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Management of the ecological safety of urban zones in terms of sources of power supply for buses

J Napiórkowski¹ and P Szczylak¹ and A Langer¹

¹ University of Warmia and Mazury in Olsztyn, Faculty of Technical Sciences, Poland
E-mail: jerzy.napiorkowski@uwm.edu.pl

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1. Introduction

A side effect of the widespread use of means of transport is air pollution. One method for its reduction in urban environments is the widespread of public transport. A bus emitting little more exhaust fumes than a passenger car transports as many people as 70 cars at the same time. Exhaust gases constitute a load of more than 15 thousand chemical compounds. Means of road transport are responsible for the emission of many hazardous substances, including nitrogen oxides and dioxides, carbon dioxide, and particulate matter suspended in the air [1, 2, 6]. All liquid, solid and gaseous substances whose content in the air exceeds the average content in clean air are called pollutants. Their harmfulness for the environment results from many factors, such as state of matter, extent of dispersion, chemical and toxic properties, concentration in the air, climatic and meteorological conditions, time of interaction, etc. [3, 7].

Vehicle exhaust fumes are more harmful to people than pollution which originates from industry, as they spread at high concentrations at low heights in the immediate vicinity of people. Basic pollutants include:

- Nitrogen oxides NO_x;
- Carbon oxide CO ;
- PM – 10.

In the case of long-term exposure all emitted substances cause the development of cancer cells. High concentrations of exhaust fumes lead to the formation of smog (London, photochemical) and to the greenhouse effect. In tables 1 acceptable levels of substances in the air in terms of health protection in accordance with applicable legislation are presented. Urban buses should be



distinguished by low noise emissions, engines equipped with filters, and catalysts limiting the content of hazardous substances in exhaust fumes [4, 5, 8].

Table 1. Substance emission values for new vehicles with compression-ignition engines

Standard	Effective from	CO [g/km]	HC + NO _x [g/km]	PM [g/km]
Euro I	07/92	3.16	1.13	0.14
Euro II	01/96	1.00	0.70	0.08
Euro III	01/00	0.64	0.56	0.05
Euro IV	01/05	0.50	0.30	0.009
Euro V	09/09	0.50	0.23	0.005
Euro VI	08/14	0.50	0.17	0.005

In the paper an analysis of the content of hazardous substances in public transport buses, depending on the type of energy source in terms of the ecological safety of the population, is presented.

2. Materials and Methods

The subject of the study comprised buses of public transport (table 2) belonging to the same class (midi) and supplied with diverse sources of energy (table 3). The study was conducted under normal operating conditions in two cities with similar populations, using an active-passive experiment. During the study the actual consumption of energy means by the full tank method, and travelled distance as indicated by odometer, were recorded. The studies were performed in May and September.

The average annual mileage for all buses was 7,700,000 km. Annually, each bus covers an average route of 46,107 km, which is 126 km daily.

The study included the following buses and their characteristics and characteristics of fuels are presented in Tables 4 and 5:

- MAN NL202 – a bus supplied with diesel fuel;
- Scania OmniLink – a bus supplied with ethyl alcohol (ethanol) C₂H₅OH;
- Scania OnmiCity – a bus supplied with compressed gas CNG (Compressed Natural Gas);
- Solbus Solcity – a bus supplied with liquefied gas LNG (Liquefied Natural Gas);
- Solaris Urbino 12 – a bus supplied with fuel oil.

Table 2. Characteristics of the study vehicles

Buses Parameters	MAN NL 202	Scania OmniLink ethanol	Scania OmniCity CNG	Solbus Solcity	Solaris Urbino 12
Engine	D0826LUH03	DC 9.01	DC 9.01	Cummins ISB6.7EV	Cummins ISB6.7
Engine displacement [l]	6.9	8.9	8.9	8.9	8.9
Number of cylinders	6	8	5	6	6
Engine power [kW]	156	169	169	184	209
EURO standard	2	5	5	6	6
Number of standing	66	70	80	82	82

places Number of seats	30	29	30	37	37
Year of production	1990	2005	2006	2008	2014

Table 3. Characteristics of fuels

Characteristic	Diesel fuel	Ethanol	CNG	LNG
Chemical formula	C ₁₅ H ₃₂ , C ₁₈ H ₃₈	C ₂ H ₅ OH	CH ₄	CH ₄
Calorific value	43 [MJ/kg]	26.8 [MJ/kg]	45-50 [MJ/kg]	45-50 [MJ/kg]
Flame temperature [K]	328 <	2185	630 - 640	600
Viscosity at 296K [cSt]	3	1.51		10.22x10 ⁶
Octane rating [OR]	72	108	130	130
Density	830 [kg/m ³]	789.3 [kg/m ³]	0.7175 [kg/Nm ³]	450 [kg/m ³]
Boiling point	175	78.37	-161.49	-161.49
Melting point	Not determined	- 114	-182.6	-182.6

3. Results

Vehicles, depending on the applied energy source, are characterised by a varied amount of consumed energy carriers (table 4).

Table 4. Consumption of energy carriers

Vehicle	Type of fuel	Average consumption of fuel		Energy consumed by vehicle [kWh/100km]
Scania OmniLink	Ethanol	73.89 [dm ³ /100km]	58.392 [kg/100km]	1564.905
Scania OmniCity	CNG	58.60 [nm ³ /100km]	42.045 [kg/100km]	1892.025
MAN NL 202	ON	39.64 [dm ³ /100km]	32.901 [kg/100km]	1414.743
Solbus Solcity	LNG	51.66 [nm ³ /100km]	37.06 [kg/100km]	1667.7
Solaris Urbino 12	ON	36.30 [dm ³ /100km]	30.129 [kg/100km]	1295.547

The largest amount of fuel was used by the bus supplied with ethyl alcohol, followed by CNG and LNG, while the lowest consumption was recorded in the case of vehicles supplied with diesel fuel. The high consumption of ethanol is caused by its low calorific value compared to other energy carriers. After the determination of the energy value stored in particular energy carriers consumed during the test at a distance of 100 km, it was found that the amount of energy stored in the used ethanol was not the highest, and equalled 1564.905 kWh. The highest amount of consumed energy was recorded in the case of the bus supplied with CNG (1892.025 kWh). Slightly less energy was used by the vehicle supplied with (1667.7 kWh), while the lowest amount was used by the modern compression-ignition engine (1295.547 kWh).

In tables 5–7 characteristics of the generation of hazardous substances during the test are presented.

Table 5. Characteristics of generated hazardous substances over a distance of 100 km [g/km]

Daily amount of generated substances (type of fuel)	MAN NL 202 (ON)	Scania OmniLink (Ethanol)	Scania OmniCity (CNG)	Solaris Urbino (ON)	Solbus Solcity (LNG)
PM	35.32	1.36	0.85	1.38	0.48
HC+NO _x	285.07	-	29.01	46.83	20.43
CO	797.17	135.34	85.32	137.74	42.5

Table 6. Characteristics of hazardous substances generated during one day [g/km]

Daily amount of generated substances	MAN NL 202 (ON)	Scania OmniLink (Ethanol)	Scania OmniCity (CNG)	Solaris Urbino (ON)	Solbus Solcity (LNG)
PM	44.5	1.70	1.075	1.74	0.6
HC+NO _x	359.18	-	36.55	59.01	25.73
CO	1004.43	170.52	107.51	173.55	53.55

Table 7. Characteristics of hazardous substances generated during one year [g/km]

Daily amount of generated substances	MAN NL 202 (ON)	Scania OmniLink (Ethanol)	Scania OmniCity (CNG)	Solaris Urbino (ON)	Solbus Solcity (LNG)
PM	16242.5	620.50	392.36	635.1	219
HC+NO _x	131100.7	-	13340.75	21538.65	9391.45
CO	366616.95	62239.80	39241.15	63345.75	19545.75

The most ecological bus was Solbus Solcity, which for 100 kg emits particulate matter at an amount lower by 41% compared to a bus supplied with ethyl alcohol, by 77% compared to a bus supplied with compressed natural gas CNG, and nearly three times less than a bus supplied with diesel fuel. The bus which was supplied with diesel fuel emitted the largest amount of hazardous exhaust fumes. The level of HC+NO_x was over 2.29 times higher, while for CO it was 3.24 times higher in comparison to the bus supplied with LNG

A bus supplied with diesel fuel produces 0.42 kg of particulate matter, 12.15 kg of HC+NO_x and 54 kg of CO yearly. In turn, these values for the supplied bus in the case of Olsztyn for 10 buses are 4.2 kg, 120 kg of HC+NO_x, 540 kg of CO.

4. Conclusions

Management of the safety of big city populations begins as early as at the time of planning the purchase of public transport means. The selection of the appropriate fleet will help to minimise the negative impact of the urban communication system on the environment. Public transport, particularly buses, will continue to be the primary means of population movements. The purchase of buses supplied with conventional fuels, in heavy traffic, contributes to increased emissions of nitrogen oxides, particulate matter, carbon dioxide and noise. The use of vehicles supplied with ethanol is ecologically justified, but the high operating costs of this type of vehicle means that public transport companies give up this solution, an example of which is the decommissioning of buses supplied with

ethanol after the completion of the test programme. Therefore, the protection of the environment of humans, and the issues of the diversification of energy sources should constitute the basic reasons for the purchase of buses supplied with gas fuel, particularly LNG.

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