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Research paper

Enhancing the heavy load performance of a gasoline engine converted for LPG use by modifying the ignition timings

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HIGHLIGHTS

- ICE performance is improved with optimised ignition timings without knock with LPG.
- Advanced ignition timing improves the performance more for leaner mixtures of LPG.
- For leaner mixtures at knock limit more control tool is needed to suppress the knock.
- Advancing the ignition timing causes increase in HC and NO_x emissions.
- The effect of ignition timing on CO emissions is negligible.

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ABSTRACT

This paper presents the results of the experiments conducted on a spark-ignition (SI) engine fuelled with liquefied petroleum gas (LPG) by varying the ignition timing at the excess air coefficients of 1.0 and 1.3. Experiments were carried out at wide open throttle (WOT) position and at engine speed of 4300 rpm aiming to determine the lean operation performance of an engine when fuelled with LPG at full load. Performance parameters, namely brake power, brake-specific fuel consumption (BSFC), brake thermal efficiency and exhaust emissions such as unburned hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides (NO_x), were studied. It was shown that advancing the ignition timing improved the performance of LPG-fuelled SI engine for excess air coefficients higher than 0.8. The highest brake power and the lowest BSFC were obtained with modified ignition timing at an excess air coefficient of 1.0. The lowest exhaust emissions were obtained with an excess air coefficient of 1.3. In general, advancing the ignition timings caused increase in HC and NO_x emissions, while the effect of ignition timing on CO emissions was negligible.

1. Introduction

With the increasing consciousness of environmental protection and energy conservation throughout the world, the research and development of motor vehicles that use clean alternative fuels has become an important subject [1,2]. Recently, LPG is widely accepted as an alternative fuel for vehicles [3] since LPG is a clean fuel and it has higher octane number and auto ignition temperature, greater flame velocity and wider flammability limit than gasoline [4].

The ignition processes strongly affect the overall performance in spark ignition engines [5]. More power and higher temperatures are generated when the spark setting is configured to give maximum pressure and temperature at approximately 5–10° after top dead centre (ATDC) [6]. A gasoline engine converted to an LPG engine has to be run with optimised ignition timing maps to achieve the best performance due to the different physical and chemical properties LPG and gasoline. In particular the dissimilarities in flame development and flame propagation periods require modifying the original ignition timing maps of gasoline engines. The maximum flame speed occurs at excess air coefficient close to 0.8 for gasoline-type fuels [6] and 0.9 for LPG [7], and any deviation in equivalence ratio from those values requires optimising the ignition timing to obtain the best performance. Power loss is a problem when using gaseous LPG compared to gasoline as a result

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of the lower volumetric efficiency [8], but the lack of power can be compensated by the optimisation of the spark timing [9].

The performance of spark ignition engines is constrained by knock [5,7]. Excessively advancing the spark timing which gives a longer time for the end gases to react before being consumed by the propagating flame front [10], causes an increase in the tendency of the engine to knock [11], and it is generally accepted that knocking combustion can be effectively suppressed by retarding the ignition timing [7,12].

With the incentives of high fuel prices, exhaust emission regulations and focus on guaranteed fuel supplies, considerable research has been conducted in utilizing lean combustion potentials and overcoming its associated problems [10]. LPG has a good potential for the lean burn condition because of its wide inflammable range [7]. Ignition timing strongly affects the overall engine lean misfire limit since the lean operation decreases the flame speed and thus the burning rate, which results in an increase in the overall combustion duration. This necessitates an earlier spark timing [13] but both over-advanced and over-retarded ignition could lead to a reduction in the lean operating area of the engine [14].

Generally, advancing the ignition timing causes increase in HC and NO_x emission levels, and the effect of ignition timing on CO emission is not a primary consideration for SI engines [5,9,15–17].

As of 2011, there were almost 17 million LPG-auto gas vehicles in use and 23.7 million tons of LPG-auto gas were consumed around the world [18]. Pike Research anticipates that by 2020 there will be more than 23 million auto gas vehicles operating on roads [19]. Although there are many reports about the effects of LPG on engine performance and emissions, there is very little information about the relationship between ignition timing and excess air coefficient in the literature. Lean operation is known as one of the methods to increase thermal efficiency and to decrease exhaust emissions and fuel consumption but the reduction in brake power can reach up to 30% at very lean conditions [13]. The mixture has to be enriched to maximise torque under very heavy load conditions (for example, WOT) [20]. This also improves resistance of the mixture against knock, which engines are much liable to under these conditions. Speed-ignition advance maps of engines shows constant advance after some high speed value. This is mainly because that increasing the spark advance more after some speed will cause excessive heat loss and therefore increasing the fuel-air ratio would be much efficient than to advance the ignition after that speed. But the result of a project carried out by the authors of this article showed that when LPG is used, by making fuel-compatible modification of spark advance, it is possible to operate the engine knock free at relatively lean mixtures without having any performance loss even under heavy load conditions. Therefore it was found valuable to study a high load speed specifically. The main objective of the present study is to show the lean operation advantages of LPG-fuelled SI engine at excess air coefficients higher than the original of 0.8 without engine knock and performance loss by optimising the ignition timing.

2. Experimental details

Tests were carried out on a 1.4 1iter Renault Clio spark-ignited engine without catalyst. The main specifications of the test engine are listed in Table 1. The LPG utilized in the engine tests consists of 30% propane and 70% butane. Physical and chemical properties of the propane, butane and gasoline fuel used in this study are listed in Table 2 [21]. The test engine was equipped with a "third-generation" after market sequential LPG conversion kit manufactured by Vikars CNG&LPG Auto Gas Systems (Ltd.) of Turkey. A typical scheme of sequential LPG vapour injection systems is shown in Fig. 1 [22]. Gas phase LPG injection process is managed by a slave ECU controlled by main gasoline ECU. In normal engine operating conditions; the duty cycle of gasoline injector control signal, which is set by gasoline ECU as a function of engine speed and load, is corrected via two-dimensional map, defined as a function of engine speed and gasoline injector opening time, by LPG ECU for defining the LPG injection duration. Then the amount of LPG delivered cycle by cycle and for any engine operating condition is corrected again by the feedback of the exhaust oxygen sensor and this closed-loop control system is provided by the engine manufacturer to optimise the amount of gasoline delivered by the original electronic injection system [23]. During the pre-tests in normal engine operating conditions at WOT, it was detected that the excess

Table 1
Specifications of the test engine.

Item	Values	Units
Engine code	K4J-712	
Max engine power	72 at 5700 rpm	kW
Max engine torque	127 at 4250 rpm	Nm
Swept volume	1390	(cc)
Idle speed	750 ± 50	(rpm)
Fuel system (make & type)	Siemens Sirius 32	
Firing order	1–3–4–2	
Ignition coil resistance, primary	0.5 ± 0.02	(ohms)
Ignition coil resistance, secondary	7500 ± 1100	(ohms)
Spark plugs (make & type)	Bosch RFC 50LZ2E	
Spark plug gap	0.9	(mm)
Injection pressure/system pressure	3 ± 0.2	(bar)

Table 2
Physical and chemical properties of LPG and gasoline.

Property	LPG		Gasoline
	Propane	Butane	
Liquid density, kg/m^3	509	585	765
Calorific value, MJ/kg	46.34	45.56	44.04
Boiling point, °C	−42	−0.5	30–210
Auto ignition temperature, °C	510	490	257
Flame temperature, °C	1980	1775	1720
Flame speed, m/s	0.4	0.4	0.35
Stoichiometric air/fuel, kg/kg	15.8	15.6	14.7
Lower flammability limit, vol.%	2.1	1.5	1.3
Upper flammability limit, vol.%	9.5	8.5	7.6
Octane number	111	103	95

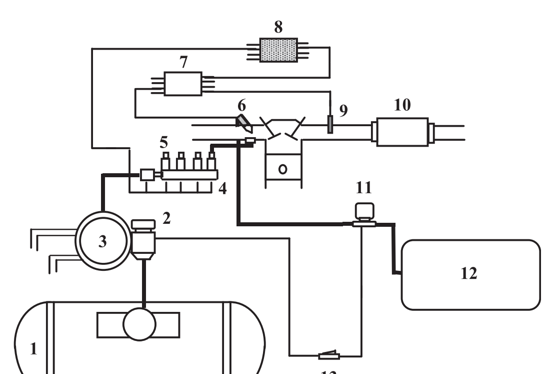

Fig. 1. Sequential LPG vapour injection system (third generation). 1. LPG tank, 2. LPG solenoid valve, 3. Regulator, 4. Injector rail, 5. LPG injectors, 6. Gasoline injector, 7. Electronic control unit for gasoline, 8. Electronic control unit for LPG, 9. Lambda sensor, 10. Catalytic converter, 11. Gasoline solenoid valve, 12. Gasoline tank, 13. LPG/Gasoline selector switch.