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

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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 NOx;
- 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 + NOx [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:

a) MAN NL202 – a bus supplied with diesel fuel;
b) Scania OmniLink – a bus supplied with ethyl alcohol (ethanol) C₂H₅OH;
c) Scania OmnìCity – a bus supplied with compressed gas CNG (Compressed Natural Gas);
d) Solbus Solcity – a bus supplied with liquefied gas LNG (Liquefied Natural Gas);
e) 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 OmnìCity CNG | Solbus Solcity | Solaris Urbino 12 |
|------------------|------------|-------------------------|---------------------|----------------|-----------------|
| Engine displacement [l] | 6.9 | 8.9 | 8.9 | 8.9 | 8.9 |
| Number of cylinders | 6 | 8 | 5 | 6 | 6 |
| Engine power [kW] EURO standard | 156 | 169 | 169 | 184 | 209 |
| Number of standing | 66 | 70 | 80 | 82 | 82 |
| places | Number of seats | Year of production |
|--------|-----------------|-------------------|
| 30     | 29              | 1990              |
| 30     | 30              | 2005              |
| 37     | 30              | 2006              |
| 37     | 37              | 2008              |
|        |                 | 2014              |

Table 3. Characteristics of fuels

| Characteristic         | Diesel fuel | Ethanol   | CNG        | LNG         |
|------------------------|-------------|-----------|------------|-------------|
| Chemical formula       | C\textsubscript{15}H\textsubscript{32}, C\textsubscript{18}H\textsubscript{38} | C\textsubscript{2}H\textsubscript{5}OH | CH\textsubscript{4} | CH\textsubscript{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      |            | 10.22\times10\textsuperscript{6} |
| Octane rating [OR]     | 72          | 108       | 130        | 130         |
| Density [kg/m\textsuperscript{3}] | 830         | 789.3     | 0.7175     | 450 [kg/m\textsuperscript{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 [km/100km] | Energy consumed by vehicle [kWh/100km] |
|---------------------|--------------|----------------------------------------|---------------------------------------|
| Scania OmniLink     | Ethanol      | 73.89 [dm\textsuperscript{3}/100km] | 58.392 [kg/100km] | 1564.905 |
| Scania OmniCity     | CNG          | 58.60 [nm\textsuperscript{3}/100km] | 42.045 [kg/100km] | 1892.025 |
| MAN NL 202          | ON           | 39.64 [dm\textsuperscript{3}/100km] | 32.901 [kg/100km] | 1414.743 |
| Solbus Solcity      | LNG          | 51.66 [nm\textsuperscript{3}/100km] | 37.06 [kg/100km]  | 1667.7    |
| Solaris Urbino 12   | ON           | 36.30 [dm\textsuperscript{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+NOx                                            | 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+NOx                              | 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+NOx                              | 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+NOx 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+NOx, 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+NOx, 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.

References
[1] Bonnel P, Weiss M, Provenza A 2011 In – use Emissions Requirements in the New and Future European Motor Vehicle Emissions Regulations: State of Play 8th Annual SUN Conference, Ann Arbor.
[2] Bougher T, Khalek I A, Trevitz S, Akard M 2011 Verification of a Gaseous Portable Emissions Measurement System with a Laboratory System Using the Code of Federal Regulations Part 1065 SAE Technical Paper Series 2010–01–1069.
[3] Kozak M, Merkisz J, Bielaczyc P, Szczotka A J 2008 Environmental Performance of Diesel-Fuel Synthetic Oxygenates: Maleates and Carbonates FISITA World Automotive Congress Monachium Deutschland 14-19.09.2008.
[4] Massod M 2007 Hydr. Energy 32 2539–2547.
[5] Nylund N O, Koponen K 2012 Fuel and Technology Alternatives for Buses VTT Technology 46 P.294+app. p. 94 Espoo Kopijvä Oy Kuopio.
[6] Pronk A, Coble J, Stewart P A 2009 J. Exp. Sci. Environ. Epidem 19 443–457.
[7] Pütz R, Schwürzingier J 2012 Options for the fully electrified operation of ruban bus lines (EBSF Study) UITP Brussels.
[8] Stieb D, Evans G, Sabaliauskas K, Chen L, Campbell M, Wheeler A, Brook J, Guay M 2007 J. Expo Sci. Environ. Epidemiol. 18 495–505.