EFFECT OF VARIATION IN LIQUEFIED PETROLEUM GAS (LPG) PROPORTIONS IN SPARK IGNITION ENGINE EMISSIONS

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ABSTRACT

This paper presents an experimental investigation of a Liquefied Petroleum Gas (LPG) fueled four-stroke spark ignition engine. The primary objective of the study was to determine and quantify the exhaust emissions from the engine. The engine used in the study was originally a four-stroke spark ignition gasoline engine and minor modifications were carried out to permit the experiments to run on LPG fuel. This includes the incorporation of an adaptor which functions as a mixer in the intake manifold of the engine. The volume percentage of LPG fuel in gasoline used in the experiments was varied at 5%, 10% and 20%, and the amount of LPG fuel injected is controlled by the PLC controller. Bubbling method was employed during calibration to approximate the amount of LPG required with the amount calculated from theory. During the running, the engine was coupled to a 5kW eddy current dynamometer to measure several engine performance parameters and a 5-gas analyzer with non dispersive infra-red (IR) was inserted into the engine exhaust tailpipe for measuring the exhaust emissions. The engine speed was maintained at an idling condition of 4000rev/min throughout the experiment. It was found that the level of carbon dioxide (CO_2) peaked at around relative air-fuel ratio of 1.0 and carbon monoxide (CO) exhibits a sharp decreased as the relative air-fuel ratio increases. Unburned hydrocarbons (UHC) also shows marked reduction as the relative air-fuel ratio exceeds stoichiometric and nitrogen oxides (NO_x) exhibits an increasing trend as the relative air-fuel ratio increases.

Keywords: Liquefied Petroleum Gas (LPG); spark ignition engine; relative air-fuel ratio; emission.

INTRODUCTION

With the increasing need to preserve fuel stock and minimize exhaust emissions in vehicular applications, many researches were carried out to improve the current combustion technology. One of the ways is to promote the use of alternative fuels such natural gas (NG), liquefied petroleum gas (LPG), and hydrogen. Liquefied petroleum gases (LPGs) are by-products of natural gas productions and refineries, and they are widely used in commercial vehicles. LPGs mainly consist of mixtures of hydrocarbons such as propane (C_3H_8), propene (C_3H_6), *n*-butane (C_4H_{10}), isobutene (methyl-propane), and various proportions of other butanes (C_4H_8). Traces of ethane may also exist in the mixture. In the present study, LPG is considered to consist of 30% propane and 70% butane, which is a major constituent of LPG in Malaysia. LPG and other gaseous fuels share common properties that make them attractive relative to gasoline. LPG has a higher octane number than gasoline and it has a high latent heat of vaporization, which can reduce the compression pressure and temperature. It has lower stoichiometric fuel-air ratio and density compared to gasoline, and therefore it could reduce the specific fuel consumption and exhaust emissions. Moreover, when LPG is used in vehicular applications, carbon dioxide (CO_2) engine-out emission is reduced due to lower carbon molecules content compared to gasoline and diesel. In Korea, it was reported that even though diesel vehicles comprises only 34% of the total vehicle count, they contribute 65% of the total pollutant, including 90% nitrogen oxides and 99% particulate matters (PM) [1]. This finding is in fact parallel to other investigations carried out in various places in the world. These researches were primarily being motivated by an increase in the cost of fuel derived from crude oil over the past decade couple with a rising concern for public health. Subsequently, engine related technologies particularly in LPGs, have been a subject of continuous improvement and constant push to the limit to alleviate these problems. The practicality and suitability of LPG as an alternative fuel have been reported and promising results were obtained in terms of exhaust gas emissions and fuel economy. Snelgrove et al. [2] for example, stated that over the European Test Cycle at 25^{o}C, an LPG operated vehicle provided a substantial benefit of reduced emissions compared to those of unleaded gasoline. Hydrocarbon (HC) was reported as 40% lower, CO as 60% lower, and CO_2 as substantially reduced, principally due to high hydrogen/carbon ratio of LPG when compared to gasoline. In addition, in terms of performance, a higher thermal efficiency and improved fuel economy were reported from internal combustion engines running on LPG. A higher octane rating for LPG makes it safe to run in higher compression ratio engine without the occurrence of detonation, and subsequently the thermal efficiency increases. However, Homeyer et al. [3], in their work stated that there was a reduction in the power output in the LPG powered vehicle mainly due to the air displacement.

EXPERIMENTAL SET-UP AND PROCEDURE

Preliminary works centered on the design and development tasks to set-up the experimental rig. The engine used in the study is a four-stroke spark ignition naturally aspirated engine with a maximum rated power output of 3.7kW at 4000 rev/min and maximum torque of 9.3Nm at 2800 rev/min. The engine specifications are listed in Table 1 below.

Table 1. Specification of test engine

Engine type	four-stroke OHV
Number of cylinder	1
Bore	67mm
Stroke	52mm
Displacement	198cc
Compression ratio	6.3:1

A new engine frame had to be designed to alleviate the vibration problems occurred in the previous study in the authors' laboratory. The frame was designed and fabricated in the workshop and the engine chassis was held in place by this steel frame. The whole structure was supported by adjustable height legs in which hard rubber was mounted to each leg of the frame. The exhaust tailpipe from the engine was held by an extended arm and the probe of the gas analyzer was inserted into the exhaust tailpipe. A shaft connector was also designed and fabricated in the authors' laboratory to connect the output shaft of the engine to the 5kW direct current (DC) dynamometer. Even though it was possible to vary the engine speed, in this study, however, it was run at a constant speed of 4000rev/min. Since the spark ignition engine is equipped with a carburetor, it has to be added with an adaptor for bi-fueling purpose when running with gaseous fuel of LPG and gasoline. The gaseous fuel injector was placed upstream of the carburetor inside the intake manifold of the engine and throughout the experiments the air control valve was fully opened. The position of the gaseous fuel injector caused minimal flow losses since the LPG was injected directly into the intake manifold during the entire experiments. A manometer was used to measure the air flow rate, and the plenum chamber was also installed to reduce the air flow fluctuations into the engine. Since the experiment was conducted at a constant speed of 4000rev/min, it was necessary to calculate the amount of LPG injected into the engine. This amount was calculated based on the composition of LPG in Malaysia, which consists of 30% propane and 70% butane. The mass flow rate required was determined and then the actual flow rate of LPG was measured using a bubbling method. Fig. 1 below provides a schematic of the bubbling method in the study.

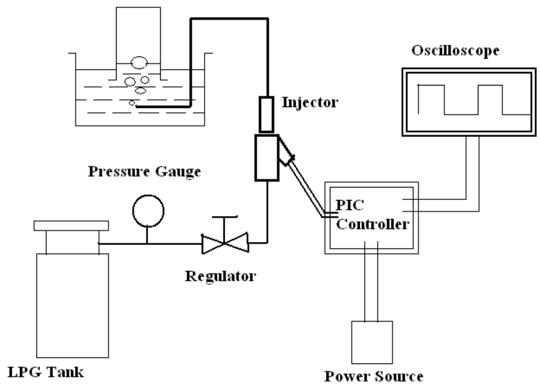

Figure 1 LPG fuel calibration via bubbling method

Various combinations of gauge pressure and types of injectors were tried and it was found out that with a gauge pressure of 2.5bar and gaseous fuel injector, the required flow rate of LPG matched with the calculated flow rate determined at 4000rev/min. A commercially available 5-gas analyzer using non dispersive infra red (IR) was used and the probe was inserted into the exhaust tailpipe of the engine. The gas analyzer measured the amount of HC, CO and CO_2 with the options for O_2 and NO_x.

The overall layout of the experimental set-up is depicted in Figure 2.

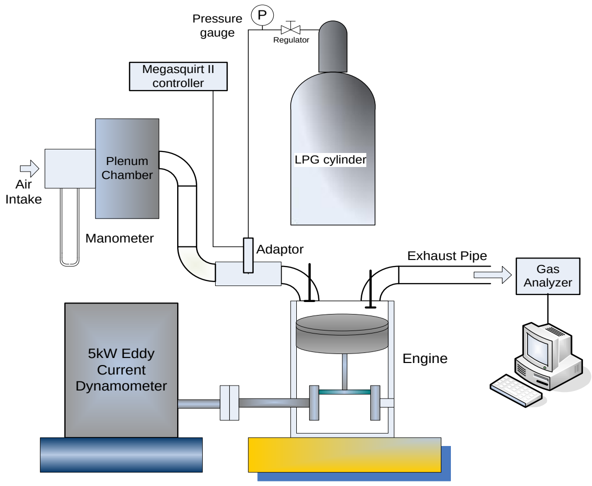

Figure 2 Experimental set-up

RESULTS AND DISCUSSION

All experiments were carried out at a constant speed of 4000rev/min, wide open throttle (WOT), and a compression ratio of 6.3:1. Relative air-fuel ratio (λ) was varied between 0.8 and 1.2. The relative air-fuel ratio, λ is equal to the reverse of fuel-air equivalence ratio, ϕ and it is defined as the actual air/fuel ratio to the stoichiometric air/fuel ratio. The stoichiometric air-fuel ratio was calculated based on the proportions of propane and butane in the LPG of 30% and 70% respectively. A compression ratio of 6.3 was chosen to avoid abnormal combustion. LPG supplied was controlled by a Megasquirt II controller and the volume percentage of LPG in gasoline was 5%, 10% and 20%. Since the LPG was injected into the intake manifold of the engine, the gasoline and LPG would have homogeneously mixed prior to the entrance of the engine combustion chamber. For each proportion of LPG in gasoline, the relative air-fuel ratio was adjusted by changing the amount of LPG injected and gasoline supplied simultaneously. In this work, the relative air-fuel ratio varies from 0.8 to 1.3. The exhaust gas constituents (CO_2, CO, uHC, and NO_x) were measured using the 5-gas analyzer which was placed at the exhaust tailpipe of the engine.

CO_2 emissions. Fig.3 below shows the CO_2 emissions measured from the engine with respect to relative air-fuel ratio λ.

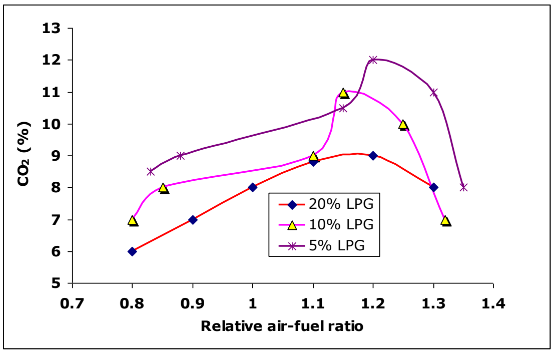

Figure 3 CO_2 emissions (%) against relative air-fuel ratio (λ)

It can be generally deduced that CO_2 emissions reduced as proportions of LPG in gasoline increased. Higher percentage of LPG in gasoline means that the combustion shifted towards complete phase and 'greener' exhaust products were subsequently released to the atmosphere. For each proportion of LPG in gasoline investigated, it was also observed that the CO_2 emissions peaked at around $\lambda = 1$ and exhibits lower percentages at rich and lean mixtures.

CO emissions. Fig. 4 presents the CO emissions against relative air-fuel ratio at various proportions of LPG in gasoline.

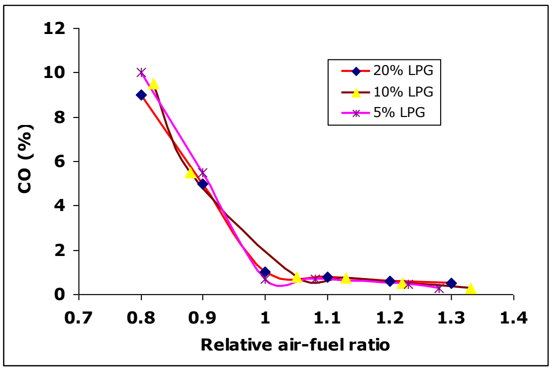

Figure 4 CO emissions (%) against relative air-fuel ratio (λ)

From the figure, it can be seen that there is no obvious and significant advantage in terms of CO emissions by increasing the amount of LPG in gasoline. The formation of CO is highly dependent on the combustion stoichiometry. In general, with the addition of LPG in gasoline mixture, and therefore less carbon in the fuel, a reduction in CO emissions can be expected. CO emissions exhibit maximum value, and as the relative air-fuel ratio increased, a sharp decrease in CO production was detected. High CO amount in the rich region is due to the insufficient supply of air to convert CO into CO_2, and as the mixture becomes leaner, oxidation of CO becomes more vigorous and subsequently its amounts dropped significantly.

UHC emissions. Fig. 5 shows the UHC emissions as a function of relative air-fuel ratio with the addition of 5%, 10%, and 20% LPG in gasoline.

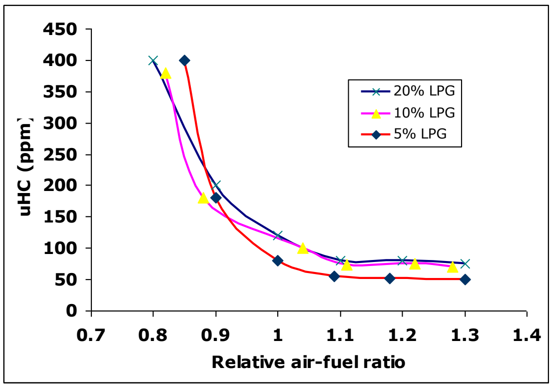

Figure 5 uHC emissions (ppm) against relative air-fuel ratio (λ)

UHC emissions are the results of incomplete combustion of fuel in internal combustion engines. As seen in this figure, UHC emissions are significantly high in the rich region and reduced as the air supplied is increased in the lean region. This could be attributed to the mechanism of formation of UHC itself. Since UHC emissions are the results of quenched combustion products in the crevice of internal combustion engine parts, it is highly likely that the extra oxygen molecules available in the lean region ($\lambda > 1$) destroys the UHC and thus a reduction in the emissions of UHC missions were recorded. On the other hand, the insufficient amount of oxygen molecules in the rich region ($\lambda < 1$) promotes faster formation of UHC in the engine cylinder as was obtained from the experiment. Another contributing factor related to the formation on UHC is the gaseous fuel state of the LPG during the induction stroke. Increasing the amount of LPG injected into the engine enhances the atomization for the mixture, and subsequently less possibility of nonvaporized fuel to occur. It was also observed that adding the proportions of LPG in gasoline produces similar trends with little difference in the amount of UHC measured throughout the experiment.

NO_x emissions. Fig. 6 shows the emission level of NOx against relative air-fuel ratio at various blends of LPG in gasoline. As can be seen from the figure, the NOx level shows little differences when the relative air-fuel ratio is less than 1.0, but the amount measured increased tremendously when the relative air-fuel ratio exceeds 1.0. The NOx concentration also shows an increase with the increase of LPG fractions in the blends of gasoline and this is due to the increase in in-cylinder combustion temperature. The formation of NOx is enhanced in an environment of high temperature and high oxygen concentration. An increasing proportion of LPG in gasoline promotes faster burning velocity of mixture during combustion. At stoichiometry, the laminar burning velocity of LPG and gasoline is 0.46m/s and 0.40m/s respectively. The difference in these values would, in turn reduce the combustion duration and subsequently the in-cylinder peak temperature increases. At high relative air-fuel ratio, the amount of NOx measured was much higher because the mixture is oxygenated in the oxygen-sufficient region.

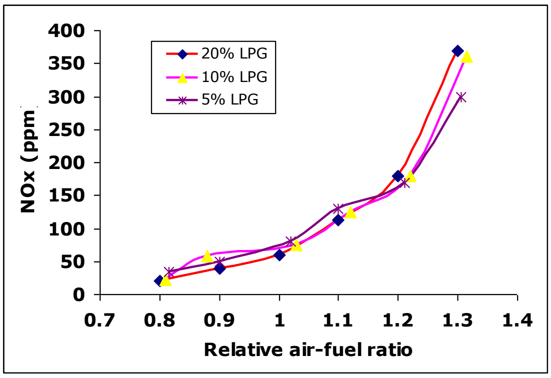

Fig. 6 NOx emissions (ppm) against relative air-fuel ratio (λ)

CONCLUSION

The present study showed that using various blends of LPG in gasoline resulted in contrasting effect to exhaust emissions. Even though in this investigation, experiments were restricted at one engine speed of 1700rev/min, the results obtained give hindsights of the suitability and practicality of running the engine on LPG. The results obtained can be summarized as follows.

(1) The CO_2 emissions exhibit maximum at around relative air-fuel ratio of 1.0 with reducing percentage at increasing proportions of LPG in gasoline.

(2) The CO emissions were clearly higher in the rich region but almost negligible when the relative air-fuel ratio exceeds stoichiometric value.

(3) An increase in the relative air-fuel ratio reduces the UHC emissions, but increases the NOx level.

It can be concluded that generally LPG will provide a viable alternative fuel to the fast depleting fossil fuels in the future, but investigators must be fully aware of the challenge ahead in particular concerning the global environmental effect.

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