COST ANALYSIS OF FUEL CONSUMPTION BY MOTOR VEHICLES

The manuscript delivered: April 2016

Abstract: The article comprises a cost analysis of fuel consumption based on the example of a passenger vehicle and a light commercial vehicle. It was calculated how many kilometers can be traveled if the tank is filled with the amount of fuel purchased for 100 PLN, and what the cost of traveling one kilometer is. The analysis was applied to vehicles powered with diesel, petrol 95, as well as vehicles equipped with LPG and CNG installations.

Keywords: vehicles exploitation, CNG installation, LPG installation

1. INTRODUCTION

These days, it is hard to imagine a life without a motor vehicle. The need to transport persons and goods have driven the civilization development and progress since time immemorial. Contemporary economic situation forces the exploitation of motor vehicles to be as inexpensive as possible. Therefore, car manufacturers constantly modernize the vehicles’ structures and their supply systems.

Exploitation costs of a motor vehicle are to a great extent conditioned by the type of the applied supply system, thus the used fuel, and the drivers notice the costs of parts amortization only after that. Since the very beginning in the automotive industry, the cars have driven with petroleum products, such as diesel fuel and petrol. Possibilities to apply alternative sources of supply were only a subject of scientific research, as it was not necessary to exploit them, because the price of fuels available on the market was relatively low.

A financial crisis, increasing demand for fuel, resulted in significant raises of prices on petrol station. Within the course of several years, the price of petrol and diesel fuel increased multiple times. Greater attention started to be paid to economic exploitation of a motor vehicle, and to application of various structural solutions that allow to reduce the
fuel consumption level. For an average user of a motor vehicles, the “economy” means minimization of costs of each traveled kilometer. Attention of users is being increasingly more often focused on unconventional fuels and technologies introduced into the automotive industry, enabling reduction in the costs of vehicle exploitation, therefore it seems justified to raise the topic.

2. CAR LPG INSTALLATIONS

Propane-butane [4] is liquid gas, which may be used to supply combustion engines. It is great in replacing common fuels, such as petroleum or even diesel fuel. The propane-butane gas is manufactured as a by-product during exploitation of natural gas and petroleum. History of this fuel may be traced since the beginning of the 20th century. During the first years of production of petrol, the problem was the fact that stored petrol evaporated quickly. As it turned out, this phenomenon was caused by propane and butane, included in its composition. In 1911, dr Walter Snelling developed a method of removing these gases from fuel.

Propane - butane is characterized with a high level of purity. In pressurized conditions, from about 6 to 10 bar, the gas is accumulated in a liquid form. This is the manner, which it can be easily transported in. In comparison to unleaded petrol, propane-butane proves greater resistance towards knocking combustion. Its octane number is about 110, in comparison to 93 - 98 octanes in case of unleaded petrol available at the petrol stations, and similar demand for air, during the combustion process it protects the engine from potential knocking combustion. Unfortunately, when compared to petrol, the calorific value of propane-butane is lower by about 30%. Therefore, while using LPG installations, the fuel consumption increases by about 20% in comparison to a situation, when the engine is supplied with petrol. However, it is not reflected in a significant increase in the traveling costs, as the price of propane-butane is currently more than two times less than the price of petrol.

Gas installations were used to drive motor vehicles together with introduction of the first mass-produced car - Ford T. Supply with propane - butane became especially popular among users of cars with spark ignition, because installation costs are multiple times lower than in case of a care equipped in compression ignition. The costs of the simplest installation to a spark-ignition engine is about 2000 PLN, while in case of the compression ignition engine it is more than 5000 PLN.

Contemporary gas installations differ in terms of the power supply system applied in the vehicle. Depending on whether the car is equipped with a carburetor, single-point injection, multiple-point injection or direct injection, a proper, more or less complicated gas installation is applied.

Application of an LPG installation for vehicles equipped with a spark ignition engine does not interfere with its operation principle. The “main” fuel is replaced with the alternative one. In case of vehicles equipped with a compression ignition engine, a park plug is installed in injector spot, and a proper injection system is applied.
2.1. GENERATIONS OF CAR LPG INSTALLATIONS

Since the time, when the fuel - especially petrol - prices started to increase drastically, constructors have been attempting to develop structural solutions at any cost, which would allow to reduce exploitation costs for motor vehicles.

Currently, there are six generations of gas installations applied in motor vehicles [4]:

– the first generation - a vacuum installation with manual adjustment, applied for engines equipped with a carburetor, without a catalytic converter and a lambda probe,
– the second generation - a vacuum installation with electronic adjustment is devoted to motor vehicles with a fuel injection system, a catalytic converter and a lambda probe,
– the third generation - continuous injection of gas in a volatile phase is devoted to motor vehicles with a fuel injection system, with a lambda probe, a catalytic converter, equipped in complex air intake systems, also often prepared from plastics,
– the fourth generation - sequence gas injection, applied in case of cars equipped with an engine with fuel injection, a lambda probe, a catalytic inverter, and the EOBD system,
– the fifth generation (completely different from the remaining ones) - sequence liquid gas injection, applied in case of cars equipped with an engine with fuel injection, a lambda probe, a catalytic inverter, and the EOBD system,
– the sixth generation is a direct injection of LPG, where the gas is fed in its liquid state through fuel injectors. They are powered by a high-pressure gas pump. Thanks to application of fuel injectors, it is not necessary to interfere with structure of the intake manifold. The injector is cooled down thanks to liquid LPG. An advantage of this generation is the fact that the engine can be started on gas supply.

Changes in the structure of car gas installations are first of all connected with development of combustion fuels and fuel systems.

3. CNG GAS INSTALLATIONS

Natural gas is high-calorific fuel. It exists independently, or it accompanies oil deposits. Its chemical composition depends on the exploitation spot, however the main component is always methane. Car engines are supplied only with natural high-methane gas, including more than 90% of methane. When gas is used to supply engines, it is usually supplied in a compressed form [1].

Application of CNG for powering vehicles has an equally long tradition as LPG [2, 6]. The principle of exploitation of natural gas as motor vehicle fuel is similar to that applied in case of LPG supply systems. Natural gas can be used as alternative fuel for supplying engines with spark ignition, and when compared to petroleum, its octane number is much higher (about 130).
The systems of natural gas supply are almost identical with the systems for LPG supply. However, elements of the CNG installation must be adapted to much higher working pressure and a different fuel state, as CNG is stored in tanks in its volatile state, and it is fed to the engine as such. In case of CNG installation, the gas is stored under very high pressure, which reaches 20MPa. Thanks to such a high pressure level, it is possible to increase the gas density, but it requires the constructors to apply proper tanks, resistant to such a high pressure level.

An engine with a spark ignition is supplied with petrol and alternatively with CNG (bi-fuel supply). Only one type of fuel is fed to the combustion chamber: petrol or gas. The engine can be supplied alternately. A disadvantage of a fuel system is lack of factory-prepared place for installation of a gas tank. The engine is started - similarly to LPG installations - on petrol. When the engine coolant reaches a proper temperature level, the system is automatically switched to gas. The fuel and air mixture is prepared in a mixer. It is mounted in the engine’s air intake channel. The board computer’s task is to maintain the air and fuel mixture in the so-called stoichiometric ration [6], through information collected from respective sensors.

Currently, the CNG systems are also installed in factories. Gas tanks in such vehicles are placed under the chassis. Fuel and gas injectors are installed separately. The engine elements are not changed in comparison to a traditional supply system. The engine, during its work on CNG, is controlled on the basis of information from the same sensors that are used by the fuel injection control system. There are plenty of factory vehicles produced in a single-fuel version - only with the CNG system. Combustion of natural gas in single-fuel systems takes place in the same manner as in case of fuel engines.

The manufacturers offer an increasing number of vehicles with a CNG installation mounted in the factory. They are: Fiat with its Natural Power series (Panda, Punto Evo, Qubo, Doblo), Opel Combo Tour CNG, Opel Zafira Tourer CNG, Opel Zafira Family CNG, Opel Astra CNG, Skoda City Go CNG, Volvo V70 Bi - Fuel, VW UP! Eco Fuel, VW Golf Eco Fuel.

**4. DETERMINATION OF FUEL CONSUMPTION COSTS IN THE SELECTED MOTOR VEHICLES**

Cost analysis of fuel consumption was carried out on the example of passenger cars by Fiat and light commercial vehicles by Mercedes.

The fuel costs forecast was prepared with formulas (1) and (2).

\[
K_{100} = S_{\mu} \cdot C \quad [\text{PLN}] \\
Z_{100} = \frac{100zI}{K_{100}} \cdot 100 \quad [\text{km}]
\]

Where:
- \(K_{100}\) – the cost of traveling 100 kilometers [PLN],
- \(Z_{100}\) – the distance that can be traveled for one hundred PLN [km]
Fuel consumption cost was analyzed each time after traveling one hundred kilometers, as well as the distance that can be traveled for one hundred PLN spent on fuel.

Table 1 presents average prices of certain fuels, which were recorded in the Sądecczyzna region, at the beginning of March 2016.

<table>
<thead>
<tr>
<th>Type of fuel</th>
<th>Petrol 95 [PLN/liter]</th>
<th>LPG [PLN/liter]</th>
<th>CNG [PLN/m³]</th>
<th>Diesel fuel [PLN/liter]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel price</td>
<td>4.09</td>
<td>1.61</td>
<td>2.87</td>
<td>3.93</td>
</tr>
</tbody>
</table>

4.1. COST ANALYSIS BASED ON THE EXAMPLE OF FIAT PUNTO EVO

Fiat Punto has been manufactured since 1993. It replaced the previously manufactured Fiat UNO. Until now, there have been three generations of Fiat Punto. Taking care of the environment, in 2009 Fiat introduced a new series of Fiat Punto called Fiat Punto Evo (Fig. 1), the engines of which meet the EURO 5 standard.

Engines of that vehicles can be powered with petrol 95, diesel fuel, LPG and CNG. In the last case, 1.4 8v Natural Power 70 HP engines are used to drive the vehicle.

First part of the Table 2 lists basic technical parameters of Fiat Punto Evo, regarding the type of the used fuel. The second part presents an average cost after traveling one hundred kilometers, as well as the distance that can be traveled for one hundred PLN spent on fuel.

Fig. 1. Fiat Punto Evo [7]
Table 2

Basic technical parameters and calculated average costs of fuel consumption and distance

<table>
<thead>
<tr>
<th></th>
<th>Petrol 95</th>
<th>LPG</th>
<th>CNG</th>
<th>Diesel fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engine parameters</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine capacity [dm³]</td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td>Engine power [kW] (HP)</td>
<td>57 (77)</td>
<td>57 (77)</td>
<td>51 (70)</td>
<td>55 (75)</td>
</tr>
<tr>
<td>CO₂ emission [g/km]</td>
<td>124</td>
<td>119</td>
<td>115</td>
<td>108</td>
</tr>
<tr>
<td>Average fuel consumption [l/100 km]¹</td>
<td>5.4</td>
<td>7.4</td>
<td>5.7</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Calculated fuel consumption costs and average distance

<p>| | | | | |</p>
<table>
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<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>The cost of traveling one hundred kilometers [PLN]</td>
<td>22.09</td>
<td>11.91</td>
<td>16.36</td>
<td>17.69</td>
</tr>
<tr>
<td>Average distance [km]</td>
<td>453</td>
<td>839</td>
<td>611</td>
<td>565</td>
</tr>
</tbody>
</table>

Source: Own study based on vehicle producers’ specifications and formula calculations (1) and (2)

Fig. 2. presents a comparison of an average fuel consumption costs and average distance that can be traveled while purchasing fuel for one hundred PLN.

Fig. 2. Comparison of fuel consumption costs and the distance for Fiat Punto Evo

The presented data suggest that engines powered with fuel 95 are least advantageous. While spending one hundred PLN on this fuel, we can travel only 453 km. While the average fuel costs needed to travel a one-hundred distance is as much as 22.09 PLN.

Engines supplied with diesel fuel are slightly more advantageous. For this option, a hundred PLN is enough to travel 565 km, i.e. about 25% more than in case of engines
supplied with petrol 95. The fuel consumption at the distance is 20% lower, and it amounts to 17.69 PLN. The situation is similar in case of CNG. The cost of traveling one-hundred kilometer distance is 16.36 PLN, and it is lower by 26% than in case of petrol 95. One hundred PLN allows to travel 611 km.

Out of the analyzed supply sources, the most advantageous seem to be the engines supplied with LPG. The cost of traveling one hundred kilometers is 11.91 PLN, what is 46% less than the cost of petrol 95. Also the distance that can be traveled for the amount spent is higher by 386 km than the one that may be traveled in case of traditional petrol.

### 4.2. COST ANALYSIS BASED ON THE EXAMPLE OF A LIGHT COMMERCIAL VEHICLE - MERCEDES SPRINTER

Mercedes Sprinter (Fig. 3) cars have been manufactured since 1995. The vehicle underwent numerous modernizations within the course of years. Among others its appearance was modified, thus improving aerodynamic parameters. Also the engines’ parameters were improved, what resulted in the fact that the currently manufactured vehicles meet EURO 6 standards.

Currently, Mercedes has enriched its vehicles assortment with cars powered with CNG, called Mercedes Sprinter NGT. It is powered with M 271 E 18 ML engine, with 158 HP engine.

First part of the Table 3 lists basic technical parameters of Mercedes Sprinter, regarding the type of the used fuel. The second part presents an average cost after traveling one hundred kilometers, as well as the distance that can be traveled for one hundred PLN spent on fuel.
Table 3.

Basic technical parameters and calculated average costs of fuel consumption and distance

<table>
<thead>
<tr>
<th></th>
<th>Petrol 95</th>
<th>LPG</th>
<th>CNG</th>
<th>Diesel fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engine parameters</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine capacity [dm³]</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>2.2</td>
</tr>
<tr>
<td>Engine power [kW] (HP)</td>
<td>115 (158)</td>
<td>117 (160)</td>
<td>115 (158)</td>
<td>120 (164)</td>
</tr>
<tr>
<td>CO₂ emission [g/km]</td>
<td>317</td>
<td>272</td>
<td>254</td>
<td>208</td>
</tr>
<tr>
<td>Average fuel consumption [l/100 km]</td>
<td>13.3</td>
<td>16.7</td>
<td>12.7</td>
<td>10.4</td>
</tr>
</tbody>
</table>

Calculated fuel consumption costs and average distance

| The cost of traveling one hundred kilometers [PLN] | 54.40 | 26.89 | 36.45 | 40.87 |
| Average distance [km]                             | 184   | 372   | 274   | 245   |

Source: Own study based on vehicle producers’ specifications and formula calculations (1) and (2)

Fig. 4 presents a comparison of an average fuel consumption costs and average distance that can be traveled while purchasing fuel for one hundred PLN.

![Fig. 4. Comparison of fuel consumption costs and the distance for Mercedes Sprinter](image)

The presented data suggest that engines powered with fuel 95 are least advantageous. While spending one hundred PLN on this fuel, we can travel only 184 km. While the average fuel costs needed to travel a one-hundred distance is as much as 54,40 PLN.

Engines supplied with diesel fuel are slightly more advantageous. For this option, a hundred PLN is enough to travel 245 km, i.e. about 61 km more than in case of engines supplied with petrol 95. The fuel consumption at the distance is 25% lower, and it amounts to 40.87 PLN. The situation is similar in case of CNG. The cost of traveling one-hundred kilometer distance is 36.45 PLN, and it is lower by 33% than in case of petrol 95. One hundred PLN allows to travel 274 km.
The most advantageous are engines supplied with LPG. The cost of traveling one hundred kilometers is 26,89 PLN, what is 51% less than the cost of petrol 95. Also the distance that can be traveled for the amount spent is higher by 188 km than the one that may be traveled in case of traditional petrol.

5. SUMMARY AND FINAL CONCLUSIONS

When analyzing the operating costs of vehicles equipped with various types of fuel systems, it is clear that among the presented vehicles, the winners in terms of the cost of 100 kilometers and a distance that may be reached with the amount of PLN 100 are those fueled with LPG. It regards both passenger and light commercial vehicles. The presented analysis is confirmed by observations of the motor vehicles market, where a great number of vehicles equipped in LPG installation may be observed.

The second place is occupied by vehicles equipped in CNG installation. According to the authors, this is the type of fuel that should be introduced on a mass scale, and it should become equally popular as LPG. This conclusion follows among others the assets that the CNG presents. First of all, price for the gas is not high in relation to traditional petrol. Additionally, there is a possibility to fill the tank at home, having purchased proper equipment. Second of all, it is ecological, as it includes a small amount of carbon, thus the exhaust fumes include a small amount of carbon dioxide. Third of all, the CNG is characterized with a high self-ignition temperature, therefore the risk of explosion is minor, and in case of leakage the gas disperses.

Another significant advantage of CNG-powered vehicles over those equipped with traditional petrol engines consists of reduced emissions of harmful pollutants, as shown e.g. by studies conducted by the authors of this work [3].

Despite all of those advantages, there are not many vehicles on the market, which would be equipped in this type of installation. Currently there are about 2000 such vehicles traveling on Polish roads. A question should be asked, why the number of such vehicles is so low? It may result from high costs for mounting the installation, or maybe from a small number of CNG stations in Poland (about 30). The authors will try to answer these questions in subsequent scientific papers.

Bibliography

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