THE ARCHIVES OF TRANSPORT *ISSN (print):* *0866-9546*
Volume 31, Issue 3, 2014 *e-ISSN (online):* *2300-8830*
DOI: 10.5604/08669546.1146986

PASSENGER CARS AND HEAVY DUTY VEHICLES EXHAUST EMISSIONS UNDER REAL DRIVING CONDITIONS

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Abstract: *In the assumptions regarding to the transport policy both at the level of country and Europe there is the concept of sustainable development of transport. Warsaw University of Technology in cooperation with Poznan University of Technology performs research work concerning the shaping of environmentally friendly transport system – Project EMITRANSYS. In this project, one of the conditions is to reduce exhaust emissions by means of transport. The paper presents the reasons for the testing of the exhaust emissions under Real Driving Emissions testing (RDE). Research potential of Institute of Combustion Engines and Transport at Poznan University of Technology in the area of road testing of passenger and heavy-duty vehicles has been presented in the paper. Example test results have been shown in the aspect of the emission-related classification of vehicles.*

Key words: *exhaust emissions, vehicle testing, real driving emissions*

1. Introduction

Currently a trend has been seen of global treatment of the environmental perils from the automotive industry. The regulations permitting the vehicle to drive on roads (homologations and production conformity), periodical inspections of the vehicle technical condition and other legal acts directly or indirectly related to the production, use and disposal of used up civilization products treat the environmental issues in a complex way. In the previous years in individual countries there were different inspection and testing systems related to the exhaust emissions yet for some time now there has been a far reaching unification going on [8,9].

The growing number of vehicles in the world and the resultant natural environment pollution leads to a growth in the emission related requirements (Fig. 1). Current level of technology advancement in all the fields of industry including transport results in a growth of the requirements for the emission measurement devices. In order for these requirements to be fulfilled to comply with the ever-changing regulations a concentration of industry became necessary in this matter. The exhaust emission tests are a sophisticated process. Modern analysers of the emissions require special laboratory conditions and the homologation procedures comprise tests on chassis and engine dynamometers that do not entirely reflect the emissions under real operating conditions. The latest results of on-road tests show that in relation to some exhaust components the emission is higher by several hundred percent for both the gaseous compounds and [1,6,7] particulate matter [10]. Hence, we can see a trend attempting at a formalization and enforcement of the on-road emission testing.

The emission of (gaseous) toxic compounds and carbon dioxide as well as particulate matter continues to be a major threat, constituting an obstacle to the development of contemporary internal combustion engines, especially compression and spark ignition engines with direct injection. Euro 6 standard is a major change for vehicle manufacturers, as it requires reducing gaseous compounds and particulate matter emissions to levels far below the current ones. Newly implemented technical and operating regulations may cause both positive and negative consequences. Well-designed regulations should affect the natural environment in a positive way, but the nature of that influence also depends on the perspective taken when the influence is assessed. Positive effects of the regulations are particularly well visible in terms of the change in pollution limits.

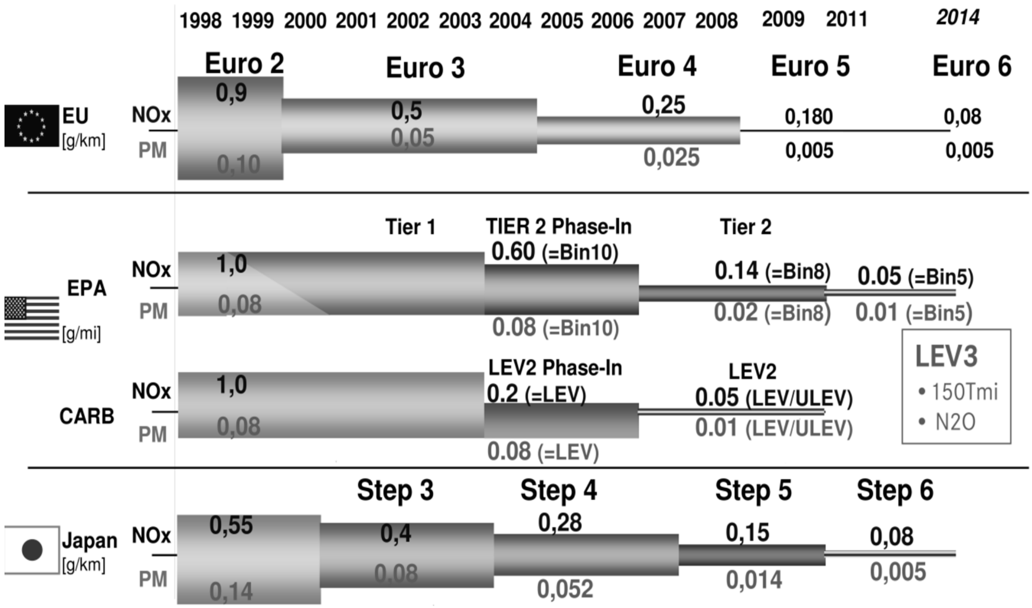


Fig. 1. The major challenge is to fulfil the worldwide emission standards [7]

2. Real Driving Emissions

Manufacturers of combustion engines are obliged to the design drive units with best possible ecological characteristics and with supreme performance parameters. In recent years the popularity of measuring parameters of combustion engines in real operating conditions has significantly increased. The latest results of tests carried out in real traffic conditions show that some components of exhaust emissions are emitted in greater amounts compared with the tests carried out on stationary engine test benches. The lack of legal provisions regarding the testing of emissions in real traffic conditions resulted in the need to determine common areas of operating of the engines in order to enable the comparison between the engines [3]. The concept of exhaust gas toxicity tests performed in real traffic conditions for passenger vehicles should be based on the following premises: determination of a consistent area of operation of the engine for all passenger vehicles in a way to the greatest extent corresponding with the most common traffic conditions, determination of the parameters measured during the road tests and the obtained emission indicators [4]. The article presents the results of the measurements concerning determination of working conditions for the engines used to drive the cars. The tests of working conditions were carried out for a group of vehicles driving along the predefined sections of roads in urban traffic and out-of-town traffic. The result of the study was the assessment of the working conditions of passenger vehicles considering determination of road emissions of pollutants.

Measurements of emissions in passenger cars are conducted during the type-approval tests on the chassis dynamometer, during the road tests in real traffic conditions and on vehicle inspection stations (there the concentration of compounds is measured and not the emission). The type-approval measurements are performed on the chassis dynamometer according to precisely determined procedures and are used only for new passenger cars. The aim of the NEDC (New European Driving Cycle), WLTP (Worldwide harmonized Light vehicles Test Procedures) and the American US 06 (Federal Test Procedure) type-approval tests for a fixed speed profile is to control whether a vehicle meets ecological requirements (Fig. 2) [7]. Road tests of passenger vehicles concerning exhaust emissions are not legally regulated as opposed to heavy goods vehicles, for which the research test NTE (Not to Exceed) has been designed – the test checking whether the vehicle does not exceed the limit values.

The fundamental differences between stationary exhaust emissions tests and tests under actual traffic conditions are as follows:

- Chassis dynamometer: testing the whole vehicles on reproducible parameters,
- Engine dynamometer: testing engines only, no relation to the actual traffic conditions of a heavy-duty vehicle.
- Under actual traffic operation variability of conditions occurs that have impact on the exhaust emissions:
- Ambient air temperature, pressure, humidity, weather conditions (wind, rain, snow etc.),
- Quality of the road surface,
- Driving style: aggressive, normal and preferred – eco-driving.

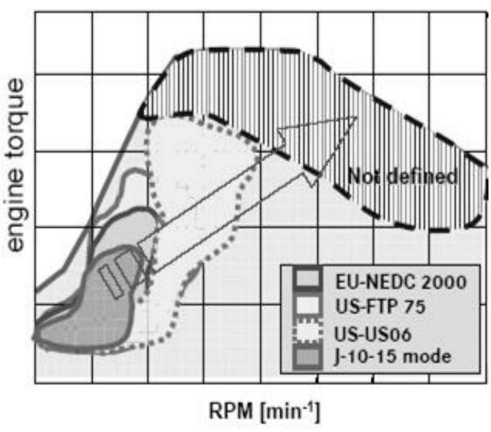


Fig. 2. Engine operating parameters in various emissions tests [7]

Now, particularly stress is put on the Real Driving Emissions, because the exhaust emission tests (up-to-date: NEDC and future: WLTP) cover only smart part of the range of operating parameters engine.

The recent developments in the European legislation reflect the interest of the regulatory authorities to shift from the chassis/engine dynamometer testing towards a real-time on-board regulation of vehicular emissions. This transition has been successfully implemented for gaseous pollutants and particulate matter. The more ambitious target of on-board particle number measurements is currently under evaluation. While a number of approaches can be considered, a successful implementation needs to effectively address a number of considerations [7]:

- It needs to incorporate a very efficient conditioning system to address the potentially elevated concentrations of volatile particles under more aggressive real world driving.
- It needs to incorporate a particle detector that would be robust enough to withstand the much harsher operating conditions during field testing,

It should be simple in operation and allow for easy on-site checks of all critical components.

3. Methodology

Currently, a growing stress is put on the measurements of exhaust emissions, particularly from combustion engines of vehicles and machinery under actual conditions of operation. These measurements, despite being realized on a selected sample of modes of transport, much better reflect the actual situation than the test procedures simulating the actual conditions of operation or stationary tests. They became possible thanks to the recent advancement of the measurement techniques. The advancement of these techniques also provided the possibility of measurement of very little concentrations of the emission components in the exhaust gas.

Literature analysis in the field of exhaust emissions research allows distinguishing two kinds of analytical research from the point of view of its aims [3]. These are:

- **Comparative research** of the exhaust emissions from passenger vehicles, heavy-duty vehicles or combustion engines alone. These could be investigations conducted on a chassis or engine dynamometer using equipment used for on-board measurements. Such investigations enable an evaluation of the exhaust emissions using the on-board methodology. These could also be comparative investigations of the exhaust emissions from vehicles fueled with different fuels including alternative fuels;

- **Research aiming at the assessment of the emission indexes by** determining of the gaseous exhaust emissions values from a given category of vehicles under actual traffic conditions (on-board measurements) and comparing them with the admissible exhaust emissions (Euro). Such indexes enable the assessment of the gaseous exhaust emissions from the discussed vehicles under actual traffic conditions [7]).

Currently, a growing stress is put on the measurements of exhaust emissions, particularly from combustion engines of vehicles and machinery under actual conditions of operation. These measurements, despite being realized on a selected sample of modes of transport, much better reflect the actual situation than the test procedures simulating the actual conditions of operation or stationary tests. They became possible thanks to the recent advancement of the measurement techniques. The advancement of these techniques also provided the possibility of measurement of very little concentrations of the emission components in the exhaust gas.

The most desirable are on-road emission tests as this is the only way to measure the actual emission level. The biggest disadvantage of this method is the price of the equipment and its adaptation to individual vehicles. Following the latest trends, Institute of Combustion Engines and Transport equipped its Combustion Engines laboratories with modern research tools such as the system of Semtech DS, Ecostar and M.O.V.E exhaust emission analysers with measuring probes (exhaust flow meters) manufactured by Sensors Inc. and AVL. The system of analysers measures the exhaust emissions from combustion engines fitted in all types of machines and vehicles under the conditions of their real operation (Fig. 3).

The authors of the paper propose an introduction of the emission indexes denoting the multiplicity of the increase or decrease of the exhaust emissions under actual traffic conditions compared to the homologation tests [7]. Such an index for a given exhaust component has been defined as follows:

$$k_j = \frac{E_{real,\,j}}{E_{NEDC(ETC,WHTC),j}} \qquad (1)$$

where: j – exhaust component for which the emission index was determined, $E_{real,j}$ – emission rate under actual traffic conditions [g/s], $E_{NEDC,j}$ – emission rate measured in the NEDC test [g/s] or other tests such as those for heavy-duty vehicles (ETC, WHTC).

The exhaust emission rate under actual operating conditions can be calculated using the vehicle operating time share characteristics $u(a,V)$ and the emission rate characteristics for an j-th exhaust component $e_j(a,V)$ expressed in grams per second:

$$E_{real,j} = \sum_a \sum_v u(a,V) \cdot e_j(a,V) \qquad (2)$$

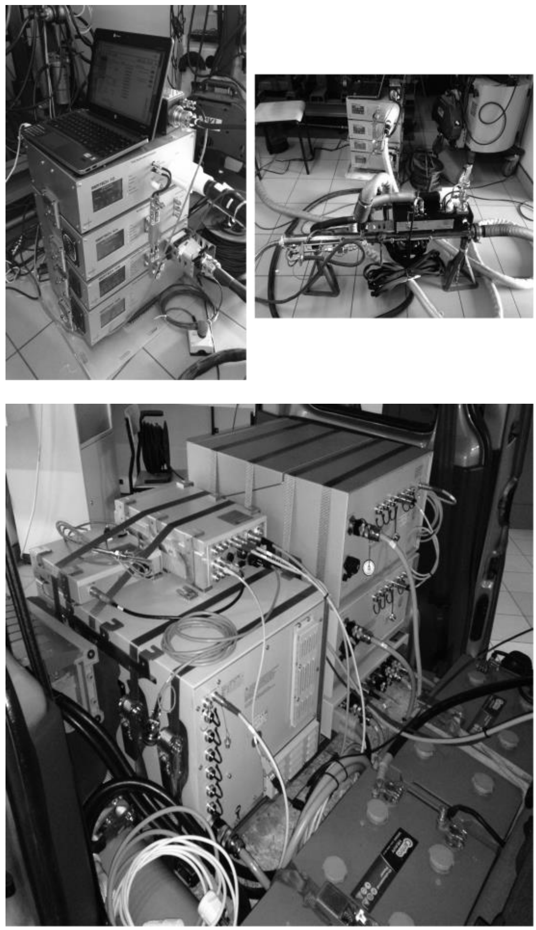


Fig. 3. The view of the analyzer for on-road emission testing of vehicles: a) Ecostar by Sensors, b) M.O.V.E by AVL

If there is no information on the vehicle exhaust emissions in the homologation test, admissible values according to the Euro emissions standard can be assumed for a given vehicle. The values of the admissible exhaust emissions for a given exhaust component expressed in g/km (or g/kWh) can be converted into the values of the exhaust emission rate (in g/s), knowing the duration (e.g. t_{NEDC} = 1180 s) and the covered distance (e.g. S_{NEDC}=11,007 m) in the homologation test (Fig. 11).

The proposed **correction factors** will adapt the homologation emission values obtained in the tests to the actual traffic conditions of a vehicle. Hence, the factors, referred to as '*k*', should be dimensionless and determined for different emission categories:

– passenger and light-duty trucks (up to 3500 kg) – for which the emission limits are prescribed in grams per kilometre [g/km],
– heavy-duty and non-road vehicles – for which the emission limits are prescribed in grams per kilowatt hour [g/kWh].

The authors of the paper propose an introduction of exhaust emission index *k*, correcting the values of the homologation emissions to the value obtained under actual operation:

for passenger vehicles and light-duty trucks (up to 3500 kg):

– for passenger vehicles and light-duty trucks (up to 3500 kg):

$$m = k\,E\,N\,S \qquad (3)$$

where: m – mass of the pollutant [g], k – emission coefficient, E – road emission of a vehicle according to the Euro standard [g/km], N – number of vehicles, S – vehicle mileage [km].

– for heavy-duty vehicles and non-road vehicles (in excess of 3.5 tons):

$$m = k\,E\,N\,W \qquad (4)$$

where: m – mass of the pollutant [g], k – actual emission coefficient, E – unit emission of a vehicle according to the Euro standard [g/kWh], N – number of vehicles, W – engine operation on a road portion [kWh] (the value of work can be pulled from the vehicle OBD system).

4. Testing of passenger vehicles

The performed tests and the obtained results (Fig. 4) have shown a wide potential to use the purchased equipment and indicated a need to perfect the measurement of particulate matter. As a result the Combustion Engines Laboratory purchased a state-of-the-art particulate matter analyser performing the measurement under real operating conditions.

For vehicles fitted with alternative drivetrains, greater exhaust emissions were observed when aftermarket LPG system was applied (Fig. 5). The emission indexes obtained for gasoline and CNG fueled vehicles (Fig. 6) characterize the vehicle on-road exhaust emission level in comparison to the exhaust emission standard applicable for this vehicle [10]. Following the assumption of CNG as primary fuel– the indexes of the exhaust emissions of a gasoline fueled vehicle are much worse: the value of the carbon monoxide index for gasoline (k_{CO} = 3.9) proves an excessive emission (four times the Euro 4 standard) for this vehicle. The outstanding values of the emission index (for hydrocarbons and nitric oxides) do not exceed the values prescribed in the emission legislation.

The conducted tests regarding the exhaust emissions from passenger vehicles fitted with combustion engines (gasoline, diesel, Euro 3–Euro 5 compliant – Fig. 7) under actual traffic conditions were the first validation of the values and usefulness of the developed tool – a universal on-board exhaust emissions measurement system. Determining the level of emissions under actual traffic conditions and comparing it with the values obtained on the chassis dynamometer in the homologation test led to the calculation of the emission index.

The determined emission index serves the purpose of providing information whether the exhaust emission under actual traffic conditions is comparable with the exhaust emissions during the homologation test. At the same time, it is a validation of the driving conditions in the homologation test (developed many years ago) compared to the actual traffic conditions.

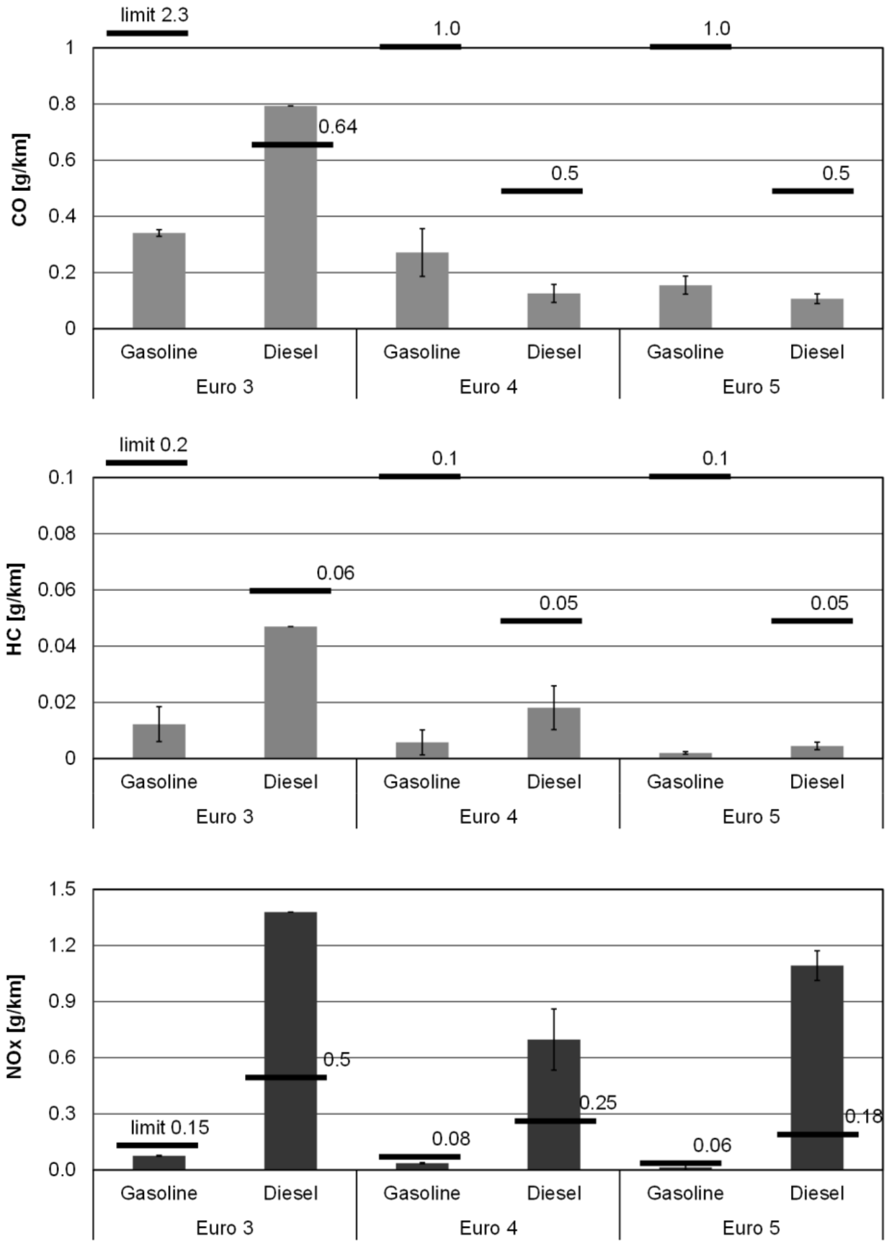


Fig. 4. The test results: passenger cars road emission of CO, HC and NOx

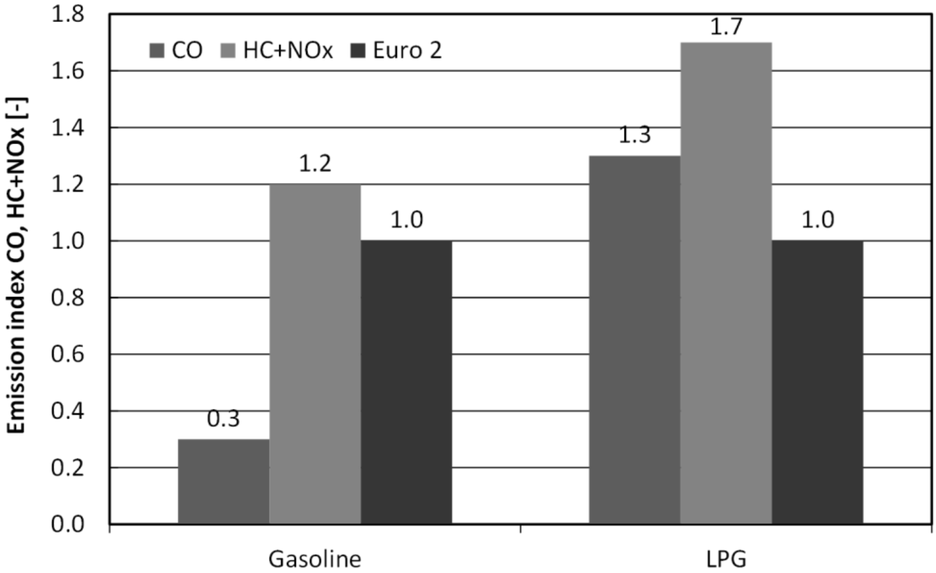


Fig. 5. Comparison of the exhaust emissions from vehicles fueled with gasoline and LPG (spark ignition engines)

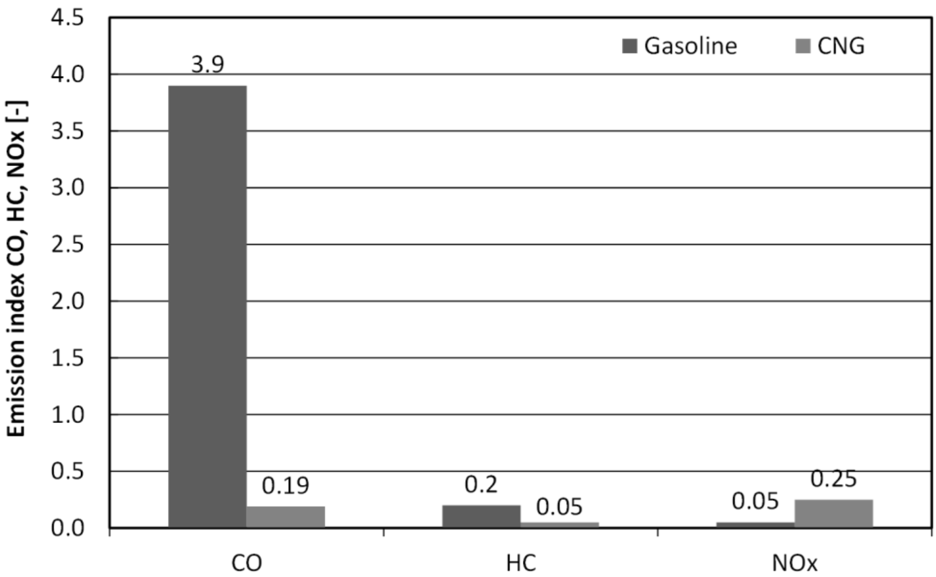


Fig. 6. Comparison of the exhaust emissions from vehicles fueled with gasoline and CNG (spark ignition engines)

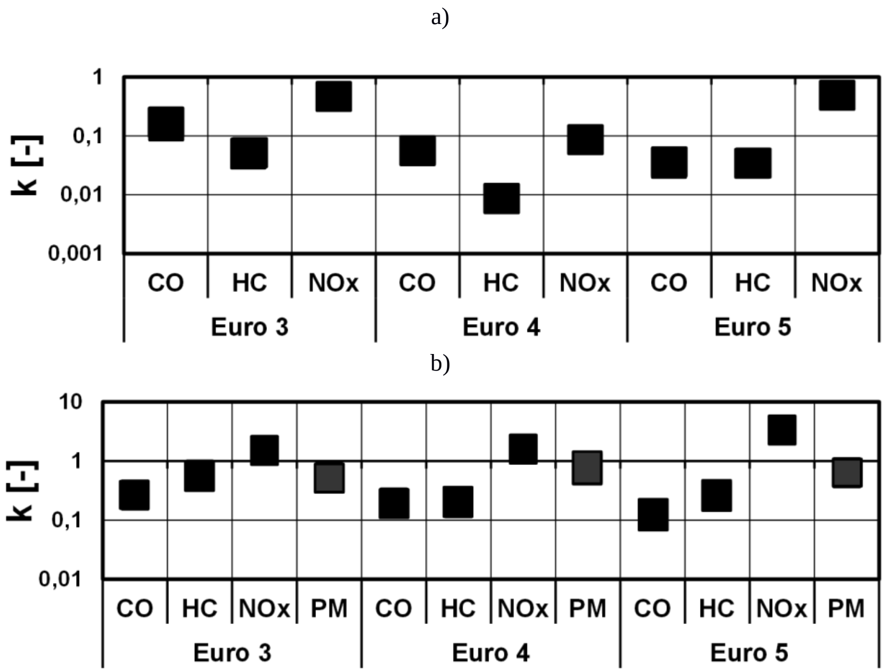


Fig. 7. Comparison of the vehicle exhaust emissions using different vehicle emission categories: a) gasoline engine, b) diesel engine

5. Testing of heavy-duty vehicles

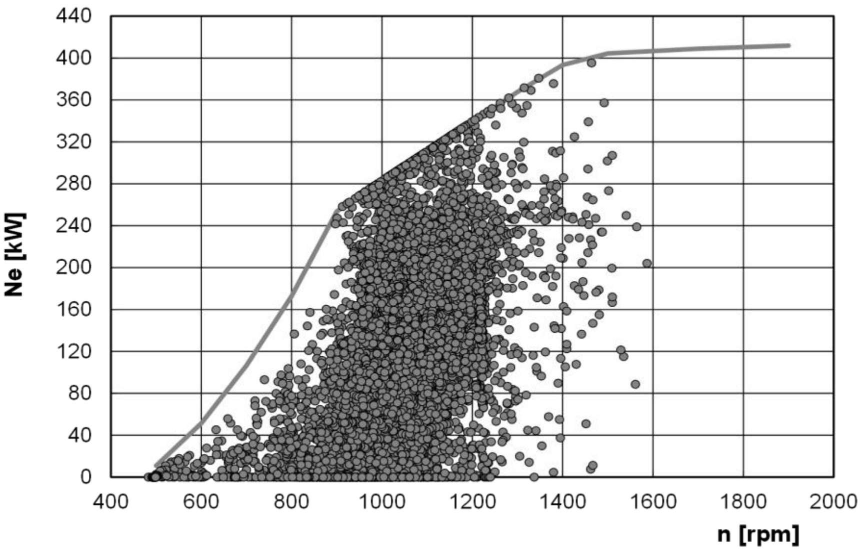
For many years, the system of vehicle inspections for exhaust emissions included type approvals and production compliance. Currently, stress is put on the exhaust emissions measurements (particularly for heavy-duty vehicles) under transient operating states that much better simulate the actual traffic conditions than the stationary tests [5]. In the new legislation, the life cycle of a vehicle has significantly been extended expressed in the vehicle mileage within which the vehicle must comply with the emission standards. Heavy-duty vehicles of the gross vehicle weight exceeding 16,000 kg will have to comply with the emission standards up to 700,000 km. This will cause a significant tightening of the quality requirements for components having impact on the exhaust emissions such as catalytic converters and diesel particulate filters.

The emissions shall be integrated using a moving averaging window method, based on the reference work (UE 582/2011 method). The principle of the calculation is as follows: The mass emissions are not calculated for the complete data set, but for sub-sets of the complete data set, the length of these sub-sets being determined so as to match the engine work measured over the reference laboratory transient cycle. The moving average calculations are conducted with a time increment Δt equal to the data sampling period. These sub-sets used to average the emissions data are referred to as ‘averaging windows’. The duration of the averaging window is determined by: $W(\Delta t) \geq W_{ref}$, where $W(\Delta t)$ is the engine work measured between the start and time t (in kWh), W_{ref} is the engine work for the WHTC (in kWh).

In order to realize that task the authors needed to estimate the value of work in the WHTC test for the conventional and hybrid buses. In order to determine work in the WHTC test we need to know the course of engine speed and the torque in this cycle. In order to determine the actual engine speeds and loads a denormalization was carried out of the engine operating parameters. Its first stage is the determination of the characteristics of the full power for each of the engines (Fig. 8). Based on that, the actual parameters (engine speed and torque) of the engines were calculated, according to the methodology given in regulation 582/2011 (Fig. 9).

The estimated value of work of a conventional engine in the WHTC test was 40.05 kWh. Knowing the reference values of work for the tested vehicles the unit exhaust emission was summed up only in the measurement windows for which the total engine work exceeded the previously given values. For the conventional vehicle the number of all proper measurement windows in the whole test was 6049. The results presented in figure 10 are averaged values for each exhaust components.

a)



b)

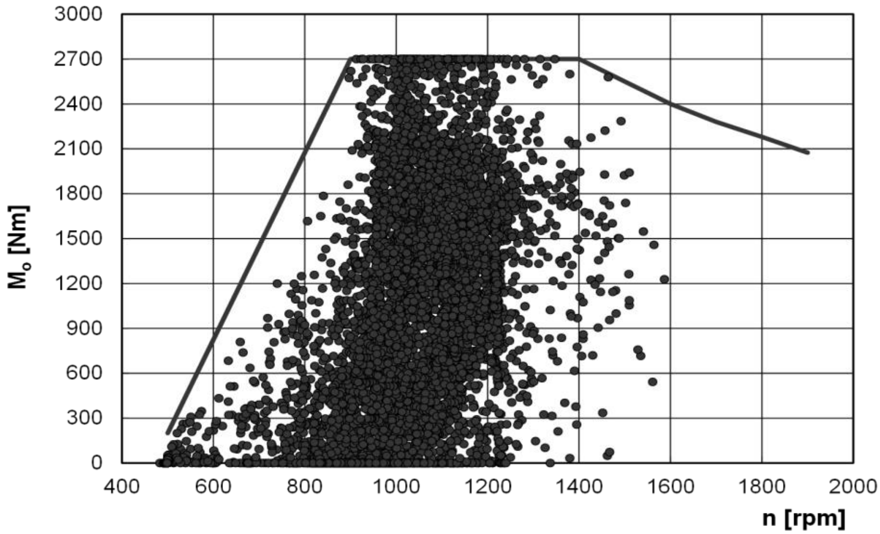
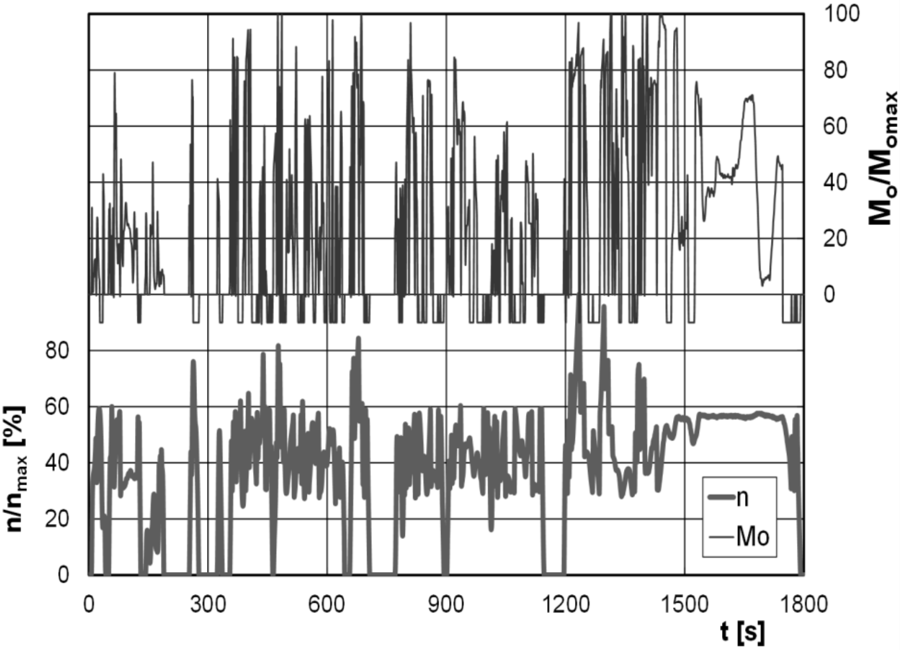


Fig. 8. Operating points in the engine operating field: a) effective power, b) torque

a)



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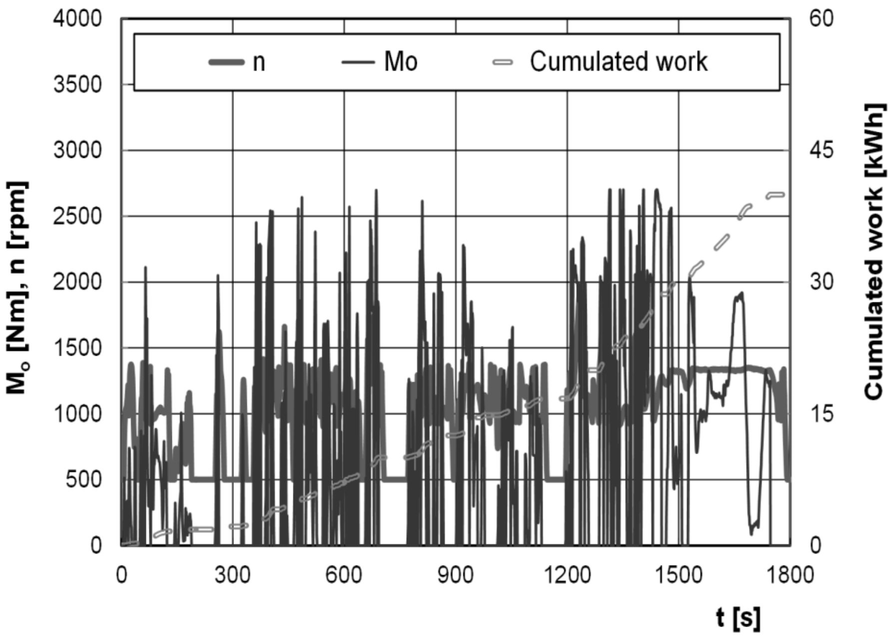

Fig. 9. WHTC cycle, engine speed and torque: a) before denormalization, b) after denormalization

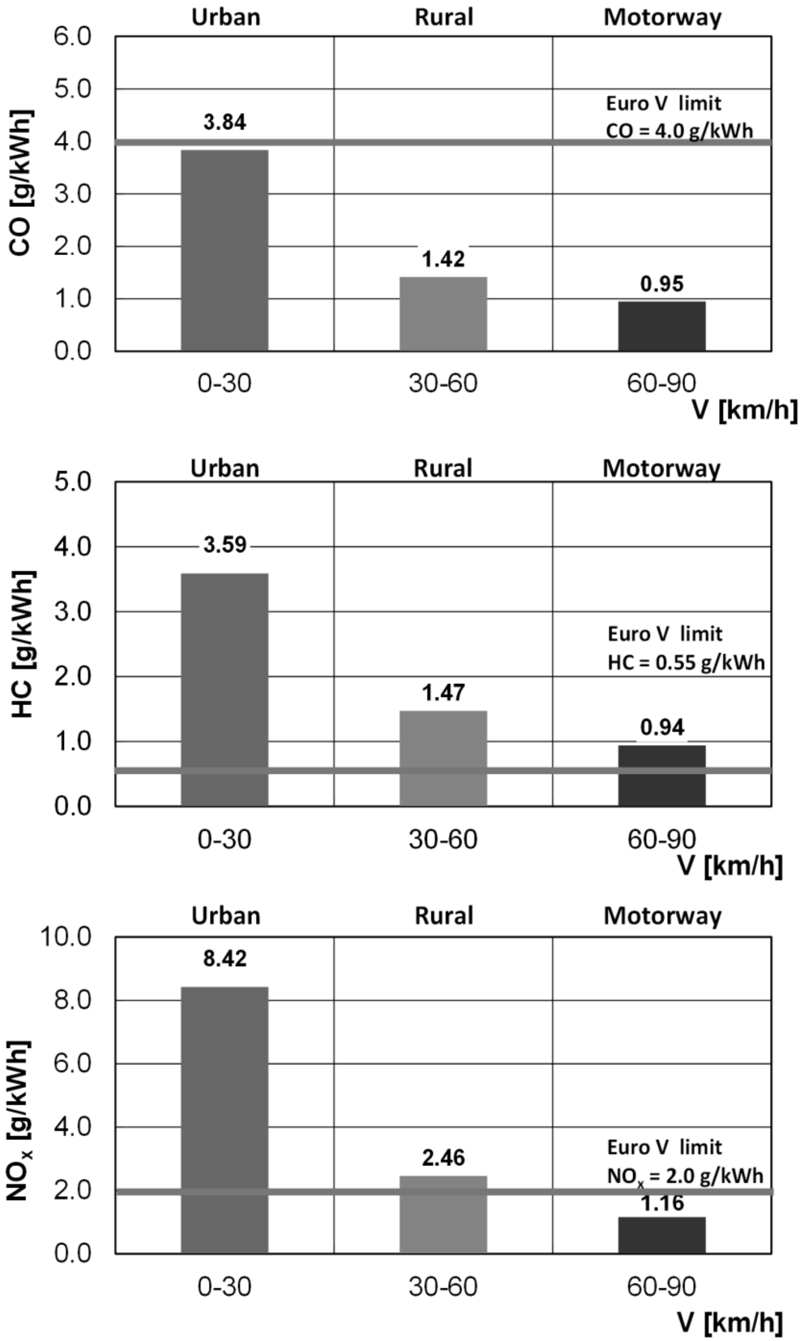

Fig. 9. On-road unit exhaust emission (haevy duty vehicle; actual traffic conditions)

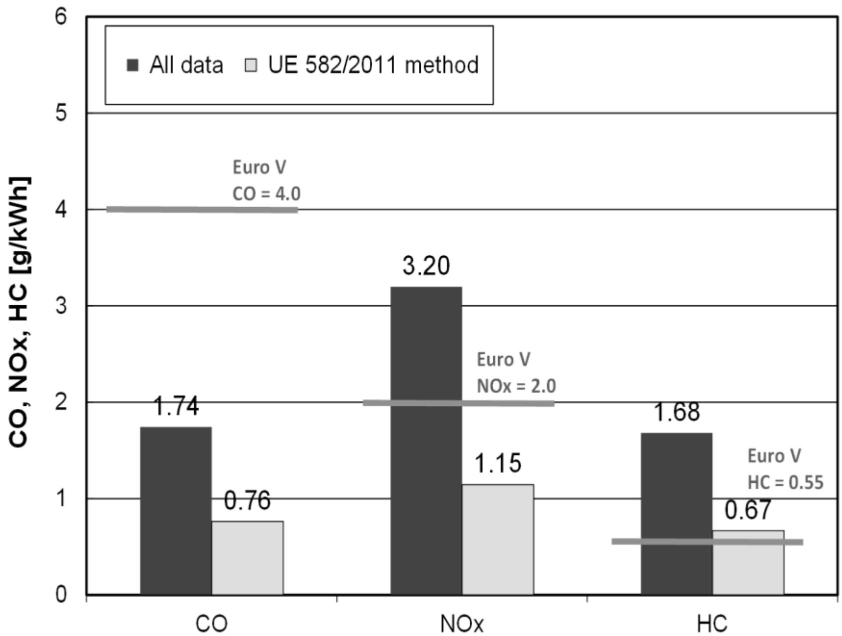

Fig. 10. On-road unit exhaust emission (actual traffic conditions) as per the method determined in EU regulation 582/2011

6. Conclusions

For the realization of the exhaust emissions tests under actual conditions of operation the authors used the testing potential of portable exhaust emissions analysers measuring all exhaust components (gaseous components and particulate matter mass and size distribution from spark ignition and diesel engines fueled with different fuels). The use of data from the on-board emissions measuring system in conjunction with the diagnostic system of an individual transport unit, based on the definable emission index, allows the assessment of the ecological performance of a vehicle in operation. The authors propose a monitoring system of all means of transport for the assessment of the ecological performance of entire groups of vehicles varying in terms of date of production (i.e. exhaust emission limits), their period of operation or conditions of operation. The emission indexes for vehicles are defined as multiplicity of the increase/reduction of the exhaust emissions during operation compared to the homologation tests designed for a given vehicle category complying with prescribed standards of emission of: carbon monoxide, hydrocarbons, nitric oxides and particulate matter (mass and size). Based on the created index for the individual modes of transport we may determine the models of exhaust emissions for different vehicles (or stationary machines) under actual conditions of operation. This will allow an ongoing monitoring of machinery fitted with combustion engines working under actual conditions of operation.

Legislators are currently working on a new test method which should limit the emissions in real traffic (Real Driving Emissions) so as to sustainably reduce gaseous emissions on the roads. In comparison with the currently valid test cycle (NEDC) this represents a significant extension of the engine operation range because on the road nearly every operating point in the engine map can be driven, even when in normal driving practice these points are never used. In this way it can be ensured that the emissions remain low in all practical driving situations. Evaluation tools from road measurements which support the recognition of normal driving are available; these are however in need of further fine tuning.

Acknowledgement

The research was funded by the National Centre for Research and Development (Narodowe Centrum Badań i Rozwoju) – research project within the Applied Research Programme (contract No. PBS1/A6/2/2012).

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