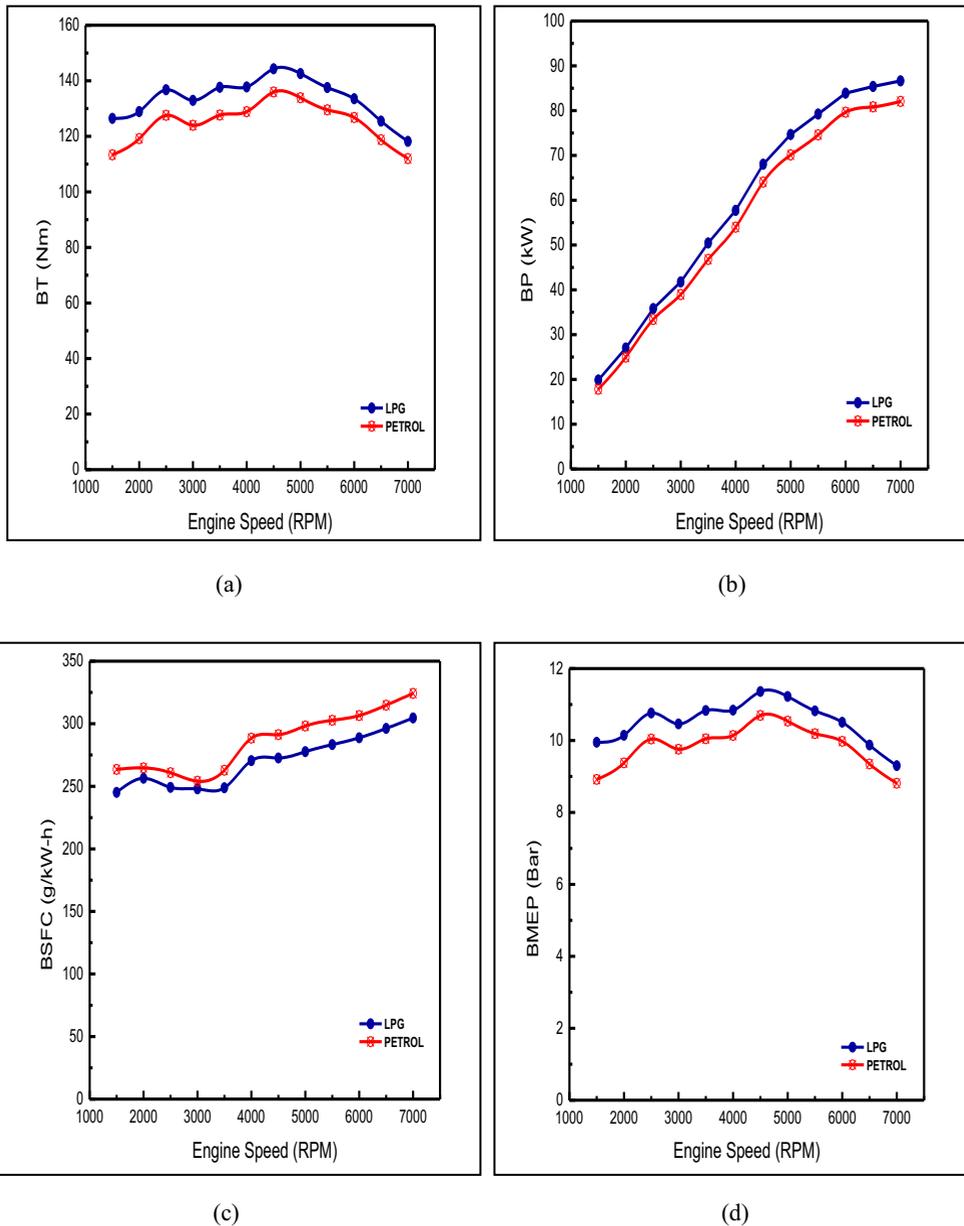
As depicted in Fig. 4(c), in term of BSFC results, the simulation model predicted around 4.47% saving improvement BSFC of LPG as engine speed increased from 1500 rpm until it reach 4000 rpm. For higher engine speed starting from 4000 rpm onwards, the percentage of fuel saving was predicted in an average of 6.24%. According to Fig. 4(d). In the perspective of BMEP, LPG can boosted a S.I. engine about 6% as engine speed increased, where the maximum BMEP is 11.35 bar was predicted at 4500 rpm.

## 5 Conclusions

As a conclusion, performances of LPG has been predicted by using 1-dimensional model simulation GT-Power software based on CAMPRO 1.6L engine. The model has been verified with the experimental results and it's shown a good agreement. Based on results, it shows that for those user who are concerning about the fuel economy and boosting the engine performances, a retrofitting S.I. engine via LPG fuelling system is the best option to be considered. The conclusion can be summarized as below:

- i. LPG produced higher BP, BT and BMEP for entire engine speeds with an average difference is 7% than gasoline.
- ii. BT increased around 7% average where the highest of BT was predicted at 144 Nm @ 4500 rpm
- iii. BP for predicted an improvement on an average of 6.55%, where the maximum value noticed at 86.63kW @ 7000 rpm

- iv. The variation of BSFC that predicted by simulation model was shown to be 5% lower than gasoline engine. Thus, the use of LPG as an alternative fuel will give benefit in fuel saving.



**Fig. 4.** Engine performances based on GT-Power.

Appreciation and acknowledgment to the Universiti Tun Hussein Onn Malaysia (UTHM) for providing the financial support under UTHM Contract Grant, VOT: U427. The author also would like to express highest gratitude to anyone who contributed to the research work.

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