EXPERIMENTAL ASPECTS OF THE USE OF LPG AT DIESEL ENGINE

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Utilizarea GPL la motoarul diesel reprezintă o soluție eficientă pentru reducerea emisiiilor poluante în condițiile menținerii economicii ridicate ce il caracterizează. Cercetări experimentale au fost efectuate pe un motor diesel cu cilindrarea de 1,5 l alimentat cu GPL la diferite procente de substituție a motorinei prin metoda diesel-gaz. Rezultatele investigațiilor experimentale au arătă o reducere accentuată a nivelului emisiiilor de fum și NOx la regimul de sarcină plină și o reducere ușoară a nivelului emisiiilor de CO2, HC și CO când procentul de substituție a motorinei cu GPL crește până la 40%.

The use of LPG in diesel engine represents an efficient solution to decrease of the pollutants emissions, maintain of the high efficiency that characterize it. Experimental researches were carried on an automotive diesel engine with 1.5 l displacement fuelled with LPG by diesel-gas method at different substitution percents of the diesel fuel. The experimental investigations results showed a significant decreasing of the smoke and NOx emissions level and a slightly decrease of CO2, HC and CO emissions level at the full load when the substitution percent of the diesel fuel with LPG increases till at 40%.

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].

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The LPG is an alternative fuel for diesel engine with real future opportunities due to the following aspects [2], [3]: the NO\textsubscript{x} emission level is lower; the PM emission is indistinguishable; CO\textsubscript{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 increase thermal efficiency which is directly related with CO\textsubscript{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\textsuperscript{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 (CO₂, HC, NOₓ, smoke), engine in-cylinder maximum pressure and maximum pressure rate during combustion process all versus to LPG substitute ratio, xₜ, 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.

Figs. 2-6 present the variation of the NOx, 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:

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

The variations of NOx relative level is shown in fig. 2. The NOx 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.

![Graph of NO$_x$ emission vs. substitute ratios $x_c$ at 100% load and 4000 rpm](image)

**Fig. 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 (fig. 5).

![Graph of HC level vs. substitute ratios $x_c$ at 100% load and 4000 rpm](image)

**Fig. 3.** HC level vs. substitute ratios $x_c$ at 100% load and 4000 rpm

Unburned hydrocarbons emission level HC decreases with $\sim 30\%$ for LPG substitution ratio increase according to engine operating regime at nominal regime (fig. 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 (fig. 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.

![Fig. 4. Smoke number vs. substitute ratios \( x_c \) at 100% load and 4000 rpm](image)

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 fig. 5. From this reason the authors recommend the LPG substitution ratio limitation at 30-40%, in order to maintain the engine...
reliability. Fig. 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 (fig. 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 fig. 8).
Fig. 7. Heat release rate diagrams for different substitute ratios $x_c$ at 100% load and 4000 rpm

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

Fig. 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 \( \lambda \) 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.
- \( \text{CO}_2 \) 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.

REFERENCES


