USE OF LIQUEFIED PETROLEUM GAS IN INTERNAL COMBUSTION ENGINES

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Abstract: The problem of global warming and the associated climate change requires solutions to reduce greenhouse gas emissions, especially carbon dioxide (CO_2). Thus, liquefied petroleum gas propulsion of vehicles seems to be a very beneficial alternative. Although liquefied petroleum gas (LPG) is a fossil fuel, it is a cleaner fuel because it causes less pollution by emitting fewer pollutants such as CO_2, carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_x) and particulate matter (PM). LPG engines reduce greenhouse gas emissions (GHG) by up to 20% compared to diesel engines and by up to 10% compared to gasoline engines.

Keywords: Liquefied petroleum gas, liquefied petroleum gas installations, emissions

1. INTRODUCTION

Road transport currently accounts for almost 45% of global oil demand. The continued growth of online shopping and home deliveries means that in the last two decades alone, the industry has seen an 80% increase in global diesel consumption due to the growth of road freight transport. If logistics sites are included, the road transit industry is responsible for an 11% increase in global CO_2 emissions [1].

The use of alternative fuels in road transit can not only reduce emissions but also increase operational efficiency, while reducing operational costs. Natural gas (NG) qualifies as an alternative fuel under Regulation 1804/13-Sept-2023 on the deployment of alternative fuels infrastructure, as it is a substitute for energy sources derived from crude oil [2]. ”Alternative fuels” means fuels or energy sources that serve, at least partially, as a substitute for fossil oil sources in the energy used for transport and that have the potential to contribute to its decarbonization and to improve the environmental performance of the transport sector (Figure 1).

Many of the fuel options for this industry, such as biofuels and natural gas, show a relatively good state of readiness, and methanol is making progress. Dimethyl ether (DME) is also emerging as a strong alternative to diesel, due to its ability to utilize

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existing LPG infrastructure. However, production readiness and costs related to e-fuels (renewable pathways) remain a challenge (Figure 2). [1].

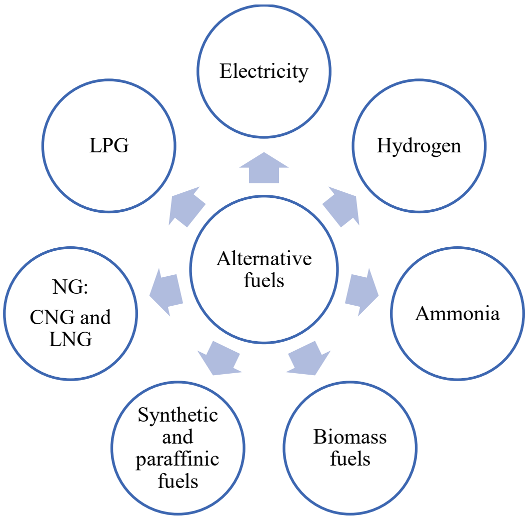

Fig. 1. Alternative fuels for the transport sector

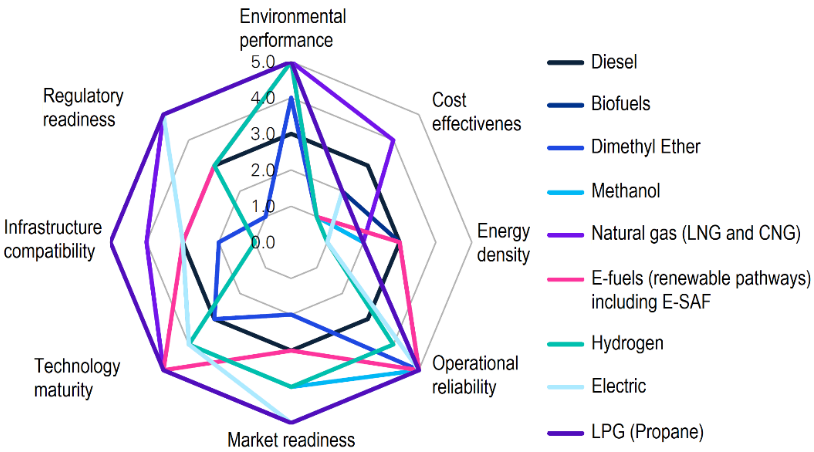

Fig. 2. Road transport alternative fuels readiness

It should be noted that [2] also considers CNG, LNG, LPG to be transitional fossil fuels. On the basis of the final national policy frameworks referred to, the Commission shall make publicly available and regularly update information on the national targets and objectives submitted by each Member State regarding the number of CNG, LNG, LPG refueling points accessible to the public for motor vehicles. Given that the market for electric vehicles is in decline [3], the use of LPG, an alternative fuel, is a viable alternative to diesel and petrol engines [4].

2. TECHNOLOGIES FOR CONVERTING VEHICLES TO LPG

The global use of LPG is high in European countries such as Poland, Romania and Italy [5]. The properties of fuels (LPG, petrol, diesel) for vehicles are presented in Table 1 [6, 7, 8, 9, 10].

Table 1. **Properties of fuels for vehicles with internal combustion engines**

Characteristic / Fuel	Explosion limits, volume % in air	Density, kg/m³	Flash point, °C	Autoignition temperature, °C	Net caloric value, MJ/kg	Net caloric value, MJ/m³(*l*)	Carbon footprint, gCO_2/MJ
LPG	1,8-15,0	533	≥-104	287	46,28	24,67	63,90
Petrol	1-6,5	741	>-40	246	44,15	32,70	70,80
Diesel	4,0–7,5%	837	>62	210	42,91	35,94	74,30

LPG system means an assembly of components (tank, valves, flexible gas pipes, etc.) and connecting parts (rigid gas pipes, fittings, etc.) fitted to motor vehicles using LPG in their propulsion system. An LPG system must contain at least the following components [11]:

- LPG tank;
- 80% filling limiter;
- level indicator;
- overpressure valve;
- remote-controlled isolation valve with flow limiter;
- pressure regulator and vaporizer, possibly combined;
- remote-controlled shut-off valve;
- filling connection;
- gas piping, rigid and flexible;
- gas connections between LPG equipment components;
- gas injection device, or gas injector or mixer;
- ECU;
- decompression device (fuse).

LPG equipment may also include the following components:

- the sealed housing, which covers the accessories mounted on the tank;
- check valve;
- pressure relief valve on the gas pipeline;
- gas dispenser;
- LPG filter;
- pressure or temperature sensor;
- LPG pump;
- tank power plug (actuators / LPG pump / fuel level indicator sensor);
- the safety supply connection is only authorized for monofuel vehicles (LPG only) not equipped with a minimum mobility system;
- fuel selection circuit and electrical system;

- fuel ramp.

LPG systems installed in vehicles consist of a pressurized gas storage tank and a conversion kit. The LPG tank is of 3 types (Figure 3), depending on the design and production techniques [12].

a. b. c.

Fig. 3. LPG tanks: a. cylinder; b. toroidal internal; c. toroidal external

LPG components for retrofitting gasoline vehicles are shown in Figure 4 [13]. Petroleum gas is compressed into an LPG cylinder through a container at a working pressure of 10 bar. The liquefied gas is transferred to the pressure regulator through the high-pressure line. The pressure regulator reduces the pressure to a level compatible with the engine's injection system. The LPG is then mixed with air in the intake manifold before the mixture enters the combustion chamber for compression. The spark plug ignites the air-gas mixture to produce mechanical power. Once the switch is pressed to allow LPG operation, the ECU opens the LPG valve and pressure regulator to allow LPG to flow to the common rail injector through the gas filter and the mean absolute pressure (MAP) sensor while blocking the petrol injectors. The oxygen sensor monitors the amount of oxygen in the exhaust and transmits this information to the ECU, which adjusts the air-fuel ratio accordingly [14].

Figure 5 [15] shows the LPG components for diesel engine vehicle retrofit. The pressurized gas is transferred from the LPG cylinder to the pressure regulator, where it is reduced to the required level in the combustion chamber. In the intake manifold, the low-pressure gas combines with the bulk air and is transferred to the combustion chambers for compression. The presence of an air-gas mixture in the engine intake air is expected to cause a significant decrease in the temperature of the fuel mixture, resulting in the failure of the air-gas mixture to ignite during the compression stage. Due to the lack of spark plugs in the combustion chamber, the diesel fuel serves as the ignition of the air-gas mixture. Meanwhile, the pressure inside the combustion chamber is already high, obstructing the flow of diesel fuel into the chamber. As a result, little diesel fuel enters, creating a strong spark to ignite the air-gas mixture during compression. In these engines, diesel fuel provides ignition and liquefied petroleum gas provides power.

3. TECHNICAL PERFORMANCE

For gasoline vehicles, technical performance is evaluated by two parameters, namely, engine performance and fuel economy [16]. Engine performance is evaluated by the following parameters, namely the vehicle's mileage when running on LPG, D_{LPG} in km and the fuel consumption over the distance traveled, C_{comb} in kg/km:

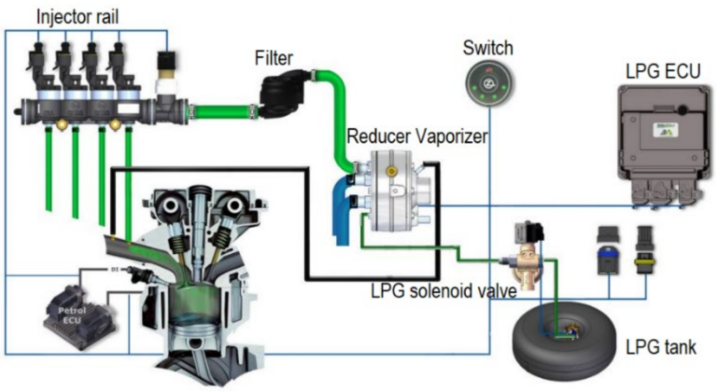

Fig. 4. Arrangement of LPG components in gasoline vehicles

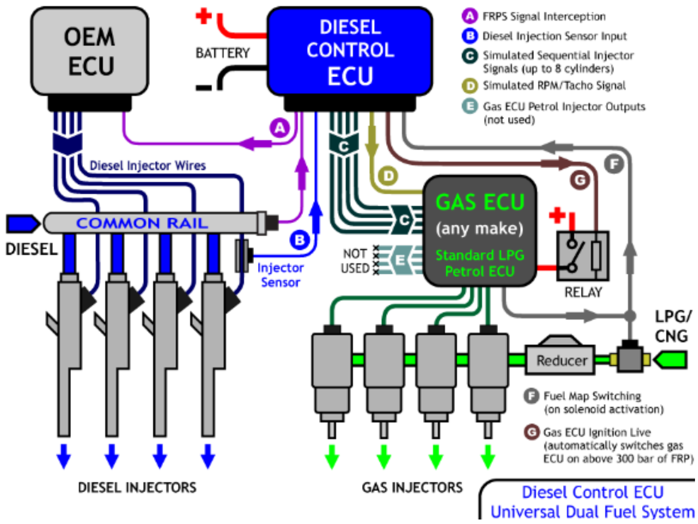

Fig. 5. Arrangement of LPG components in diesel vehicles

$$C_{comb} = Q_{LPG}/D_{LPG}, kg/km \tag{1}$$

where Q_{LPG} is the amount of LPG consumed, in kg.

For diesel vehicles, the technical performance is evaluated by two parameters, namely, the vehicle mileage when dual fuel (diesel + LPG), D_{dual} in km and the fuel consumption reduction when using dual fuel over a certain distance, Q_{red} in liters [16]:

$$Q_{red} = [(Q_{diesel} - Q_{dual})/Q_{diesel}] \times 100\%, \tag{2}$$

where Q_{diesel} is the amount of diesel fuel consumed while driving with diesel.

The latest emissions regulations in Europe have introduced the so-called Real Driving Emissions (RDE) test procedure, in which the vehicle is measured under real driving conditions using portable emission measurement systems (PEMS) [17].

According to [12], the use of LPG in a vehicle has the following advantages over gasoline (Figure 6):

- CO_2 emissions are 12% lower;
- PM emissions are 95% lower;
- the distance traveled is ≈150% greater.

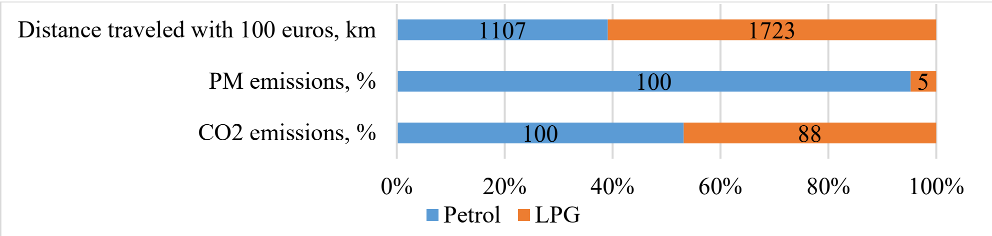

Fig. 6. Comparison between emissions and distance traveled by an LPG and a gasoline vehicle

Also, the results obtained by [4] (Figure 7) demonstrate that during the operation of a car with gasoline, CO and CO_2 emissions are higher than during the operation with LPG. However, hydrocarbon (HC) and NO_x emissions are higher during the operation with LPG.

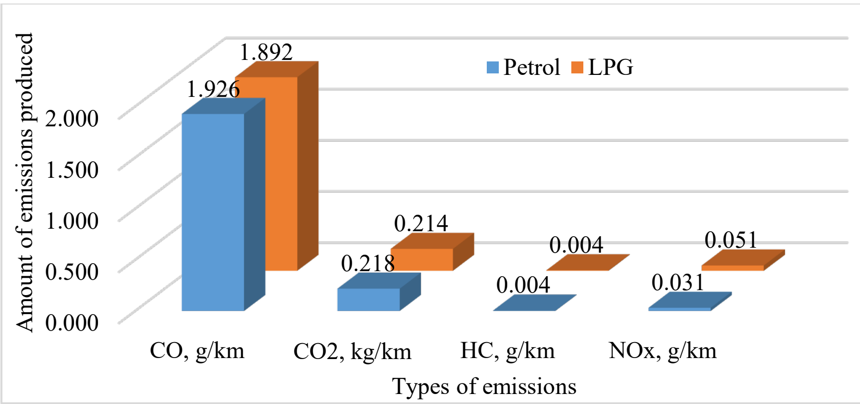

Fig. 7. Emission production comparison

From the studies it is shown that the use of LPG in diesel engine is one of the capable methods to reduce the PM and NO_x emissions but at the same time at part load condition there is a drop in efficiency and power output with respect to diesel operation [18, 19, 20, 21].

An LPG installation mounted on a Dacia Logan 2 MPI 4-cylinder may consist of the following: CIL 28L PL1 tank (Figure 3.a); AGR AC R02 reducer (Figure 8); Stag-200 Plus ECU (Figure 9); AC W01 injection rail (Figure 8); AT02 Tomasetto multivalve (Figure 10).

Fig. 8. Reducer and injection rail

Fig. 9. ECU

Fig. 10. Multivalve

The price of the installation with installation is 3,223 lei. According to [22], with an LPG installation, a monthly saving of 360 lei is achieved, given that a monthly mileage of 1000 km is achieved, the vehicle having a gasoline consumption of 10 liters/100 km, and the price of LPG is 3.42 lei/liter and that of gasoline is 7.36 lei/liter. The liter consumption of LPG for an engine is maximum 10% higher than the gasoline consumption, due to the density of LPG which is lower than that of gasoline. Taking into account the aspects presented above, a real saving of approximately 40-45% is achieved. Due to this fact, the amortization of the investment for installing an LPG installation is relatively easy (approximately 10,000-15,000 km), only from the difference in gasoline-LPG cost.

4. CONCLUSIONS

LPG is a promising alternative fuel because it is readily available, produces clean emissions and its performance is comparable to that of petrol or diesel. However, there are some disadvantages in using LPG as a vehicle fuel: power difference, 2-3% lower than petrol engine power, longer and more frequent refueling, high initial costs and safety concerns. We note in Europe an upward trend in quality of two of the Westport group brands: Prins from the Netherlands and Zavoli from Italy which have a very extensive technical background focusing all their experience and expertise on new technologies in the field. PRINS VSI-3 DI represents the new range of LPG installations for latest generation engines with direct petrol injection. Fuel consumption is optimized so that of the total gasoline consumption of the car, after installing the LPG system it will consume 95% LPG and 5% gasoline, meaning that if the car consumed 10 liters of gasoline/100 km, after installing the LPG system it will consume 9.5 liters of LPG and 0.5 liters of gasoline per 100 km. Installations are being tested and approved that comply with the latest pollution standards up to Euro6 but also with the latest types of injection for TSI, TFSI and GDI passenger cars, which use the original injectors of the car and start directly on LPG, no longer needing to start on gasoline as with normal LPG systems. LPG systems for Diesel engines are also being tested, both for passenger cars and for trucks.

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