SEMARAK ILMU
PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Fluid
Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Enhancing the Spark Ignition Engine Performance for Use LPG Liquid Phase by Modified the Ignition Timings

Mohd Mustaqim Tukiman[1], Shahrul Azmir Osman[1,*], Mas Fawzi[1] , Norrizal Mustaffa[2]

[1] Automotive Research Group (ARG), Centre for Energy and Industrial Environment Studies (CEIES), Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia
[2] Automotive and Combustion Synergies Technology Group, Advanced Technology Centre (ATC), Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, Malaysia

ARTICLE INFO

Article history:
Received 23 December 2021
Received in revised form 5 April 2022
Accepted 9 April 2022
Available online 9 May 2022

Keywords:
LPG; liquid phase sequential injection; spark ignition timing; MBT location

ABSTRACT

LPG is one of the potential alternative fuels use in a spark-ignition engine. This paper presents the result of the experimental effect that modified the spark ignition timing for the latest generation LPG, using liquid phase. The objective of this study is explicitly to determine the quality of engine performance behavior at the maximum brake torque (MBT) condition as compared to gasoline fuel. Experiments were carried out at engine speed from 1500rpm to 3500rpm and the throttle positions were tested at 25%, 50% and 75%. Both of fuels have excess air coefficient at the stoichiometric ratio for the completed combustion process. Performance parameters, namely brake power (BP) and brake specific fuel consumption (BSFC) studied. It was shown, the LPG liquid phase significantly improves the engine performance in the range of 0.3% to 12.63% when the spark ignition was adjusted at -20 °CA to -10°CA BTDC from low to high engine speed as produced MBT condition. The fuel consumption also improves by 4.5% to 13.6%. The result showed that the LPG liquid phase had improved more than conventional fuel with modified ignition timing until the achieved the MBT condition.

1. Introduction

The sprawling use of automotive for transportation is increasing annually. The effect is a crisis of crude oil and its limited source worldwide. This also potential to an alarming trend of environment, especially from exhaust emission. However, with increasing consciousness of environmental protection and energy conservation, the study and development of motor vehicles that use clean alternative fuel as a substitute for conventional fuels have become an important subject [1,2]. The selection of alternative fuel is not the end of the task, which is the best of performance a bit of modification to serve the task for which it was chosen. Commonly, alternative fuels were divided into liquid and gaseous types. Liquid fuels such as biofuel can also improve carbon emission, but the problem is the high cost of the processing; thus its makes it unviable to be commercially used [3]. Unlike gaseous fuels such as LPG, the production is from natural gas from the refineries process [4].

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[*] *Corresponding author.*
E-mail address: shahrula@uthm.edu.my

https://doi.org/10.37934/arfmts.95.1.7684

Generally, the composition contents are referred to the propane (C_3H_8) and butane (C_4H_{10}). Therefore, the composition ratio is affected by performance and exhaust emission when used in the spark-ignition engine during the combustion process [5,6]. In another view, the LPG has high octane number and high calorific value are among the properties that might be an advantage to the internal combustion engine [7].

Table 1
Summary of the spark ignition timing range for the previous technology

LPG phase	Range of optimized spark ignition angle	Analyzed parameter	Researchers
Gaseous	23°CA BTDC at WOT	IMEP (representing torque)	Campbell *et al.,* [8]
Gaseous	29°CA BTDC at idling condition and 18°CA BTDC at WOT	Brake torque	Saraf *et al.,* [9]
Gaseous and liquid	25°CA to 30°CA BTDC at WOT	Brake torque and exhaust emission	Li *et al.,* [10]
Gaseous	30°CA BTDC at WOT	Brake thermal efficiency	Pundkar *et al.,* [11]
Gaseous	Advanced 2 °CA BTDC for performance and Advanced 4°CA BTDC for BSFC	Performance and emission	Erkus *et al.,* [12]
Gaseous	28 °CA BTDC at WOT	Brake power, volumetric efficiency, BSFC, BTE and exhaust emission	Erkuş *et al.,* [1]
Gaseous	60°CA BTDC (lean limit) at WOT	Effect of piston squish area and modified the spark ignition angle on the performance	Krishnaiah *et al.,* [13]
Gaseous and liquid	Static ignition 5°CA BTDC at WOT	In-cylinder pressure, ROHR ROPR and exhaust emission	Chitragar *et al.,* [14]
Liquid	33°CA BTDC at WOT	BSFC and exhaust emission	Kim *et al.,* [15]

Actually, the previous LPG generation, which is a gaseous phase was successfully installed in the SI engine and running without any problem, but there are several issues such as the engine output is under power than conventional fuel and the higher emission from CO and NO_X is give a bad impression on the environment [16-18]. So the latest generation was introduced to handle this issue, where the liquid phase was used in the fuel delivery system. Thus, the engine output was improved, but the engine needs proper tuning in part of spark ignition timing. This is because it gives many potentials nearly the effect of engine output and is essential for efficiency [19]. Thus, the ignition timing needs to advances or retard until the producing MBT at specific engine conditions. In particular, the dissimilarities of flame development and flame propagation period require modifying a gasoline engine's original ignition timing maps. In contrast, if the spark ignition is too over advanced, the pressure builds up early during the compression stroke and potentially gives the next process expansion stroke pressure low and loses the output torque. But with too over retarded condition spark ignition timing, the pressure built-up is late in the compression stroke. Thus, the expansion stroke can not compensate for the losses earlier [15,16]. The previous study about spark ignition timing was shown in Table 1. It was founded a range of spark ignition timing is from 60 °CA to 23 °CA BTDC. Therefore, the modifying of spark ignition timing is depends on the engine load and LPG phase.

2. Methodology

The experiments were conducted using two different fuels, showing in the properties comparison in Table 2, LPG and gasoline. The Gasoline fuel was used as a benchmark for comparing the result of the experiment in the spark-ignition engine. The study was tested at five different engine speeds, which were 1500rpm to 3500rpm with 500rpm increment. Each engine speed was tested at three different throttle positions, 25%, 50% and 75% valve position opening. In addition, the various spark ignition timing was also modified from -5 °CA to -35 °CA (BTDC) to determine the MBT condition.

Table 2
Comparison of properties LPG and gasoline [9-17]

Properties	LPG	Gasoline
Chemical formula	Butane C_4H_{10} and Propane C_3H_8	C_8H_{18}
RON	96.5-105	89-95
Lower calorific value (KJ/Kg)	45600-46500	42100-44000
Flame speed (cm/s)	37-38.2	37.5
Stoichiometric air-fuel ratio (kg/kg)	15.5-15.8	14.7-14.9

All arrangements of equipment during the experiment are shown in Figure 1. The test was carried out by a 1.6-liter in-line four-cylinder spark-ignition engine from Proton Gen 2 (S4PH) model equipped with a multi-port fuel injection (MPI) fuel delivery system. The engine test was retrofitted the LPG system, namely liquid sequential injection (LSI) as the latest generation. The installation method follows the Malaysia standard MS 775:2005; (LPG Fuel Delivery System in Internal Combustion Engine). The stock engine control unit (ECU) was removed and replaced with the ECU stand-alone unit controller system (SAC), which can manipulate and modify the signal from the sensor. These allow the stock ECU has a limitation for a controlled parameter such as ignition timing and air/fuel ratio mixer. Meanwhile, the ECU LPG was also installed as a slave system to control all functions of the LPG fuel delivery system in the engine. The modified spark ignition timing starts from -5 °CA to -35 °CA (BTDC) and the target of air/fuel ratio was adjusted at the stoichiometric ($\lambda=1$) condition for both fuels. The test engine was a couple to 600 kW Dynapack eddy-current chassis dynamometer to simulate the specific engine speed data to collect data such as brake power. To measure fuel consumption for both fuels, the Ono Sokki: FZ-2100 mass flow meter was installed in the fuel delivery system, employing the Coriolis principle. To ensure the test engine runs smoothly without problem, the Bosch scan tolls KTS 570 V1.2 was connected to the OBD-II system. All data values were monitored in real-time and the sensor's failure was also detected while running the experiment.

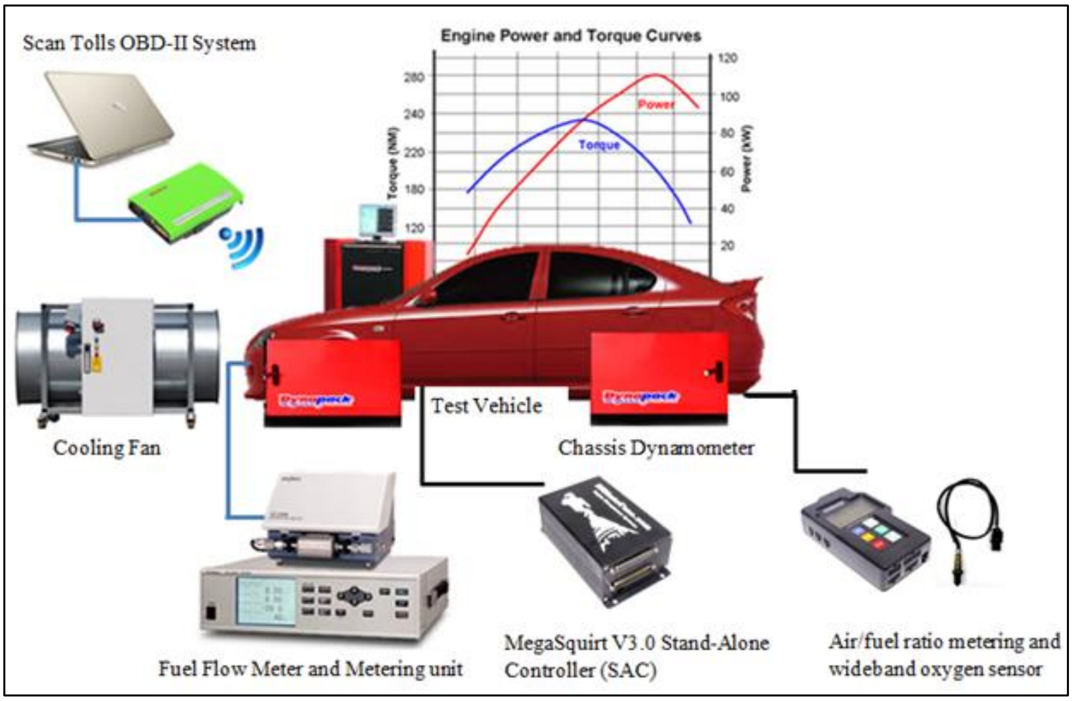

Fig. 1. Arrangement of equipment during the experiment

3. Results and Discussion

3.1 Performance

The analysis on the performance was divided into five engine speed conditions which are 1500rpm, 2000rpm, 2500rpm, 3000rpm and 3500rpm. The engine test was modified at various spark ignition timing from at -5 °CA to -35°CA BTDC. The throttle position (TP) was set at 25%, 50%, and 75% to identify the comparison engine load.

3.1.1 Comparison of spark ignition timing to produced MBT condition at 1500rpm to 3500rpm

This result showed in Figure 2 that the MBT for LSI-LPG continuously leads than gasoline at all engine conditions. This is because the LPG had a higher calorific value and energy than gasoline. Thus, LPG can produce more engine output in performance and reduce fuel consumption [23]. When the spark ignition is tuned from -5 °CA to -35°CA BTDC for determining the MBT location for both fuels, the trend of brake torque is a steep upward trajectory at the MBT location and the trend are slowed down noticeably. The result shows that LSI-LPG is improved in the range of 0.3% to 12.63% compared with gasoline at all engine conditions. The improvement of engine output depends on the engine speed and throttle position.

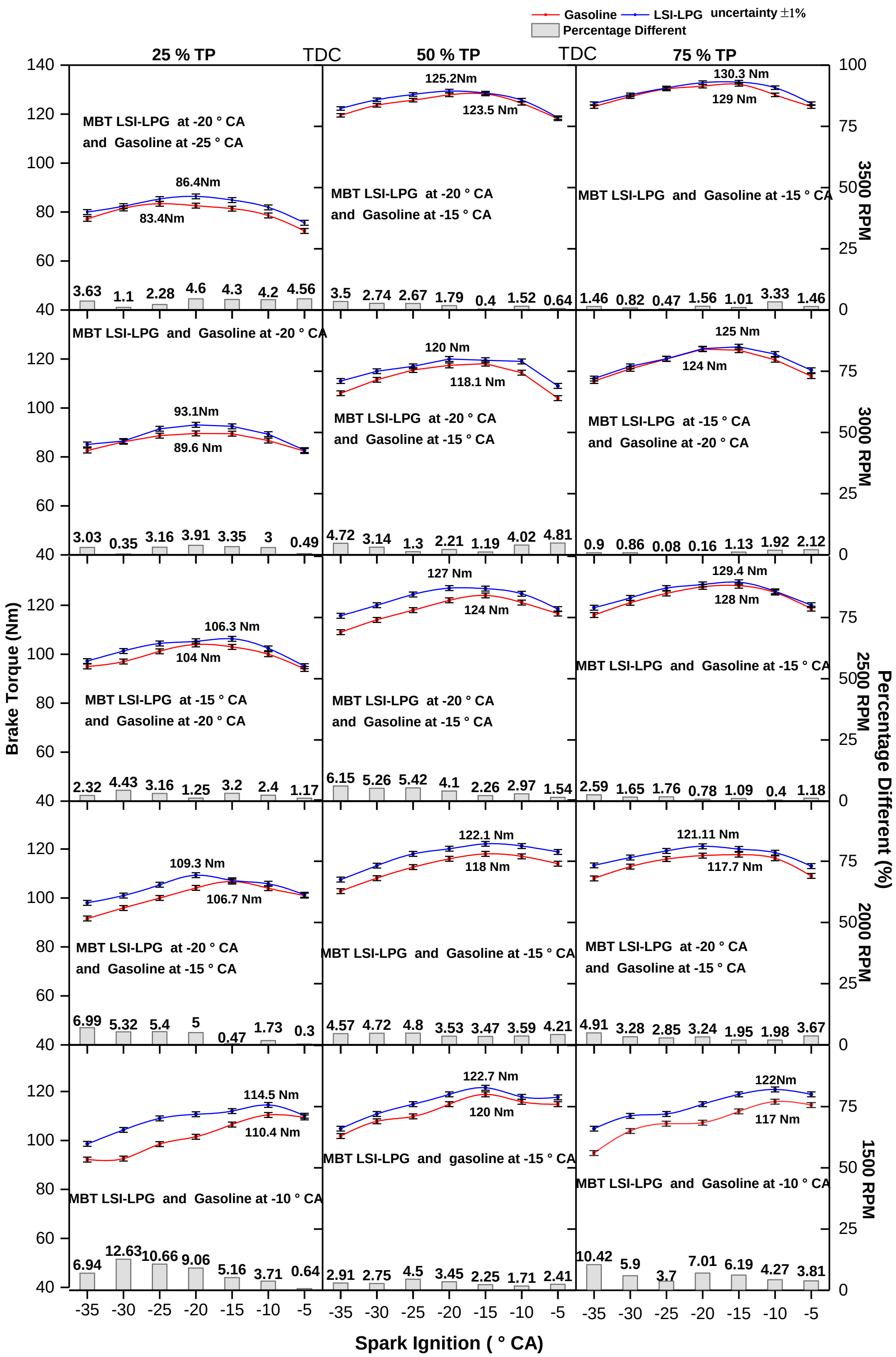

Fig. 2. Comparison of the variable spark ignition to produced MBT location

In the low engine speed, 1500 rpm condition for LSI-LPG shows the spark ignition timing has achieved the MBT at -10°CA BTDC for 25% and 75% TP with produced 114.5 Nm and 122Nm, respectively. It contradicts for 50% TP, where the spark ignition timing needs to advance 5°CA for achieved the MBT condition and produced 122.7 Nm. In a similar situation for 2500rpm at 50% TP, the spark ignition timing also advanced to 5°CA as having a maximum engine output with a value of 127 Nm. The shifting spark ignition timing toward the advancing condition because the mass of air/fuel ratio was increased and affected to the intake manifold charge temperature during the combustion process. Thus, the density charge was decreased and the mixture was forced it displaced more volume in the intake manifold. Therefore, the delay has occurred and flame speed decreased than gasoline during the flame development process. Those, to counterbalance this problem, the spark ignition timing required advanced conditions for ensuring the complete combustion occurred in this condition [19-22].

The identifying of the MBT location for producing the maximum engine output was continuous until 3500rpm. This condition shows that the spark ignition timing is gradually advanced to the produced MBT condition, parallel with the increment of the TP. Nevertheless, at 75% the spark ignition timing required to retarded 5°CA. This problem also occurred at condition 2000rpm on 50% TP. This is because the higher engine speed was affected by the increment of the turbulent variation of intake airflow into the combustion chamber. It tends to affect the quality of mixture preparation during starting of combustion and enhance the combustion duration in every cycle in the cylinder.

3.1.2 Comparison of BSFC at MBT location for 1500rpm to 3500rpm

Figure 3 presents the result of BSFC at 1500rpm for 25% to 75% TP shows improvement in the range of 9.84% to 16.39% compared with gasoline. The BSFC was recorded at about 258.14g/kWh at 25% TP in the MBT location. Meanwhile, for 50% and 75% TP, the fuel consumes about 241g/kWh to 242.38 g/kWh. At 25% to 50% TP for a medium engine speed of 2000rpm, the fuel consumption also improved about 5.2% and produced 267.37g/kWh to 253.42g/kWh respectively MBT location for LSI-LPG. The improvement also occurred at 2500rpm for 25% to 50% TP, where the fuel consumption was successful to reduced about 4.5%. This trend of lower BSFC for LPG also has good agreement with the previous study [23,24]. The lower BSFC when using LPG because of the Higher Heating Value (HHV) than gasoline leads to higher heat release and peak pressure and can produce a good fuel mixture in the correct spark ignition timing location [11-25]. In addition, the LPG has a higher octane number, greater flame velocity and the flammability limit is wider than gasoline [1].

However, at 75% TP with engine speed 2000rpm, the BSFC was increased dramatically by about 30% and stayed at 329.34 g/kWh. At 2500rpm, the improvement is 13.6% if compared with 50% TP. This happens because the nature of LPG density is lower and requires more fuel to be displaced into the combustion chamber, affecting the amount of fresh air induced into the intake manifold [29]. When the engine speed increased to cruising mode at 3000rpm, the result for 25% to 75% TP fluctuated at a minimum range of about 0.9% to 1.6 %. When the BSFC is compared with LPG and gasoline, the result shows an improvement of up to 15.29%, which consume between 260.35 g/kWh to 264.51 g/kWh. The engine speed was continued until 3500rpm for three throttle positions. As a result, LPG has improved approximately up to 10.19% at respectively MBT location. It clearly showed that the LPG could lower fuel consumption when the load and engine speed are higher. This is because LPG is easy to mix with the air during the intake process at high temperatures. Thus, the processing time of flame propagation is enough to produce an optimum MBT condition and reduce fuel consumption [22]. In addition, the LPG is leads to producing a homogenous mixture than gasoline before the combustion process occurs [31].

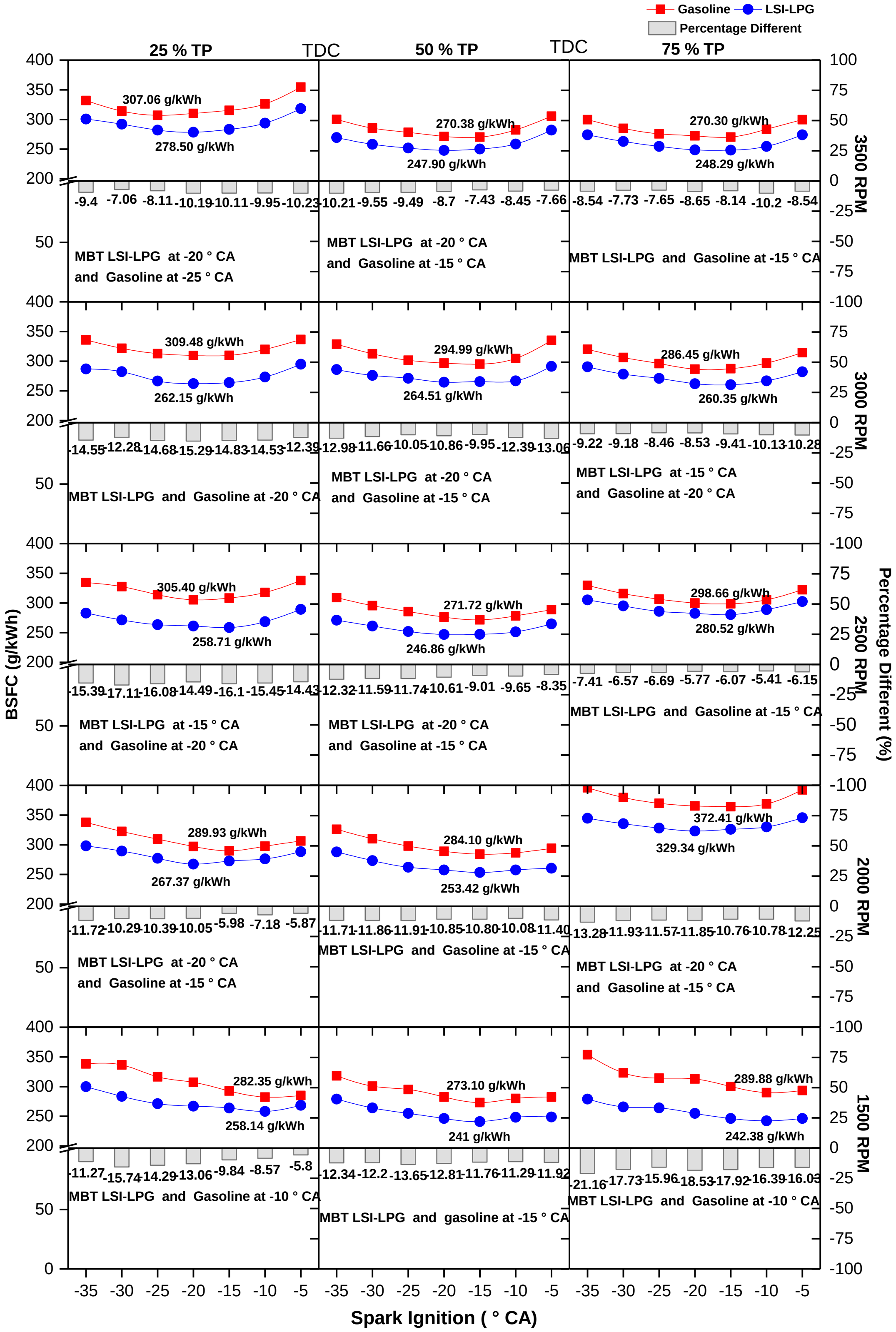

Fig. 3. Comparison of the BSFC at various engine speed and throttle positions

4. Conclusions

The extensive experimental study was performed on the MPI four-cylinder SI engine and equipped with LSI-LPG for the latest generation LPG with different spark ignition timing until the MBT location has been found. The significant finding of the experimental based research work can be summarized as follow

i. The low engine speed at condition 1500rpm with an increment of throttle position 25%, 50% and 75% found the optimum spark ignition timing at -10°CA, -15°CA and -10°CA BTDC for produced the MBT locations.
ii. The medium and high engine speed condition found the MBT occurred at -20°CA, -20°CA and -15°CA BTDC, respectively, with an increment of throttle position conditions.
iii. The experiment data was shows the improvement of the performance for LSI-LPG that only 0.3% to 12.63% when compared with gasoline at the MBT location.
iv. The BSFC for LSI-LPG was improved by 6.6% at 1500rpm. In medium engine speed (2000rpm to 2500rpm), the improvement of BSFC in a range of 4.5% to 13.6%. Lastly, the higher engine speed, which is from 3000rpm to 3500rpm, shows an improvement in a range of 1.6% to 10.19% respectively at the MBT location.

Acknowledgement

Communication of this research is made possible through monetary assistance by Universiti Tun Hussein Onn Malaysia, specifically under Postgraduate Research Grant via Vot U963 and the UTHM Publisher's Office via Publication Fund E15216.

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