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The comparison of the emissions and fuel consumption in vehicles fitted with different powertrain under real operating conditions

Abstract: Light-duty vehicle exhaust emissions tests are currently carried out on a chassis dynamometer in the NEDC cycle in Europe and FTP75 in the U.S. It should be noted that tests performed in this way do not entirely reflect the real road operating conditions of vehicles. Hence, vehicle road tests (real traffic conditions) rapidly gain in importance. The tests performed under real traffic conditions provide invaluable information on the relations between the engine parameters, vehicle parameters and traffic conditions (traffic congestion) on one side and the exhaust emissions on the other. The necessity to reduce the exhaust emissions from vehicles forces the engineers to seek alternative powertrains. Solutions like fuel cells are still relatively distant. We should expect that in the coming years powertrains based on the process of combustion would remain a prevailing solution, though probably in a hybrid configuration or using alternative fuels. The paper presents the result of road tests obtained in an urban and extra-urban cycles for vehicles fitted with different engines (spark ignition engine, compression ignition engine, spark ignition LPG fueled engine, hybrid engine). For the tests, a portable emission analyzer SEMTECH DS. By SENSORS was used. This analyzer provides online measurement of the concentrations of exhaust emission components on a vehicle in motion under real traffic conditions. The tests were performed in city traffic. A comparative analysis has been presented of the obtained results for vehicles with individual powertrains.

Keywords: emissions, real operating conditions measurement

Emisja związków toksycznych spalin w rzeczywistych warunkach eksploatacji z samochodów z różnymi źródłami napędu

Streszczenie: Badania emisji związków szkodliwych spalin z pojazdów typu light-duty obecnie są wykonywane na hamowni podwoziowej w teście NEDC w Europie i FTP75 w USA. Należy zauważyć, że tak przeprowadzone badania nie w pełni odzwierciedlają rzeczywiste warunki ruchu drogowego. W związku z tym coraz większego znaczenia nabierają badania prowadzone w rzeczywistych warunkach eksploatacji pojazdu, czyli wykonywane w ruchu ulicznym. Badania wykonywane w rzeczywistych warunkach eksploatacji dostarczają cenne informacje na temat zależności miedzy parametrami pracy silnika, parametrami jazdy samochodu, jak również warunkami drogowymi (natężeniem ruchu) a emisją związków toksycznych spalin. Zmniejszenie emisji związków toksycznych spalin wymusza poszukiwanie alternatywnych źródeł napędu pojazdów. Rozwiązania takie jak ogniwa paliwowe nadal wydają się stosunkowo odległą perspektywą. Należy spodziewać się, że w najbliższych latach nadal będą dominować układy napędowe wykorzystujące silniki spalinowe, zapewne coraz częściej w układzie hybrydowym lub zasilane paliwami alternatywnymi. W artykule przedstawiono wyniki badań drogowych uzyskane w cyklu miejskim, wykonane dla pojazdów wyposażonych w różne źródła napędu: silnik benzynowy, silnik o zapłonie samoczynnym, silnik o zapłonie iskrowym zasilany LPG i hybrydowy i pozamiejskim. Do pomiarów tych wykorzystano mobilny analizator spalin SEMTECH DS. firmy SENSORS. Jest to analizator, który umożliwia badanie stężeń związków szkodliwych spalin on-line podczas jazdy samochodem w rzeczywistych warunkach drogowych. Badania drogowe wykonano w ruchu miejskim. Przedstawiono analizę porównawczą uzyskanych wyniki badań dla pojazdów z poszczególnymi źródłami napędu.

Słowa kluczowe: emisja związków toksycznych, pomiary w warunkach drogowych

1. Introduction

The need to limit emission of exhaust emissions and fuel consumption by transport means has led to development of several concepts of powertrains in the recent years. Engineers of vehicles raise hope, first of all, for hybrid powertrains and fuel cells, however, presently the latter seems to be impossible to use on a broad scale further on. It may be estimated that this solution will be used in approximately 20-30 years. A solution, which is quite commonly used in vehicles, involves hybrid powertrains, i.e. combinations of combustion engine and electric engine. Presently, most of personal vehicle manufacturers in the world offer such vehicles or conduct research on the model and, in many cases, the research is considerably advanced. One should expect that in a few years the production and sale of personal vehicles equipped with hybrid powertrains will increase considerably. However, one should note that intensive research and development works are being conducted on improvement of combustion engines with spark ignition and compression ignition, which will probably be used for many years to come as main power sources for vehicles and other means of transport.

2. Testing methods

The tests were performed on three passenger cars with different powertrains and similar maximum power. The first vehicle was equipped with spark ignition engine fuelled by petrol and LPG; the other was equipped with compression ignition engine and the third was a vehicle with a hybrid powertrain (spark ignition engine and two electric engines). The basic data of the tested cars are given in table 1 and the view of the car is presented in figure 1.

Table 1

Vehicles used in tests

	Vehicle 1	Vehicle 2	Vehicle 3
Data of the power unit	SI engine fuelled with petrol and LPG, 3.3 dm^3, power - 130 kW	CI engine, 2.0 dm^3, power – 137 kw	SI engine, 1.8 dm^3, power – 70 kW + 2 electric engines with the power of 60 kW
Mileage	140 000 km	25 000 km	1000 km
Model year	2009	2009	2010
Exhaust aftertreatment system	Three-way catalytic converter	Oxidation catalytic converter +DPF	Three-way catalytic converter

Fig. 1. The cars with the measurement equipment

Exhaust emissions tests (CO, HC, NO_x, PM, CO_2) were performed in real operating conditions of the vehicle in traffic in the city of Poznań. The vehicle route during the tests is shown in figure 2. The length of the route was 12.71 km, it was diversified and included a typical urban section and an extra-urban section, where it was possible to drive at highway speed (with maximum speed of 120 km/h). The extra-urban section was 5.5 km long. As shown in figure 2, the length of the vehicle route during the road test was similar to the length of the vehicle route in the NEDC test. The time of drive in road tests, approximately 1200 s, was similar to the time of drive in the NEDC test.

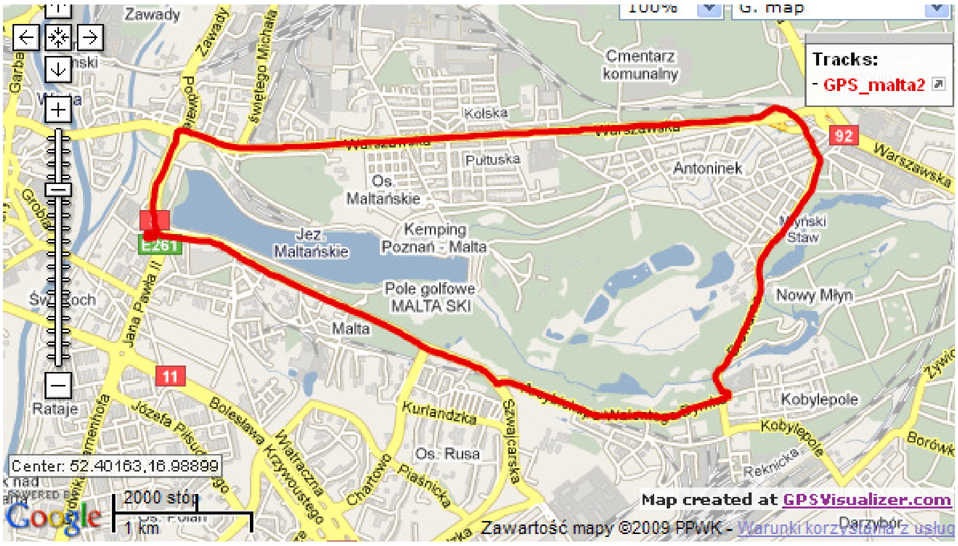

Fig. 2. The marked road used for the testing of exhaust emissions (created at www.GPSVisualizer.com)

3. Experimental equipment

In order to measure the concentration of toxic compounds IN EXHAUST GASES a portable analyzer for exhaust emissions tests SEMTECH DS by SENSORS company was used. The analyzer allowed for the measurement of harmful compounds concentration with the simultaneous measurement of the flow rate of the exhaust gases. Exhaust gases were introduced to the analyzer as a probe maintaining the temperature of 191°C then the particle matter was filtered out (CI engine) and the exhaust probe was directed to the flame-ionizing detector (FID) where HC concentration was measured. Then the exhaust gases were cooled down to temperature of 4°C and the measurement of concentration of NO_x (NDUV analyzer), CO, CO_2 (NDIR analyzer) and O2 followed in the listed order. It is possible to add data sent directly from the vehicle diagnostic system to the central unit of the analyzer and make use of localization signal GPS (table 2). In the tests measurements of emissions were used and also, for the purpose of comparison, signals from an on-board diagnostic system were registered, e.g. engine speed, load, vehicle speed, temperature of inlet air. Some of these signals served to specify time density maps presenting participation of operating time of the vehicles in real exploitation conditions.

Table 2

Characteristics of a portable exhaust analyzer SEMTECH DS

Parameter name	Measurement method	Accuracy
1. Emissions		
CO	NDIR, range 0–8%	±3%
HC	FID, range 0–10.000 ppm	±2%
$NO_x = (NO + NO_2)$	NDUV, range 0–2500 ppm	±3%
CO_2	NDIR, range 0–20%	±3%
O_2	Electrochemical, range 0–25%	±1%
2. Data storage capacity	Over 10 hours at 1 Hz data acquisition rate	
3. Vehicle interface capacity	SAE J1850 (PWM), SAE J1979 (VPW) ISO 14230 (KWP-2000) ISO 15765 (CAN), ISO 11898 (CAN) SAE J1587, SAE J1939 (CAN)	

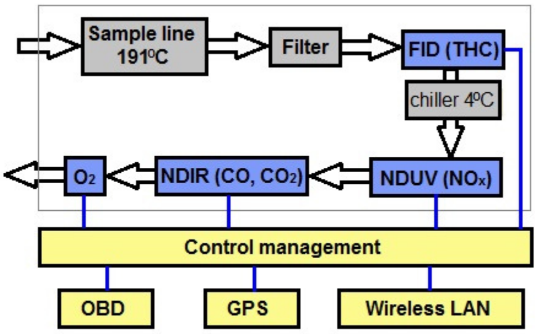

Fig. 3. A diagram of a portable analyzer SEMTECH DS; exhaust gas flow channels (arrow) and electrical connections circled (blue line)

4. The test results

Measurements of exhaust emission (CO, HC, NOx and CO2) as well as measurements of the flow rate of the exhaust gases were made with the use of a portable analyzer. Moreover, basic operating parameters of engines of the tested vehicles were recorded (e.g. engine speed, engine load). Figures 4–6 present most frequently used ranges of operation of the tested engines, i.e. ranges of the most frequently used engine speeds and engine loads. In the case of the hybrid powertrain (figure 1), a significant share of the engine operation (approx. 50%) was recorded for the zero load and zero engine speed, i.e. for driving with combustion engine switched off. The test was conducted mostly in urban road conditions, which are characterised by high intensity of traffic. In such road conditions, the vehicle most frequently used the electric power and recuperated energy (recharged batteries) during braking, which is shown in fig. 1. Moreover, another significant share of the engine operation was observed for high loads (80–90% of the maximum load). This range of operation was mainly used during acceleration and driving in extra-urban conditions.

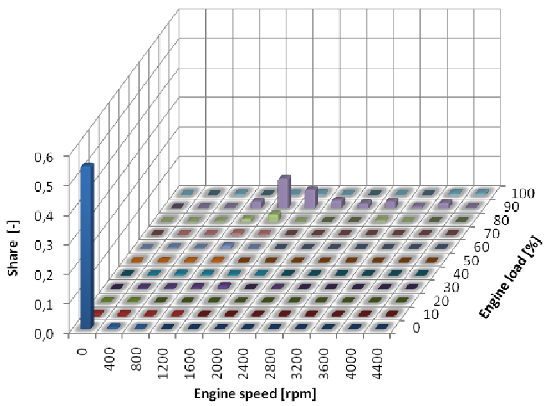

Fig. 4. Characteristics of the share of engine speeds and engine load during the test, SI engine of hybrid powertrain

Figure 5 presents the share of operation of a spark ignition engine during the test and figure 6 presents the share of operation for a compression ignition engine (both engines for the vehicle with a classic powertrain). In the case of a classic powertrain with a compression ignition engine, a broader range of the most frequently used engine speeds and loads is visible as compared to the combustion engine in the vehicle with a hybrid powertrain. In comparing the operation of powertrains equipped with a spark ignition and a compression ignition one may observe that during the test the spark ignition engine operated mainly within the range of low loads (up 40% of maximum load) in the entire range of engine speed, whereas the compression ignition engine operated in a narrower range of engine speed and mainly within the range of medium and low loads (0 – 70% of maximum load).

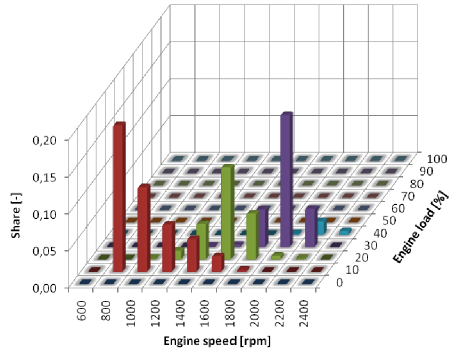

Fig. 5. Characteristics of the share of engine speeds and engine load during the test, SI engine

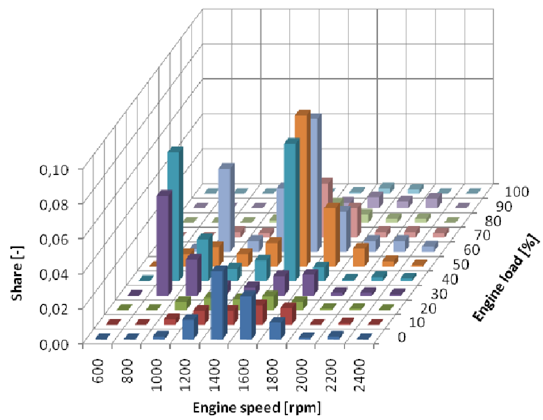

Fig. 6. Characteristics of the share of engine speeds and engine load during the test, CI engine

Figure 7 presents results of exhaust emission tests for vehicles with different powertrains. The highest value of the CO_2 emissions/fuel consumption was observed for the vehicle with the spark ignition engine fuelled with petrol and the value of emissions was slightly lower for the same engine fuelled with LPG. In the case of the vehicle with a hybrid powertrain and the vehicle with a compression ignition engine, the emission of CO_2 was lower by approximately 50% as compared to the vehicle equipped with a spark ignition engine. In the case of emissions of CO and HC, the highest values were observed for the vehicle with a spark ignition engine. The emissions are considerably (over ten times) higher that for the vehicle with a hybrid powertrain and the vehicle with a compression ignition engine. In the case of use of classic powertrains equipped with a combustion engine, the emission of NO_x is comparable (the maximum difference of 7%) and it is much lower for the vehicle equipped with a hybrid powertrain.

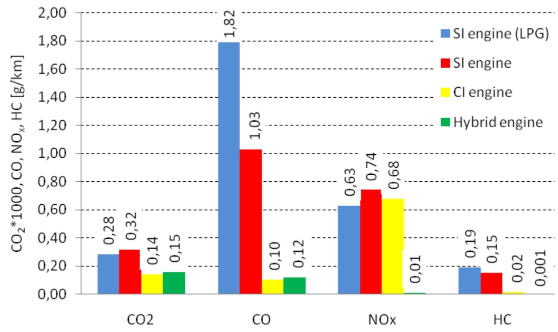

Fig. 7. Exhaust emission in vehicles with different powertrains during tests under real traffic conditions

Favourable results obtained for the vehicle equipped with a hybrid powertrain stem from the use of the electric power of the vehicle in urban trafic conditions characterised by frequent halts and low speed driving. In such conditions, the combustion engine was switched off. The combustion engine was also switched off during braking and at the same time batteries were being charged in the electric part of the powertrain. This fact is shown in figure 4 and additionally confirmed in figure 8 which shows the vehicle speed and engine speed for the vehicle with a hybrid powertrain. One may observe sections of vehicle driving with zero engine speed (the combustion engine switched off). Such conditions are most often observed in typical urban traffic conditions in which the vehicle often halts, accelerates and brakes (from 0 to 600 s, fig. 8). In this section of the test the vehicle maximum driving speed did not exceed 55 km/h.

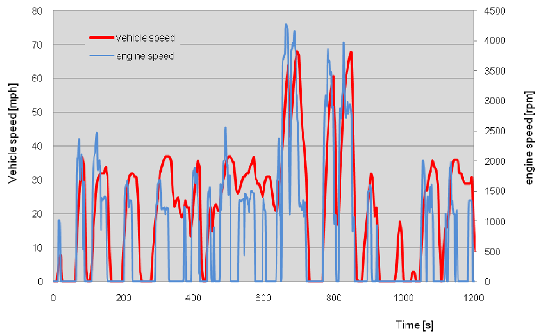

Fig. 8. The vehicle speed and engine speed for the vehicle with a hybrid powertrain during tests under real traffic conditions

5. Conclusions

The tests showed differences between exhaust emissions from vehicels with different powertrains under real traffic conditions. As far as the problem of ecology is concerned, most favourable results were obtained for the vehicle with a hybrid powertrain, which is characterised by considerably lower exhaust emission as compared to classic powertrains using spark ignition engines. Presently, one may assume that owing to favourable ecological properties, vehicle with hybrid powertrains will probably be most frequently used on the roads. Such vehicles should mainly be used in cities, which are characterised by high intensity of traffic. The electric power is most often used in urban traffic conditions, which makes it possible to reduce exhaust emission. It should be noted that this article presents only selected test results which are a part of a more extensive research project relating to measurement of exhaust emission under real traffic conditions. Further interpretation of the test results is planned in next publications issued upon completion of the project.

Nomenclature

CLD – Chemiluminescent Detector
CVS – Constant Volum System
CFS – Constant Flow System
EUDC – Extra Urban Drive Cycle
FID – Flame Ionization Detector (HFID – Heated FID)
FTP75 – Federal Test Procedure
GPS – Global Position System
LAN – Local Area Network
LDV – Light Duty Vehicle
LPG – Liquified Petrolum Gas
NEDC – New European Drive Cycle
NDIR – Non Dispersive Infra Read
NDUV – Non-Dispersive Ultra-Violet
OBD – On Board Diagnostic
UDC – Urban Drive Cycle

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