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INFLUENCE OF LIQUID LPG INJECTION CHANGE PRESSURE ON THE INJECTION CONTROL

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Summary. This article presents selected results of research, connected with change of LPG fuel injection pressure influence on liquid injection system parameters. LPG pressure is related with propane and butane fraction – the main components of fuel. Changing of trade LPG composition is connected with vapour pressure into the fuel tank, and involves injection pressure change. This produces varying of fuel dose and necessity of injection time regulation, for assurance of suitable air-fuel mixture ratio. In the modern internal combustion engines, precision of fuel dosage is indispensable for the reception of optimally useful parameters and toxicity standards fulfillment. The research results show that relatively small injection pressure change significantly affects both the fuel dose and engine parameters.

Key words: LPG pressure, liquid LPG injection, sequential injection.

INTRODUCTION

LPG liquid injection systems are defined as V generation. An example of this kind of system for SI engines is offered in the Polish market as VIALLE LPI system. In VIALLE system a fuel pump is inside the LPG tank. This pump feeds fuel into the injectors with about 0,5 MPa higher pressure than the fuel vapour pressure inside the tank. Fuel pressure in this system is regulated by a pressure regulator. Injectors are opened according to signals generated into the LPG control unit. Main signals which feed into the control unit are: signals of petrol injection time, battery voltage and LPG pressure. Operation principle of this fuel system is the same as petrol engine sequential systems. The difference is pressure inside the fuel system. In the LPG system the pressure is variable and may reach 3 MPa.

Quality of LPG injector is higher than of petrol injector for the same type of engine. Petrol injection time is longer than LPG injection time, for the same working point of an engine. Electronic control unit of LPG injection system [VIALLE 2001] realizes, among other things, the following functions (Fig.1):

- steering LPG injectors (petrol injection time conversion on the LPG injection time, which allow for pressure and battery voltage correction),

- steering fuel switching (starting an engine is always in petrol, change-over LPG is on heated-up engine),
- LPG pump supply and control of its rotational speed (steering of rate of delivery of a pump),
- closing LPG valves after the stopping of engine,
- petrol injectors cut-off.

For liquid injection it is unacceptable to have vapour-lock formation in the fuel pipe (into the hot engine room) [Cipollone 2002, Dutczak 2003, Jaworski, Kuszewski 2005]. Fuel recirculation system pumps the fuel and keeps LPG temperature considerably below the temperature inside the engine room. This enables correct engine work for higher fuel pressure than pressure inside a tank.

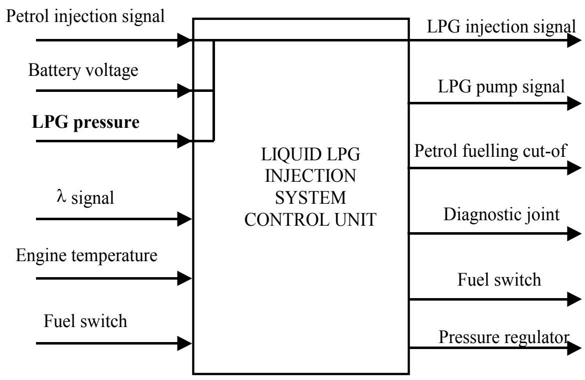

Fig. 1. Main input and output signals of liquid LPG injection system control unit

LPG CHARACTERISTICS IN ASPECT OF SI ENGINES FUEL FEED

LPG fuel in different countries has different ratios of propane and butane. Table 1 presents average fraction of propane and butane in selected European countries.

Table 1. Average fraction of propane and butane in selected countries

Country	Propane [% vol.]	Butane [% vol.]
Austria	50	50
Belgium	50	50
Denmark	50	50
France	45	55
Greece	20	80
Ireland	100	-
Spain	30	70
Holland	50	50
Poland	18÷55	>45
Sweden	95	5
United Kingdom	90	10
Italy	25	75

Difference of LPG composition is connected with vapour pressure of the main fuel components. Propane is more volatile than butane (Fig. 2). When the temperature gets lower, fraction of propane in LPG fuel increases. Quality of LPG fuel in Poland is specified by regulations [Dz.U. 2006 nr 251 poz. 1851, PN-EN 589:2004]. The standards do not precise percentage of propane and butane in the mixture for vehicles, but only specifies LPG vapour pressure in fixed temperature (Table 2).

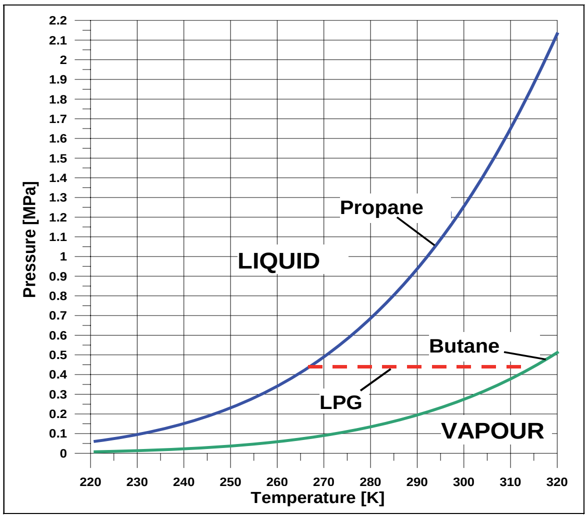

Fig. 2. Vapour pressure of main LPG fuel components: propane and butane (dashed line determines constant value of vapour pressure for different composition of LPG fuel)

Table 2. Quality requirements of LPG

Property	Unit	Range	
		minimum	maximum
Motor octane number	-	89	-
Total content of dienes	% molar	-	05
Hydrogen sulfide	-	Lack	
Total content of sulfur (with odorant)	mg/kg	-	50
Test of copper corrosion (1h in temp. 40ºC)	Corrosion class	Class 1	
Rest after evaporation	mg/kg	-	100
Relative vapour pressure in temp. 40ºC	kPa	-	1550
Temperature, for relative vapour pressure above 150 kPa: - in winter time¹ - in summer time²	 ºC ºC		 -10 +10
Water content		Lack of water in temp. 0ºC	
Odour ³	-	-	
¹ from 1 November to 31 March ² from 1 April to 31 October ³ smell of gas typical of offensive odour for 20% of lover explosive limit			

An analysis of literature on this subject [Cipollone 2000, Cipollone 2002, Sykes 1999] proves a significant influence of temperature and fuel composition change on the injection parameters. In the work [Cipollone 2000] two fuels were tested:

– fuel A, consisting of 20 % propane and 80 % butane (lower volatile fuel),

– fuel B, consisting of 96 % propane and 4 % ethane (higher volatile fuel).

Difference of LPG fuel A and B composition lead to diversified change of pressure inside the fuel tank with temperature. In injection fuel system it cannot be avoided, that real opening injector time differs from the time of driving signal. The difference is connected with delay of opening injector and delay of closing injector. These delays are different for pressure change. This involves change of real fuel dose supplied into the engine.

Considering the quality of liquid fuel injection control is difficult, especially that LPG fuel composition is not constant. LPG composition is a mixture of hydrocarbons with different properties. In respect of LPG composition, a fuel dose necessary to stoichiometric air-fuel mixture changes. If steering of fuel dose injection is concerned with liquid phase, difference of injected LPG fuel volume for practical range of pressure amounts to about 3 %. Compared to petrol fuelling, needful differences of fuel dosage for varying petrol do not exceed 1 % [Majerczyk 2003].

If we take into consideration toxicity of exhaust gas for LPG fuelling, a lot of effort in selection and regulation of engine control system is required to get improved. Another aspect is the necessity of total integration with OBD vehicle system.

In respect of air demand for combustion of LPG liquid injection system fuelling, for different LPG composition, the required mass of fuel to air is approximately constant, however for the sake of higher density (for the same injection time) the volume flow rate of liquid butane is about 14 % higher than propane [Sykes 1999]. Control system, receiving information from oxygen sensor (λ signal), can manage with such fuel composition changes if a vehicle is operated under partial load after different composition LPG refuelling. However, there can be special cases (for example after refuelling on the express road), when the time for system adaptation in full load engine condition will be insufficient. It would be perfect, if composition of propane and butane mixture were independently determined, for example by temperature and pressure inside the tank measurement.

DESCRIPTION OF STUDIES

The tested object was six-cylinders spark ignition engine MD-111ET with turbocharger Čz K36. This engine is the modification of compression-ignition engine MD-111E.1 of „PZL Mielec" Engines Company. The engine was adopted for liquid LPG sequential injection system of VIALLE [Jaworski, Lejda 2006, Lejda 2007].

The view of the engine in test stand is presented in Fig.3. The configuration of the test stand included:

- hydraulic brake Schenck D-630E, which enables smoothness change of engine load in the all range rotational speed and output power,
- automated mass fuel consumption system AVL with two Micro Motion sensors F025M and F010M,
- mass air flowmeter system AVL, enables to observe combustion air factor,
- combustion gas analyzing system PIERBURG type AMA 2000 for measurement of hydrocarbons and nitric oxides in the exhaust gas,
- combustion gas analyzer BOSCH type BEA-350 for measurement of carbon monoxide in the exhaust gas and for combustion air factor λ analysis,

- computer system of high-variable signals acquisition, used for measurement of injector control signals, pressure into the suction manifold, engine valves lift, pressure course in the cylinders 1 and 6 and crankshaft position; it included the measuring card National Instruments AT-MIO-16E-1 and signal separator type NI-SCXI 1125.

Research of pressure influence on the useful parameters of the engine was realized for constant rotational speed and load. The principal aim of research was determination according to pressure changes (in comparison with the range of theoretical changes of LPG fuel pressure from about 5000 kPa to about 25000 kPa) influence on mixture ratio, for fixed conditions of engine working. Investigations were conducted for trade LPG fuel with constant composition. For the constant value of master control unit injection time (petrol), there was determined stoichiometric air-fuel mixture. Then the rotational speed of LPG pump was changed, which resulted in changes of fuel injection pressure.

Fig. 3. View of the engine in the test stand

In each working point of the engine there were measured the following parameters:

- rotational speed of the engine n [rpm],
- engine load Mo [Nm],
- fuel consumption Gh [kg/h],
- air consumption Gp [kg/h],
- temperatures inside the suction manifold [°C],
- LPG pressure [kPa],
- LPG temperature [°C],
- time of steering signal of LPG [ms],
- LPG density [kg/m^3],
- start of fuel injection before TDC [° OWK],
- inlet valve lift h_d [mm],
- outlet valve lift h_w [mm],
- pressure into the cylinder p_c [bar],
- crankshaft angle position φ [°OWK],

– temperatures: of fuel T_{LPG}, of ambient T_o, of coolant T_{ch}, of combustion gas Ts [°C],
– concentration of CO in exhaust gas [%],
– concentration of CO_2 in exhaust gas [%],
– concentration of NO_x in exhaust gas [ppm],
– concentration of HC in exhaust gas [ppm],
– pressure into the suction manifold p_k [Pa],
– atmospheric pressure p_a [Pa].

RESEARCH RESULTS

Selected results of research are presented in Fig. 4 and 5. If fuel pressure increases, LPG control unit decreases injection time (Fig. 5). This change does not allow for assurance of air-fuel mixture in the stoichiometric range (λ=0,97-1,03). This causes an increase of injected fuel dose (Fig. 4). An increase of fuel pressure from 1285 kPa to 1370 kPa produces an increase of fuel dose and engine torque. Whereas the total efficiency of engine decreases, which is connected with an increase of specific fuel consumption.

Changes of injection pressure have an influence on toxicity compounds concentration in engine exhaust gas, too. An increase of pressure produces an increase of CO and HC concentration in exhaust gas. It decreases concentrations of NO_X and CO_2. This is a result of air-fuel mixture change.

On the grounds of simulation calculations [Jaworski 2005] an influence of injection pressure on the injected fuel dose, as well as injector opening time were determined. Fig. 6 presents the relation between LPG (propane and butane) injection pressure and injection time for partial load of engine. Because the density of propane is lower than density of butane, injection time of propane for stoichiometric air-fuel mixture is longer than for butane injection time.

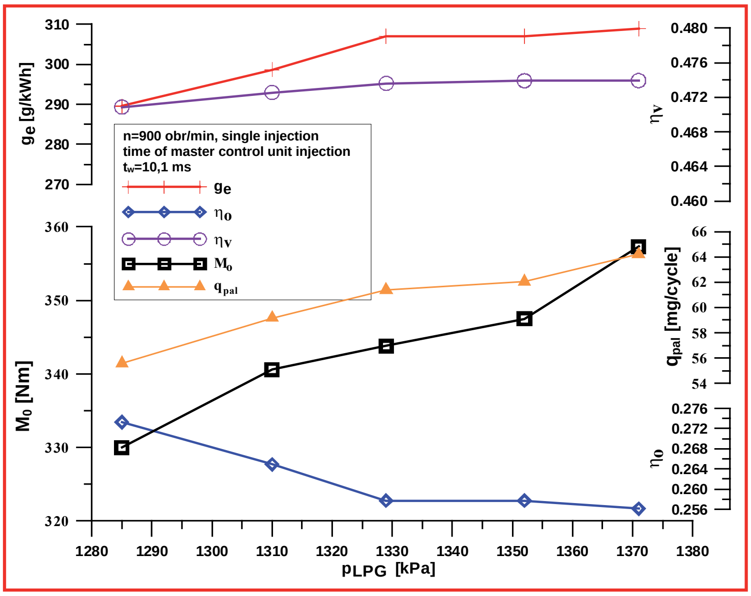

Fig. 4. An influence of LPG fuel pressure change on the torque M_o, total efficiency η_v, volumetric efficiency η_v, fuel dose q_{pal} and specific fuel consumption g_e

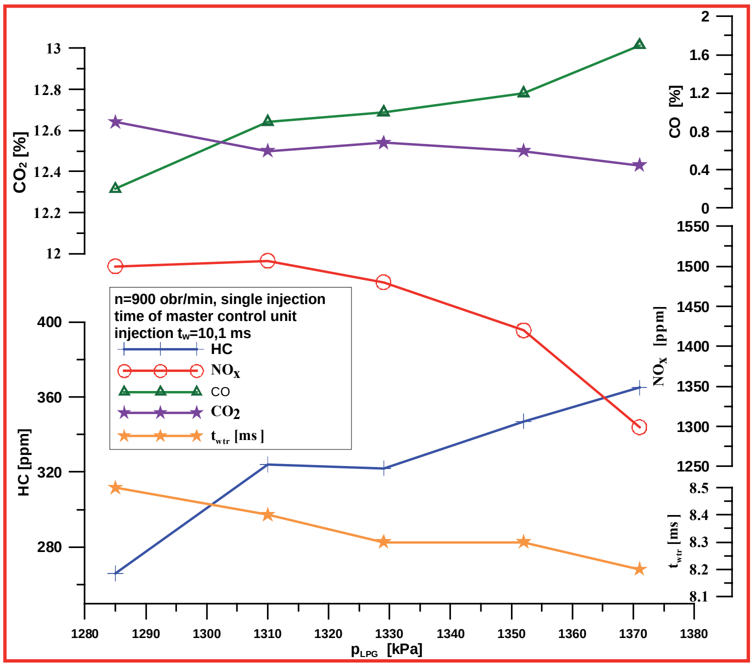

Fig. 5. An influence of LPG fuel pressure change on the signal time of LPG injectors t_{wtr}, concentration of HC, concentration of CO, concentration of NO_x and concentration of CO_2

It was found that percentage composition of propane-butane mixture in the LPG fuel has a slight influence on the size of mean droplet diameter of the injected fuel. Taking into consideration that an increase of propane fraction permits an increase of vapour pressure inside the fuel tank, it has an influence on injection pressure of LPG.

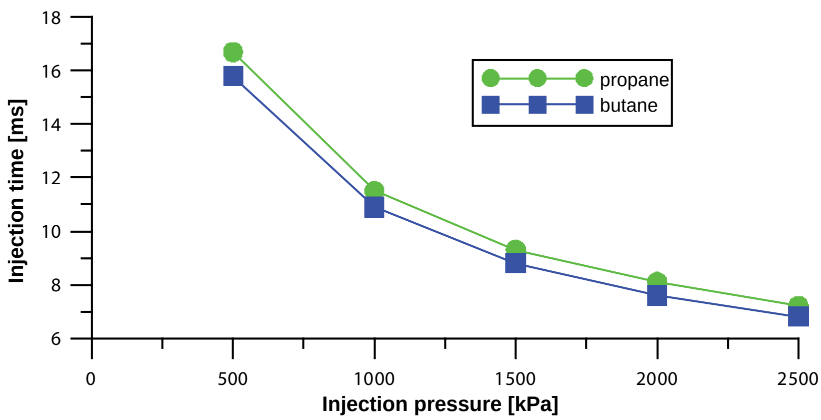

Fig. 6. An influence of propane and butane injection pressure on injection time (λ=1, η_v=0,5)

CONCLUSIONS

On the basis of the provided theoretical analysis and engine research we can formulate the following conclusions:

1) change of pressure of LPG liquid sequential injection fuelling system is a significant parameter, which makes a proper engine work difficult,

2) an increase of injection pressure makes the injected fuel dose larger, in spite of the shortening of injection time by LPG control unit,

3) allowing for change of pressure in the fuel supply system is not a sufficient factor for proper system control to assure the constant level of air-fuel mixture,

4) for correct injection control, we should make an allowance for fuel composition, by measurement of temperature and pressure of fuel,

5) an increase of injection pressure produces an increase of fuel dose and generates the growth of CO and HC emissions,

6) an optimization of toxic compounds emission and useful parameters of the engine for different mixtures of LPG fuel is considerably more difficult than for petrol fuel.

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