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Traffic and Environment (Ecology)
Preliminary Communication
Accepted: Mar. 4, 2011
Approved: July 5, 2012

IMPACT OF FUEL TYPE ON THE INTERNAL COMBUSTION ENGINE CONDITION

ABSTRACT

The paper studies the influence of liquefied petroleum gas as alternative fuel on the condition of the internal combustion engine. The traffic, energy, economic and ecological influence as well as the types of fuel are studied and analyzed in an unbiased manner, objectively, and in detail, and the obtained results are compared with the condition of the engine of a vehicle powered by the stipulated fuel, petrol Eurosuper 95. The study was carried out on two identical passenger cars with one being fitted with gas installation. The obtained results show that properly installed gas installations in vehicles and the usage of LPG have no significant influence on the driving performances, but they affect significantly the ecological and economic parameters of using passenger cars.

KEY WORDS

liquefied petroleum gas (LPG), propulsion of motor vehicles, alternative fuel

1. INTRODUCTION

This paper presents the results of an integral, systemic research studying all the aspects of the influence of liquefied petroleum gas as alternative fuel on the reliability, durability and efficiency of internal combustion engines. At the same time, also the economic and ecological aspects of implementing this energy source as fuel are studied. The research was carried out by independent, competent scientific and research institutions with the assistance of expert institutes and companies which guarantees the objective results.

The need for this research resulted from the fact that in objective technical and scientific literature it is very difficult to find concrete data and research results about the influence of liquefied petroleum gas as fuel (after a certain number of travelled kilometres) on the characteristics and the durability of the engine, and about the impact of using this energy source on the environment. The manufacturers of the equipment for the propulsion of LPG-driven vehicles as well as the journals indicate a number of advantages of gas as fuel for motor vehicles: lower fuel price, cleaner exhaust gases, better operation, as well as slower wear of the vehicle engine. One may also often hear arguments against gas as vehicle fuel: lubrication is much worse, excessively high combustion temperatures, danger of gas explosion and explosion of installations inside the engine, etc. The reasons of these conflicting arguments lie in the lack of knowledge of the concrete data, but also in the subjectivity of the researchers, i.e. the objective often being promotion or increase in the sales of certain products and equipment. At the same time, these diverse and conflicting pieces of information incur suspicions and indecisiveness in using LPG and hinder wider implementation of this energy source regardless of its price and availability.

Therefore, the goal of this research is to obtain objective results and to determine the energy, economic and ecological impact of liquefied petroleum gas on the condition and performances of the internal combustion engine.

1.1 Liquefied Petroleum Gas (LPG)

Liquefied petroleum gas (LPG, propane-butane) is gaseous fuel which consists mostly of the mixture of propane and butane i.e. its isomers. In atmospheric conditions the liquefied petroleum gas is in gaseous state, and it is liquefied at relatively low pressures: from 1.7 to 7.5 bar. During liquefication its volume decreases up to 270 times which makes its transportation much easier. It is very suitable for transport, storage and usage since it can be transported and stored in liquefied state, and used in gaseous state [1].

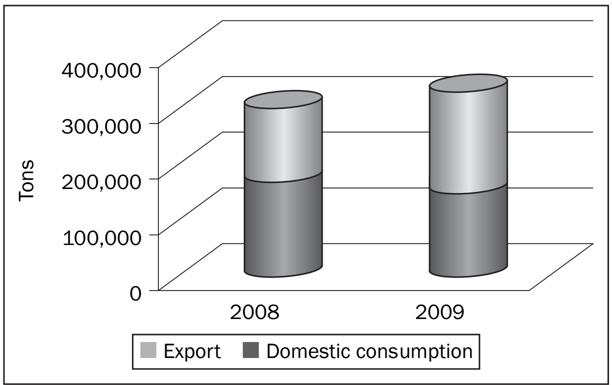

Figure 1 – Production o LPG in the Republic of Croatia

LPG is the only energy source which is produced in the Republic of Croatia in sufficient quantities for domestic requirements, and a large part is exported (*Figure 1*).

The diagram in *Figure 1* shows the growing trend of LPG production in our country, which is in agreement with the Croatian Energy Strategy and the strategy of energy source producers. However, the diagram shows also the fall in the consumption of liquefied petroleum gas in Croatia, whereas export is rising significantly. The structure of liquefied petroleum gas consumption for 2009 is presented in the diagram in *Figure 2* where it may be noted that most part of the liquefied petroleum gas consumption is accounted for by traffic, i.e. most LPG is spent for the propulsion of vehicles with internal combustion engines.

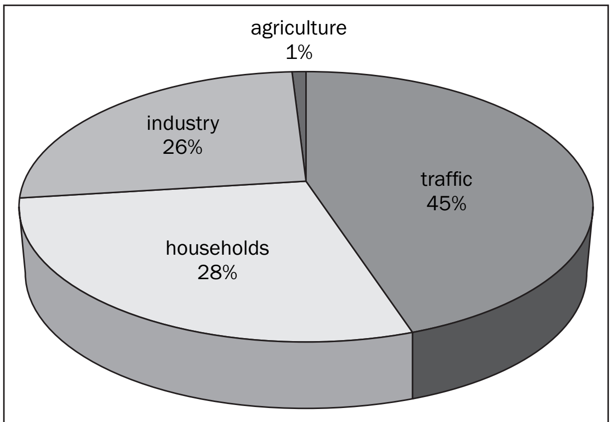

Figure 2 – Structure of LPG consumption in the Republic of Croatia for 2009

1.2 Liquefied petroleum gas for propulsion of motor vehicles

According to available statistics, in the world liquefied petroleum gas today is mostly used as fuel for internal combustion engines for the propulsion of vehicles, when it is usually called auto-gas. LPG started to be used for these purposes in the 1920s, and today it represents the most frequent alternative fuel for petrol and diesel. Currently in Europe LPG powers around 7,000,000 vehicles, which represents about 2% of the total number of vehicles in Europe. Regarding the properties that accompany combustion in petrol engines LPG is similar to petrol fuel.

Apart from economic factors the main promoter of vehicle modification to LPG propulsion is certainly the ecological factor. The comparison of exhaust emissions in LPG-powered vehicles and other fuels has been studied in several places, and a clear overview and concrete facts are presented in [2]. The basic conclusions of this study of several years carried out on a number of vehicles under various loads can be summarized as follows:

- LPG-powered vehicles have a significantly lower emission of NOx in comparison to Diesel vehicles (96%) and petrol vehicles (68%). Emission of particulates depends on the driving conditions but amounts to from 100 to 1,000 times less than in Diesel vehicles. The emission of other pollutants is similar or lower compared to Diesel vehicles, and especially in oxygen compounds (95% less of formaldehydes, 70% less of acetaldehydes) and benzene (similar to Diesel, but 80% less compared to petrol);
- CO_2 emission in LPG powered vehicles is much lower than in petrol vehicles and approaches the CO_2 emissions in Diesel vehicles. In certain situations on the motorway lower LPG emission has been recorded than in vehicles using Diesel.

The economic and ecological reasons of using LPG as fuel are often decisive in making decisions about vehicle modification and fitting of gas installations. Very rarely does one consider the impact of this alternative fuel on the characteristics and the service life of the engine and its parts. The conventional wisdom says that LPG, as alternative fuel, does not act harmfully but rather contributes to a longer service life of the engine and its better and quieter running. However, at the same time there are breakdowns and malfunctions on engines fitted with gas installations that had not been known before. There are no objective and unambiguous data about the durability and reliability of LPG-powered vehicles. In literature, different information can be found, depending on the sources: gas installation manufacturers mention mainly the advantages of LPG as fuel and their own equipment, vehicle manufacturers are sceptical towards this alternative fuel, and the users i.e. motorists have both positive and negative experiences with LPG installations [3].

2. RESEARCH PLAN

In order to obtain optimal and comparative research results regarding the impact of LPG on the engine condition, the study was concurrently carried out on two identical passenger cars with the petrol engines of the same type. For this purpose, two new cars were purchased, Volkswagen type Golf 1.6 with identical petrol engines of 75kW, that are common on our roads (*Figure 3*).

Figure 3 - Test vehicle

The engine of one of the cars (ZG-6652 DH) was modified and fitted with gas installations. The installation was carried out at the Auto Tim Ltd. Company, where a multi-purpose device was installed for LPG, manufactured by “Landi Renzo”. The vehicles were used in usual driving regimes, and the research lasted for more than two years, i.e. about 40,000 travelled km per vehicle, i.e. each vehicle travelled about 20,000km per year. During this time the vehicles were maintained according to the manufacturer’s instructions and all the important parameters were continuously monitored and the planned tests of engine and installation conditions carried out. These included laboratory and field tests on both test vehicles including: ferographic analysis, power measurements, moments measuring, measurement of emissions and composition of exhaust gases. At the end of the study, the engines of both vehicles were completely disassembled, dimensions were controlled and the conditions of functional surfaces analyzed.

3. TESTING

3.1 Ferographic analysis

Ferographic analysis is a method of determining the engine condition which is based on continuous sampling of motor oil from the vehicle during exploitation and analysis of particulates that are found in the samples. These particulates are pollutants and products of wear of the system through which the oil passes. All tests were performed on devices at the Institute for Materials, Faculty of Mechanical Engineering and Naval Architecture in Zagreb and the following methods were applied: ASTM D445, ASTM D2896, ASTM D893 and ICP-OES.

The research tested the wear intensity index (WPC) by means of ferographer with direct PMA 90S reading. This index represents the ratio of the small and big deposited particulates in oil. The index has been determined from the expression

$$WPC = DL + DS \ (\%)$$

where:

- WPC – wear intensity index;
- DL – percentage of area covered by large particulates;
- DS – percentage of area covered by small particulates.

During research the oil sample for ferographic analysis from both cars was taken every 2,500km. Five repeated analyses each were carried out from every sample of oil. The analyses measured the DL and DS values, and calculated the value of wear intensity index (*Figure 4*).

By comparing the obtained diagrams it may be noted that they are in agreement with the characteristic diagrams for internal combustion engines. Both diagrams feature intensive wear at the beginning of operation, the so-called running-in period marked by A in Figures 4a and b. Following the running-in period, stabilization of the wear intensity index is expected at a certain value which will remain constant during the entire duration of research. In tested vehicles the period of “normal” wear occurs after having travelled 25,000km and it is marked as B in Figures 4a and b.

According to literature and empirical data, the wear intensity index, in the field of normal wear represents a value which corresponds to the operation conditions and is representative for the vehicle engine condition. Therefore, if index values are compared for both vehicles in area B, it may be concluded that the wear intensity index for the petrol engine (1.00%) is significantly higher compared to the wear intensity index of the vehicle engine powered by liquefied petroleum gas (0.60%). In both vehicles an intensive increase in wear has been noted after the travelled 20,000km (arrow in diagrams in Figures 4a and b). Since a peak appears

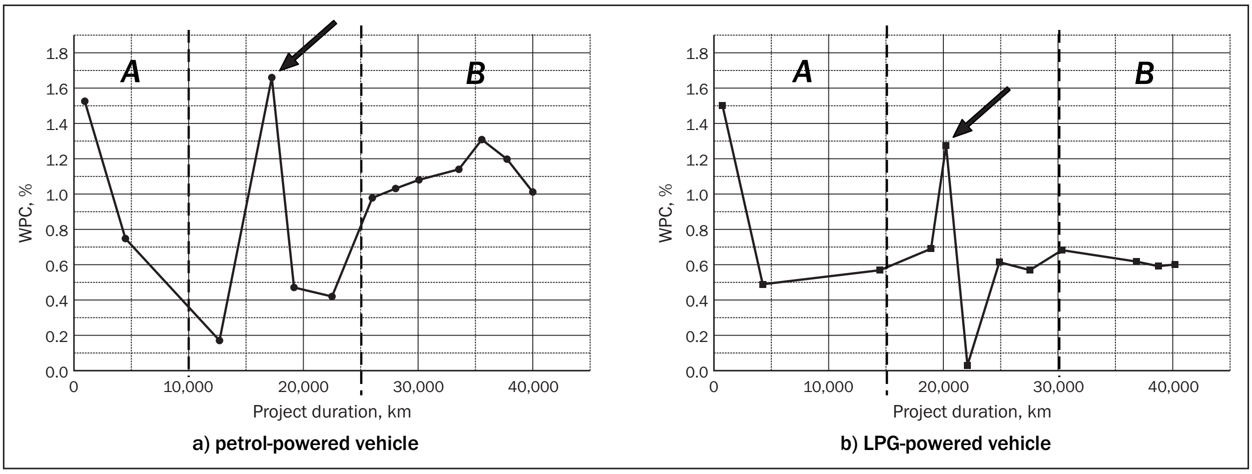

Figure 4 - Diagram of wear intensity (WPC)

in both diagrams after an approximate number of travelled kilometres, it may be assumed that this refers to a systemic occurrence of wear of a certain mechanical part (e.g. sag of surface coatings or similar layers) which does not need to be taken into consideration during the testing.

3.2 Measuring engine power and torque

Continuous testing and measuring of engine power and moment on the tested vehicles were carried out at the Croatian Centre for Vehicles. The testing was carried out on rollers intended for this purpose located at the Institute for Vehicles in Velika Gorica and have resulted in the power and moment diagrams depending on the number of revolutions [4].

Testing was carried out on every test vehicle four times each. The last measurement was done at the end of the project, i.e. two years after having started the testing, that is, after 40,000 of travelled kilometres. *Figure 5* shows the power and moment diagrams for petrol-powered vehicle at the beginning of testing (5a) and after travelled 37,090km (5b).

As expected, the analysis of diagrams in *Figure 5* does not show any significant differences in power and the torque of the petrol vehicle at the beginning of testing and after the test period. The gas-powered vehicle was tested while using both types of fuel, i.e. when powered by gas and when powered by petrol. This allows comparison depending on the type of fuel of the test vehicle, as well as the comparison with the other petrol car. *Figure 6* shows the diagrams of power and moment for the test vehicle with gas installation powered by LPG (6a) and powered by petrol (6b) at the beginning of testing.

Figure 7 presents the diagrams of power and moment for the test vehicle with gas installations powered by LPG (7a) and powered by petrol (7b) at the end of testing (40,464km).

The comparison of results of studying the moment and power of a vehicle with gas installations at the beginning of the test period leads to the conclusion that gas installations are very well designed and that there is no significant difference in the trend and the values depending on the fuel. This conclusion is in agreement with the declarations that go with gas

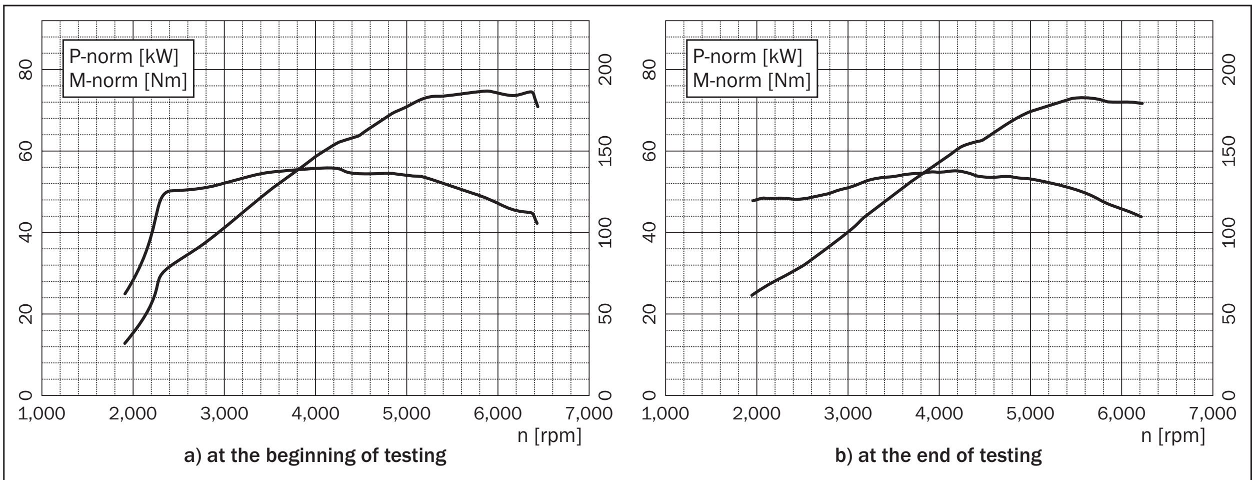

Figure 5 – Moment and power diagram of petrol-powered vehicle

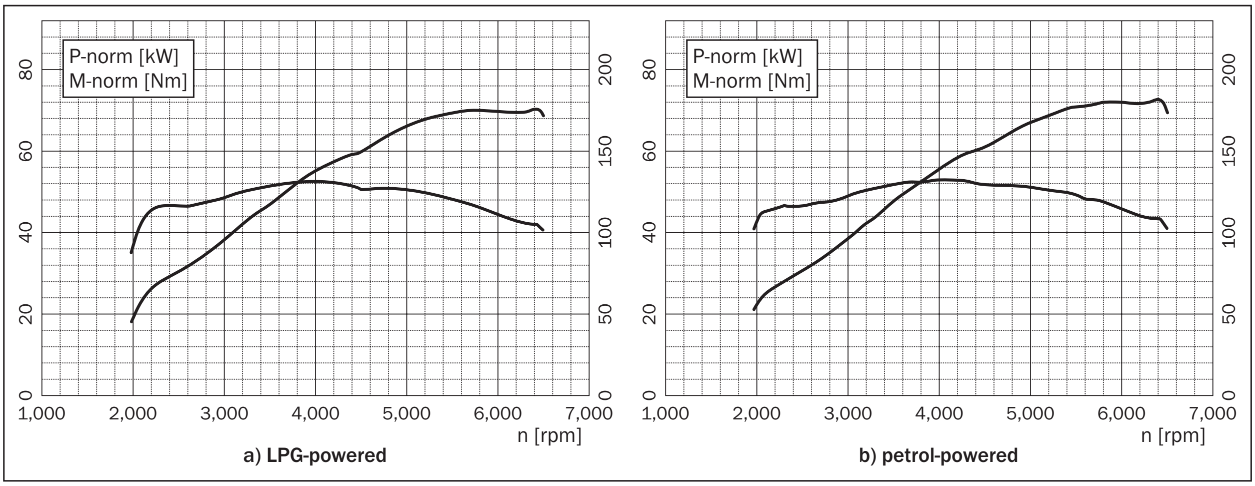

Figure 6 - Diagram of moment and power of vehicle with gas installations at the beginning of testing

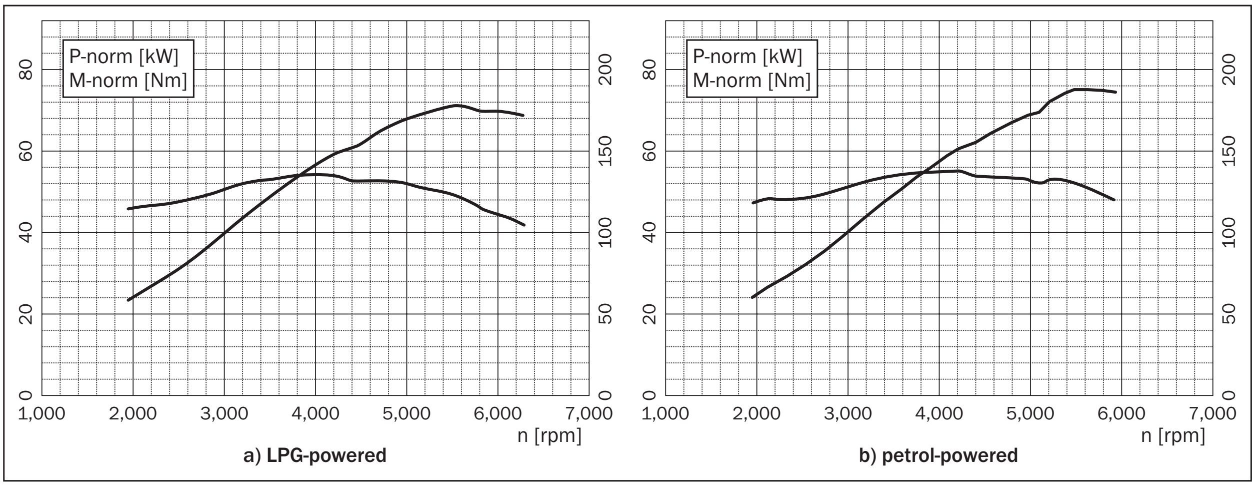

Figure 7 - Diagram of moment and power of vehicle with gas installations at the end of testing (40,464km)

installations and claim that in case of installations with injectors there is no significant deviation in the vehicle characteristics. The same situation can be observed by the analysis of the diagrams obtained at the end of the test period, where there are no significant differences either.

Comparing all the obtained diagrams no significant differences can be found in the measured moments and measured power on both test vehicles regardless of the type of fuel.

3.3 Exhaust gas analysis

At the Institute for Vehicles of the Croatian Centre for Vehicles the vehicle exhaust gases were analyzed. The analyses were performed by means of conventional test instrument which is used during the technical inspection of motor vehicles. All the measured values comply with the current laws, and in gas-powered vehicles lower CO_2 emissions have been observed.

3.4 Disassembling the vehicle engine and measuring dimensions and shapes

After the end of the test period of two years, the vehicles were driven to the Porsche Inter-auto Ltd. where the engines of both vehicles were disassembled, visually analyzed and the condition of parts was compared, important dimensions were measured and data collected about the engine condition from the on-board computers. This disassembling was preceded by all the analyses and testing which had been planned by the testing schedule.

The travelled kilometres of the vehicles on the day of testing amounted to:

- petrol-powered vehicle – 37,100km
- vehicle powered by petrol + LPG – 40,500km

The engines were disassembled at the workshop of the company and all the engine parts were disassembled which were affected by the gas-powered driving. This refers first of all to pistons, valve assembly (valves, valve seats, valve gaskets) and the exhaust

a) vehicle powered by petrol   b) vehicle powered by petrol + LPG

Figure 8 - Disassembled engine

system. Visual inspection was performed and the parts from the gas-vehicle and petrol-vehicle were compared (*Figure 8*).

Visual inspection of all the vital engine parts of test vehicles performed by experts with many years of experience in working with this type of vehicles has not shown any traces of uncommon or increased wear of the parts of either of the disassembled and analyzed engines. Special attention was directed to the comparison of the condition of engine parts of both vehicles: even in this comparison under larger magnification (macro-analysis using magnifiers and stereo-microscope) no significant differences were found in their condition and form, which might have been the consequence of using the alternative fuel. Therefore, a detailed and precise measurement of dimensions of all the important engine parts was carried out, and the results are presented in Tables 1 and 2.

Table 1 – Dimensions of petrol engine parts

VW Golf 5 ZG – 6651 DH (petrol)				
Piston	1	2	3	4
Diameter [mm]	80.95	80.95	80.95	80.95
Cylinder ovalness	0.005	0.01	0.003	0.015
Crankshaft	41.963 – 41.965			
Cylinders [Φ]	STD 81.01			
Travelled km	37,100			

Table 2 – Dimensions of parts of the engine with gas installations

VW Golf 5 ZG – 6652 DH (petrol + LPG)				
Piston	1	2	3	4
Diameter [mm]	80.95	80.94	80.95	80.95
Cylinder ovalness	0.03	0.02	0.01	0.04
Crankshaft	41.962 – 41.965			
Cylinders [Φ]	STD 81.01			
Travelled km	40,500 in ratio 25% petrol : 75% LPG			

In consultations with experts who have been doing such measurements every day for many years, it was found that the existing differences are not significant and that they are most probably consequence of the factory conditions of manufacturing the parts, and not a consequence of applying the alternative fuel.

4. ECONOMIC ANALYSIS OF USING LIQUEFIED PETROLEUM GAS

For the purpose of economic analysis of using LPG, a parallel register of the fluctuation of retail prices for petrol and autogas was kept, and the average prices were calculated for the period of testing. The average price for petrol amounted to 8.20kn per litre, whereas the price of liquefied petroleum gas during testing did not change and amounted to 3.35kn/l. The average consumption of the test vehicle while powered by petrol amounted to 8 l/100 km whereas autogas consumption was larger and the increase varied from 7% to 20%, depending on the driving regimes. For the sake of simplification, the budget of the liquefied petroleum gas consumption was calculated with average consumption of 9 l/100 km. The fuel cost calculation during the test period is presented in *Table 3*.

Apart from the difference in the price of fuel, the using of the liquefied petroleum gas as fuel brings also additional costs: gas installations and its installation, servicing of gas installations and Tax for using public roads for LPG as fuel when registering the vehicle (*Table 4*).

The analysis did not take into consideration the costs of regular servicing of the engine and the spare parts since their price is the same for both test vehicles. The overall cost of using test vehicles over a

Table 3 – Fuel cost calculation during testing

	Vehicle		
	Petrol	with gas installations	
		petrol	LPG
Travelled path [km]	40,000	10,000	30,000
Average consumption [kn]	8 l/100km	8 l/100km	9 l/100km
Total consumption [l]	3,200	800	2,700
Average fuel price [kn]	8.20	8.20	3.35
Price of consumed fuel [kn]	26,240.00	6,560.00	9,045.00
Price of fuel during testing [kn]	26,240.00	15,605.00	

Table 4 – Costs of using LPG

Type of cost	Amount
Gas installations and fitting [kn]	12,000.00
Servicing of gas installations [kn]	500.00 × 2 = 1,000.00
Public road tax [kn]	550.00 × 2 = 1,100.00
Total [kn]:	14,100.00

Table 5 – Overall cost of using vehicles during 40,000km

	Petrol	Petrol + LPG
Fuel cost [kn]	26,240.00	15,605.00
Additional costs [kn]		14,100.00
Total [kn]:	26,240.00	29,705.00

period of two years, i.e. travelled 40,000 km are presented in *Table 5*.

The calculations presented in Tables 3, 4 and 5 show that the initial investments into gas installations on-board vehicles already at the beginning significantly increase the vehicle price. The price of using the vehicle with gas installations is additionally burdened by the costs of servicing the gas installations and by the duties charged during the technical inspection of vehicles. The mentioned costs are offset over time by the significantly lower price of autogas and, after a certain number of travelled kilometres there is return on the investment. Further usage of the vehicle results in savings proportional to the travelled path.

The diagram in *Figure 9* shows the flow of costs of the usage of test vehicles up to 40,000km and the projection of costs caused by continued usage of vehicles. A trend of costs regarding the usage of vehicles without gas installations (petrol) and with installed gas installations (petrol and LPG) can be seen. The diagram was developed according to the driving regimes and fuel prices that were valid during the test period. The diagram shows that the investment into gas installations would be completely paid back after 60,000 travelled kilometres, i.e. after three years. The main factor of the line inclination i.e. determining the profitability point of fitting the gas installations is certainly the fuel price.

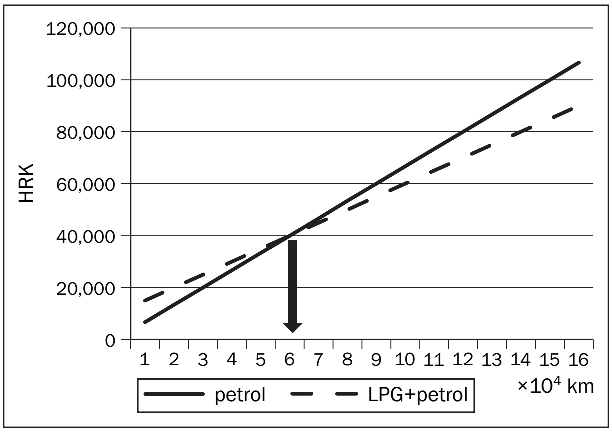

Figure 9 - Costs of using vehicle during testing

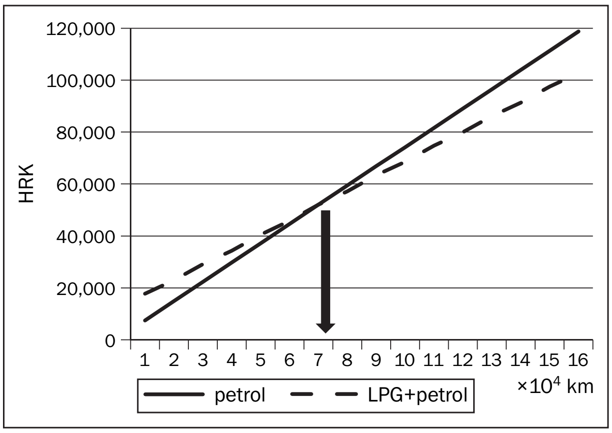

Figure 10 – Costs of using vehicle based on fuel prices in February 2011

Therefore, the diagram of the cost flow of using the vehicle powered by petrol and by liquefied petroleum gas was developed, according to the prices valid as of 10 February, 2011 (*Figure 10*). The diagram shows that investments into gas installations are completely paid back after 70,000km through the fuel price Eurosuper BS 95 of 9.28 kn/l (INA) and autogas price of 4.92 kn/l (PROPLIN).

5. CONCLUSION

Based on the obtained results and their analysis it is possible to conclude the following:

- testing was carried out according to the plan and protocol;
- the complex tests of engine conditions and its parts as well as operating parameters during 40,000km, that the vehicles travelled during the test period, have not shown any significant differences caused by the use of liquefied petroleum gas as alternative fuel. The results of ferographic analyses have shown that the autogas-powered vehicles have on the average lower values of wear intensity index WPC and minor deviations from the average compared to the wear intensity index of vehicles powered only by petrol. Such relation of surface condition and the shape of parts was confirmed also at the final inspection, where both engines were completely disassembled and no significant differences were noted. Precise measurements of the dimensions of important engine parts did not result in any differences in dimensions that would have been consequences of using the alternative fuel. The test results of the working parameters of both test vehicles have shown unchanged engine power and moment values during the testing, regardless of the vehicle and used fuel. Neither did the analysis of data from vehicle on-board computers show any differences caused by the use of liquefied petroleum gas as fuel;
- the results of exhaust gas analysis show significantly lower CO_2 emissions when using liquefied petroleum gas as fuel compared to petrol. All other emissions and measured values comply with the existing laws. Using literature data that additionally indicate significantly lower NO_X emissions, and especially solid particulates such as e.g. soot, liquefied petroleum gas represents an ecologically more favourable alternative to the usage of petrol and diesel for motor vehicle powering;
- the analysis of costs regarding usage of test vehicles has shown that vehicles with gas installations have been much burdened by additional costs. These include fixed costs of fitting gas installations, their servicing, additional costs regarding vehicle registration and costs of increased fuel consumption. The variable cost is the price of liquefied petroleum gas which has been changing from the beginning of testing (40% of the price of a litre of petrol Eurosuper BS95) until February 2011 (53% of the price of petrol Eurosuper BS95). The carried out analyses show that even in case of a higher auto-gas price the driving is 19% cheaper compared to driving using the mostly used petrol Eurosuper BS95. The time of return on investments in gas installations depends significantly precisely on these additional costs, and especially in relation to the price of petrol and autogas. During the test period, when the fuel prices were lower, the investment into gas installation was paid back after having travelled 60,000km. With the fuel price increase to values actual in January 2011 the profitability of gas installations shifted to 70,000km.

The liquefied petroleum gas has proven to be alternative fuel for which in this study no negative impact on the technical condition and driving performance of the test vehicles has been found. At the same time, the usage of this energy source significantly reduces the harmful exhaust emissions thus favourably influencing the environment. Taking into consideration the fact that liquefied petroleum gas is an energy source which is produced in large quantities in the Republic of Croatia and whose production is greater than consumption, the research has additionally indicated the need for various forms of giving incentives to vehicle owners for the fitting of gas installations.

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SAŽETAK

UTJECAJ VRSTE GORIVA NA STANJE MOTORA S UNUTRAŠNJIM IZGARANJEM

U radu je ispitan utjecaj ukapljenog naftnog plina kao alternativnog goriva na stanje motora s unutrašnjim izgaranjem. Nepristrano, objektivno i detaljno se ispituje i analizira prometni, energetski, ekonomski i ekološki utjecaj te vrste goriva, a dobiveni rezultati se uspoređuju sa stanjem motora vozila pogonjenog propisanim gorivom, benzinom Eurosuper 95. Ispitivanje je provedeno na dva istovrsna osobna automobila od kojih je u jedan ugrađena plinska instalacija. Dobiveni rezultati pokazuju da ispravno ugrađene plinske instalacije u vozila i korištenje LPG-a nema znatnog utjecaja na vozne performanse, a značajno utječe na ekološke i ekonomske parametre korištenja osobnih vozila.

KLJUČNE RIJEČI

ukapljeni naftni plin (UNP), pogon motornih vozila, alternativno gorivo

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