

The growth in the use of methane fuel for fuelling urban buses

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Abstract. Urban transport vehicles have a large share in city traffic. This results in higher emission of hazardous substances and poses direct threat for human life by causing smog. Research and implementation works are underway to prevent this situation. In city transport attention is given to electric and hybrid vehicles, as well as gas vehicles that are used. The last group, i.e. city buses with engines fuelled with methane fuels have positive impact on decreasing emission of certain hazardous substances. This article addresses internal tests and their results that confirm the rationality underlying the use of these fuels in city transport buses.

1 Introduction

The emission of pollution in cities is to a great extent caused by the use of vehicles. The number and age of vehicles and in a sense also other means of road transport, e.g. city buses in a particular area depend largely on the wealth of the inhabitants [1]. For this reason a considerable number of used cars are encountered. Poland is a good example of this phenomenon – the average car age in the country is approx. 15 years.

Another important issue is the fact that transport largely depends on petroleum derivative substances. The share of these fuels in producing energy in transport at the end of the 20th century accounted for as much as 97% [2]. Since then its share has not changed much [4, 5]. The combustion of these fuels results in emission of exhaust gases the main components of which include non-toxic substances: nitrogen, carbon dioxide and vapour. Exhaust gases also comprise substances hazardous for people and the natural environment, such as nitrogen oxides, hydrocarbons, particulate matter and carbon dioxide [13].

With the implementation of more and more stringent standards, those emissions are gradually reduced, in particular in road transport [15]. The hazard posed by goods and passenger transport for human health and natural environment can be lessened also by matching types of transport to specific transport tasks [1]. Such approach requires – among others – a comparison of emissions of toxic exhaust gases by different types of buses emitting them. This article discusses comparison tests of city buses. This is essential as there is great likelihood that municipal authorities will limit the traffic of private passenger cars in city

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centres. Therefore, it is necessary to focus on urban transport as city buses will emit hazardous substances in city arteries [14]. This article presents a comparison of hazardous substances emission by city buses with self-ignition engines, fuelled with diesel oil and spark-ignition engines fuelled with CNG, in true conditions of road traffic.

2 Gasification of urban transport

Fuelling buses with compressed natural gas is becoming more and more popular in Poland. The main component of natural gas is methane, which qualifies it as a methane fuel. Methane and its homologues are flammable components of natural gas. Non-flammable components include e.g. nitrogen or carbon dioxide.

The use of natural gas for fuelling diesel engines has direct impact on the emission of hazardous exhaust substances. The emission levels depend on many factors, including but not limited to the engine construction, its technical conditions, shape and size of the combustion chamber, characteristics of the fuelling system and setting options [3]. Table no. 1 shows some parameters of methane fuel as compared to parameters of the commonly used conventional motor fuels [3].

Table 1. The properties of conventional fuels and alternative gaseous fuels [6–8, 10].

	Gasoline	Methane CH ₄	LPG (C ₃ H ₈) (C ₄ H ₁₀)	Diesel
The calorific value of the mixture (> = 1)	-3.7 MJ/m ³ (fuel from gases)	3.37 MJ/m ³	= 3.66 MJ/m ³	3.7 MJ/m ³
Laminar burning rate [m/s]	0.3–0.6 (2–22 um)	0.34	0.39 Prop. 0.379 But.	
Air requirement/kg of fuel	15 kg/kg	17.2 kg/kg	15.5 kg/kg	14.5 kg/kg
Octane rating	< 98	110–130	100–115	
Density [kg/m ³] relative to air	(0.72-0.76) kg/dm ³	0.717 kg/m ³	2 kg/m ³ C ₃ H ₈ 2.7 kg/m C ₄ H ₁₀	0.86 kg/dm ³
Flash point T21 [°C]	Normal 220°C Super 270°C Jet -400°C	650°C	4819 C ₂ H ₁₀ 4309 C ₄ H ₁₀	220°C
Flammability range (practical) K	0.7–1.25	0.6–1.9(2)	0.4–1.91 C ₃ H ₈ 0.34–1.74 C ₄ H ₁₀	0.19–0.98
Explosion limit	(1.3–7)%	(5–15)%	(2.12–9.35)% P (1.8–8.5)% B	0.6–6.5%

CNG-fuelled engines characterise with unvarying operation, which brings reduced noise emission as compared to noise emitted by engines fuelled with conventional fuels [3]. The use of – among others – CNG to fuel city transport buses has a number of advantages compared to diesel oil, for example as regards the usually very low emission of particulate matter, advantageous road emission of nitrogen oxides, without the use of any additional exhaust filtering systems.

The pros and cons of using CNG as a fuel for fuelling bus engines are proved by tests conducted on the chassis dynamometer of heavy vehicles in West Virginia University. The tests involved eight Orion buses with diesel engines and CNG engines (three CNG buses with John Deere RGG081 engines (poor mixture), three CNG buses with Cummins CG-280

engines (stoichiometric mixture) and two buses with Detroit Diesel Corporation engines (DDC) [11]. The tests included 16 driving cycles and one idle-run cycle [11].

The tests proved that except for hydrocarbon emissions the tested vehicles characterised with a similar emission of NO_x and PM. The CO emission was low for buses with a self-ignition engine and for buses with John Deere (CNG) engines. However, buses with Cummins (CNG) engines emitted more carbon oxide. Carbon dioxide emission was lower for CNG-fuelled buses by approx. 20% compared to self-ignition engines as a result – as claimed – chemical properties of fuel. The methane emission from the exhaust system in the tested buses fuelled with CNG ranged from 4 to 47 g/km, on average 12 g/km for buses with John-Deere engines and 21 g/km for buses with Cummins engines [11, 16]. Nevertheless, the results of the tests do not reflect fully the results of tests in true conditions of road traffic.

Vehicles fuelled with natural gas are popular in a number of countries, e.g. Pakistan, Iran, Argentina, Brazil, India or in Europe – in Italy. For instance by the end of 2011 there were over 14 million of such vehicles across the world, including more than 430.000 of buses. In Poland their number was estimated at roughly 2000, including c.a. 270 buses [9]. At present the number of buses is estimated at approx. 400. At the end of 2011 there were almost 20 700 natural gas filling stations (presently approx. 26 700 stations) worldwide, 33 public stations in Poland, while currently there are less although 52 new stations to be built are planned [9].

The greatest fleet of CNG-fuelled buses in Poland is in Tychy. The bus transport fleet of the city has approx. 73% of vehicles with CNG-fuelled engines, i.e. more than 70 CNG-fuelled buses [12].

3 Internal tests

The rationality of using methane fuels in urban transport is confirmed by internal tests comprising articulated city buses of Euro VI emission level in true traffic conditions. One of the tested buses was powered with a self-ignition engine. The other was powered with a CNG-fuelled engine. The basic engine parameters of the tested buses were as follows: self-ignition engine – engine displacement $V_{ss} = 10.5 \text{ dm}^3$ and nominal power $N_{zn} = 235 \text{ kW}$, CNG-engine displacement $V_{ss} = 12,8 \text{ dm}^3$ and nominal power $N_{zn} = 228 \text{ kW}$.

3.1 Devices and the test route

Internal tests were performed with the use of mobile PEMS measuring devices on urban routes where the tested buses are used on a daily basis.

The exhaust gases emission and fuel consumption of two buses had been measured in a range of driving conditions. The emission of hazardous exhaust substances and fuel consumption were compared owing to measurements made with two devices. Both vehicles moved one after another, which allowed for eliminating errors due to driving style or changeable weather conditions.

The test route combined elements of urban and extra urban (Fig. 1). Parameters of the test route are represented in Table 2.

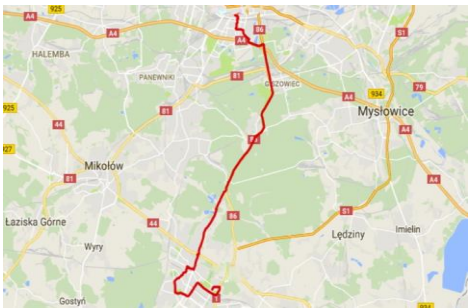


Fig. 1. Test route consisting urban and extra urban part.

Table 2. Characteristics of test route.

Test route	
Length	26 km
Change of altitude	minimum 183 m maximum -178 m
Max. slope	4.7%
Min. slope	-6.9%
Average positive slope	1.3%
Average negative slope	-1.3%

3.2 Test results

The tests were performed with the use of two mobile PEMS devices. The results could be compared because the tests had been conducted simultaneously. For this reason the impact of weather and the driver can be omitted. To better verify the similarities of tests a summary of respective driving phases of both tested buses was provided as shown in Table 3.

Table 3. Values of respective driving phases of tested buses.

	Value	Bus powered by CNG fuel	Bus powered by diesel fuel
Acceleration	%	38	40
Fixed velocity	%	19	9
Braking	%	28	35
Stopover	%	15	17

With the test results, it was possible to determine the content and intensity of flow, depending on the route. Fig. 2 presents the results for CO₂ with reference to the road, for both tested cities buses.

Studies also permitted to determine the present temporary and average fuel consumption, also with reference to the route of both vehicles (fig. 3).

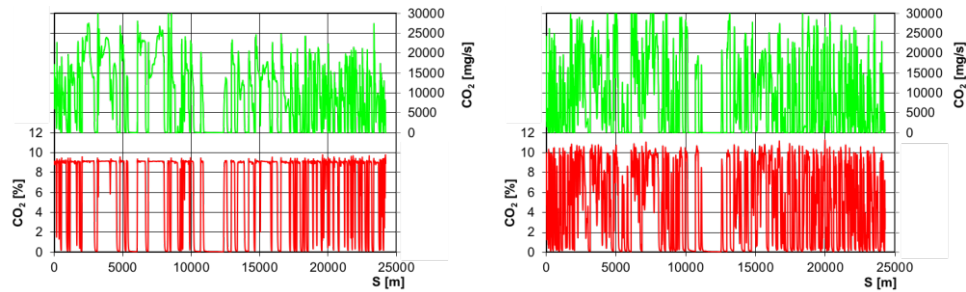


Fig. 2. Concentration and intensity of CO₂ emission with reference to the completed road: I bus – left (CNG-fuelled), II bus – right (diesel fuelled).

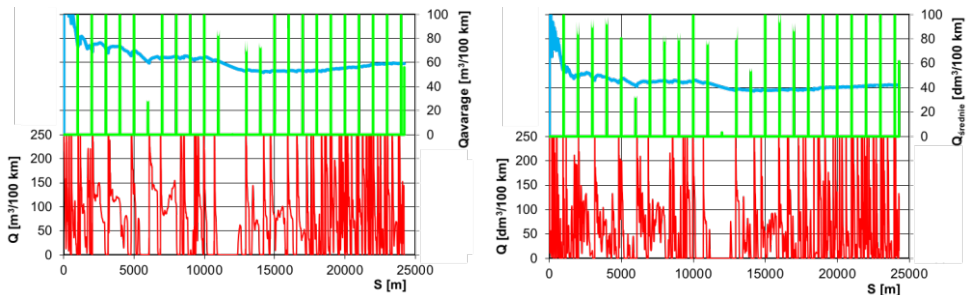


Fig. 3. Characteristics of temporary and average fuel consumption with reference to the completed road: I bus – left (CNG-fuelled), II bus – right (diesel fuelled).

Owing to the tests it was possible to determine time courses for the intensity of emission of hazardous substances of exhaust gases for both buses. Hense, correlations were developed characterising the impact of dynamic properties of public transport buses on the emission of harmful compounds. Dynamic properties of vehicles were included indirectly, using the entire velocity range and the range of measured acceleration in urban traffic for a matrix of intensity of emissions of respective pollutants. Those figures were averaged in respective velocity and acceleration ranges.

Therefore, characteristics of operation in respective ranges and the matrix of emission of harmful compounds had been determined.

According to data presented in Fig. 3 there is a similarity in the portion of operating time for the tested buses. Also, a greater portion of operation is observed in the area of minimum driving speed (stopover) and high driving speeds (10–18 m/s) and zero bus acceleration.

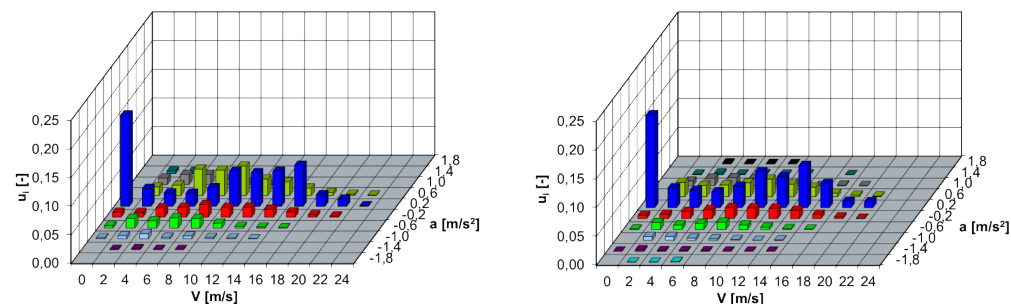


Fig. 4. Two-dimensional histograms of vehicle's operating time in relation velocity – acceleration: I bus – left (CNG-fuelled), II bus – right (diesel fuelled).

Two-dimensional histogram of intensity of CO₂ emission [mg/s] in the relation velocity – acceleration is presented in Fig. 4. It represented indirectly the fuel consumption during the tests. The bus fuelled with CNG was comparable. Histograms of intensity of CO₂ emission during the tests for averaged velocities are represented in Fig. 5.

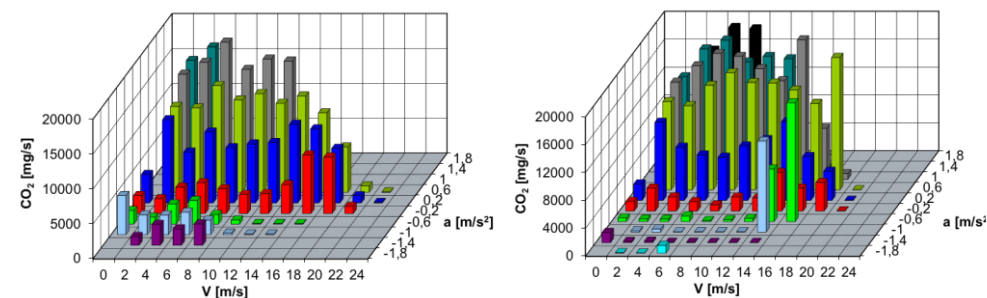


Fig. 5. Two-dimensional histograms of CO₂ emission intensity during the tests in relation velocity – acceleration: I bus – left (CNG-fuelled), II bus – right (diesel fuelled).

In case of the CNG-fuelled bus, attention must be given to NO_x emission, which is lesser than in the diesel-fuelled bus. Fig. 6 presents a two-dimensional histogram of NO_x emission intensity during the tests in the relation velocity – acceleration.

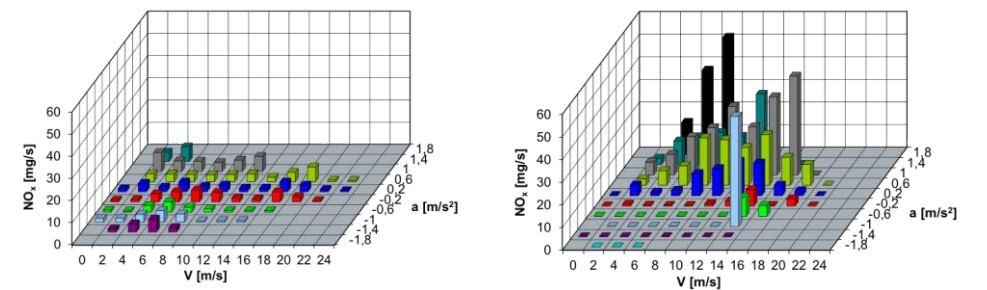


Fig. 6. Two-dimensional histograms of NO_x emission intensity during the tests in relation velocity – acceleration: I bus – left (CNG-fuelled), II bus – right (diesel fuelled).

Also, in case of HC emission intensity, the CNG-fuelled bus manifests lower emission than the diesel-fuelled bus. This is reflected in Fig. 7.

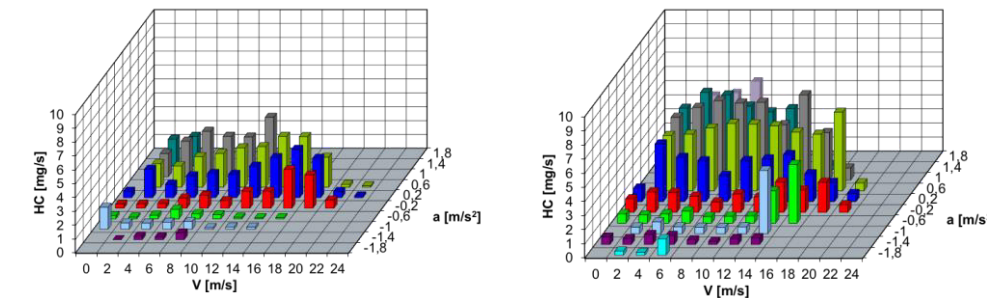


Fig. 7. Two-dimensional histograms of hydrocarbons emission intensity during the tests in relation velocity – acceleration: I bus – left (CNG-fuelled), II bus – right (diesel fuelled).

Fig. 8 presents a comparison of the results of fuel consumption and exhaust emissions during tests.

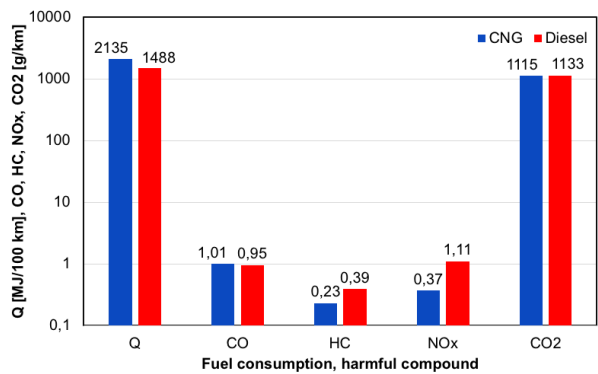


Fig. 8. Comparison of fuel consumption and emission of exhaust gases during tests: ■ – I bus (CNG-fuelled), ■ – II bus (diesel fuelled).

4 Conclusions

The following conclusions follow from tests in true conditions of road traffic:

- fuel consumption (natural gas): approx. 2135 MJ/100 km (CNG-fuelled bus) and approx. 1488 MJ/100 km (diesel-fuelled bus);
- CO emission: 1.01 g/km (CNG-fuelled bus) and 0.95 g/km (diesel-fuelled bus) – increase by ~6% – CNG/ON ratio),
- hydrocarbons emission: 0,11 g/km (CNG-fuelled bus) and 0.39 g/km (diesel-fuelled bus) – decrease by ~40%,
- nitrogen oxides emission: 0.37 g/km (CNG-fuelled bus) and 1.11 g/km (diesel-fuelled bus) – decrease by ~67%,
- CO₂ emission: 1115 g/km (CNG-fuelled bus) and 1133 g/km (diesel-fuelled bus) – decrease by ~1.6%.

The results of the road tests prove that the use of methane fuel such as CNG in city buses can be beneficial in terms of emissions of hydrocarbons and nitrogen oxides.

In the Law on electromobility and alternative fuels (Law of January 11, 2018), compressed natural gas (CNG), including biomethane from CNG, is considered to be an alternative fuel. The minister responsible for energy prepares the National framework for the development of alternative fuels. The national framework includes in particular:

- national target for the number of refueling points for compressed natural gas (CNG),
- list of municipalities and transport networks in which, taking into account market needs, refueling points for compressed natural gas (CNG) are to be deployed.

The minimum number of CNG refueling points located in municipalities until December 31, 2020 shall be at least:

- 6 in communes (population > 1,000,000, registration of at least 60,000 motor vehicles and per 1000 inhabitants there are at least 700 motor vehicles);
- 2 in communes (population> 100,000, registration of at least 60,000 motor vehicles and per 1000 inhabitants there are at least 400 motor vehicles).

The number of CNG refueling points includes CNG refueling points located along the TEN-T core network.

It should be assumed that currently in Poland we are at an essential moment in the development of the use of CNG in road transport.

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