EXPERIMENTAL ASPECTS OF THE USE OF LPG AT DIESEL ENGINE

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Abstract. *The use of LPG in diesel engines represents an efficient solution to decrease of the emissions for the automotive engines and of the preservation of the high efficiency that characterizes the standard diesel engine. Experimental researches were carried on an automotive diesel engine with 1,5 l displacement fuelled with LPG by diesel-gas method at different engine operating regimens and different substitution percents of the diesel fuel with LPG on a test bench adequate instrumented. The experimental results showed a significant decreasing of the smoke and* NO_x *emissions level at full load. At the same load,* CO_2*, HC and CO emissions level slightly decreases when the substitution percent of the diesel fuel with LPG increases till at 40%. Following the efficiency and maximum gases pressure limitation criterions of the diesel fuel with LPG substitute ratios of the 30-40% are defined as optimal range values.*

Keywords: LPG, emissions, combustion, diesel-gas

1. Introduction

The use of the alternative fuels at automotive diesel engine is necessary as much as for the classic fuels replacing and also for the pollutants emissions level decreasing.

The potential benefits of using LPG in diesel engines are on economical and environmental side [1].

The LPG is an alternative fuel for diesel engine with real future opportunities due to the following aspects [2], [3]: the NO_x emission level is lower; the PM emission is indistinguishable; CO_2 emission is maintained to the same level; the engine power is the same or can increases; the automotive autonomy increases; the HC and CO emissions level decreases; LPG protects the particles filter and environment because doesn't contains sulphur; the infrastructure for LPG distribution already exists. In order to reduce the pollutants emissions level and to

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increase thermal efficiency which is directly related with CO_2 emission level is advantageous to use LPG also for diesel engine. Is very difficult to use only liquid LPG direct injection in the diesel engine because of its higher auto-ignition endurance (CN = -2….-3). In this case becomes necessary the use of peroxides additives [4] for LPG but the explosion danger is very high. Another impediment appears at the liquid LPG direct injection: poor oiling properties of the LPG comparative to diesel fuel. This deficiency is eliminated by oiling additives use [4] or by special covering operations for the mobile components of the injection system as the inside surface of the pump cylinder and injector nozzle with fluorine-polymeric substances [3]. [5], [6], [7], [8]. These disadvantages are removed through the use of the diesel-gas method proposed by authors: the LPG is injected in gaseous phase in the front of the inlet valve and one small quantity of diesel fuel is injected into combustion chamber assuring the ignition of the air-LPG mixture and the flame propagates in this mixture.

The research works were performed at University POLITEHNICA from Bucharest [9]. The fuelling system has two separate circuits: one corresponding to diesel fuel and the second to LPG. The LPG is injected in gaseous phase in the front of the inlet valve and one small quantity of diesel fuel is injected into combustion chamber assuring the ignition of the air-LPG mixture. The injection of LPG in the front of the inlet valve provides a precise LPG dose control, all the injectors being electronic actuated. The engine keeps up its classic diesel fuelling system which is adjusted for dual fuelling. The electronic control unit for the LPG injection system (EU-LPG) is attached by the engine Electronic Control Unit (ECU) and the engine electronic control is provided by the communication between these two electronic control units. This fuelling method is very easy to imply to the existing engines or to the new engines without major constructive modifications.

The objective of the present paper is to find the optimum substitute ratio of the diesel fuel with LPG at engine full load and different speeds which assures the best small emissions level and a high efficiency. The paper presents some experimental results obtained by authors from a research program developed for an automotive diesel engine with 1500 cm^3 displacement fuelled by diesel-gas method. Are shown the influences of LPG dose on energetically and polluting engine performance.

2. Experimental investigations and results

The experimental researches were carried on an automotive diesel engine type K9K 790–1.5 dci equipped with a LPG injection system at different engine operating regimens and for different substitution percents of the diesel fuel with LPG. The experimental engine was mounted on a test bench (figure 1) equipped with the next necessary instruments for measuring operations: Schenck dynamometer type E90 equipped with controller and engine speed transducer, throttle position control unit and actuator that work in parallel with the dyno in order to operates the control lever of the injection pump, connecting drive shaft, real time AVL data acquisition system which also include an PC and an electronic modulus AVL Indimodul for processing and storage of measured data's, AVL in-cylinder pressure transducer line, cables, charge amplifier, AVL gas analyzer for five regulate gases and equipped with opacimeter for diesel engines, OPTIMAS mass flow meter for diesel and LPG, engine inlet air flow meter, thermo resistances for dynamometer supply water temperature, for engine cooling liquid temperature, engine oil and air intake temperatures and thermocouples for exhaust gas temperature, manometer for air pressure from engine intake manifold, LPG gas detector for test bad cell. All instrumentation was calibrated prior to engine testing. Experimental research's carried out to obtain fuel consumption characteristics for different speeds and engine full load and to determinate the energetically and pollutant engine performance. Based on fuel consumption characteristics were obtained some graphic representations for different parameters such as: brake specific fuel consumption (BSFC), pollutants emissions level (CO_2, HC, NO_x, smoke), engine in-cylinder maximum pressure and maximum pressure rate during combustion process all versus to LPG substitute ratio, x_c, for all operating regimes.

Also was obtained the engine speed characteristics at full load for diesel fuelling and for LPG –diesel fuelling. The engine power can be increased at the LPG fuelling but in order to not affect engine reliability and to improve engine running by maintaining or improving its efficiency and to decrease the emissions level, the authors choose to maintain the standard engine power value.

The fuelling system for LPG was design in an easy way to apply to the engine and use an injectors unit connected to engine intake manifold controlled by a second electronic control unit in order to establish the LPG cycle dose for every operating regime. There for the LPG electronic control unit works in parallel with the main ECU of the engine and is connected to a computer which allows the modification of the LPG injectors opening duration. This process is correlated with diesel fuel injectors command for the reduction of diesel quantity at the increase of LPG dose and maintain in this way the same air-fuel ratio value. The fuelling system include also an vaporizer mounted between injectors unit and LPG mass flow meter, in order to achieve the LPG vaporisation and to provide the intake manifold air-LPG mixture forming.

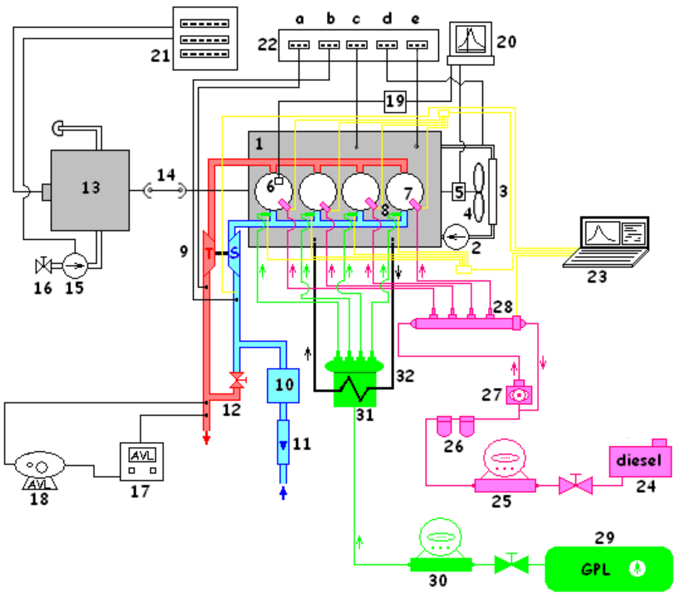

Fig.1 Test bench schema

1 – 1.5 dci diesel engine; 2 – cooling pump; 3 – water cooler; 4 – 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 –Schenck E 90 dyno cooling water valve; 17 –AVL Dicom 4000 gas analyser; 18 –AVL Dicom 4000 Opacimeter; 19 –AVL charge amplifier; 20 – PC + AVL hardware; 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 vaporizer cooling liquid circuit; 33 –angular encoder tap

Figures 2-6 present the variation of the NO_x, HC, smoke number and BSFC versus to LPG substitute ratio, x_c, at 100% load and 4000 rpm.

The diesel fuel with LPG substitute ratio x_c is defined as:

$$x_c = \frac{m_{LPG}}{m_{LPG} + m_{dieselfuel}} \cdot 100 \quad [\%]$$

The variations of NO_x relative level is shown in figure 2. The NO_x emission level continuously decreases with almost 20% at LPG substitution ratio increase for nominal regime, at x_c =40% (much lower comparative to the values registered for engine low speed regimes because of a higher engine thermal stress). For all investigated operating regimes at the x_c percent increase the reduction of the NO_x emission level was obvious.

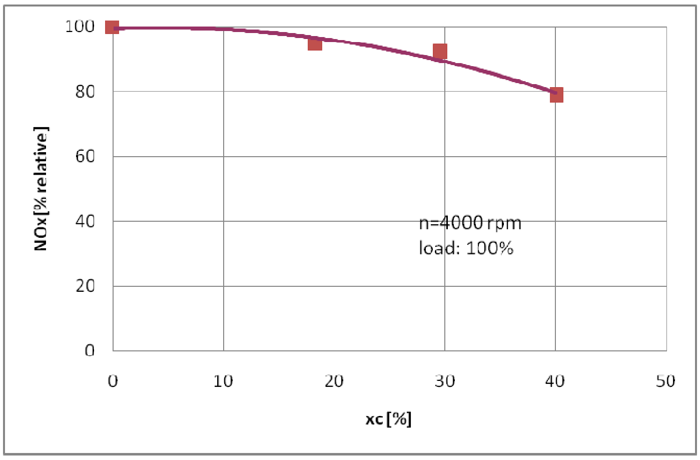

Figure 2. NO_x emission vs. substitute ratios x_c at 100% load and 4000 rpm

NO_x continuous reduction tendency is remarkable also for higher LPG substitute ratio values but the x_c value is limited in order to reduce the maximum pressure increase inside the engine cylinder (figure 5).

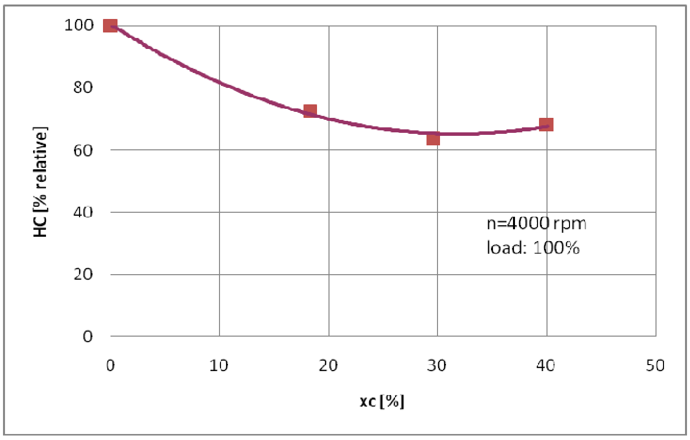

Figure 3. HC level vs. substitute ratios x_c at 100% load and 4000 rpm

Unburned hydrocarbons emission level HC decreases with ~30% for LPG substitution ratio increase according to engine operating regime at nominal regime (figure 3).

For all investigated regimes the HC emission level also decreases, the reduction was around 30%. These differences are explained by the influence of engine speed on combustion process, the burning time duration decreases at the increase of engine speed. Smoke emission decreases (GF smoke number) when LPG substitution ratio increases with 30% for nominal regime (figure 4). The smoke emission, evaluated by smoke number and opacity value, decreases with almost 30% at LPG fuelling (x_c =40% for 4000 rpm) comparative to reference values (figure 4). The lowest value is reached for x_c around 20%, but at the increase of substitute percent x_c over 20% at 4000 rpm the smoke emission slightly increase comparative to the previous x_c value, but the emission level is under the values registered for standard engine.

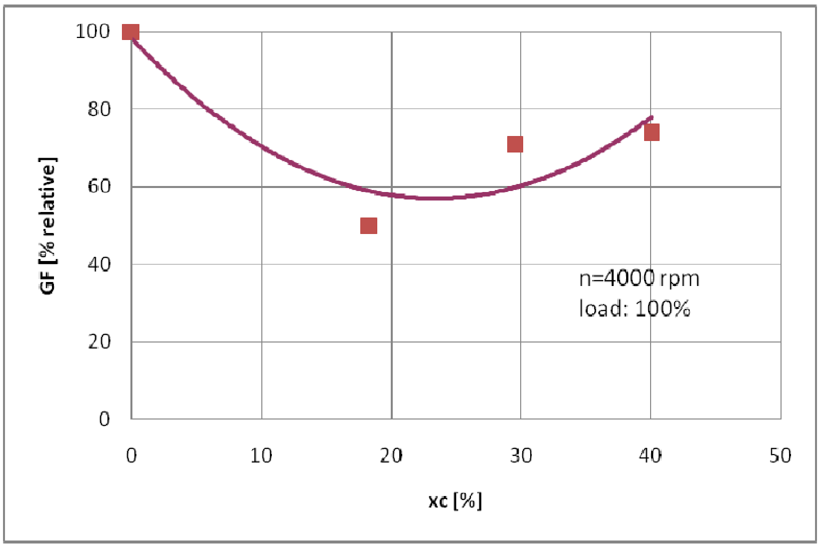

Figure 4. Smoke number vs. substitute ratios x_c at 100% load and 4000 rpm

For lower engine speed operating regimes the LPG substitute ratio was limited because the supercharge pressure is lower. This fact leads to the reductions of the inlet air quantity and mixture rich tendency which implies lower combustion efficiency and an increase of smoke emission. CO_2 and CO emissions levels are maintained at the same level comparative to standard engine.

The brake specific fuel consumption (BSFC) is maintained at the same level or slightly decreases for x_c= 40, comparative to standard engine assuring thus the possibility CO_2 emissions reduction. The increasing of the gases maximum pressure value inside the engine cylinder when the LPG substitution ratio also increases is showed in figure 5. From this reason the authors recommend the LPG substitution ratio limitation at 30-40%, in order to maintain

the engine reliability. Figure 6 shows the pressure diagrams registered for different substitute ratios x_c 18.3, 29.5 and 40 comparative to diesel at 100% load and 4000 rpm engine speed. The increase of LPG dose leads to a higher maximum pressure value (see also figure 5) and of the maximum pressure rate. A higher cycle maximum pressure value can be explained by the increase of the maximum heat release rate (figure 7) when the LPG cycle dose increases. Heat release diagrams can be also correlated with smoke number chart (figure 4) confirming the decrease of smoke at the increase of LPG substitute ratio.
The engine emissions level can decrease without engine performances decreasing, maintaining the engine energetically efficiency closer to diesel values, BSFC registering closer values to diesel fuelling for all substitute ratios (see figure 8).

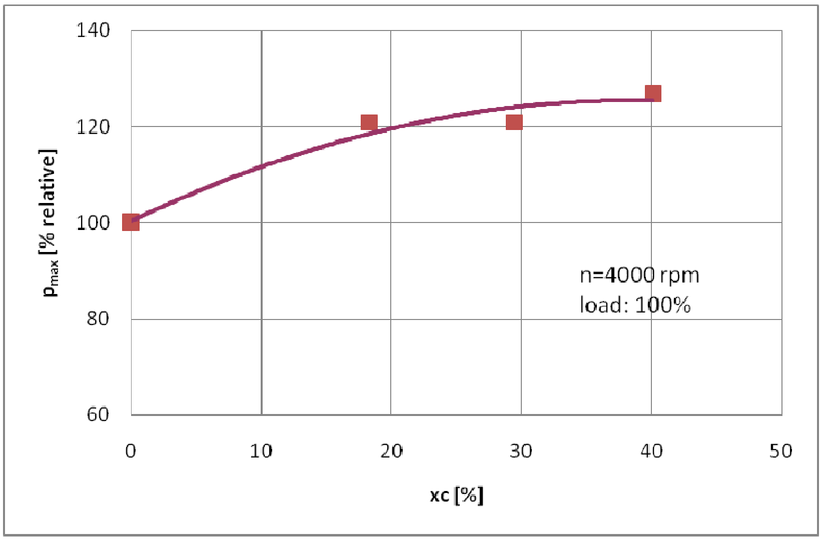

Figure 5. p_{max} vs. substitute ratios x_c at 100% load and 4000 rpm

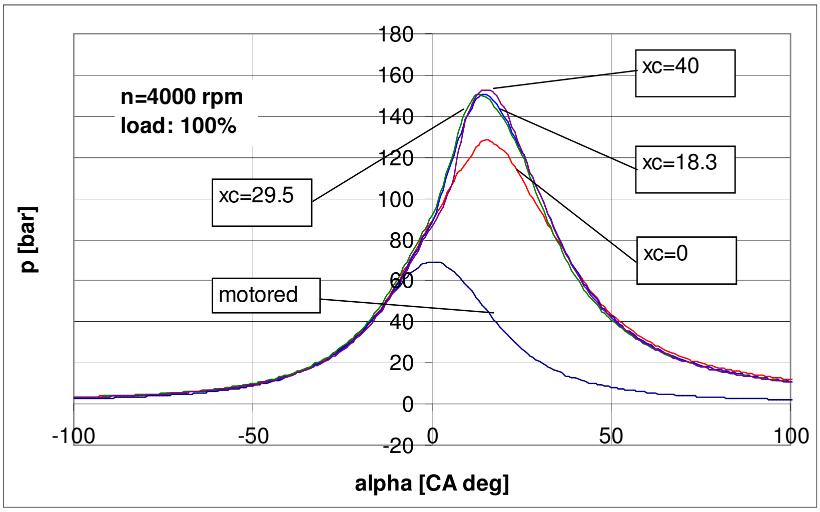

Figure 6. Cylinder pressure diagrams for different substitute ratios x_c at 100% load and 4000 rpm

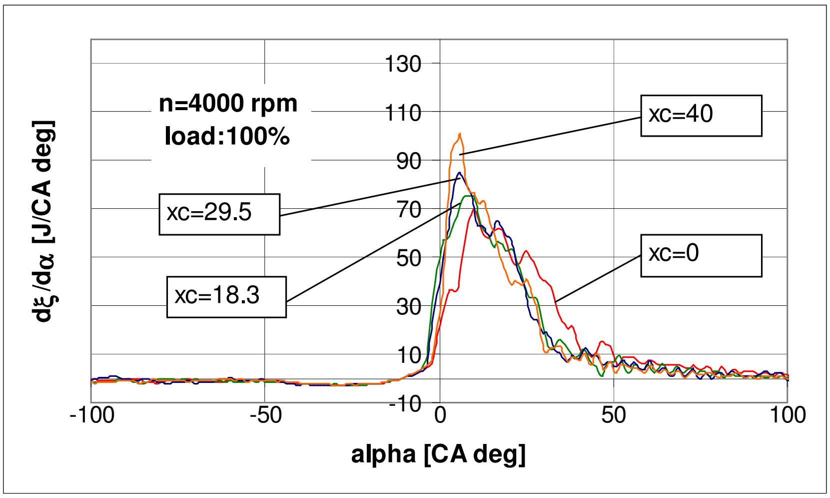

Figure 7. Heat release rate diagrams for different substitute ratios x_c at 100% load and 4000 rpm

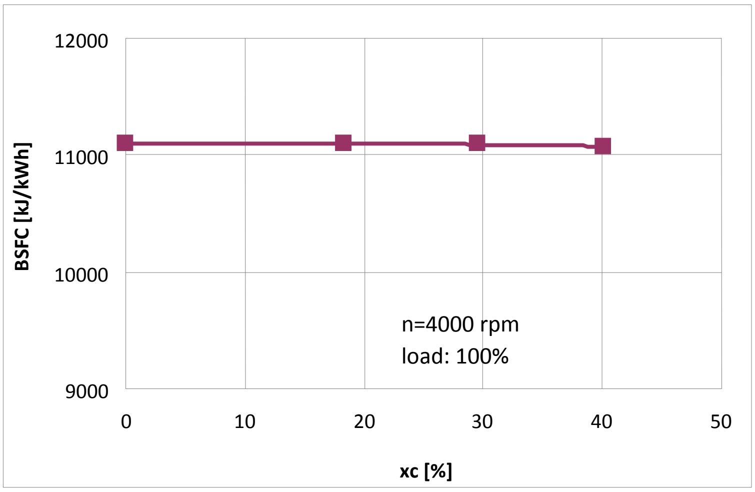

Figure 8. BSFC for different substitute ratios x_c at 100% load and 4000 rpm

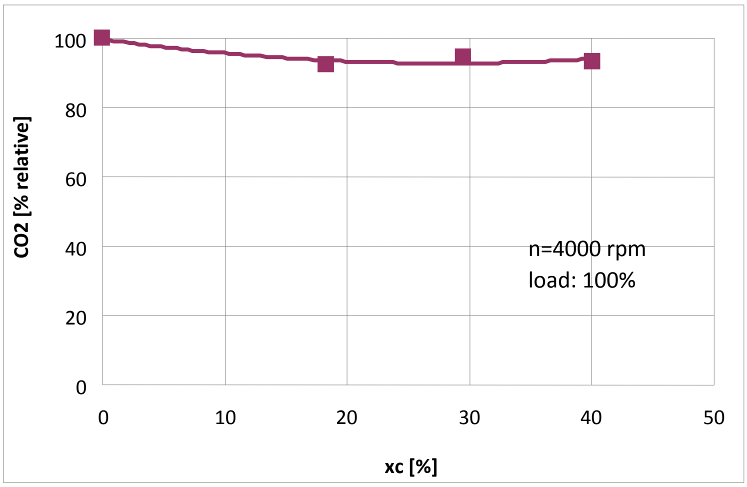

Figure 9. CO_2 for different substitute ratios x_c at 100% load and 4000 rpm

6. Conclusions

Following the experimental results analysis, next conclusions can be formulated:

- Increasing of the used LPG substitute ratio x_c, the air-fuel ratio λ is reduced to assure flame propagation in homogenous air-LPG mixture
- Significant decreasing of the HC and NO_x emissions level
- Significant decreasing of the smoke emission level

- CO_2 emissions level slightly decreases for the substitute ratio percent x_c= 18.3 and 40 and after this x_c its value will increases because air-fuel ratio is reduced
- The BSFC slightly decreases when the substitute ratio percent x_c increases to 40 and in rest maintains its values in a values range closer to diesel fuelling, keeping the engine efficiency
- The limitation of the maximum pressure rate imposes the used LPG substitute ratio x_c limitation. Also following the efficiency criteria and maximum gases pressure limitation criteria the LPG substitute ratio x_c= 20 - 30 is defined as optimal range values
- LPG is a viable alternative fuel for the diesel engine

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