An experimental approach on fuelling a passenger car diesel engine with LPG

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Abstract. In the last years the interest on reducing harmful pollutant emissions of a passenger car engine has been greatly increased either because the number of cars increased or because the cities growth rate became very fast. The interest in improving driveability and the comfort of the passengers also increased. This can be achieved by reducing engine vibrations and improving smooth engine functioning. A viable solution for the diesel engine is fuelling with alternative fuels and in special with Liquefied Petroleum Gas. The advantage of LPG is that this fuel is an economical solution to protect the environment because its components are light hydrocarbons, without sulphur and with a number of carbon atoms less than the diesel fuel. The paper presents experimental investigations results of a car diesel engine fuelled with diesel fuel and liquefied petroleum gas. Also experimental investigations results on cyclic variability are presented. The engine used for investigations is a turbocharged 1.5 l diesel engine which and the investigated regimen was 2000 rpm and 70% engine load. The LPG fuelling led to a decrease in pollutant emissions level and to an increase in the smooth engine running, evaluated by the variability coefficient.

1. Introduction
Improved energetic performances of diesel engines and reduced level of pollutant emissions are important goals which need to be achieved across the world. The use of alternative fuels is one of the recommended solutions to reduce the level of pollutant emissions of a compression ignition engine. From all alternative fuels liquefied petroleum gas (LPG) is a clean and efficient fuel, its use being possible without major structural changes of the engine and also can be implemented easily on existing engines. Liquefied petroleum gas is usually a mixture of two hydrocarbons, propane and butane in different ratios, depending on season and manufacturing company. Generally it has a good price and this combined with its very good combustion properties make LPG a very efficient and sustainable solution to fuel a compression ignition engine. Some important properties of LPG are presented in table 1, compared with diesel fuel properties.

Liquid LPG density is lower than diesel fuel density, 503 kg/m³ for LPG and 800-840 kg/m³ for diesel fuel [1], therefore the mass of the same volume is lower and the vehicle autonomy on LPG is lower.
The LPG vaporisation heat is lower than that of diesel fuel, permitting LPG to vaporise faster and to consume a lower 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 [1], which underlines the bad self ignition properties. Therefore to fuel a diesel engine with LPG we have to use specific fuelling methods.

The flame temperature of LPG is lower than the diesel fuel flame temperature and this conduct to a reduction in the nitrogen oxides emission.

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

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

The Diesel-Gas method involves the injection of gaseous LPG in the intake manifold of the engine using a conventional LPG fuelling system. In the combustion chamber burns LPG ignited by the flames occurred in the pilot diesel fuel sprays. The diesel engine is equipped with two fuelling systems: one standard for diesel fuel injection and another fuelling system for LPG injection. The LPG quantity injected in the intake manifold is adjusted consistent with the load and limited by the knock (because of the higher compression ratio), and by the smoke emission, which at higher substitute ratios has a higher level. Also the engine can be affected at higher substitute ratios mainly because of the pressure increase.

Dual-fuelled compression ignition engines produce fewer pollutant emissions than conventional engines without major design changes. The emissions of smoke and soot are much lower in the case of Diesel-LPG compared to the standard diesel engine only [2]. Reducing the amount of air admitted in the engine, due to the presence of gaseous fuel slightly increases the emissions of HC and carbon monoxide [3]. In the paper [4] a 4 in-line cylinders diesel engine was fuelled with LPG with a 4% engine efficiency increase at full load. At partial loads the engine efficiency increased with the increasing substitute ratio of diesel fuel with LPG. By LPG fuelling the emission of nitrogen oxides increased with 38% at full load and decreased with 40-60% at partial loads [4]. Also, the smoke emission level decreased with 40 to 60% compared to diesel fuel [4]. Poonia, M. P. et al. in the paper [5] studied the effects of LPG fuelling on a single cylinder diesel engine. It was desired to investigate the influence of the EGR, intake temperature and intake air quantity at 20% and 40% engine load. The engine speed was kept constant at 1500 rpm and the air quantity was modified by using a throttle. At low engine load, in the case of a dual fuel engine, the mixture is very lean and the flame propagation is not complete due to the flame extinguishing phenomenon [5]. It results in large

### Table 1. LPG properties and diesel fuel properties [1].

| Properties                      | Diesel fuel | LPG          | Propane | Butane |
|---------------------------------|-------------|--------------|---------|--------|
| Density                         | [kg/m³]     | 800-840      | 503     | -      |
| Vaporization heat               | [kJ/kg]     | 465          | 420     | -      |
| Self ignition temperature       | [ºC]        | 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               | [ºC]        | 2054         | 1990    | -      |
| Lower heating value             | [MJ/m³]     | 36000        | 23000   | -      |
| Lower heating value             | [MJ/kg]     | 42.5         | 46.34   | 45.55  |
| Cetane number CC                | [-]         | 40-55        | -2      | -      |

The LPG properties and diesel fuel properties [1].
quantities of unburned hydrocarbons and reduced engine efficiency. Using the throttle the amount of permissible air per cycle is lower and the air excess ratio decreases, leading to improved engine efficiency. At high loads the throttle use worsens the performances of the engine due to the decrease in the cylinder filling efficiency. This led the authors to not use it for high engine loads. The fuel consumption decreased [5] and the amount of HC decreased by using the throttle at 20% engine load regimen plus 0% EGR, with a 50% throttle opening. The HC emission was reduced by 130 ppm using the throttle plus 18% EGR, compared with a level of 50 ppm obtained in the case of the throttle plus 0% EGR [5]. By LPG fuelling a car diesel engine is also possible to obtain a reduced smoke and nitrogen oxides emission levels due to the lower carbon content and the lower flame temperature, as shown in [6], [7] and [8]. Also in the same papers improved energetic specific fuel consumption is achieved.

2. Experimental study

The experimental study was carried out on a car compression ignition engine type K9K, with 4 in line cylinders. The specifications and performances of the engine are presented in the table 2.

| Table 2. Specifications and performances of the K9K engine. |
|----------------------------------------------------------|
| Number of cylinders | 4 |
| Bore | 76 mm |
| Stroke | 81 mm |
| Displacement | 1.5 l |
| Compression ratio | 18.3 |
| Rated power | 55 kW/3900 rpm |
| Maximum torque | 156 Nm/2000 rpm |
| Admission type | turbocharged |

The test bed consists of: K9K 792 1.5 dCi diesel engine, equipped with a LPG fuelling system. Laboratory equipments (figure 1) are: 1 – 1.5 dei 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 E90 dynamo 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 E90 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. The test bed diagram is presented in the figure 1.

First time was determined the reference, fuelling the engine only with diesel fuel, then the diesel fuel quantity has been reduced and the LPG quantity has been increased using the diesel-fuel/LPG controller (an external control unit mounted in parallel with engine ECU), aiming to maintain the same engine power like in the standard case of fuelling with diesel fuel. The LPG injection control is done using the external control unit which modifies the LPG injector injection time according to the value sent by the control software. Thus the values introduced in the control software are sent by the
The energetic substitute ratio was calculated with the following relation:

$$X_c = \frac{m_{\text{LPG}} H_{\text{LPG}}}{m_{\text{LPG}} H_{\text{LPG}}} + m_{\text{diesel fuel}} H_{\text{diesel fuel}}$$  \hspace{1cm} (1)

where:  
- $m_{\text{LPG}}$ - the LPG dose;  
- $m_{\text{diesel fuel}}$ - the diesel fuel dose;  
- $H_i$ - the caloric heating value.

The investigated energetic substitute ratios of the diesel fuel with LPG was situated between [0-52]%. The experimental investigations were carried out at 70% engine load and 2000 rpm.

3. Results

Experimental investigations were carried out also to determine the cyclic variability for the studied cases. The cyclic variability is a very important parameter which describes the engine running and for the purpose of this paper 300 individual engine cycles were processed in order to determine the indicate mean effective pressure variability coefficient. The indicate mean effective pressure coefficient of variability is evaluated by the following mathematical relation [9]:

$$COV_{\text{imep}} = \frac{\sqrt{\Sigma_{i=1}^{n}(\text{imep}_i - \overline{\text{imep}})^2}}{\overline{\text{imep}}} \times 100$$  \hspace{1cm} (2)

The experimental investigations and have led to the following results:
3.1. In cylinder maximum pressure
The in cylinder maximum pressure increased for all the investigated energetic substitute ratios of diesel fuel with LPG \(x_c\) because the burning process intensifies when the homogeneous mixture of air-LPG is present in the combustion chamber. The figure 2 presents the measured in cylinder maximum pressure for all the investigated cases.

![Figure 2. The maximum in cylinder pressure.](image)

3.2. The nitrogen oxides emission level
The nitrogen oxides emission level decreased for substitute ratios of diesel fuel with LPG between [5-45]% because liquefied petroleum gas has a lower combustion temperature than diesel fuel. For higher substitute ratios of diesel fuel with LPG the nitrogen oxides emission level increased due to the increase in temperature and due to the high degree of homogeneity of the air-LPG mixture. A solution to decrease the emission for this substitute ratios is to use exhaust gas recirculation. The nitrogen oxides emission level variation is presented in the figure 3.

![Figure 3. The nitrogen oxides emission level.](image)

3.3. The smoke emission level
The smoke emission level decreased for substitute ratios of diesel fuel with LPG between [5-25]% because when LPG is present in the combustion chamber the burning rate of diffusive mixtures decreases and the burning rate of preformed mixtures increases. For substitute ratios which are higher
than 25% the smoke emission level increases because the LPG is injected in high quantities in the intake manifold and replaces a large amount of admitted air. The figure 4 presents the smoke emission level, evaluated by the exhaust gases opacity. Even if the smoke emission level increases it still not exceeds the normative values imposed by the pollution rules.

![Figure 4. The smoke emission level.](image)

3.4. The brake specific energetic consumption
The brake specific energetic consumption decreases for all the investigated substitute ratios of diesel fuel with LPG. The figure 5 presents the brake specific energetic consumption variation.

![Figure 5. The brake specific energetic consumption variation.](image)

3.5. The cyclic variability
As far as the cyclic variability is concerned, evaluated by the indicate mean effective pressure variability coefficient, the LPG fuelling led to very good results, COV$_{\text{imep}}$ reduced compared with the standard case of fuelling with diesel fuel. The variability coefficient variation is presented in the figure 6.
4. Conclusions
At the LPG engine fuelling were observed the following:

- The brake specific energetic consumption decreased with ~20% when the substitute ratio was $x_c=10$.
- The nitrogen oxides emission decreased with ~26% for the substitute ratio $x_c=10$. For higher substitute ratios of diesel fuel with LPG the nitrogen oxides emission level increased due to the increase in temperature and due to the high degree of homogeneity of the air-LPG mixture. A solution to decrease the emission for this substitute ratios is to use exhaust gas recirculation
- The smoke emission level decreased for substitute ratios of diesel fuel with LPG between [5-25]% because when LPG is present in the combustion chamber the burning rate of diffusive mixtures decreases. For substitute ratios which are higher than 25% the smoke emission level increases because the LPG is injected in high quantities in the intake manifold and replaces a large amount of admitted air.
- The maximum in cylinder pressure increased in the case of LPG fuelling because the burning process intensifies when the homogeneous mixture of air-LPG is present in the combustion chamber.
- As far as cyclic variability is concerned, evaluated by the indicate mean effective pressure variability coefficient, the results was very good, the smooth engine running being increased.
- As far as the energetic and pollution performances are concerned, LPG is a viable solution to fuel a diesel engine.

5. References
[1] Popa M G, Negurescu N, Pană C 2003 Motoare Diesel, vol I, II (București: Matrix Rom)
[2] Liu Z, Karim G A 1997 An examination of the exhaust emissions of gas fuelled diesel engines Journal of American Society of Mechanical Engineers pp. 256-262
[3] Karim G A, Burn K S, 1980 The combustion of gaseous fuels in a dual fuel engine of the compression ignition type with particular reference to cold intake temperature conditions, in Proceeding of SAE Congress 800263
[4] Sudhir C V, Vijay H, Desai S, Kumar Y, Mohanan P 2003 Performance and emission studies on the injection timing and diesel replacement on a 4-S LPG-Diesel-fuel engine, SAE Transactions 2003-01-3087
[5] Poonia M P, Bhardwaj A, Jethoo A S, Pandel U 2011 Experimental Investigations on Engine
Performance and Exhaust Emissions in an LPG Diesel Dual Fuel Engine  *International Journal of Environmental Science and Development* 6

[6] Pana C, Negurescu N, Popa M G, Cernat Al 2010 Experimental aspects of the use of lpg at diesel engine, *U.P.B. Sci. Bull. Series D* 1

[7] Pana C, Negurescu N, Popa M G, Boboc G, Cernat Al 2005 Reduction of NOx, Smoke and BSFC in a Diesel Engine Fueled with LPG *MECCA Journal of Middle European Construction and Design of Cars, Praha, Czech Republic* 4 pp 37-43

[8] Pana C, Negurescu N, Popa M G, Cernat Al, Despa P, Bujgoi Fl 2008 Aspects of the LPG Use in Diesel Engine by Diesel-Gas Method, *FISITA World*

[9] Apostolescu N, Chiriac R 1998 The process of combustion in the internal combustion engines. Fuel economy. Reduction of pollutant emissions (Bucuresti: Editura Tehnica)

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