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COMPARISON OF THE ENVIRONMENTAL EFFECT OF M1 CATEGORY VEHICLES FED WITH TRADITIONAL AND ALTERNATIVE FUELS

PORÓWNANIE EFEKTU ŚRODOWISKOWEGO POJAZDÓW KATEGORII M1 ZASILANYCH PALIWEM TRADYCYJNYM I ALTERNATYWNYM

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Summary

The fuels under comparison and the exhaust gas components have been briefly characterized. The pollutant emissions from vehicles powered with traditional fuels and natural gas have been compared with each other, based on the EURO 5 and EURO 6 exhaust emission standards for M1 category vehicles. The emissions from vehicles such as Fiat Panda, Volkswagen Up, Volkswagen Passat, Volkswagen Touran, and Volkswagen Caddy, according to results of type-approval tests and the EURO 5 and EURO 6 standard specifications, have been analysed. Data on noise emission levels, fuel consumption, and vehicle operation costs (fuel costs), related to feeding the vehicles with both conventional and alternative fuels and measured for individual vehicles under consideration, have been presented. According to the data, the CNG-fuelled vehicles were characterized by lower specific distance emission of carbon monoxide in comparison with the similar vehicles powered with petrol. Conversely, the vehicles fuelled with petrol showed lower specific distance emissions of hydrocarbons and nitrogen oxides as against the corresponding vehicles powered with CNG. An exception was Volkswagen Passat,

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for which the test results were different. For all the CNG-fuelled vehicles, the specific distance emission of carbon dioxide was lower than that measured for the similar vehicles powered with conventional fuels.

Keywords: CNG, M1 category vehicles, EURO 5, EURO 6

Streszczenie

W artykule przedstawiono krótką charakterystykę porównywanych paliw oraz składników gazów spalinowych. Porównano emisję zanieczyszczeń pojazdów zasilanych paliwami tradycyjnymi oraz gazem ziemnym, zgodne ze standardem emisji Euro 5 i Euro 6 w kategorii pojazdów M1. Przeanalizowano emisję pojazdów takich jak: Fiat Panda, Volkswagen UP, Volkswagen Passat, Volkswagen Touran, Volkswagen Caddy zgodnie z badaniami homologacyjnymi oraz z normami Euro 5 i Euro 6. Przedstawiono dane dotyczące poziomu natężenia hałasu w poszczególnych opisywanych pojazdach oraz zużycie paliwa i koszty eksploatacyjne (koszty paliwa) związane z zasilaniem pojazdów, zarówno paliwami konwencjonalnymi, jak i paliwami alternatywnymi. Na podstawie danych przedstawionych w niniejszym artykule wynika, iż pojazdy zasilane CNG charakteryzowały się mniejszą emisją drogową tlenku węgla w porównaniu do analogicznych pojazdów zasilanych benzyną, natomiast mniejszą emisję drogową węglowodorów i tlenków azotu wykazały pojazdy zasilane benzyną w stosunku do analogicznych pojazdów zasilanych CNG za wyjątkiem testów dotyczących pojazdu Volkswagen Passat. We wszystkich analizowanych pojazdach zasilanych CNG emisja drogowa ditlenku węgla jest mniejsza niż w analogicznych pojazdach zasilanych paliwami konwencjonalnymi.

Słowa klucze: CNG, M1, Euro 5, Euro 6

1. Introduction

A lively discussion has been held for quite a long time to answer the question, whether traditional or alternative fuels, with natural gas, either compressed (CNG) or liquefied (LNG), being counted among the latter, are more environment-friendly. Apart from explaining the specificity of operation of the engines under consideration and the properties of the fuels used to power the engines, an attempt has been made here to describe the components of gaseous fuels and to compare the pollutant emissions for different M1 category vehicles. The M1 category covers vehicles of category M, i.e. motor vehicles designed and constructed primarily for the carriage of persons and their luggage, comprising not more than eight seating positions in addition to the driver's seating position, with no space for standing passengers; the number of seating positions may be restricted to one (i.e. the driver's seating position) [1]. The comparison between specific distance pollutant emissions has been made in accordance with the European Exhaust Emission Standards (referred to as "EURO 5" and "EURO 6" standards) and with results of type-approval testing of specific vehicles. Apart from the specific distance emissions of individual exhaust gas components, determined at type-approval tests carried out in compliance with the EURO standards, the specific distance emissions of carbon dioxide, noise levels, and annual vehicle operation costs based on fuel consumption have been additionally compared for individual vehicles.

In this paper, the comparison was made for the following vehicles with factory-installed CNG systems and powered by traditional fuels: Fiat Panda and Volkswagen Up in the group of small passenger cars (with engines under 1 000 cm^3), and Volkswagen Passat, Volkswagen Touran, and Volkswagen Caddy in the group of larger passenger cars (with engines of not less than 1 000 cm^3 capacity). The relevant specifications of the vehicles mentioned above have been given in Table 1.

Table 1. Specifications of the vehicles under analysis

Vehicle / fuel	Engine type	Year of manufacture	Engine cubic capacity [cm^3]	Effective power rating [kW]	EURO standard
Fiat Panda					
Petrol	SI*	2013	875	63	5
CNG	SI	2013	875	63	5
Volkswagen Up					
Petrol	SI	2013	999	44	5
CNG	SI	2013	999	50	5
Volkswagen Passat					
Petrol	SI	2013	1 390	118	5
CNG	SI	2013	1 390	110	5
Volkswagen Touran					
Petrol	SI	2013	1 390	103	5
CNG	SI	2013	1 390	110	5
Volkswagen Caddy					
Diesel oil	CI**	2013	1 968	81	5
CNG	CI	2013	1 984	80	5

*SI – Spark-ignition engine
**CI – Compression-ignition engine

2. Description of the fuels compared and the engines powered by them

Petrol (also referred to as motor spirit or gasoline) is a mixture of hydrocarbons belonging to the groups referred to as alkanes, alkenes, and aromatic hydrocarbons, with their boiling points ranging from 30 °C to 215 °C and the numbers of carbon atoms per molecule varying from C_4 to C_{10}. At present, petrol also contains non-hydrocarbon components such as ethers and alcohols as well as some additives that improve its operating characteristics. The fuel that can be used for spark-ignition engines must intensively evaporate in the engine feeding system or in the engine cylinder; it may have the form of either a liquid or a gas.

The spark-ignition engine may be fuelled with the use of carburettor, fuel injection system (direct or indirect, single-point or multi-point), or gas mixer [2].

Diesel oils are mixtures of hydrocarbons with the numbers of carbon atoms per molecule varying from C_{11} to C_{25} and with the boiling points of the hydrocarbons ranging from 150 °C to 360 °C. The properties of the fuels intended for compression-ignition (CI) engines significantly differ from those of petrol fuels [3].

CNG (Compressed Natural Gas) is natural gas compressed to a pressure of 20-25 MPa [4]. It is used for the fuelling of motor vehicles with both SI and CI engines. The calorific value of 1 m^3 of CNG in standard reference conditions (Nm^3) is approximately equal to that of 1 dm^3 of petrol. The mass of 1 Nm^3 of natural gas is about 0.7 kg and it depends on the actual gas composition. Thanks to the use of natural gas, the emission of carbon dioxide, which is counted among the greenhouse gases, may be considerably reduced in comparison with that obtainable in the case of petrol fuelling [3]. CNG installations are particularly suitable for spark-ignition engines of large cubic capacity; in the national markets where diesel engines predominate, however, the use of CNG engine fuelling systems is more complicated [5]. One of the problems encountered when CNG is to be used as a fuel may be the necessity to install high-pressure (about 20 MPa) tanks in vehicles [4]. In Poland, the network of CNG filling stations is being continuously developed, but with an insufficient rate. It should be mentioned here that the location of such stations depends on the gas supply infrastructure, because CNG is not supplied by road tankers; instead, it is provided by compressing the natural gas taken from the national grid.

3. Exhaust gas components

It should be remembered that the use of motor vehicles does not only mean facilitation connected with trouble-free moving from one place to another, because it also entails a great problem arising from the emission of exhaust gases generated during the combustion of air-fuel mixture. Motor vehicle exhaust gases constitute the greatest source of environmental pollution, as they load the environment with many chemical compounds. The motor vehicle exhaust gases are much more harmful for people than industrial pollutants because they spread in high concentrations at low heights in immediate people's surroundings. This is the reason for which worldwide actions have been undertaken to determine the maximum acceptable concentrations of the major toxic substances in the environment. The European Union has developed a series of directives in pursuance of which increasingly stringent requirements were successively introduced as regards the contents of toxic substances in fuels. The maximum acceptable exhaust emissions from new vehicles sold within the EU territory have been specified in the European Exhaust Emission Standards (see Section 4).

The vehicles that do not meet the exhaust emission requirements must not be sold within the EU territory. This exclusively applies to new vehicles, while those having already been used on EU roads are not subject to such restrictions. New engine models must be in conformity with the existing or planned standards; however, engine versions subjected to some limited modifications may be allowed in the case of vehicle models with short service life. Individual vehicle types are subject to different standards.

The components of engine exhaust gases are divided into toxic compounds, i.e. carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO_x), and non-toxic compounds, i.e. carbon dioxide (CO_2), oxygen (O_2), nitrogen (N_2), and water vapour (H_2O).

The toxic fuel combustion products, even in very low concentrations, may cause various adverse effects. One of the chemical compounds generated in result of incomplete fuel combustion is carbon monoxide formed in the engine combustion chamber at insufficient supply of air (oxygen). Carbon monoxide is a highly poisonous, colourless, and odourless gas. High carbon monoxide content values indicate too rich air-fuel mixture and this will lead to incomplete combustion of fuel components. In vehicles provided with catalytic converters, carbon monoxide undergoes further oxidation and is transformed into carbon dioxide, thanks to which the carbon monoxide emission in engine exhaust gases is reduced [6, 7].

Other exhaust gas components, which are emitted as products of incomplete fuel combustion or as unburnt fuel particles, are hydrocarbons (HC) [8]. These compounds are particularly toxic, very harmful to the human body. Among them, polycyclic aromatic hydrocarbons constitute the most dangerous group. Dissolving in fats, hydrocarbons may accumulate in human and animal tissues. In vehicles provided with catalytic converters, hydrocarbons oxidize to form carbon dioxide and water vapour.

The chemical compounds emitted to the atmosphere with exhaust gases also include nitrogen oxides. The nitrogen oxide emission rate depends on the pressures and maximum temperatures (exceeding 1 800 °C) that occur during the combustion process in the engine cylinder. During the process, nitrogen reacts with oxygen to form nitrogen monoxide and small quantities of nitrogen dioxide and dinitrogen monoxide (nitrous oxide) [6]. These substances are counted among the most toxic combustion gases. Nitrogen monoxide [9] is a colourless gas, which swiftly reacts in the human body with haemoglobin and oxidizes in body tissues to nitrogen dioxide [10]. The nitrogen dioxide, red-brown in colour, with sharp smell and poisonous properties, is always accompanied by other nitrogen compounds. In small concentrations, it causes irritation to the respiratory tract; when its concentration in air exceeds 0.38 mg/dm^3, it leads to fatal poisoning. In vehicles provided with catalytic converters, reduction of the nitrogen oxides contained in exhaust gases takes place, i.e. oxygen is detached from nitrogen oxides and pure nitrogen is liberated.

Apart from the compounds mentioned above, particulate matter (PM) may also occur in the engine exhaust gases [8]. The term "particulate matter" refers to products having a liquid or solid consistency, escaping from the engine exhaust system and comprising, *inter alia*, particles of carbon, sulphur and nitrogen compounds, metals, and heavy hydrocarbons. Such particles predominantly consist of soot and unburnt hydrocarbons. They are considered harmful because of a tendency of carcinogenic substances coming from the unburnt fuel to settle on them; moreover, they cause engines to smoke.

4. European Exhaust Emission Standards (the EURO standards)

The European Exhaust Emission Standards define the acceptable specific distance exhaust emissions from new vehicles sold within the European Union territory; they are popularly referred to as EURO standards. At present, maximum pollutant emission limits have been laid down for most types of transport facilities and other machines, i.e. passenger cars, motor trucks, buses, tractors, construction machinery, as well as seagoing vessels and aircraft. Individual machine types are subject to different standards provided in the form of European Directives. Furthermore, different specific distance emission limits have been introduced by EU regulations for vehicles with compression-ignition and spark-ignition engines. The vehicles fuelled with diesel oil are subject to more stringent standards as regards the specific distance emission of carbon monoxide; on the other hand, higher specific distance emissions of nitrogen oxides have been allowed for them. At present, the requirements to be met by all the new vehicles, whether provided with CI or SI engines, are those laid down in the EURO 6 standard.

This paper presents a comparison of exhaust emissions from vehicles fuelled traditionally and with natural gas; the emissions were determined in accordance with the EURO 5 and EURO 6 emission standards for M1 category vehicles (Table 2).

Table 2. European standards for specific distance emissions of individual exhaust gas components from passenger cars (category M1) [7]

Values in [g/km]	Diesel oil		Petrol	
	EURO 5	EURO 6	EURO 5	EURO 6
Effective from	**September 2011**	**September 2014**	**September 2009**	**September 2014**
CO	0.5	0.5	1	1
HC	0.05*	0.09*	0.1	0.1
HC+NOx	0.23	0.17	0.16**	0.16**
NO_x	0.18	0.08	0.06	0.06
PM	0.005	0.005	0.005	0.005

* Value unspecified in the emission standard, determined as a difference between the $HC+NO_x$ and the NO_x specific distance emission values

** Value unspecified in the emission standard, determined as a sum of the HC and NO_x specific distance emission values

The emissions from the vehicles listed in Table 1 were analysed in accordance with results of type-approval tests and with the EURO 5 and EURO 6 standard requirements. Data obtained from type-approval tests, presented on the EcoScore project website [11], were used for the analysis. The EcoScore project is aimed at estimating the harmful environmental impact of specific vehicle types and models used in Belgium, both new and old.

The results of testing the vehicles listed in Table 1, used for this analysis, were provided for the needs of the EcoScore project by the Dutch authority that handles vehicle registration issues (*Rijksdienst voor Wegverkeer* (RDW)).

The data for the vehicles under consideration have been presented below in the form of tables and graphs. At the first stage, dedicated to small passenger cars, the measured pollutant emissions from the Fiat Panda car were analysed. The specific distance emissions of carbon monoxide, hydrocarbons, nitrogen oxides, and particulate matter from the petrol-fuelled vehicle of 875 cm^3 engine capacity and 63 kW effective power rating were compared with the corresponding data for the vehicle fuelled with CNG; the emissions were also compared with the EURO 5 and EURO 6 standard requirements. Although the analysed models of this vehicle were in conformity with all the specific distance pollutant emission limits set in the EURO 5 and EURO 6 standards, specific distance pollutant emission values were not identical for different fuelling types. For the vehicle powered by CNG, the carbon monoxide emission was found to be lower by 0.006 g/km than that for the car fuelled with petrol. Conversely, the CNG-fuelled car showed higher specific distance emissions of hydrocarbons and nitrogen oxides in comparison with the car fuelled with petrol. Thus, the conversion of this car from petrol to CNG fuelling has resulted in mere 3 % reduction in the specific distance emission of carbon monoxide, which cannot be considered satisfactory, especially when compared with the increased specific distance emissions of hydrocarbons and nitrogen oxides.

Table 3. Specific distance pollutant emissions from Fiat Panda, according to results of type-approval tests and EURO standard specifications

[g/km]	EURO 5	EURO 6	Petrol	CNG
CO	1	1	0.264	0.258
HC	0.1	0.1	0.039	0.055
NO_x	0.06	0.06	0.027	0.031
PM	0.005	0.005	0	0

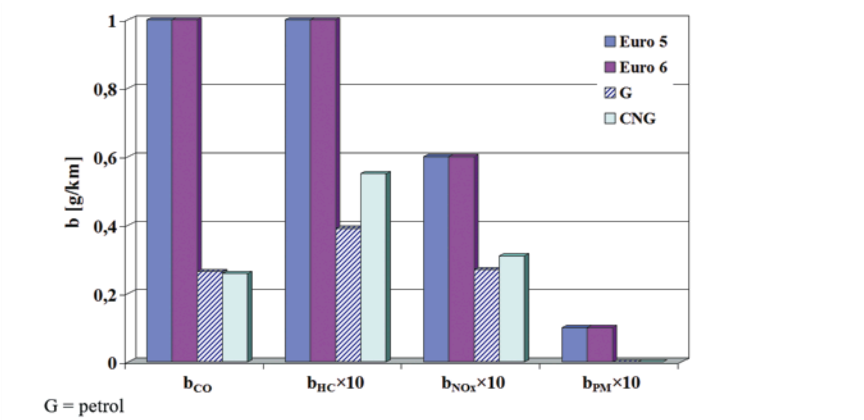

Fig. 1. Specific distance pollutant emissions from Fiat Panda, according to results of type-approval tests and EURO standard specifications

As another sample of the group of small passenger cars, the Volkswagen Up vehicle model was examined. Two such cars were compared with each other. They were provided with engines of identical cubic capacity equal to 999 cm^3 but of different effective power ratings, equal to 44 kW and 50 kW for the petrol and CNG fuelling, respectively. Both of the vehicles under examination were in conformity with the current exhaust emission standard

EURO 6. However, the vehicle fuelled with CNG emitted far less carbon monoxide than the car with a petrol engine. On the other hand, the specific distance emissions of hydrocarbons and nitrogen oxides were found again to be lower for the vehicle with petrol fuelling. Thus, the general trend observed for the Volkswagen Up was similar to that for the Fiat Panda; however, the fact that the use of a CNG engine resulted in a significant reduction in the specific distance emission of carbon monoxide (to as little as one-sixth of that from the petrol-fuelled vehicle) is a strong argument for the Volkswagen model powered by CNG.

Table 4. Specific distance pollutant emissions from Volkswagen Up, according to results of type-approval tests and EURO standard specifications

[g/km]	EURO 5	EURO 6	Petrol	CNG
CO	1	1	0.336	0.055
HC	0.1	0.1	0.033	0.06
NO_x	0.06	0.06	0.009	0.013
PM	0.005	0.005	0	0

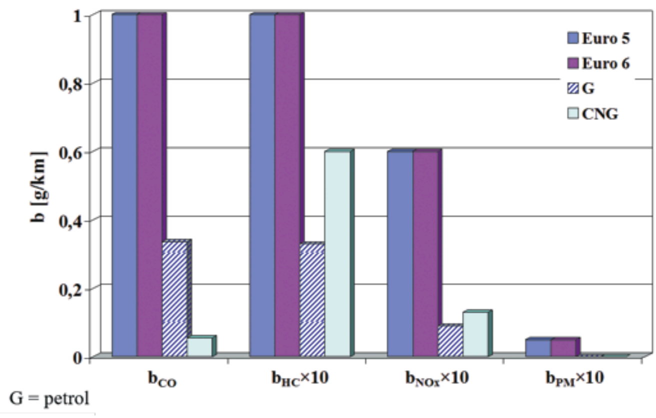

Fig. 2. Specific distance pollutant emissions from Volkswagen Up, according to results of type-approval tests and EURO standard specifications

At the next stage, the comparison was carried out for larger M1 vehicles. At first, two Volkswagen Passat cars were examined, provided with engines of 1 390 cm^3 capacity each and fuelled with petrol and CNG, of 118 kW and 110 kW effective power rating, respectively. Again, both of these vehicles met the EURO 6 emission standard requirements. In this case, too, the CNG-fuelled car, like Fiat Panda and Volkswagen Up, showed lower specific distance emission of carbon monoxide in comparison with that from the corresponding car with a petrol engine (reduced almost to one-third in this case). Simultaneously, in contrast to the case with the Fiat Panda CNG and Volkswagen Up cars, the specific distance emission of nitrogen oxides was lower, and by a half at that, than this emission from the corresponding car fuelled with petrol. As it was observed at the examination of small cars, the specific distance emission of hydrocarbons from the CNG-powered vehicle was found to be higher than that from the vehicle fuelled with petrol. At the same time, insignificant specific distance emission of particulate matter occurred in the case of the petrol engine.

Table 5. Specific distance pollutant emissions from Volkswagen Passat, according to results of type-approval tests and EURO standard specifications

[g/km]	EURO 5	EURO 6	Petrol	CNG
CO	1	1	0.281	0.094
HC	0.1	0.1	0.042	0.049
NO_x	0.06	0.06	0.053	0.025
PM	0.005	0.005	0.001	0

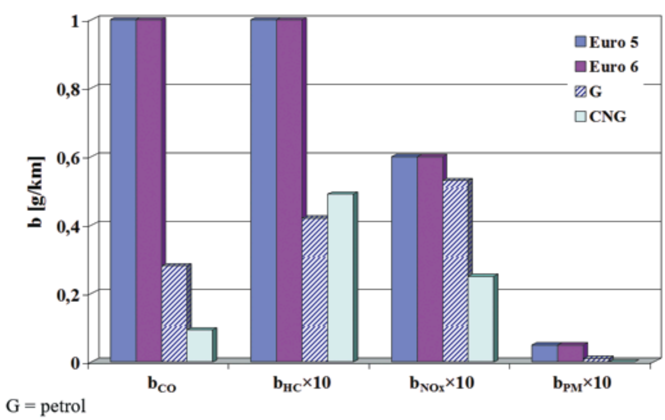

Fig. 3. Specific distance pollutant emissions from Volkswagen Passat, according to results of type-approval tests and EURO standard specifications

As the next pair, Volkswagen Touran cars were analysed, with petrol and CNG engines of 1 390 cm^3 capacity in both cases, of 103 kW and 110 kW effective power rating, respectively. As it was in the case of smaller cars, the specific distance emission of carbon monoxide from the CNG engine was lower (reduced to one-sixth) and the specific distance emissions of hydrocarbons and nitrogen oxides were higher than the corresponding emissions from the petrol engine, which is consistent with the general trend observed for the CNG-fuelled vehicles. Simultaneously, some small particulate matter emission was recorded for the petrol engine.

Table 6. Specific distance pollutant emissions from Volkswagen Touran, according to results of type-approval tests and EURO standard specifications

[g/km]	EURO 5	EURO 6	Petrol	CNG
CO	1	1	0.661	0.108
HC	0.1	0.1	0.065	0.078
NO_x	0.06	0.06	0.028	0.046
PM	0.005	0.005	0.003	0

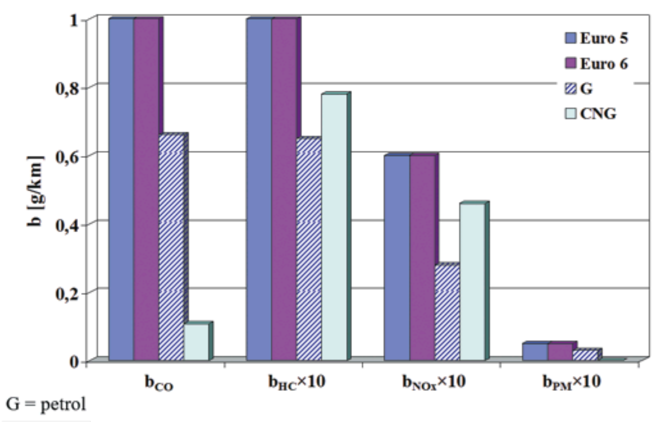

Fig. 4. Specific distance pollutant emissions from Volkswagen Touran, according to results of type-approval tests and EURO standard specifications

At last, the comparison was carried out for Volkswagen Caddy cars. In this case, one of the vehicles under examination was provided with a CNG engine of 1 984 cm^3 capacity and 80 kW effective power rating and the other one had a compression-ignition (CI) engine powered by diesel oil, of 1 968 cm^3 capacity and 81 kW effective power rating. Both vehicles met the EURO 5 standard requirements but only the vehicle with a CNG engine was in conformity with the EURO 6 standard. The diesel car failed to meet the EURO 6 requirements because of excessive sum of the specific distance emissions of hydrocarbons and nitrogen oxides. The vehicle with a diesel engine showed a lower specific distance emission of carbon monoxide; in respect of the other emissions examined, better results were obtained for the car fuelled with CNG. This can be explained by CI engine's design features.

Table 7. Specific distance pollutant emissions from Volkswagen Caddy, according to results of type-approval tests and EURO standard specifications

[g/km]	EURO 5	EURO 6	Diesel oil	CNG
CO	0.50	0.50	0.358	0.377
HC	0.05	0.09	0.06	0.029
NO_x	0.18	0.08	0.116	0.017
$HC+NO_x$	0.23	0.17	0.176	0.046
PM	0.005	0.005	0	0

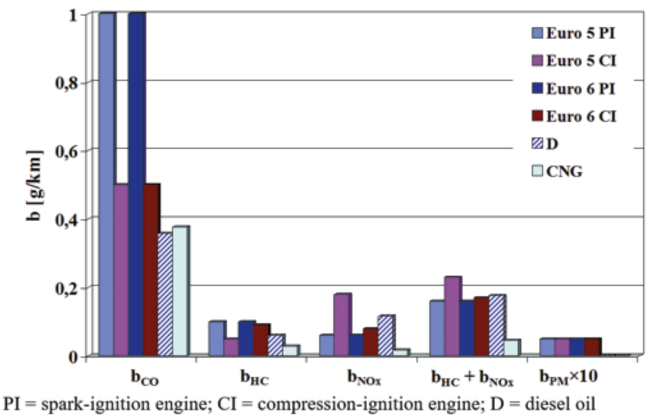

Fig. 5. Specific distance pollutant emissions from Volkswagen Caddy, according to results of type-approval tests and EURO standard specifications

5. Specific distance emission of carbon dioxide

The specific distance emission of carbon dioxide from the vehicles under consideration has been presented in Table 8 and, split into vehicle groups, in Figs. 6 and 7 (calculated for the assumed annual average numbers of kilometres travelled as specified in Section 7).

Table 8. Specific distance emission and annual emission of carbon dioxide from the vehicles under test

Vehicle / fuel	Specific distance CO_2 emission [g/km]	Annual CO_2 emission [kg/a]
Fiat Panda		
Petrol	99	1 188
CNG	86	1 032
Volkswagen Up		
Petrol	95	1 140
CNG	79	948
Volkswagen Passat		
Petrol	142	1 704
CNG	119	1 428
Volkswagen Touran		
Petrol	154	1 848
CNG	125	1 500
Volkswagen Caddy		
Diesel oil	168	2 016
CNG	156	1 872

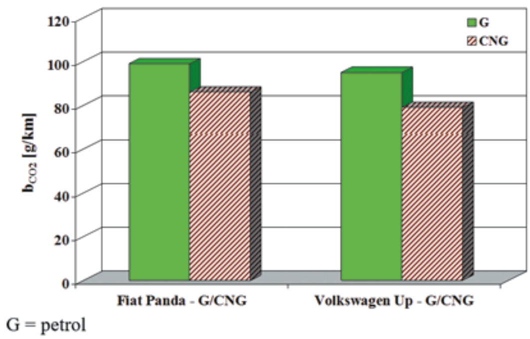

Fig. 6. Specific distance emission of carbon dioxide from small passenger cars

For the small passenger cars with petrol engines, i.e. Fiat Panda and Volkswagen Up, the values of the specific distance emission of carbon dioxide were close to each other (the difference was 4 g/km), with these results being at the same time definitely worse (by about 13-16 g/km) from those obtained for the CNG cars of the same category.

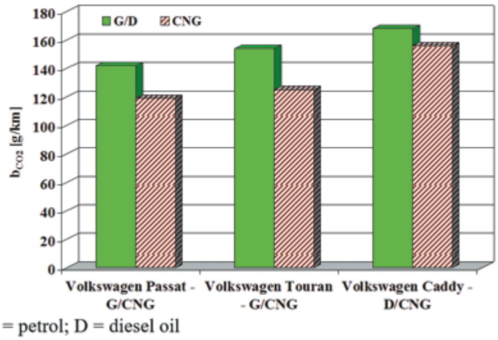

Fig. 7. Specific distance emission of carbon dioxide from larger passenger cars

For the larger cars with petrol engines, the values of the specific distance emission of carbon dioxide were definitely higher as against those recorded for the cars with CNG engines. A similar situation could be observed for the diesel and CNG versions of the Volkswagen Caddy vehicle: the car with a CNG engine emitted significantly lower quantities of pollutants than the car powered by diesel oil did, but this emission was anyway higher than the values recorded for the examined cars with petrol engines.

6. Noise level

Data on the noise emission from individual vehicle models under examination have been presented in Table 9 and in Fig. 8. The span of the levels of noise emitted from individual car models under consideration was 6 dB. When the vehicles with petrol and CNG engines were compared with each other, it was only in the single case of petrol-fuelled Volkswagen Passat that the noise emission was lower than that observed for the corresponding car model powered by the alternative fuel.

In this group of vehicles, noteworthy are the particularly poor Fiat Panda noise performance parameters. The noise emission from this vehicle reached the highest levels for both the petrol and CNG fuelling.

For the vehicle versions under examination provided with CI engines, the noise emission remained at the same level whether the vehicle was fuelled with diesel oil or CNG and this level reached the highest values among the emissions from all the vehicles discussed here.

Table 9. Noise emissions from the vehicles examined

Vehicle / fuel	Noise emission [dB]
Fiat Panda	
Petrol	73
CNG	72
Volkswagen Up	
Petrol	71
CNG	69
Volkswagen Passat	
Petrol	68
CNG	70
Volkswagen Touran	
Petrol	70
CNG	69
Volkswagen Caddy	
Diesel oil	74
CNG	74

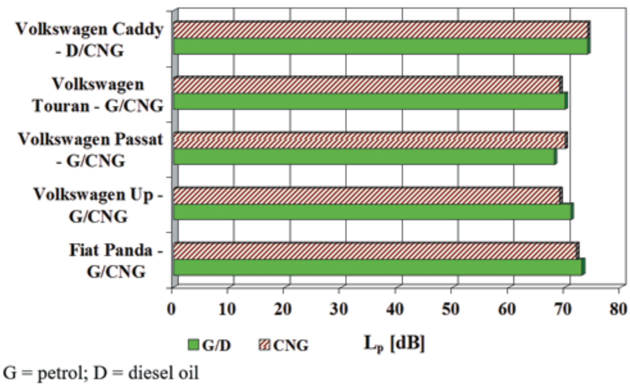

Fig. 8. Noise emitted from individual car models under consideration

7. Fuel consumption and annual fuel costs

For the needs of these calculations, the annual average number of kilometres travelled by a passenger car was assumed as about 12 000 km. This figure is an estimate based on experts' knowledge of the numbers of kilometres travelled by new vehicles. According to literature, the average numbers of kilometres annually travelled by passenger cars, depending on the fuel used, are 5 876 km for petrol, 12 016 km for diesel oil, 10 093 km for LPG, and 12 000 km for CNG [12]. The fuel consumption was assumed on the grounds of results of tests carried out for individual vehicle models (see Table 10).

For all the vehicle groups, the lowest operation costs (fuel costs) are borne in the case of vehicles powered by CNG, where these costs as against those for the vehicles powered by conventional fuels are lower by even more than 30 %. In the group of small cars, the vehicle characterized by the lowest operation costs is Volkswagen Up. This is because of lower petrol and CNG consumption in comparison with that of Fiat Panda. For the larger cars fuelled with CNG, the operation costs are lower by about 30 % in comparison with those of the corresponding models with petrol engines.

The smallest difference, equal to about 15 %, in the fuel costs was recorded for Volkswagen Caddy cars with diesel and CNG engines, to advantage of the latter. The fact that this difference was so small was caused by relatively higher consumption of CNG in comparison with that of diesel oil.

Table 10. Operation costs (fuel costs) for the vehicles under consideration

Vehicle / fuel	Operational fuel consumption per 100 km	Annual fuel consumption	Gross fuel price [PLN]*	Annual fuel cost [PLN/a]
Fiat Panda				
Petrol [dm^3]	4.2	504	4.37 [2]	2 202.48
CNG [Nm^3]	4.8	576	3.29** [13]	1 895.04
Volkswagen Up				
Petrol [dm^3]	4.1	492	4.37	2 150.04
CNG [Nm^3]	4.4	528	3.29	1 737.12
Volkswagen Passat				
Petrol [dm^3]	6.1	732	4.37	3 198.84
CNG [Nm^3]	6.7	804	3.29	2 645.16
Volkswagen Touran				
Petrol [dm^3]	6.6	792	4.37	3 461.04
CNG [Nm^3]	7.0	840	3.29	2 763.60
Volkswagen Caddy				
Diesel oil [dm^3]	6.4	768	4.30 [2]	3 302.40
CNG [Nm^3]	8.7	1 044	3.29	3 434.76

* As of 2 Dec. 2015
** Price in Warsaw

8. Conclusions

The following conclusions may be formulated, based on the data presented and analysed in this paper:

1. All the vehicles examined where petrol or CNG engines were used met the current exhaust emission standard EURO 6.

2. For all the vehicles examined, whether fuelled with petrol or CNG, the specific distance emission of carbon monoxide was lower for the CNG version. However, different values of this emission were recorded for specific vehicles.

3. As regards the specific distance emissions of hydrocarbons and nitrogen oxides, lower emission values were recorded for vehicles fuelled with petrol as against their CNG versions, except for the test results obtained for Volkswagen Passat, whose CNG version showed a specific distance emission of nitrogen oxides being lower by more than a half in comparison with that of the corresponding petrol-fuelled car.

4. The examination of comparable vehicles fuelled with diesel oil and CNG resulted in a finding that the CNG vehicle version was in conformity with the EURO 6 exhaust emission standard, while the version powered by diesel oil met only the EURO 5 standard requirements (the total value of its specific distance emissions of hydrocarbons and nitrogen oxides exceeded the acceptable limit specified in the EURO 6 standard).

5. For all the vehicles examined with CNG fuelling, the values of the specific distance emission of carbon dioxide were lower in comparison with those recorded for the corresponding vehicle versions powered by conventional fuels. The smallest difference occurred for the vehicle with a CI engine.

6. For all the vehicles examined, the noise emissions were found to be at a similar level regardless of the fuel type used.

7. The costs of the fuel consumed by all the vehicles under examination were lower in the case of CNG fuelling as against those recorded for the corresponding vehicles where conventional fuels were used. The savings may even reach 30% in annual terms.

Based on this analysis, a statement may be made that vehicles fuelled with CNG are more environment-friendly than the corresponding vehicles powered by conventional fuels. Admittedly, not all the emissions of the pollutants under consideration were lower in comparison with those from the corresponding vehicles powered by conventional fuels. Nevertheless, the differences occurring were relatively small and the total emission of harmful substances was definitely lower.

Moreover, the CNG purchase cost is considerably lower than that of conventional fuels. It should also be remembered that the costs of traditional fuels actually cannot be predicted and most likely, they will not decrease, while the prices of compressed natural gas may be reduced thanks to diversification of supply sources and possible use of shale gas.

The full text of the article is available in Polish online on the website http://archiwummotoryzacji.pl.

Tekst artykułu w polskiej wersji językowej dostępny jest na stronie http://archiwummotoryzacji.pl.

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