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Effects of LPG Fuel on Catalyst Temperature of a SI Engine under Real Life Driving Conditions

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***Abstract*— For this experiment, a spark ignition engine designed to use gasoline has been modified to use LPG, so it has become bi-fuel engine. Catalyst temperature for different speeds and engine loads is evaluated. Thanks to an OBD2 diagnostic interface and its specific software, a handful of sensors of the car can be reached.**

It is widely accepted that LPG causes overheating of engine, and so LPG converted engines have lower lifespan. In order to evaluate the effect of LPG on catalyst, catalyst temperatures are used. Experiments are executed under real life driving conditions, on a straight track at various speeds using cruise control feature for more accuracy.

The results indicate that there isn't any significant temperature increase when the engine is running on LPG. Most important reasons of increasing temperature in cylinders are incorrect air/fuel ratio under LPG operating conditions, and lack of control over advance timing on LPG. Reasons of this are going to be discussed further.

***Keywords*— Spark Ignition, Four Stroke Engine, LPG, Gasoline, Temperature.**

I. INTRODUCTION

In the following years fossil fuels cannot meet the increasing energy demand of the world. Despite conventional fossil fuels are attractive by reasons of availability, price, and high energy density, depletion of fossil sources and emissions of these fuels are a matter of concern [1]. There are lots of researches going on about alternative fuels that can be used in internal combustion engines. One of the researched alternative fuels is LPG which is the most important alternative fuel in internal combustion engines, because of its much lower price, availability, and lower emissions.

LPG is mostly used in Turkey, Italy, Poland, South Korea, Russia as well as other European countries like Holland, Germany, and England. It is not surprise that LPG conversion kit companies like Atiker in Turkey, BRC, Romano, Landirenzo, Lovato, Zavoli, OMVL, Tartarini in Italy, Prins in Holland, Stag, KME, LPG Tech in Poland founded in these countries which uses the LPG most. Most LPG consumption is in South Korea; whereas most LPG converted cars are in Turkey with about 4 million [2].

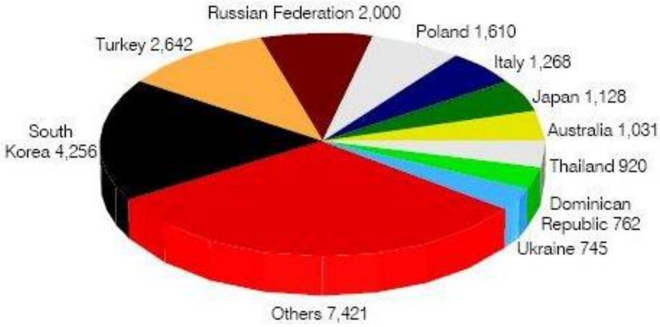

Fig. 1 LPG consumption of the countries (in thousands of tonnes) [2]

LPG is a mixture of propane and butane whose ratios are adjusted volumetrically 30%:70% in summer and 50%:50% in winter generally in Turkey. However every country has its own propane-butane ratio.

TABLE I
PROPANE-BUTANE RATIOS IN COUNTRIES ACCORDING TO SEASONS

Country	Summer	Winter
Turkey	30% : 70%	50% : 50%
Germany	100% : 0%	100% : 0%
Denmark	30% : 70%	70% : 30%
England	100% : 0%	100% : 0%
Austria	20% : 80%	80% : 20%
Holland	30% : 70%	70% : 30%
Sweden	50% : 50%	100% : 0%
Switzerland	100% : 0%	100% : 0%

LPG is attractive alternative fuel because its chemical properties are close to gasoline, it has higher octane number which results more thermal efficiency when used in engines with higher compression ratio. Also LPG has lower emissions thanks to higher hydrogen-carbon ratio [3]. LPG yields 50% less CO, 40% less HC, 35% less NOx, and also it has zero particulate emission which is the main pollutant of diesel and gasoline direct injection engines [4-8]. On the other hand LPG emits a slightly more CO_2 per km than diesel fuel, and a slightly less than gasoline fuel [8-10].

Because of lower energy density per liter and lower volumetric efficiency, LPG converted cars consumes about %20-30 more fuel volumetrically than gasoline ones like Opel Crossland X and Ford Falcon which are offered also factory fitted LPG versions, as can be seen in Figure 1 and 2. Some brands doesn't change much the internal parts of the engine while offering factory fitted LPG versions of their cars, so power and torque decreases as much as 7% like Opel Crossland X. On the other hand, some brands changes most of the internal parts and the design of the engine with factory fitted LPG cars like increasing compression ratio, lighter internal parts, more heat tolerant valves. Hence these can result more power and torque than running on gasoline. One of these types is Ford Falcon LPI. Gasoline version of it produces 195 kW power and 391 Nm torque, while LPG version produces 198 kW power and 409 Nm torque with the help of liquid phase injection and increased compression ratio. This new type of LPG conversion system is used in direct injection and multiport engines and liquid LPG directly injected into the engine without phase change, unlike traditional LPG conversion systems which uses LPG regulator to change the LPG to gas. This LPI system increases thermal efficiency because it removes heat from engine while phase change after the injection into the engine. After all, lower LPG prices offer up to %30-40 reduction of running costs in spite of volumetrically %20-30 more LPG fuel consumption. These cause widely acceptance in the countries where gasoline prices are high and governments encourage their citizens for environmental regulations.

TABLE II
PROPERTIES OF GASOLINE, PROPANE, AND BUTANE [11]

Properties	Gasoline	Propane	Butane
Stochiometric AFR	14.7:1	15.57:1	15.36:1
Density at 15ºC	0.73-0.78	0.508	0.584
Lower Heating Value (MJ/kg)	44	46,4	45,6
Latent Heat of Vaporization (kJ/kg)	300	426	385
Boiling Point (ºC)	30-225	-43	-0.5
Adiabatic Flame Temperature (ºC)	1993	1980	2008
Self-Ignition Temperature (ºC)	493-549	482-538	257
RON	96-98	111	103
MON	82-94	97	92

Overall Rating	Vehicle Details	Fuel Type	Fuel Consumption L/100km Comb	Urban	Extra	CO_2 g/km Comb
★★★★½	Ford FG Mk II Falcon XT 4.0L 6cyl, Auto 6 speed Sedan, 5 seats, 2WD	LPG	12.3	18.5	8.7	199
★★★½	Ford FG Falcon XT 4.0L 6cyl, Auto 6 speed Sedan, 5 seats, 2WD	Petrol 91RON	9.9	14.6	7.2	236

Fig. 2 Fuel consumption and CO_2 emission comparison of LPG converted and gasoline versions of Ford Falcon XT

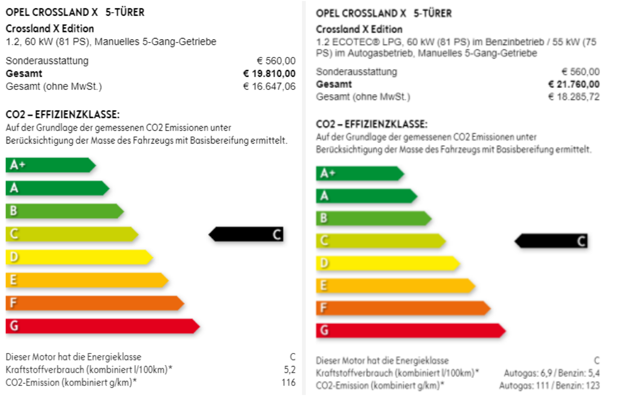

Fig. 3 Fuel consumption and CO_2 emission comparison of LPG converted and gasoline versions of Opel Crossland X

There are many researches about LPG used in carbureted gasoline, fuel injected gasoline, gasoline direct injected, and diesel engines. Selim Mohamed et al. [12] investigated water addition in a dual-fuel engine. They found that addition of water vapor in dual-fuel diesel engine reduces NOx emission. Vijayabalan and Nagarajan [13] used LPG as a primary fuel in a diesel engine under the precence of a glow plug. As a result they achieved 3% thermal efficiency increase and 69% hydrocarbon, %50 monoxide, %9 smoke reductions.

Nayak et al. [1] researched performance of a spark ignition engine with LPG and gasoline at dual-mode with various ratios. They found that with 50% LPG usage, brake thermal efficiency incrases 2%, with higher ratios engine works in the lean region, however HC and CO emissions are at minimum, while NOx emission are higher in-cylinder temperature. Erkuş et al. [14] experimentally investigated the effect of ignition timing on LPG injected engine. They proceed with base, +2, and +4 degree timing advance maps. With +2 degree timing advance highest brake power and torque at 2000 and 4000 rpms had been achieved. Furthermore with +4 degree timing advance lowest brake specific fuel consumption had been obtained at 2500 rpm. Base timing advance map offers average power, torque, and brake specific fuel consumption values through rpm band.

Karamangil et al. [15] investigated effect of LPG on exhaust valves. They realized that while mechanical stress decreases because of decreasing in-cylinder pressure at exhaust timing, thermal stress occurs on the exhaust valves because using LPG in a gasoline engine prevents carbon build-up, so valves are exposed to higher temperature. Higher temperature fluctuations can be risky for clean valve surfaces. Lopez et al. [16] investigated LPG converted car which has carbureted gasoline engine. They found out that using LPG increases temperatures of the exhaust, oil, coolant, and intake. Çınar et al. [3] researched valve lift profiles on a LPG injected spark ignition engine. The experiments made with both LPG and gasoline at 7 and 8 mm valve lifts. They realized that increasing valve lift results reducing emissions and brake specific fuel consumption, while power and torque decrease.

On the other hand using LPG causes higher exhaust gas temperatures. Lee et al. [17] researched catalyst temperature in an SI engine under various engine loads, equivalence ratios, and ignition timings. By using commercial simulation software they analyzed the catalyst temperature for different conditions. They found numerical results are very close to the experimental results and misfiring rate increases catalyst temperature because unburned gases are treated in catalyst.

Considering the researches in literature there is still lack in research understanding the LPG conversion. There are very limited studies about LPG converted cars, and how LPG affects the engine and other systems in daily use at the hands of the end users. In this paper catalyst temperature is investigated in detail using a LPG converted car in a test track.

II. Material And Method

A scheme of the experimental model can be shown in Figure 4. All the tests are performed by using 2010 model Mazda 3 1.6 lt. engine 4-speed automatic transmission car. For these tests 1.6 lt. multiport injection engine whose specifications can be seen in Table 3 is modified to run on LPG by installing open loop sequential injection LPG system. Parts of the installed system can be seen below in Figure 4. After the installation adjusting the LPG map for open loop LPG systems is crucial for remaining equivalence ratio at 1 under various speeds, rpms, and engine loads. Otherwise not adjusting the LPG map results rich or lean mixtures under varying driving conditions and can cause problems in the car eventually.

TABLE III
Engine Specifications

Specifications	**Resources**
Cylinder	4
Position of Cylinders	Inline
Valves	16
Bore (mm)	78
Stroke (mm)	83.6
Displacement (cc)	1598
Fuel System	Multi Point Injection
Valvetrain	DOHC
Compression Ratio	10:1
Max. Power (hp)	105
Max. Torque (Nm)	148

Tests were conducted on the same straight track at constant speeds. 60, 80, 100, and 120 km/h speeds were evaluated and cruise control feature was used for speed accuracy across test track. Additional tests were conducted in a combined track which features city and urban driving conditions. All tests were performed first with gasoline fuel, and then LPG in the same track. The experiments began with the vehicle stopped, then vehicle was accelerated to the test speed, and later speed was maintained using cruise control. After 2.3 km U turn was made, and process was repeated until reaching the starting point. Test track was 4.6 km long. All tests were performed after the engine temperature reached its operating temperature.

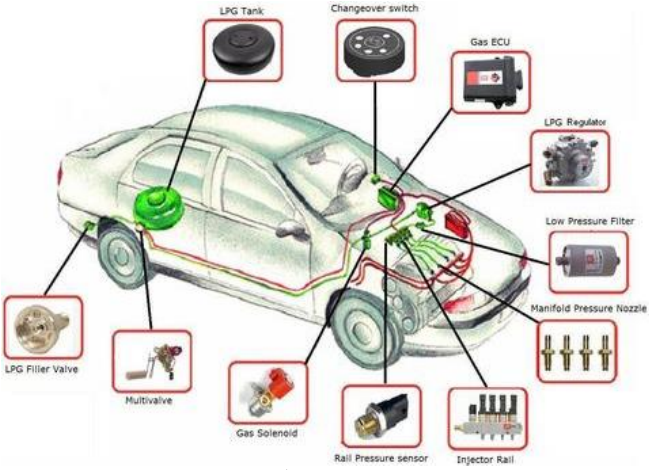

Fig. 4 Schematic layout of LPG sequential injection system [18]

Sensors of the car are used for data acquisition. Modern cars are much smarter than their predecessors. Main ECU of these cars can reach a handful of data. These data from the ECU are accessible via OBD2 port and a dedicated diagnostic cable.

III. Results

Data of each run were evaluated by statistical methods, and velocity weighted temperatures and standard derivations were calculated. For calculations of the weighted average temperatures at constant speeds, catalyst temperatures during the hard acceleration above the 80% of the samples were excluded. Standard deviations were compatible with each run.

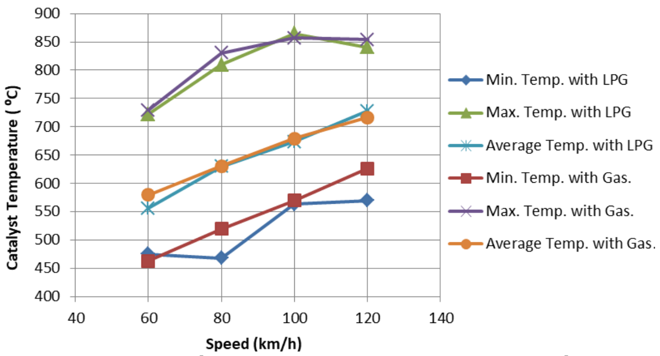

Fig. 5 Catalyst temperature variation at constant speed

As can be seen in the Figure 5 above minimum, maximum, and velocity weighted average catalyst temperatures according to constant speeds are presented. Average catalyst temperature increases linearly with increasing speed. Catalyst temperature reaches its maximum during the acceleration because of %100 engine load.

Catalyst temperature across the test track for LPG and gasoline can be seen in Figure 6 below. It is obvious that catalyst temperatures are low at lower speeds because engine load is lower at lower speeds. Because of lower engine load, less exhaust gas is produced, so catalyst temperature decreases. At full stops for U turn, temperature decreases, and during acceleration till the specified speed temperature is at maximum, then decrease starts at constant speeds. Because of imperfections on the track, engine load changes across track, so temperature fluctuates.

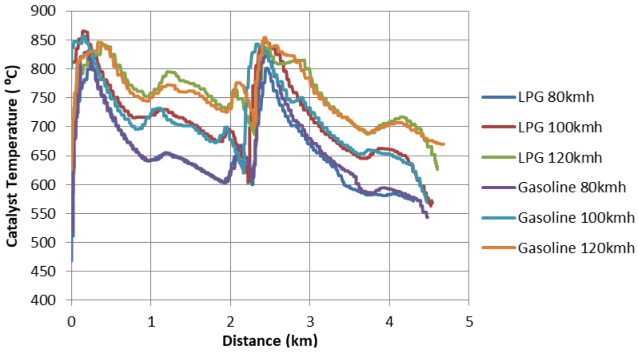

Fig. 6 Catalyst temperature across the track

As can be seen in the figures, using LPG or gasoline fuel doesn't change the temperature; actually temperature slightly decreases with LPG. Only case that catalyst temperature using LPG is higher than with gasoline is with 120 km/h speed. That can be result of wrong LPG map, so at that speed mixture can be in rich region. Viswanatha et al. [19] found similar results supporting that LPG cause lower catalyst temperature than gasoline fuel in a spark ignition engine. This can be result of lower unburned gas and HC emissions when using LPG, so in catalytic converter less exothermic reactions take place.

IV. Results

The use of LPG is advantageous. It is cheaper, has lower CO, HC emissions, and zero particulate emission. Despite its advantages, some problems may occur because of incomplete conversion installations. For open loop LPG conversion systems adjusting LPG map is essential. If it is not done properly engine stall, power loss, catalyst poisoning, engine overheating can be encountered.

Catalyst temperature doesn't increase when proper adjustments are made for LPG like in this study. Main reason of increasing catalyst temperature is exothermic reactions which are results of unburned gases, hydrocarbon emissions reacting in catalyst converter to turn into carbon dioxide and water. In the events of LPG map adjustments which stay in richer mixture, catalyst poisoning can be encountered. On the other hand leaner mixture can harm engine itself. To put in a nutshell leaner mixture can harm engine, richer mixture can harm catalyst.

As a result, all these LPG map adjustments can be resolved with closed loop LPG conversion systems which communicate with engine ECU and adjust the LPG fuel trims accordingly, so problems resulting from LPG mixture adjustments can be minimized.

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