Emission tests in city buses under real road conditions

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Abstract

The paper presents the results of real road emission measurements performed under real traffic conditions in the city of Poznan. The tests were carried out in the morning and afternoon hours. The conditions were pre-selected so as to ensure the highest possible reflection of the actual traffic conditions: passenger count on a given bus route that would reflect typical parameters for the Poznan routes. The tests were carried out over a period of two days (Friday, Saturday) characteristic of a very small and very high passenger count and high and medium traffic congestion. The objects of the tests were the buses manufactured by Solaris: one of the vehicles was fitted with a hybrid engine (Hybrid H18) and the other operated on a conventional drive train. The buses were selected based on their similarities in terms of passenger capacity and length. They were selected to enable a comparison of their functionality and environment friendliness under real road conditions (the engines complied with the Euro V standard).
Keywords: emissions, diesel engine bus, hybrid bus, real road conditions.

1 Introduction

European emission regulations for heavy-duty vehicles, contained in directive 1999/96/EC are commonly known as Euro I through V standards. Since October 2005 all homologation vehicles and since October 2006 all newly registered *Heavy Duty Diesel* vehicles – including buses – have had to comply with the Euro IV emission standard. Further standards such as Euro V will become binding from October 2008 and 2009 respectively. Another directive 2005/55/WE adopted in 2005 introduces an additional standard of EEV

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Enhanced Environmentally Friendly Vehicle for vehicles of particularly low emission. The purpose of this directive is primarily to replace the previous directives through the unification of the there contained regulations and gathering them in a single act [1, 3, 8].

A portable SEMTECH DS by SENSORS was used for the emission measurements. The device allowed a measurement of the fuel consumption and emission level. The central unit of the analyzer received data directly from the OBD system and a Satnav. Using the portable system an emission level of CO, HC, NO_x, CO_2 with the resolution of 1 second was performed as well as the variations in the engine speed and torque – the parameters obtained from the vehicle OBD (CAN SAE J1939) and then used to calculate the engine unit energy. The recording of the geographical location (Satnav) enabled a visualization of the trajectory and the calculation of the length of the road portions [4, 5, 9, 10].

The conclusions proved emission indexes – the real emissions of the hybrid and conventional buses have been compared with the emission levels provided for the Euro V standard. The analysis of the emission indexes calculated for the buses shows that the hybrid vehicle despite its obvious economic advantages (lower CO_2 emission – fuel consumption) is very advantageous in terms of ecology (the emission levels for CO and HC are lower than 1). This means that the bus in operation releases fewer toxic compounds than in the dynamic ETC test (the transient dynamic tests better reflect the real road operating conditions under heavy traffic conditions as opposed to the static tests and that is why the emission index should be generated with the use of the data obtained in the transient test) [2, 6, 7].

2 Methodology of the exhaust emission tests

The exhaust emissions tests under real road operating conditions were performed in the city of Poznan. The tests were carried out on bus route number 67 in the morning and midday hours (Table 1). The conditions were pre-selected so as to ensure the highest possible reflection of the actual traffic conditions: the passenger count on us route number 67 was in line with the average passenger count in all the routes in the city of Poznan. The tests were carried out in a period of two days (Friday, Saturday) characteristic of a very small and very high passenger count and high and medium traffic congestion. The objects of the tests were the buses manufactured by Solaris: one of the vehicles was fitted with a

Table 1: Characteristics of the tests on the city buses.

Tested object	Conventional bus		Hybrid bus	
Test day	Friday	Saturday	Friday	Saturday
Test start	7:00	8:00	8:00	8:00
Test end	14:00	13:00	13:00	14:00
Number of run	1–6	7–12	13–16	17–22

Table 2: Technical data of the tested buses.

Parameter	Conventional bus (diesel engine)	Hybrid bus (diesel electric)
Engine type	DAF PR 228 S2	Cummins ISB 250
Displacement [cm^3]	9200	6700
Emission standard	Euro 5	Euro 5
Transmission	VOITH DIWA 86 4.5	ALLISON Ep50
Vehicle weight [kg]	16,700	17,800

hybrid engine (Hybrid H18) and the other operated on a conventional drive train (characteristics shown in Table 2). The buses were selected based on their similarities in terms of passenger capacity and length. They were selected to enable a comparison of their functionality and environment friendliness under real road conditions (the engines complied with the Euro V standard).

The tests were carried out by repeating the runs on a bus route several times (Poznań, Os. Sobieskiego–Os. Dębina). The duration of each run has been presented in fig. 1a, and the average values including the standard deviation in Fig. 1b. The duration of the bus runs in high congestion (Friday) are similar and at the same time 10–15% higher than the duration of the runs on Saturday. The characteristics of the route length were comparable for all the bus runs (Fig. 2). Small differences resulted from the fact that the return run at a given portion of the road continued through a different street (one way streets – even numbers of runs).

For the measurement of the exhaust emissions a portable SEMTECH DS exhaust emissions analyzer (Fig. 3) was used [9, 16]. It measured the fuel consumption and exhaust emissions including the mass flow of the exhaust. The exhaust mass flow was measured at the same time. The exhaust gases uptaken

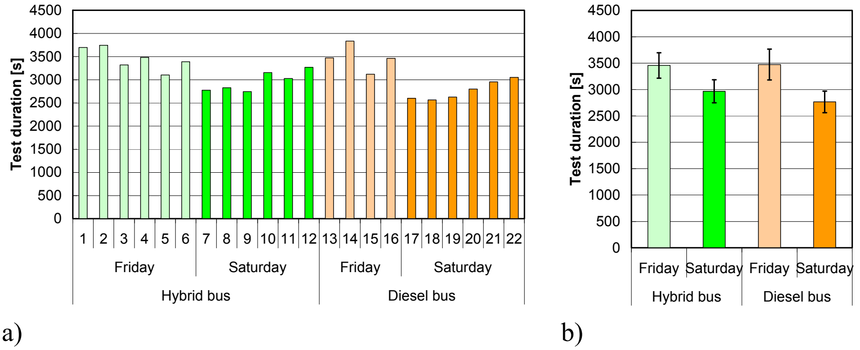
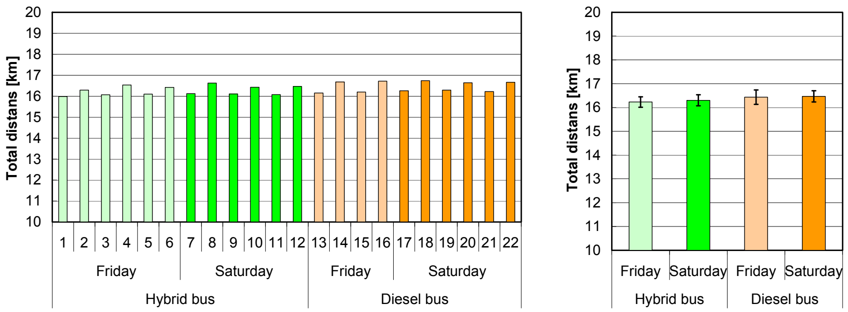


Figure 1: The comparison of the test duration for the hybrid and conventional buses: a) all runs, b) average values with the measurement uncertainty marked.



a) b)

Figure 2: The comparison of the total test distance for the hybrid and conventional buses: a) all runs, b) average values with the measurement uncertainty marked.

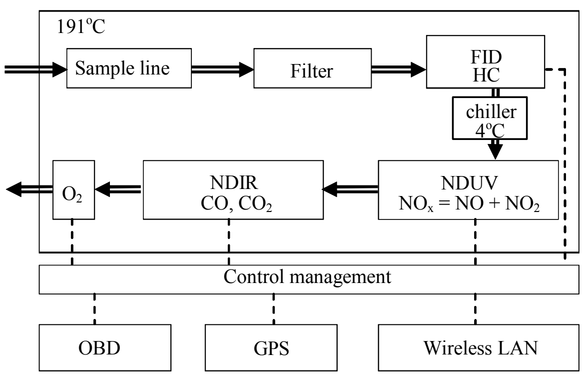


Figure 3: A diagram of a mobile analyzer SEMTECH DS; exhaust gas flow channels (===) and electrical connections circled (– – –).

into the analyzer through a measuring probe maintaining the temperature of 191°C were filtered out of the particulate matter (diesel engines) and then the measurement of hydrocarbons took place in the FID analyzer. Then the exhaust gases were cooled down to the temperature of 4°C and the measurement of nitrogen oxides took place (non-dispersive ultraviolet method) enabling a simultaneous measurement of nitrogen monoxide, nitrogen dioxide, carbon monoxide, carbon dioxide (non-dispersive infrared method) and oxygen (electrochemical analyzer). The analyzer central control unit received data directly from the vehicle OBD system and GPS (Fig. 4).

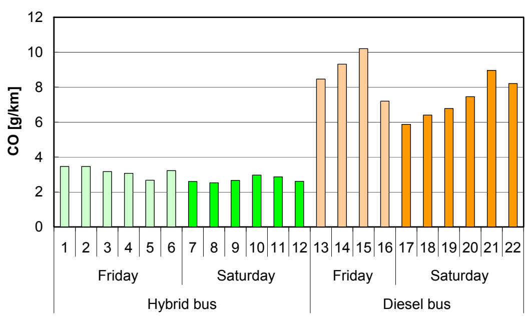
a) b)

Figure 4: The view of the measuring equipment (exhaust emission measurement unit Semtech DS) fitted in the bus during the tests: a) hybrid, b) conventional.

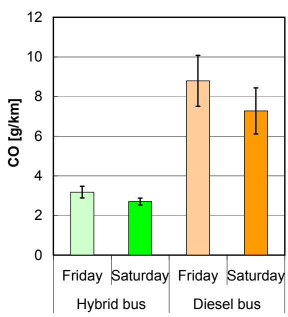
3 Emission tests results and analysis

Using the portable emission analyzer, the exhaust emissions of CO, HC, NO_x and CO_2 were performed with one second resolution along with the measurement of the changes in the engine speed and torque – the parameters retrieved from the CAN SAE J1939 and used for the calculations of the emissions related to the unit energy of the engine. The hybrid vehicle ECU was characterized by the ability to reduce the torque transmission from the combustion engine while driving away– while accelerating up to the speed of 5 km/h, an electric motor was used and the diesel engine operated at idle (lower exhaust emissions).

The road emissions of carbon monoxide during individual runs were fairly similar for the hybrid bus but for the conventional bus the spread of the results was higher (Fig. 5). The average value of the emissions for the hybrid bus and high traffic congestion (Friday) amounted to 3.2 g/km and for the low traffic congestion (Saturday) this value was lower by 15% and amounted to 2.7 g/km. For the bus with the conventional drive train the authors have obtained the following values: 8.7 and 7.3 g/km respectively. The road emission of carbon monoxide for the hybrid bus was several times lower than for the conventional bus.



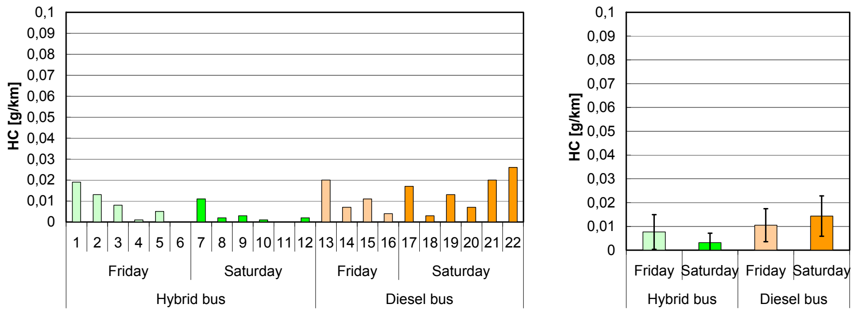
a)



b)

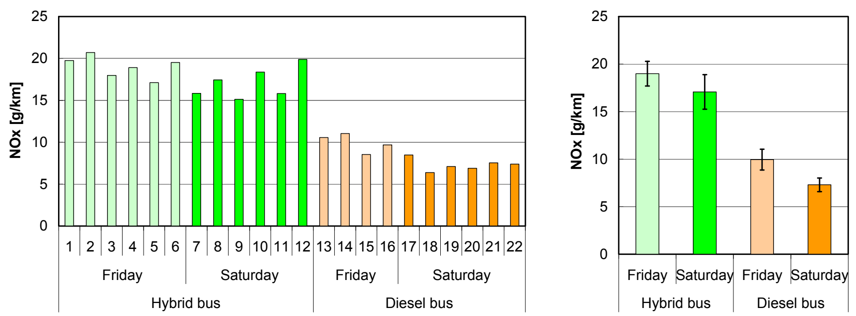
Figure 5: The comparison of the road emissions of carbon monoxide during the testing of the hybrid and conventional buses: a) all runs, b) average values with the measurement uncertainty marked.

The road emission of hydrocarbons during the individual runs showed a significant spread in the result values: this resulted from very low measured values for the hybrid bus. For the conventional bus the spread was lower (Fig. 6) as the values of the hydrocarbons were higher. The average value of the emissions for the hybrid bus and high traffic congestion (Friday) amounted to 0.0076 g/km and for the low traffic congestion (Saturday) this value was lower by 50% and amounted to 0.0032 g/km. For the bus with the conventional drive train the authors have obtained the following values: 0.11 and 0.14 g/km respectively. The road emission of the hydrocarbons for the hybrid bus is approximately twice as low as the conventional bus.



a) b)

Figure 6: The comparison of the road emission of hydrocarbons during the testing of the hybrid and conventional buses: a) all runs, b) average values with the measurement uncertainty marked.



a) b)

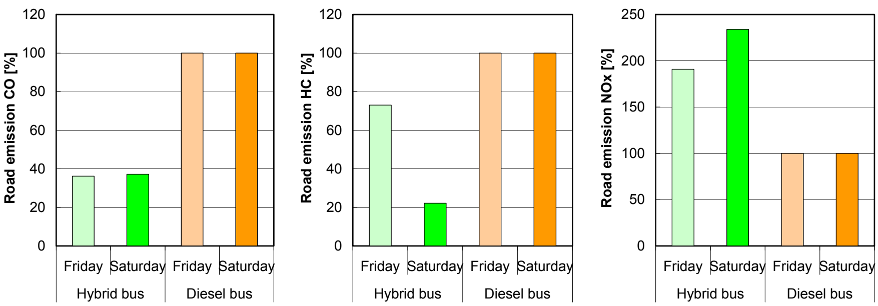
Figure 7: The comparison of the road emission of nitrogen oxides during the testing of the hybrid and conventional buses: a) all runs, b) average values with the measurement uncertainty marked.

The road emissions of the nitrogen oxides during individual runs have shown a small spread for both hybrid and conventional buses (Fig. 7). The average value of this emission for the hybrid bus and high traffic congestion (Friday) amounted to 19 g/km and for the low traffic congestion (Saturday) this value was lower by 10% and amounted to 17 g/km. For the bus with the conventional drive train the authors have obtained the following values: 9.9 and 7.3 g/km respectively. The emission of nitrogen oxides for the hybrid bus is approximately twice as high as the conventional bus. This resulted mainly from the fact that the hybrid bus was fitted with a diesel engine of an insufficient power output.

4 Conclusions – comparison of the engine exhaust emissions

Using the above results the emission level (real road measurement under heavy – Friday – and low – Saturday – traffic conditions) from the two buses has been compared. The comparison has been made in relation to both the road emissions (comparison of the emissions of the buses and fuel consumption in relation to the distance covered) and unit emissions (comparison of the mass of an individual toxic component in relation to the energy used in each test). The following results have been obtained for the hybrid bus as compared to the conventional bus in terms of the road emissions (Fig. 8):

- Heavy traffic (tests performed on Friday):
  - CO reduced by 65%,
  - HC reduced by 24%,
  - NO_x increased by 80%,
  - CO_2 reduced by 18%,
  - Fuel consumption – reduced by 18%,
- Low traffic (tests performed on Saturday):
  - CO reduced by 63%,
  - HC reduced by 78%,
  - NO_x increased by 130%,
  - CO_2 reduced by 15%,
  - Fuel consumption – reduced by 15%.



a) b) c)

Figure 8: Relative change in the road emissions of the hybrid as opposed to the conventional one (for which the reference values of 100% were adopted): a) carbon monoxide, b) hydrocarbons, c) nitrogen oxide.

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