Journal of KONES Powertrain and Transport, Vol. 21, No. 2 2014

ISSN: 1231-4005
e-ISSN: 2354-0133
ICID: 1133896
DOI: 10.5604/12314005.1133896

COMBUSTION ENGINES DEVELOPMENT AND REAL DRIVING EMISSIONS

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Abstract

The article characterizes state-of-the-art PEMS (Portable Emission Measurement System) equipment for exhaust emissions measurement under actual operating conditions. This equipment allows measurement of the exhaust emissions from all modes of transport. Besides, the article contains the results of exhaust emission research for engines of a variety of transport applications such as light duty vehicles and heavy-duty vehicles. Own exhaust emission research results performed under different traffic conditions of new motor vehicles fuelled with different fuels (gasoline, diesel fuel and natural gas) have been compared with the type approval values that define the vehicle emission indexes. The analysis has been performed in relation to a vehicle but the proposed measurement methodology is also knit to the engine operating conditions. The testing of heavy-duty vehicles described in the book was divided into several stages for which the results obtained for these vehicles were compared for loaded and unloaded vehicles. Ecological advantages of the city buses of different powertrain configurations have been determined (diesel, hybrid) on selected regular bus lines in city centre.

Keywords: *exhaust emission, portable emission measurement system, real road conditions*

1. Introduction

The need to reduce negative environmental impacts has become the key factor in the development of techniques and technologies in all industries. The use and development of advanced technologies involve constant verification of the existing conditions of human, machine labour, and the consequences of its environmental impacts. Transport is considered to be one of the most rapidly changing industries, first and foremost because of reducing hazardous emissions.

Apart from improving the classic propulsion (internal combustion engine), research works are underway to develop alternative power train systems. However, on the basis of the existing analyses one can assume that internal combustion engines will continue to prevail until 2030 [1]. There are currently around 700 million vehicles owned throughout the world, which is predicted to increase to approximately 2.0 billion by 2050 [2]. The developed markets such as Europe, North America and Japan are expected to reach saturation in the near future, because these countries enter a period of population decline.

2. Combustion Engines Development

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).

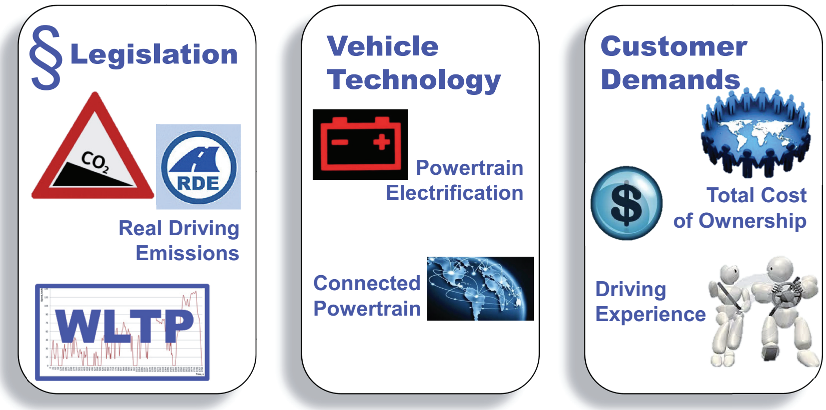

Fig. 1. Main factors influencing the development of future combustion engines [3]

The main issues faced by the internal combustion engine in the future include reducing atmospheric pollution and adapting to the diversification of fuels. Partially due to stringent regulations, vehicle emissions are already cleaner than the surrounding air in some urban environments. However, further efforts are planned to reduce the emissions (that including the reduction of gases that contribute to the greenhouse effect) (Fig. 2).

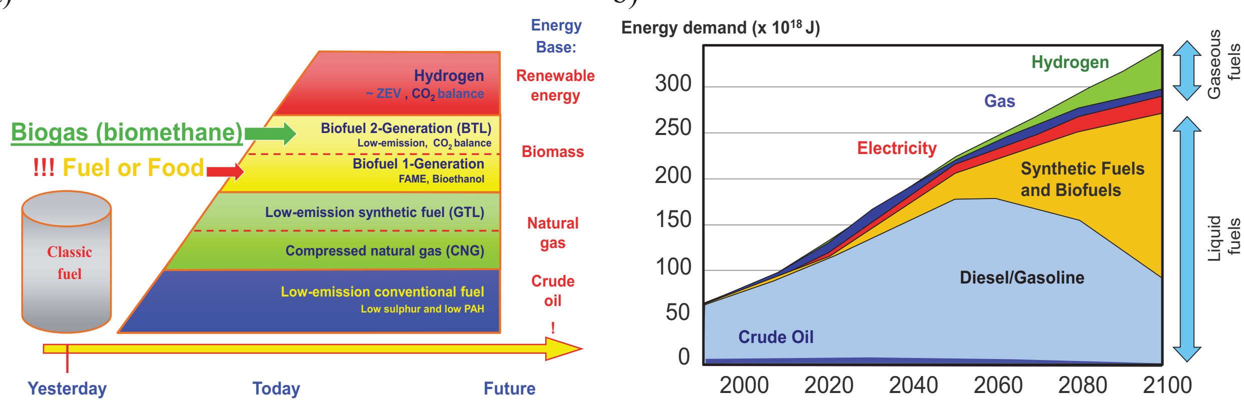

Fig. 2. Development of fuels for transport: a) diversification of sources, b) forecast of automotive fuel demand [4]

The spark ignition engine has a significant potential to contribute to further fuel consumption improvements of the vehicle. Boosting systems will play an important role as they enable downsizing strategies. Technologies are available that further improve performance and transient behaviour. Turbocharged engines, in general, have an advantage relative to their supercharged counterparts with regard to the fuel consumption and the cost-to-benefit ratio. Hybridization of turbocharged engines is a very appealing new path. The additional torque in the low speed range helps to improve the transient response and adds the known advantages of hybrid systems. The hybridization can be integrated on a modular basis. With this concept, the same boosted engine can be used in some vehicle applications just by itself and, for vehicle applications desiring significant downsizing, the hybrid technology can be added (Fig. 3).

Fig. 3. Green energy also in F1 (Gasoline)

For more than 50 years there were several attempts to win the hardest endurance race of the world with a Diesel engine. AUDI has developed an innovative powerplant for this purpose. With the first run at last year's 24 h race a historical victory was achieved. The new engine shows a very low weight, a very compact design and a new type of particulate filter system. In combination with a sophisticated combustion process and an extremely high injection pressure, a remarkable power output along with low consumption and very low emissions are guaranteed in the race (Fig. 4).

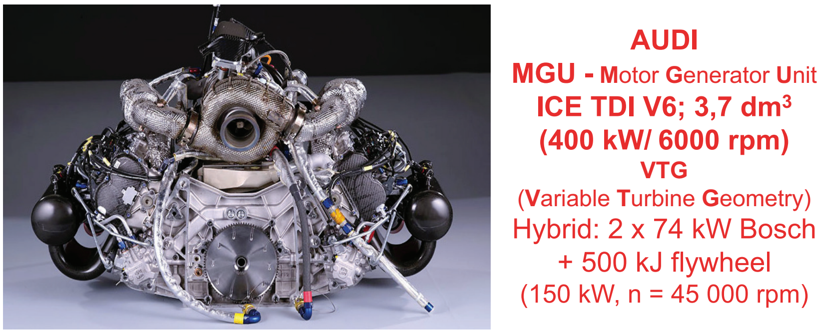

Fig. 4. Green energy in 24 Le Mans (Diesel)

The near term scenario of automotive propulsion systems will be achieved, in different maturity steps, by further enhancement & refinement of "conventional" configurations and alternative fuels. The Diesel engine will share with the Gasoline one the leadership of the market, with shares depending mainly from regional contingencies. Both Diesel & Gasoline engines have further development opportunities adopting additional technologies (Fig. 5).

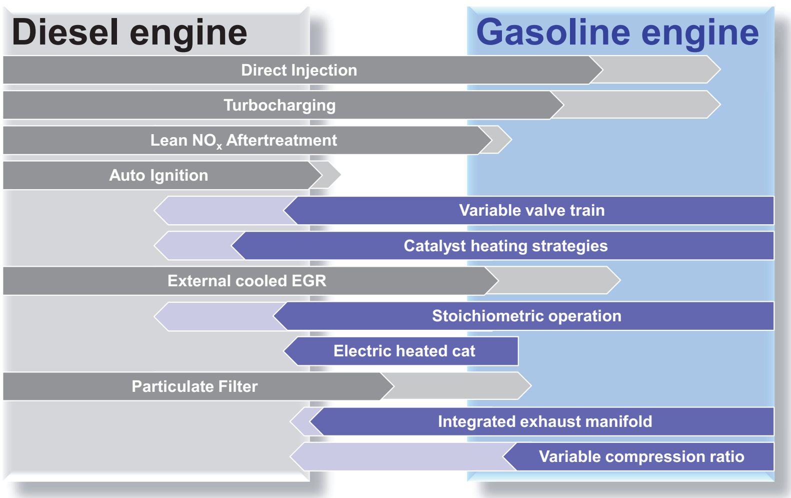

Fig. 5. Technology transfer between Diesel and Gasoline engines [5]

In the middle timeframe, where Hybrid powertrains will gain a relevant position, the Diesel engine could became a very interesting opportunity, because of its potential of further improving the fuel consumption and the fun-to drive features of hybrid systems (Fig. 6 and 7).

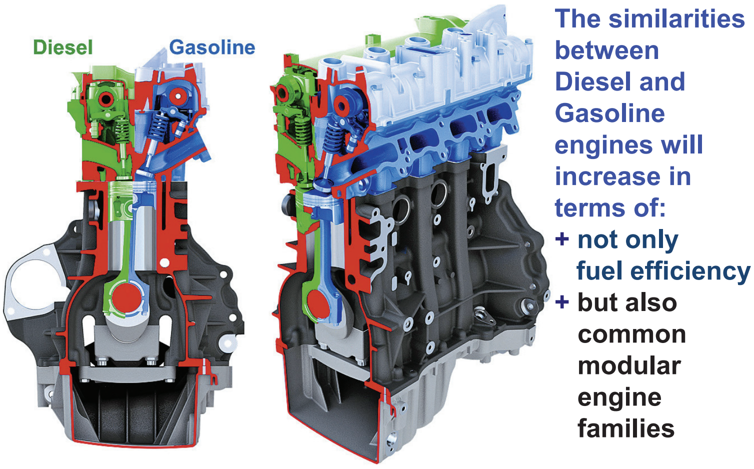

Fig. 6. AVL – Modular Diesel / Gasoline engine concept [6]

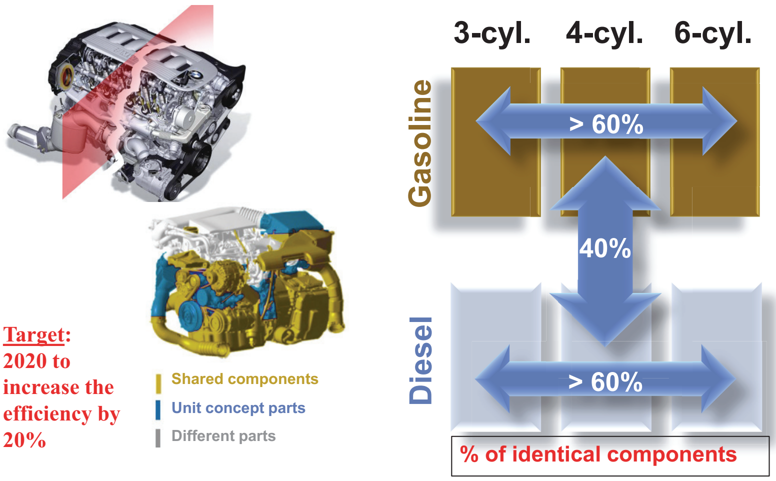

Fig. 7. The similarities between Diesel and Gasoline engines by BMW [7]

3. Real Driving Emissions

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, had 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 [8]. 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 [9]. 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 fuelled 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 [10, 11]).

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 (Fig. 8). These measurements, despite being realized on a selected sample of modes of transport, had 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 (Fig. 9).

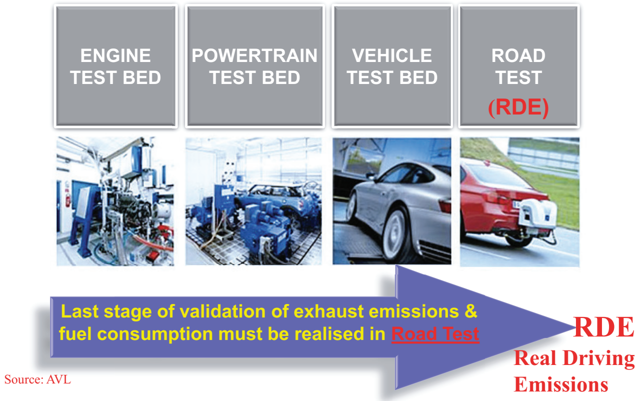

Fig. 8. Aim of the research on the vehicle exhaust emissions [5]

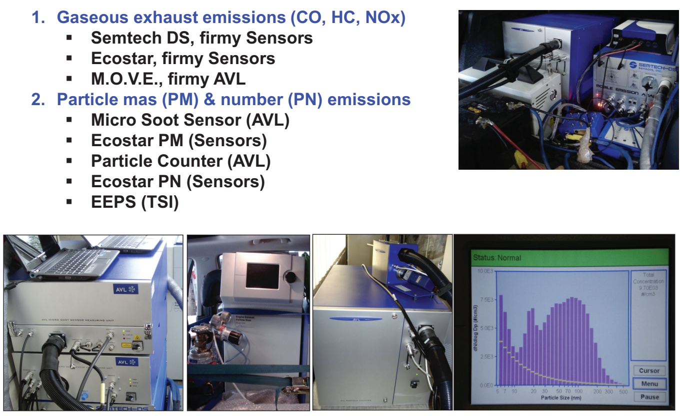

Fig. 9. Exhaust emissions measurement equipment

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.

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 (Fig. 10).

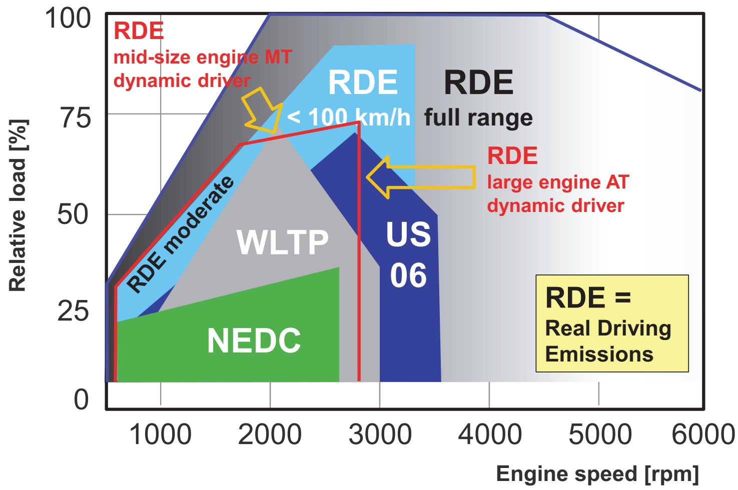

Fig. 10. Engine operating parameters in various emissions tests [16]

The author 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 [12]. Such an index for a given exhaust component has been defined as follows:

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

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 a j-th exhaust component $e_j(a,V)$ expressed in grams per second:

$$E_{real,j} = \sum_a \sum_V u(a,V) \cdot e_j(a,V)\,. \tag{2}$$

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). Such relations serve the purpose of determining the exhaust emissions presented in the further part of the paper.

4. Testing of passenger vehicles

The conducted tests regarding the exhaust emissions from passenger vehicles fitted with combustion engines (gasoline, diesel, Euro 3–Euro 5 compliant – Fig. 12) 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.

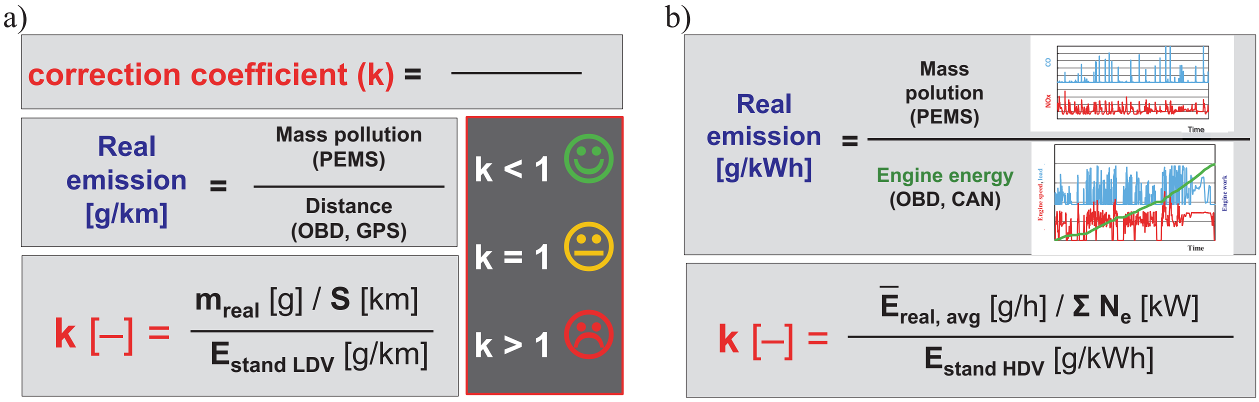

Fig. 11. Definition of correction coefficient: a) for passenger cars, b) for heavy-duty vehicle

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.

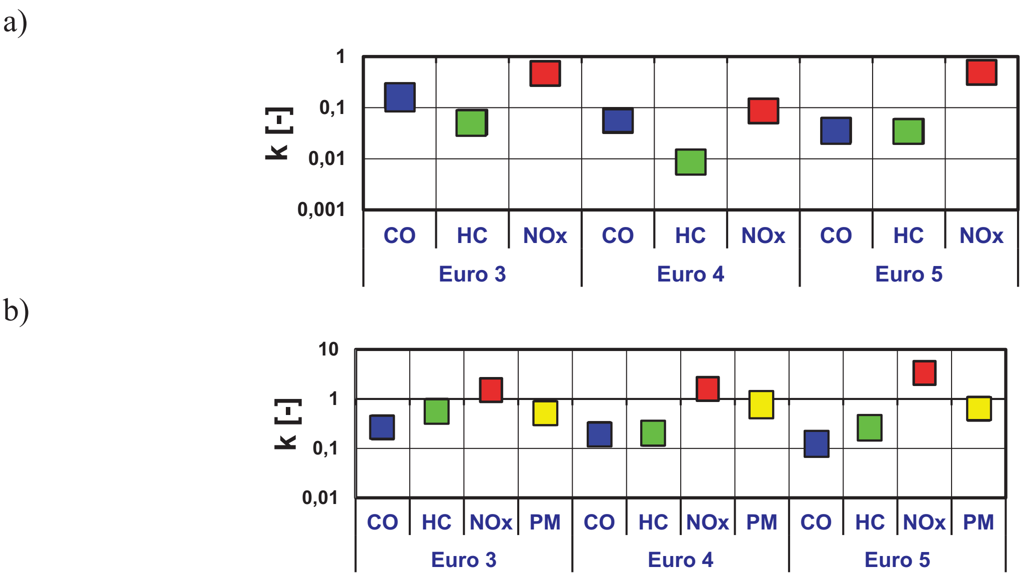

Fig. 12. Comparison of the vehicle exhausts emissions using different vehicle emission categories: a) gasoline engine, b) diesel engine

For vehicles fitted with alternative drivetrains, greater exhaust emissions were observed when aftermarket LPG system was applied (Fig. 13a). The emission indexes obtained for vehicles fuelled with gasoline and CNG (Fig. 13b) characterize the vehicle on-road exhaust emission level in comparison to the exhaust emission standard applicable for this vehicle [13]. Following the assumption of CNG as primary fuel–, the indexes of the exhaust emissions of a vehicle fuelled with gasoline 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.

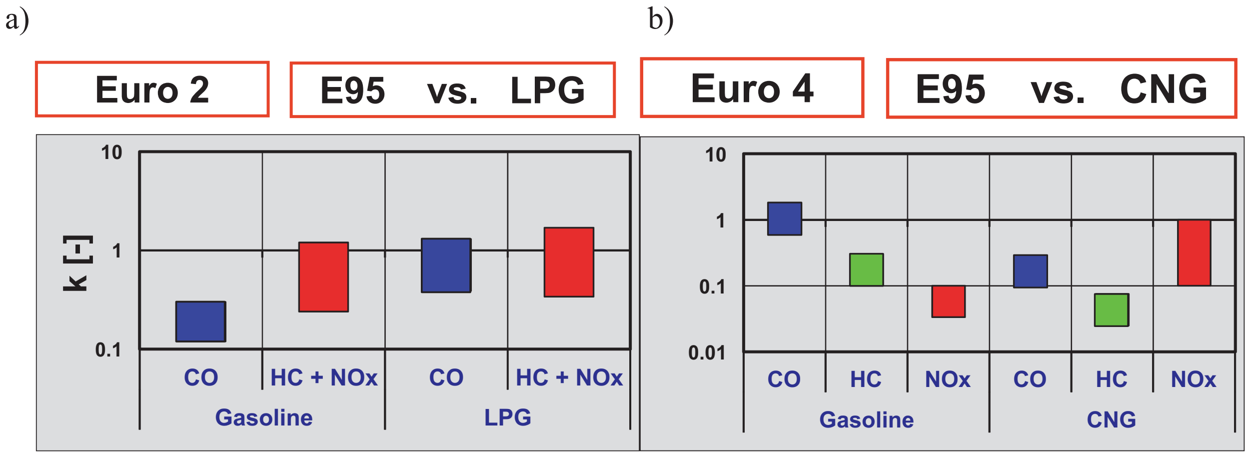

Fig. 13. Comparison of the exhaust emissions from vehicles: a) fuelled with gasoline and LPG (spark ignition engines), b) fuelled with gasoline and CNG (spark ignition engines)

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 had much better simulate the actual traffic conditions than the stationary tests. 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 investigations of the influence of the vehicle load on the exhaust emission for heavy-duty vehicles indicate that the emission grows almost twice (Fig. 14).

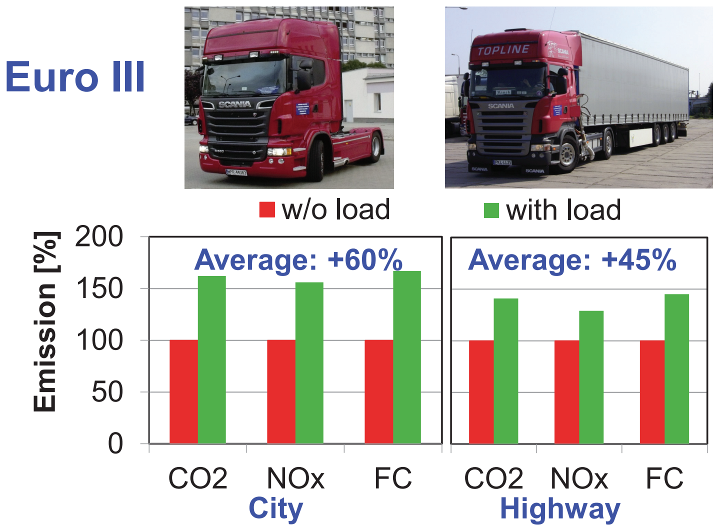

Fig. 14. Exhaust emissions test results for heavy-duty vehicles

The emission level of city buses, due to the specificity of their use, can only be assessed during actual conditions of their operation. The most suitable tests for these buses are performed on the urban routes. Using a portable exhaust emission measurement system, the authors measured the emission level of a hybrid and a conventional bus in city traffic in the city of Poznan. The conditions were selected to enable the most accurate reflection of the actual traffic conditions:

the traffic on the selected bus route was in line with the average traffic of the Poznan city routes. The objects of the tests were Solaris conventional and hybrid buses. The buses were selected for their similarities and for enable a comparison of their functionality and ecological performance under actual traffic conditions, (the bus engines complied with the Euro 5 standard).

For the tested buses, the emission indexes were determined – the actual emissions of the conventional and the hybrid buses were compared with the values prescribed in the EEV standard. The obtained data on the unit emissions were compared with the transient test (ETC). From the analysis of the emission indexes calculated for the vehicles with different drivetrains (Fig. 15) in the ETC test it follows that parallel and serial hybrid vehicles have the CO emission index lower than 1. It is noteworthy that the emission index for nitric oxides exceeded the admissible limit for the bus fitted with the conventional drivetrain (maximum value) 2.5 times and up to 4 times for the hybrid buses. This confirms a lower conversion rate of the selective catalytic reduction system. This may have been caused by the mismatched SCR as far as the engine operating characteristics are concerned.

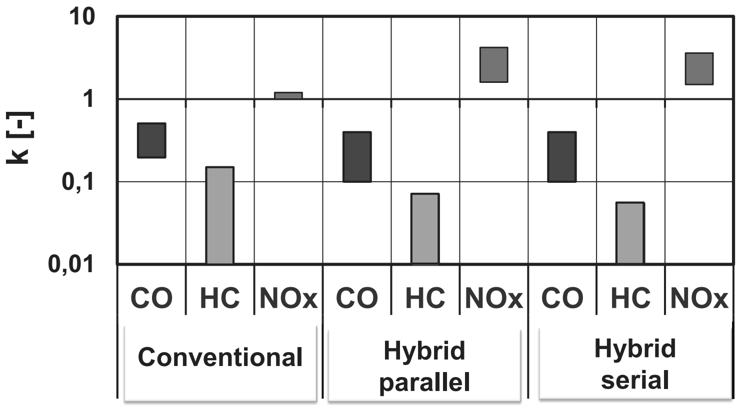

Fig. 15. Exhaust emission indexes of the buses were determined based on data on the actual on-road emission and assuming the admissible values according to different homologation tests (EEV standard) in the ETC test

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 fuelled 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.

This is a unique exploratory achievement, as in the US, attempts to implement such tests for heavy-duty vehicles are still in the stage of development while for passenger vehicles the developed concept and testing methodology is pioneer worldwide ([14, 15]).

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 3,500 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 author of the paper proposes 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 3,500 kg):

$$m = k\,E\,N\,S, \tag{3}$$

where:
m – mass of the pollutant [g],
k – actual 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):

$$m = k\,E\,N\,W, \tag{4}$$

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).

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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