Experimental investigations of LPG use at the automotive diesel engine

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Abstract. The liquefied petroleum gas has a great potential to improve energetically and pollution performance of compression ignition engines due to its good combustion properties. This paper presents results of the researches carried on a car compression ignition engine with a 1.5 dm³ displacement, fuelled with diesel fuel and liquefied petroleum gas by diesel-gas method at the operating regimens of 70% and 55% engine load, engine speed of 2000 rpm and for substitute ratios between (6-19)%. A specific objective of this paper is to establish a correlation between the optimum adjustments and the substitute ratio of the diesel fuel with liquefied petroleum gas for the investigated regimens to limit the maximum pressure and smoke level, knock and rough engine functioning and having regard to decrease the fuel consumption and the level of the pollutant emissions.

1 Introduction

In the last years, the internal combustion engines and especially compression ignition engines increased the energetic performances either because of the researcher's continuous work or because of the need of fossil fuels saving, whose resources are exhaustible. The smoke and the smell of exhaust gases imposed reticence of many users to use vehicles equipped with compression-ignition engines. This behavior of the compression-ignition engine has been greatly improved by solutions adopted to limit the environmental pollution and by the adoption of legislative rules. Tougher legislation on emission level imposed the adoption of solutions to reduce it to the legislated levels. One of the recommended solutions to reduce emissions from compression ignition engine is the use of alternative fuels. Of these, liquefied petroleum gas (LPG) is a clean and efficient alternative fuel, its use being possible without major structural changes of the engine.

Liquefied petroleum gas is a fuel which generally consist of a mixture of 2 hydrocarbons, propane and butane, in different ratios, depending on season. Because of its good burning properties and because of the price liquefied petroleum gas is a very good

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alternative fuel for the compression ignition engine. The LPG properties, comparative with the diesel fuel properties are presented in the Table 1.

Table 1. LPG properties, compared to diesel fuel properties [1].

Properties	Diesel fuel	LPG	
		Propane	Butane
Density [kg/m ³]	800-840	503	-
Vaporization heat [kJ/kg]	465	420	-
Self ignition temperature [°C]	355	481	544
Inflammability limits [%]	0.6-5.5	2.1-9.5	-
A/F ratio [kg/kg]	15	15.71	15.49
Flame temperature [°C]	2054	1990	-
Lower heating value [MJ/m ³]	36000	23000	-
Lower heating value [MJ/kg]	42.5	46.34	45.55
Cetane number CC	40-55	-2	-

Liquid LPG density is lower than diesel fuel density, 503 kg/m³ for LPG and 800-840 kg/m³ for diesel fuel [1], thus the mass of the same volume of fuel is lower, leading to a lower autonomy for the vehicle fuelled with LPG.

The vaporization heat of LPG is lower than diesel fuel vaporization heat (420 kJ/kg to 465 kJ/kg for diesel fuel [1]), allowing to vaporize faster and to consume less local heat in the case of direct injection in the combustion chamber.

The LPG self ignition temperature is higher than the diesel fuel self ignition temperature, 481 °C – propane, 544 °C –butane, 355°C diesel fuel [1], which underlines the worsening of self ignition properties. Therefore fuelling a diesel engine with LPG requires the use of specific methods.

The flame temperature of LPG lower than the diesel fuel flame temperature leads to an important reduction in nitrogen oxides emissions..

The LPG lower heating value higher than diesel fuel lower heating value provides an increase in the amount of heat released during the combustion of fuel for the same fuel quantity.

The extremely low cetane number of LPG underlines its very low self ignition properties. Therefore to fuel a diesel engine with LPG involves specific methods. In this paper the authors chose to fuel the engine by Diesel-Gas method.

1.1 The Diesel-Gas method

The Diesel-Gas method consists of gaseous LPG injection in the intake manifold of the engine, using a conventional LPG fuelling system. Thus in the combustion chamber burns LPG, prior injected in the intake manifold on the intake stroke and ignited by the flames occurred in the pilot diesel fuel sprays. The diesel engine is equipped with another fuelling system for LPG injection. The LPG quantity injected in the intake manifold is tuned with the load and limited by the occurrence of knock (because of the higher compression ratio), and by the smoke emission, which at higher substitute ratios is in high concentrations in exhaust gases. Also the durability of the engine can be affected at higher substitute ratios.

1.2 The state of the research art

Results of a compression ignition engine fuelled with LPG are presented by Qi et. al. in the work [2]. The authors experimented direct injection of a LPG-diesel fuel mixture (with the help of a nitrogen tank) with different proportions: 0, 10, 20, 30, 40 %, leading to a

decrease in the pollutant emissions of the engine. In the work [3] the authors decreased the level of the nitrogen oxides emission fuelling the diesel engine with LPG. Although the level of nitrogen oxides emission decreased, the level of unburned hydrocarbons increased. To reduce this emission the authors used a glow plug [3]. The same solution was found by [4], but in this case the engine was fuelled with methane. An increase of the level of unburned hydrocarbon emission was obtained also in [5, 6]. To reduce the level of the unburned hydrocarbons emission the authors used exhaust gas recirculation. In the work [7] by fuelling a four cylinders diesel engine with LPG an increase in the engine efficiency with 4% was obtained, when the engine functioned at full load. At partial loads the efficiency of the engine increased with increasing substitute ratio of the diesel fuel with LPG [7]. Also the smoke emission level was with 40-60% lower than in the case of the standard engine, fuelled with diesel fuel [7]. The reduction of the smoke emission level by fuelling a compression ignition engine with LPG is presented also in the paper [8].

2 Experimental investigations

Experimental investigations were carried out on a K9K 792 1.5 dCi diesel engine, equipped with a LPG fuelling system, corresponding to Diesel-Gas method, at 70% and 55% engine load and 2000 rpm. Laboratory equipments (Figure 1) are: 1 – 1.5 dci diesel engine; 2 – engine cooling system; 3 – engine water cooler; 4 – intercooler fan; 5 – engine angular encoder; 6 –AVL piezoelectric pressure transducer; 7 – diesel fuel injector; 8 – LPG injector; 9 – Turbocharger; 10 – intake air drum; 11 – intake air flow meter; 12 – exhaust gas recirculation; 13 –Schenck E90 dyno; 14 – dyno-engine coupling; 15 –Schenck E 90 dyno cooling water pump; 16 –dyno cooling system; 17 –AVL Dicom 4000 gas analyzer; 18 –AVL Dicom 4000 Opacimeter; 19 –AVL charge amplifier; 20 – PC + AVL data acquisition system; 21 –Schenck E 90 dyno controller; 22 – temperatures displays: a) – exhaust gas; b) – intake air; c) – engine oil; d) – engine cooling liquid; e) – engine oil pressure; 23 – diesel fuel and LPG injection control Laptop; 24 – diesel fuel tank; 25 – diesel fuel mass flow meter; 26 – fuel filters; 27 – high pressure pump for common Rail; 28 –Common Rail; 29 – LPG tank; 30 – LPG mass flow meter; 31 – LPG vaporizer; 32 –LPG ECU; 33 –diesel engine ECU; 34 –intercooler; 35- supercharge pressure measuring system; 36- throttle actuator.

Fig. 1. Test bed diagram.

The engine parameters are presented in the Table 2.

Table 2. Engine parameters

Bore	76 mm
Stroke	80.5 mm
Connecting rod length	134 mm
Maximum power/speed	52 kW @ 3900 rpm
Maximum torque/speed	156 Nm @ 2000 rpm

2.1 The working procedure

First was determined the reference, fuelling the engine with diesel fuel, than the diesel fuel cyclic dose was decreased, and the LPG cyclic dose was increased. The engine power was maintained the same like in the case of standard fuelling with diesel fuel. The energetic substitute ratio has the mathematical relation presented in equation 1.

$$x_c = \frac{m_{LPG}H_{i_{LPG}}}{m_{LPG}H_{i_{LPG}} + m_{dieselfuel}H_{i_{dieselfuel}}} \cdot 100 \text{ ,} \tag{1}$$

where: m_{LPG} [kg]- the LPG dose; $m_{dieselfuel}$ [kg]-the diesel fuel dose; H_i [kJ/kg]- the caloric heating value.

The investigated energetic substitute ratios of the diesel fuel with LPG was between [0-11.85] % for 70% engine load and [0-19]% for 55% engine load. The substitute ratio of diesel fuel with LPG was limited in both cases (70% engine load and 55% engine load) to limit the maximum pressure and smoke level, knock and rough engine functioning. Also to limit the nitrogen oxides emission level and to proper position the combustion near top dead center the injection timing advance was reduced with [1.1-6.7] °CRA, depending on the regimen.

3 Results

The experimental and theoretical investigations led to the following results.

3.1 In cylinder pressure

The pressure inside the cylinder decreased for all the investigated substitution ratios of diesel fuel with LPG. This can be explained by the reduction of the diesel fuel injection advance, to limit the nitrogen oxides emissions level. The figure 2 shows the measured in cylinder pressure for the investigated cases.

Fig. 2. The in cylinder pressure for 70% engine load, (a) – 70% engine load, (b) – 55% engine load.

3.2 The maximum rate of pressure rise

The combustion noise, evaluate by the maximum rate of pressure rise decreased for all the investigated substitute ratios of diesel fuel with LPG either for 70% engine load or 55% engine load because the diesel fuel injection timing advance was reduced in order to limit the nitrogen oxides emissions level. The maximum rate of pressure rise is presented in the figure 4.

Fig. 4. The maximum rate of pressure rise, (a) – 70% engine load, (b) – 55% engine load.

3.3 The nitrogen oxides emission level

The nitrogen oxides emission level was lower than in the case of fuelling only with diesel fuel for all the investigated substitute ratios x_c . This was possible because in the case of engine fuelling with LPG by Diesel-Gas method, the cylinder global temperature decreases due to good LPG burning properties and due the reduction of injection timing advance, which has a major role in temperature decreasing. Also the reduction of injection timing advance leads in reducing the time required for forming reaction of nitrogen oxides. The nitrogen oxides emission level is presented in the Figure 5, for all the investigated cases.

Fig. 5. The nitrogen oxides emission level, (a) – 70% engine load and (b) – 55% engine load.

3.4 The smoke emission level

The smoke emission, measured with the opacimeter and evaluated by the coefficient of absorption k , had a lower level than in the case of standard engine for low substitute ratios of diesel fuel with LPG and a higher level for the maximum substitute ratio investigated (11.85 for 70% engine load and 19 for 55% engine load). The smoke emission level increases with increasing substitute ratio because of the intake process worsening, LPG being injected in the intake manifold and replacing a part of the intake air. Table 3 presents the smoke emission level.

Table 3. The smoke emission level.

70% engine load		55% engine load	
x_c [%]	k [1/m]	x_c [%]	k [1/m]
0	0.38	0	0.58
6.57	0.36	5	0.42
11.85	0.91	19	1.13

3.5 The fuel consumption

The energetic specific fuel consumption (Table 4) decreased for all the investigated substitute ratios of diesel fuel with LPG.

Table 4. The energetic specific fuel consumption.

70% engine load		55% engine load	
vc1%	celk.l/kWhl	vc1%	celk.l/kWhl
0	11163	0	13486
6.57	8980	5	13300
11.85	9083	19	12813

4 Conclusions

- The experimental investigations led to the following conclusions:
1. The level of the nitrogen oxides emission decreased with ~34% for 11.85% substitute ratio of the diesel fuel with LPG for 70% engine load and with ~7% for 19% substitute ratio and 55% engine load.
 2. The level of the smoke emission decreased with ~5% for 70% engine load and with ~27% for the 55% engine load;
 3. The level of the maximum pressure decreased when the diesel fuel was substituted with LPG;
 4. The maximum rate of pressure rise decreased for all the investigated cases, the maximum value of 2.65 bar/°CRA being recorded for the maximum substitute ratio. When the engine was fuelled only with diesel fuel the maximum rate of pressure rise was ~3 bar/°CRA.
 5. The brake specific energetic consumption decreased with ~19% when the diesel fuel was 11.85% substituted with LPG for 70% engine load and with ~ 5% when the diesel fuel was 19% substituted with LPG for 55% engine load.

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