JOURNAL OF MECHANICAL AND TRANSPORT ENGINEERING
Vol. 70, no. 3 2018
DOI 10.21008/j.2449-920X.2018.70.3.01

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(Received 06 Jul 2018, Received in revised form 22 Nov 2018, Accepted 11 Mar 2019)

CONSTRUCTION CHANGES FOR VEHICLE ENGINES POWERED WITH LPG MADE TO EXTEND THE ENGINE LIFESPAN BASED ON 1.4 GASOLINE ENGINE

The article investigates the factory-made adjustments in the 1.4 liter gasoline engine construction used in an Opel Mokka as basis to determine the most common changes and adjustments made by vehicle manufacturers when producing vehicles that are to be powered with LPG. Comparisons are drawn to multiple other Opel vehicles, such as Adam, Astra, Meriva, and Insignia, all of which do have a factory-made LPG system installation. Other vehicle manufactures also offer new vehicles with a factory-installed LPG supply system. Among the considered vehicles are Hyundai i20, Dacia Sandero, and Skoda Fabia, as direct comparisons of the engine solutions applied to models designated for the addition of an LPG installation.

Keywords: LPG, engine, lifespan, alternative fuels

1. INTRODUCTION

Due to the significantly improved fuel economy of vehicles powered with LPG fuel their popularity has been steadily increasing, especially in Poland, which has the 2nd highest number of LPG-powered vehicles in Europe [Chłopek and Waśkiewicz, 2013]. The number of such vehicles implies that changes in engine construction that could improve the engine reliability, power, ecology, fuel economy, or other operating parameters [Mustaffa et. al., 2016], are sought after by most of the competing car manufacturers, leading to an increase in LPG and CNG-specific research and development [Okeke and Lebele-Alwa, 2013]. Most of the

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results of this research, however, is not shared by manufacturers due to the competitive nature of the vehicle market.

The vehicle market has always been dominated by two fuel types: gasoline and diesel oil. The popularity of compression ignition (CI) and spark ignition (SI) engines varies between countries. Share of diesel cars range from 50-70% for Italy, Portugal and Ireland, to just 10-29% for Norway and the Netherlands. More recently hybrid and electric vehicles have begun to grow in popularity, largely thanks to the significant subsidies provided by the governments to incentivize private car owners to switch to electric. This has been the effect of an EU-wide trend of promoting electromobility affecting the market for several years now, but the charging infrastructure is still lacking in scope and capacity in most countries. Vehicles powered by alternative fuels have managed to carve out their own market share in a number of European countries. Among the countries with the largest numbers of vehicles adjusted for LPG use are: Turkey (2 394 000 vehicles), Poland (2 325 000 vehicles), and South Korea (2 300 000 vehicles) as seen in Fig. 1. There are just a handful of countries for whom LPG became a reasonably common fuel, to the point where fueling stations commonly offer this fuel for sale.

Table 1. List of countries with the highest LPG fuel consumption
[based on data from WLPGA, 2011]

Country	Consumption (thousand tons)	Vehicles (thousands)	Refueling sites
Korea	4 450	2 300	1 611
Turkey	2 490	2 394	8 700
Russia	2 300	1 282	2 000
Poland	1 660	2 325	5 900
Italy	1 227	1 700	2 773
Japan	1 202	288	1 900
Australia	1 147	655	3 200
World	22 866	17 473	57 150

Passenger cars can be equipped with LPG systems in two ways. First is the factory-made LPG system, where the additional devices, such as the LPG fuel tank, gas distributor, gasoline-LPG switch and the fuel supply control system are installed as a part of the vehicle production process. Examples of vehicles with factory made LPG systems include: Chevrolet Spark, Dacia Sandero, Hyundai i20, Skoda Fabia, Fiat Bravo or Mitsubishi Colt. But most gasoline powered vehicles can be equipped and re-fitted with the systems and devices allowing for a dual gasoline-LPG fuel supply [Mustaffa et. al., 2016]. There are many authorized workshops in Europe that can add an LPG system to a vehicle, but the systems used have to be from a legal and certified manufacturer. Among the best known manufacturers of LPG installations for vehicles are: BRC, PRINS and STAG.

2. LPG SYSTEM GENERATIONS

2.1. Generation I

There are currently 5 generations of LPG systems for gasoline cars. Generation I systems were used in vehicles equipped with a carburetor. These were very simple systems with no electronics that relied entirely on mechanical devices for fuel supply. They relied on variable pressure in the intake manifold. The LPG fuel was released in liquid form through a multivalve and sent to the reducer-evaporator, after which it was further fed to the engine. This required the reducer-evaporator to obtain its operating temperature in order to enable it to vaporize fuel to be used in the engine, which required the engine to first reach the appropriate temperature by operating on gasoline fuel. Once vaporized the natural gas is sent to the mixer, where an air-fuel mixture is created, before being sent into the intake manifold.

2.2. Generation II

Generation II systems can be used for both single- and multi-point injection engines equipped with a lambda sensor. This type of a system also relies on variable intake manifold pressure. This generation uses an electronic control module to manage the composition of the air-fuel mixture. It's a system that can make the air-fuel mixture richer or leaner based on feedback from the lambda sensor, throttle position sensor, and the engine speed sensor. The main downside of this LPG system generation is that it relies on the gasoline injection emulator to cheat the vehicle into thinking that the injectors are still operating, while LPG operation continues to mix air and fuel in the intake manifold. This can lead to flame jumping from the combustion chamber into the intake manifold, which for manifolds made out of synthetic materials can lead to extensive damage.

2.3. Generation III

Generation III is a rarely used system that does away with the mixer, replacing it with a special dose controller. This system's main limitation is that the fuel dose sent to each cylinder is the same in each cycle.

2.4. Generation IV

Generation IV systems, also known as sequential systems, use as many LPG injectors as cylinders, which are mounted in the intake manifold. The opening and closing of injectors as well as injector timing are determined for each cylinder separately, same as for gasoline supply. The LPG dosage is controlled by the engine control unit, which eliminates the need to use emulators. Such systems are more complex, however, leading to more difficulty in their installation and settings adjustment. The efficient operation of the LPG system also requires high fuel purity, resulting in a gaseous phase filter being used.

2.5. Generation V

Generation V is the newest type of an LPG system, which injects LPG fuel in liquid phase into the intake manifold, or directly into the cylinder through the gasoline injectors. Same as for generation IV the gas injection control is performed by the engine control unit. The need to use a regulator-evaporator has been eliminated, leading to a simpler fuel supply system without needing to interfere in the vehicle cooling system. The main downside of such a solution is that the liquid gas pump is located directly next to the fuel tank, with the filter being further along. This led to an increased wear of the fuel pump. This pump can also be affected by poor quality LPG fuel, containing too much water, which leads to the lubricating oil being pumped out, also resulting in increased wear, as well as a drop in the fuel supply system pressure.

3. TECHNICAL SOLUTIONS USED IN THE LPG SYSTEM FROM OPEL

The LPG system used in Opel Mokka supplies fuel for the 140 KM 1.4 gasoline engine. This vehicle has a fuel economy of 7.7 dm^3 of LPG per 100 km, and meets the Euro 6 emissions standard. The characteristic solutions used in the investigated vehicle included the use of hardened valves and valve seats, along with a more heat resistant engine head. As a result of these changes the engine is characterized by increased durability. The wear of valves and valve seats has been researched in the context of CNG and LPG fueled engines [Londhe and Kshirsagar, 2014, Borawski 2015]. These problems have been recognized for a long time, as comparable solution has already been patented by Nissan over a decade ago, including a valve protecting apparatus [Tanaka and Nakatani, 2003].

Due to the different combustion characteristics the engine head, valves and valve seats tend to be subject to excessive heat wear resulting in valve seat recession in LPG and CNG systems. This is why manufacturers advise the use of satellite welded valve seats for valves fitted on LPG, CNG and biogas powered engines. Heat dissipation is an issue in such systems due to a different properties of fuel, including vaporization energy. These problems could be solved by a control system to manage the fuel temperature before injection [Ceviz et al. 2015]. On the other hand lower calorific value of LPG fuel means that most dual fuel engines must use gasoline for cold engine start. A solution to that problem was proposed by Ugurlu et al. [Ugurlu and Gumus, 2017]. Pictures of the engine installation for Opel Mokka have been shown in Figures 1-3.

Fig. 1. Picture of the engine under the hood in Opel Mokka

Fig. 2. The injectors placement in Opel Mokka

Fig. 3. The fuel delivery system in Opel Mokka

4. CONCLUSIONS

CNG and LPG are the cheapest commonly available fuel types (Fig 4). Despite the lower energy value and the added overhead costs of an LPG fuel system installation this system is still more economically viable for vehicles, especially those expected to reach high mileage. This includes costs of replaceable elements, such as gas filters, gas pump (Gen V), spark plugs, injectors, and fuel lines. Early generations of LPG systems were cheaper to install, but due to their simplicity they failed to reduce exhaust emissions. The new generations IV and V have addressed most of the problems regarding LPG usage for vehicles with spark ignition engines. But aside from the costs of conversion and fuel itself, the availability of LPG refueling stations should be taken into consideration when evaluating the viability of using this fuel for vehicles.

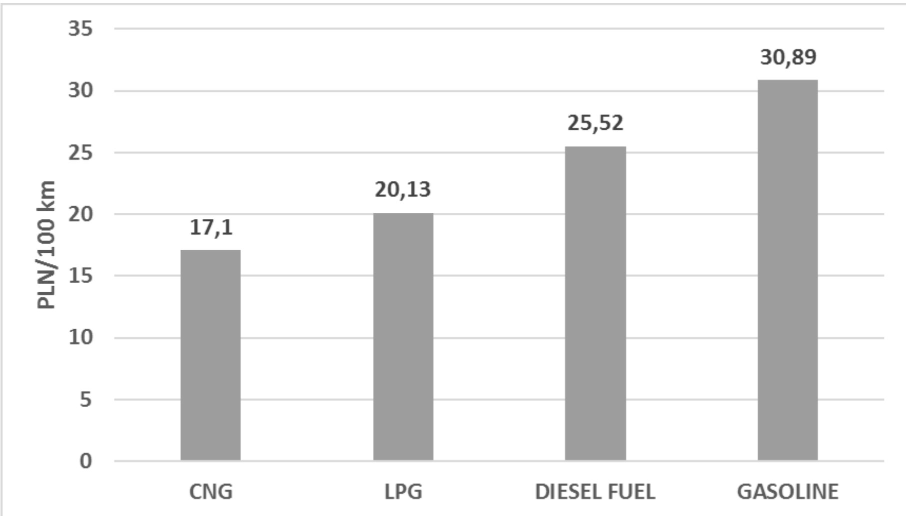

Fig. 4. Cost of driving 100km on each fuel type (calculated for Opel Mokka)

The new practice of adding an LPG supply systems as a part of the factory setup, instead of being added later on by a 3rd party, resulted in further reduction of installation costs and improvement of both fuel economy, emission control, and reliability of components in LPG powered dual-fuel vehicles. The factory-added alternative fuel system is also characterized by a better integration with the on board computer and display devices. The drop in lifespan and reliability of the engine components has always been a downside to installing an LPG system in a gasoline powered vehicle. This has been investigated many times before, for example by Jae Soo Hong et. al. [Hong, Kim and Chun, 2012]. Even including the service costs of new elements or elements with potentially lower lifespans the difference in fuel costs lead to better fuel economy for LPG vehicles. Especially as new machining techniques and technical solutions are discovered and implemented to further reduce the impact that adding an LPG system has on the lifespan of some engine components. As the number of vehicles with factory-built LPG systems continues to grow, with manufacturers noticing the growing market demand, the variety and availability of LPG powered vehicles will continue to increase. Studies suggest that LPG as an alternative fuel could find applications in mass transport vehicles [McLean and El-Sayed, 2015] as well as several other applications where the fuel costs could have a significant impact on the economic viability of various vehicles.

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ZMIANY KONSTRUKCYJNE ZWIĘKSZAJĄCE DŁUGOŚĆ ŻYCIA SILNIKA ZASILANEGO LPG NA BAZIE SILNIKA 1.4 O ZAPŁONIE ISKROWYM

Abstract

W artykule przedstawiono zmiany frabryczne dokonane w konstrukcji silnika o zapłonie iskrowym 1.4 i jego osprzętu na przykładzie pojazdu Opel Mokka w odniesieniu do różnych rozwiązań stosowanych przez producentów pojazdów przy konwersji systemu zasilania na układ LPG. Do analizy wykorzystano informacje dotyczące innych pojazdów marki Opel, m.in.: Adam, Astra, Meriva i Insignia, wszystkich, które wyposażono w fabrycznie dostosowane układy zasilania paliwem LPG. W pracy wzięto pod uwagę również pojazdy innych producentów z podobnymi rozwiązaniami technicznymi dla fabrycznego układu zasilania LPG m.in.: Hyundai i20, Dacia Sandero i Skoda Fabia.

Keywords: LPG, silnik, czas operacyjny, paliwa alternatywne