TECHNICAL-ECONOMIC ASPECTS OF CNG GAS USAGE IN BUSES OF URBAN COMMUNICATION

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Abstract. After Poland's accession to the European Union, CNG supply began to be popularized. Jelcz buses powered by engines using diesel and CNG were used for comparative studies. The analysis was performed based on actual data obtained from the observation of the use of buses in the Municipal Transport Company in Przemyśl (MZK Przemyśl). We present, among other things, a comparative analysis of the direct operating costs of public transport buses powered by compressed natural gas and diesel fuel. CNG as a fuel allows to reduce the emission of harmful substances to the atmosphere, which is not without significance in the case of public transport, and this aspect of CNG gas use should be emphasized the most. The research showed differences in the operation and service of the vehicles powered by CNG installation in relation to the vehicles powered by diesel fuel, which may be important in connection with the conduct of transport activities.

Keywords: city buses, fuel consumption, maintenance, power supply.

Introduction

In Europe, we are observing an increase in the interest in the CNG fuel and the number of cities using this fuel in public transport is constantly growing. This is evidenced by scientific publications from various European centres [1-3]. After Poland's accession to the European Union, CNG supply began to be popularized. In Poland, however, there are only around 27 (in 2014) open-access CNG refueling stations and no public LNG refueling stations. All leading European vehicle manufacturers offer natural gas-powered vehicles – this also applies to bus manufacturers. However, despite the promotion of natural gas as a fuel in Poland, we do not see a significant increase in the number of vehicles powered by it. Compressed natural gas is considered as one of the most promising alternative fuels for transportation because of its ability to reduce greenhouse gas emissions and its abundance [4; 5]. Low emission of toxic compounds should be a strong incentive to introduce it as a fuel for city vehicles (buses and municipal vehicles). Automotive emissions are low emissions – they take place at heights that cover the range of human growth.

Transportation problems are among the most pressing strategic development problems in many cities and are often considered as a major constraint for long-term urban development [2]. Apparently, the transport sector plays an important role in development of every country, but it also consumes significant amount of energy, being also the main source of environmental pollution [6]. Energy intensity of transport is a current topic around the world [7]. All sites of transport service are trying to improve vehicle fuel consumption, which is the biggest part of the energy consumption in transport [7]. While assessing the cost-efficiency of a bus, numerous factors must be taken into consideration [8]. They are: efficiency of public transport, personal expenses, the value of the established transportation tariff, fuel and operating costs, etc. The municipal transport company should assure a continuous monitoring on maintenance process in terms of current availability of the used fleet [9]. A comprehensive explanation of the selected problems of the efficiency of public transport can be found in detail in other scientific articles [8; 10; 11].

As reported by Poliak et al. [12] and Bukova [13], the transport market does not have an equal status in the transport market within the European Union. Public transport plays a vital role because the transport of passengers to schools, public healthcare establishments and work are ensured. Taking into account the above information, concerning the environmental requirements of the vehicles used in public transport, more attention is paid to the use of vehicles powered by alternative fuels. The use of alternative fuels is one of the main solutions allowing the reduction of pollutant emissions nowadays [14]. In many scientific papers the subject of the research is using various alternative fuels [15-17], and reduction in the consumption of lubricating oils and plastic lubricants [18]. One of the chief benefits of CNG is that it provides a source of affordable energy [19]. Environmental considerations play the main role in the dissemination of combustion engines with natural gas. Natural gas engines in the form of CNG or LNG emit much less toxic compounds than their counterparts powered by diesel or gasoline.

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In the case of services (municipal) and transport (public transport), the decisive factor for their success is profit, therefore, the success of a particular solution is determined by the costs associated with its implementation and application. The authors decided to compare the actual costs incurred by the user of a vehicle powered by CNG in relation to an analogous vehicle powered by conventional fuel. The results of the analyses should allow to explain the reasons for low popularity of the CNG fuel.

Materials and methods

MZK public transport buses in Przemyśl were selected for comparative research. Miejski Zakład Komunikacji in Przemyśl is one of the first transport companies in Poland, which uses buses powered by CNG. For comparative studies, comparatively designed Jelcz buses were selected. The technical data of the tested buses are presented in Table 1. By choosing comparable buses with a similar design differing only in the propulsion unit and the type and location of the fuel tanks, we can omit all costs associated with maintaining their other systems and components.

Table 1

Technical data of compared buses

Parameter	City bus Jelcz 120M/1 CNG	Modernized city bus Jelcz PR110	City bus Jelcz PR120M
Fuel	CNG		Diesel fuel
Engine type	WSK MIELEC MD111M6	SW680 adapted for CNG	SW680
Number of cylinders	6	6	6
Arrangement of cylinders	In line	In line	In line
Engine capacity	11100 cm^3	11100 cm^3	11100 cm^3
Power	152 kW at 2000 rpm	138 kW at 2000 rpm	148 kW at 2000 rpm
Maximum torque	765Nm at 1300 rpm	730Nm at 1300 rpm	743Nm at 1200 rpm
The vehicle's own weight	10620 kg	11590 kg	9900 kg
The maximum total weight of the vehicle	17500 kg	17000 kg	17500 kg
Number of seating / standing places	34/62	36/43	34/70
Largest allowable axle load	115 kN	110 kN	110 kN
Unit power factor	8.68 W·kg^{-1}	8.12 W·kg^{-1}	8.46 W·kg^{-1}

Jelcz PR 110 buses with SW 680 engines were adapted to be supplied with CNG gas during major repairs by the company “Mielec – Diesel Gaz” Sp. z o.o. in Mielec. They were equipped with gas cylinders with a total capacity of 900 liters mounted to the bottom of the chassis. Jelcz 120M/1 CNG buses are factory-fitted to CNG and were equipped with MD111M6 engines manufactured by WSK MIELEC. Jelcz PR 120M buses are equipped with diesel engines SW 680.

Autobuses adapted to be powered by CNG are heavier than a bus powered by diesel. The modernized Jelcz PR110 bus is the heaviest and weighs 1690 kg more than a bus powered by diesel and about 970 kg more than the Jelcz 120M/1 CNG bus. The increase in the weight of CNG-powered vehicles results from the need to assemble heavy gas cylinders and it is not without influence on their operating parameters. In the case of the increase of the own weight of the bus it was necessary to reduce the amount (mass) of transported passengers. This number is 8 lower for the Jelcz PR120M/1 CNG bus and as much as 27 less for the Jelcz 120M/1 CNG bus. The traction of buses is influenced by the ratio of the engine power to total weight of the vehicle (unit power factor). The highest unit power factor equal to 8.68 W/kg has the Jelcz 120M/1 CNG bus. This bus is equipped with the engine with the highest power 152 kW. The other two buses have lower rates, respectively 8.46 W·kg^{-1} for the Jelcz PR120M bus powered by diesel fuel, and 8.12 W·kg^{-1} for the Jelcz PR110 bus, in which the SW680 engine was adapted to be supplied with CNG gas.

Results and discussion

The analysis was based on the data provided by the MZK in Przemyśl. The obtained data covered a period of four months (May, June, July, August) 2014 (total monthly mileage of all buses is summarized in Table 2). Figure 1 shows graphically the shares in the number of kilometers driven by all MZK Przemyśl buses divided into vehicles powered by diesel fuel (ON) and compressed natural gas (CNG) in individual months.

Table 2

Mileage of all compared buses by used fuels

Month	Total mileage in kilometers of tested buses powered by ON	Total mileage in kilometers of tested buses powered by CNG	Total mileage in kilometers of tested buses from MZK Przemyśl
May	110 628	59 599	170 227
June	108 353	55 320	163 373
July	112 516	55 660	168 176
August	106 086	52 579	158 665
Total	437 593	223 158	660 741

Buses powered by CNG gas support an average of 39.8 % of all routes. On the basis of the data on the amount of fuel refueled, the average fuel consumption per 100 km mileage was calculated in the subsequent analyzed months of operation (Figure 1).

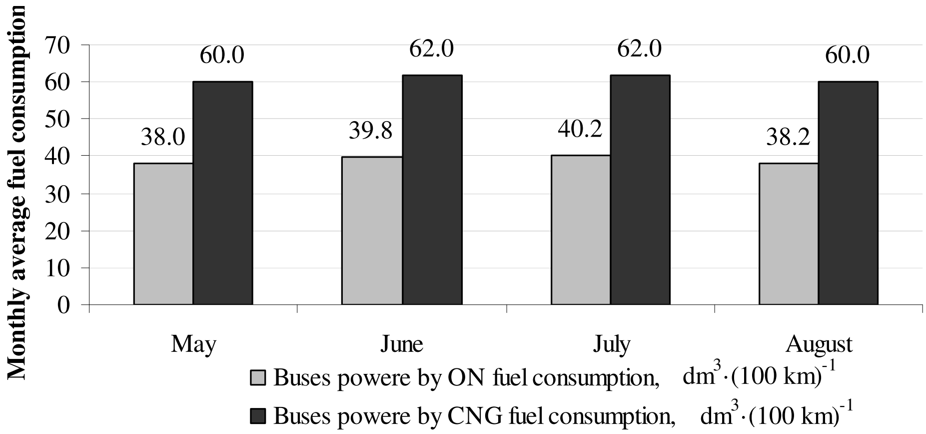

Fig. 1. **Summary of average monthly fuel consumption of ON / CNG during period considered**

Taking into account the fuel prices applicable at that time, diesel fuel prices (PLN 4.127 per 1 dm^3) and CNG gas (PLN 3.30 per 1nm^3) were calculated for average costs of travelling 100 km. The results of the calculations are shown in Figure 2, indicating the fuel costs in PLN and Euro accordance with the applicable conversion rate at the time: 1 EUR – 4.17 PLN. As it can be seen, the cost of fuel for the buses powered by conventional diesel fuel is about 20 % lower than for the buses powered by CNG.

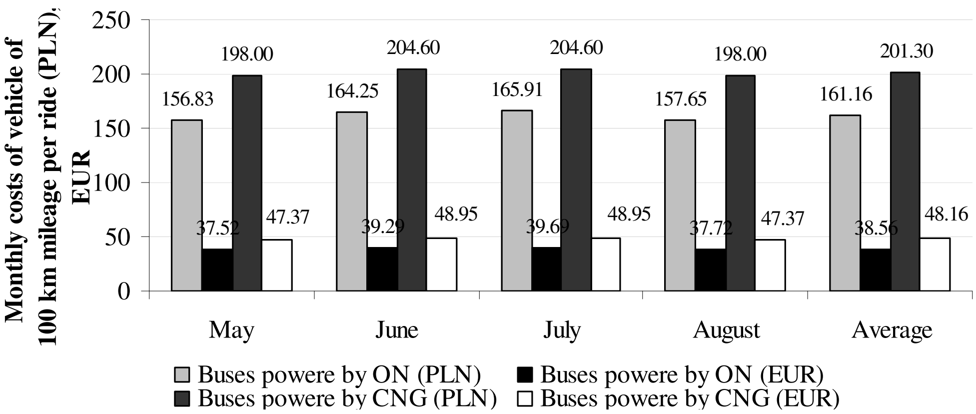

Fig. 2. **Comparison of cost of driving 100 km by buses powered by diesel fuel ON and CNG**

The costs related to the transport of one passenger per unit length of 1 km were also analyzed. In addition to the fuel consumption, the number of seats for passengers has been taken into account. It was assumed that the number of passengers carried is equal to the number of seats on the bus. Fuel consumption corresponds to the average value for the CNG vehicles. The results of the calculations are shown in Figure 3.

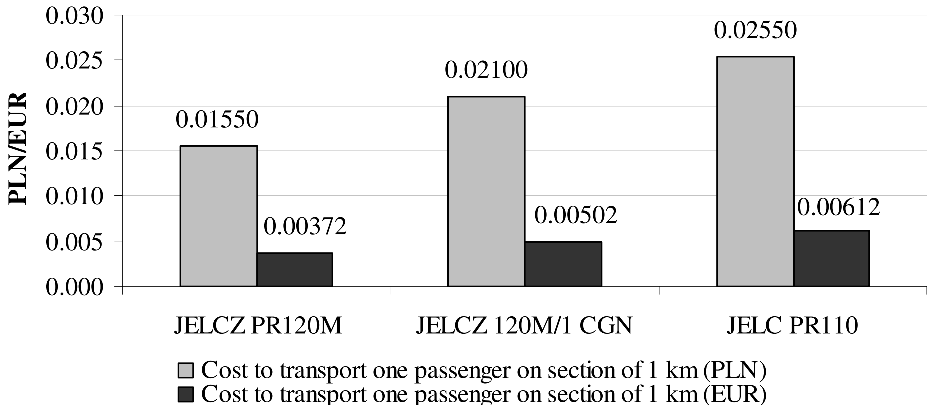

Fig. 3. **Comparison of average cost of transporting one passenger on 1 km stretch for test buses**

In the case of urban communication companies, there are two ways to earn income. The first one involves lump sum payment by the contracting party for a transport service, for example, the City Hall. This fee is calculated for 1 km of the route, and its total amount depends on the total mileage of vehicles. In this aspect, the companies are interested in vehicles with the lowest operating costs (fuel, service and repair costs). The second one involves getting a payment directly from the passenger. Therefore, bus companies are interested in vehicles, in which the transport cost of one passenger is the smallest. The higher fuel costs of the buses powered by CNG in relation to the buses powered by ON cause limited interest in this type of transport. In Poland, the price of $1nm^3$ of CNG gas has been linked to the price of ON and cannot currently amount to less than 55 % of the price of $1dm^3$ of this fuel. At the moment: April 2018, it is 3.47 [PLN] for $1nm^3$. The difference between this value and the price of gas sales for households, taking into account additional charges and the calorific value of gas, is currently around 2 [PLN] per 1 nm^3. The difference of these prices is the excise tax for the CNG fuel.

Conclusions

1. The CNG bus market has the greatest development potential in smaller municipalities and on longer routes, e.g. suburban ones. The typical range of a CNG-fueled bus is 350-400 km, its equivalent powered by diesel fuel is 600-900 km, while the e-bus is currently 120-230 km.
2. The average cost of running 100 km by a bus powered by classic diesel fuel is about 20 % lower than by an analogous CNG gas bus.
3. The average cost of one passenger transport per 1 km of vbuses powered by CNG is higher than in the case of a bus powered by ON. Assuming 100 % of the cost of passenger transport by a bus powered by ON, the analogous cost for a CNG gas-powered bus, depending on the bus type is from 35 to 60 % higher.
4. A gas price in the analysed period of PLN 3.30 per one normal cubic meter has a significant impact on the transport costs for the buses powered by CNG.
5. Nevertheless, environmental aspects being decisive for choosing this type of fuel are prevailed nowadays. Thus, it is for a bus company to decide upon the choice of a bus powered by standard diesel fuel or alternative CNG gas fuel. Merkisz et al. in their paper [3] found a reduction in NOx emissions, when buses are fueled by gaseous fuel.

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