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EXHAUST EMISSION MEASUREMENTS IN THE DEVELOPMENT OF SUSTAINABLE ROAD TRANSPORT

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Abstract

Economic development of nations leads to a higher living comfort of the society. Rich societies want to move safely and independently and demand immediate availability of purchased goods or – in the case of Internet shopping – delivery in the shortest possible time. Such an approach facilitates a continuous growth in the number of road vehicles. At the current level of technology advancement, an increasing number of vehicles results in a growth of the consumption of fossil fuels, which entails increased exhaust emissions and that, in turn, has a negative impact on the health of the living organisms. Another negative consequence of an increased number of vehicles (increased road congestion) is the emission of noise. This problem is particularly significant in large agglomerations where people are surrounded by moving vehicles. This paper presents the extent of influence of the automotive industry on the natural environment and the extent of changes in vehicle design and organization of road infrastructure that were instituted to reduce the transport's environmental burden. The further part of the paper presents a definition of the development of sustainable transport, its advantages and hurdles that we may encounter when modernizing a transport system. Subsequently in the paper, the measurements under actual vehicle operating conditions were described together with the possibilities of analysis of the research results and the advantages resulting from such an approach during the assessment of the impact of the automotive industry on the natural environment.

Keywords: *exhaust emission, noise emission, real road conditions, sustainable transport, health protection*

1. The impact of vehicles on the environment

An advanced transport network is of key importance for the economy and the living comfort of societies. It facilitates investment projects and economic activity in both industrial and service sectors. Transport networks enable a flow of people and goods, thus generating trade and people mobility. However, the development of transport networks (a growth in the number of transport tasks in each of the transport modes) also generates negative impact on the environment, including human health. These impacts are road congestions, exhaust and noise emissions and depletion of natural resources through fuel consumption.

The European Union has one of the densest road networks in the world, which results from the population density and a very high demand for transport services. According to the estimates of the European Environment Agency, approximately 25% of the people living in the EU (except

Romania and Bulgaria) live at a distance not greater than 500 m from a road of a traffic rate of 3 million vehicles per annum [4].

Road transport consumes the greatest amount of energy generating a total of 26% of final energy consumption in the European Union [12]. It is also a branch of the largest share of the greenhouse gases emission, i.e. 93% of the total emissions generated by transport (In the total emissions, aviation and marine transport on extra-EU connections and the wear of the railroad traction/railroad electricity consumption have not been taken into account) [12]. The advancement of the infrastructure of road transport influences landscape and land development as road network divides natural land into small areas limiting natural expansion of flora and fauna. Another significant issue related to transport is the emission of noise. World Health Organization estimates that in Europe the noise generated exclusively by transport deprives people of over a million of years of a healthy life [8].

Yet another negative phenomenon in transport is direct life threatening condition. Despite a considerable advancement in road safety, the annual number of casualties in the EU amounts to almost 43 thousand. This constitutes 97% of the casualties in all modes of transport [12].

Recently, a significant progress has been made in reducing of the negative impact of vehicles on the environment. This improvement is mainly related to the reduction of the exhaust emissions in modern powertrains, the use of alternative fuels, reduced exploitation of natural resources, reduced amount of waste (owing to recycling of end-of life-vehicles) and lower noise emission.

According to the data originating from ACEA, the noise generated by passenger vehicles has been reduced by 90% compared to 1970 [3]. Currently 85% of the vehicle weight is reused in the form of spares, recycled material or as a source of energy and from 2015; only 5% of the end-of-life vehicle weight will remain stored and unrecycled. A great progress has been observed in the area of exhaust emissions. In road transport, they are much higher than in other branches of industry. A single vehicle manufactured in the 1970s of the last century generated as much pollution as 100 modern vehicles today [3]. The limits for gaseous components and particulate matter prescribed in the Euro 6 standard are many times lower than the ones applicable today. Today Diesel particulate filters can reduce the emission of this component from diesel engines by 99%. In 1995 80% of new vehicles generated more than 161 g/km CO_2 and as few as 3% not more than 140 g/km. In 2008, as much as 42% of new vehicles generated less than 140g/km CO_2 and only 31% exceeded 161 g/km (Fig. 1). Due to very stringent emission standards, the exhaust gases emitted from vehicles are very often cleaner than the intake air surrounding them, particularly in the cities [3]. Despite this fact, further actions are planned aiming at an increase in the exhaust gas cleanliness and a reduction of the emission of greenhouse gases.

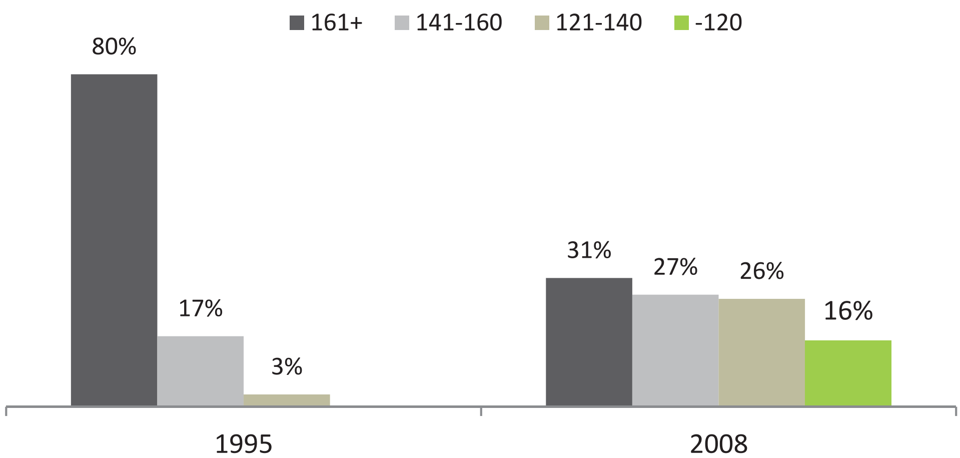

Fig. 1. Changes in the emission of CO_2 [3]

2. Sustainable transport system

A sustainable transport system is a system that ensures availability of transport services and mobility of all inhabitants of a given area in a safe and environment friendly way contributing to the economic development and wealth of the society.

A sustainable transport system possesses all features of a transport system, yet, when designing such a system, the following aspect are also taken into consideration [1]:

- Economic – to make the transport system most efficient at given costs or to obtain a given efficiency at the lowest possible cost (measurable and immeasurable). An increase in the efficiency can be achieved by, *inter alia*, appropriate traffic management (traffic lights, the possibility of inverting traffic directions on selected lanes, as needed), the use of intelligent transport systems (technologies enabling selection of routes to stimulate smooth and even traffic and minimization of traffic jams),
- Ecological – to reduce the negative impact of the functioning transport system on the environment (exhaust emissions, noise level). A reduction in the exhaust emissions may be achieved by increasing the smoothness of the traffic flow and a reduction of the number of motor vehicles in city centres, integration of road transport with other modes of transport within the Park&Ride, Park&Go systems or increasing the quality and availability of public transit,
- Social – to make the transport system most useful for the society by reacting to the transport needs that will guarantee access to all destinations. The social function may be realized through a developed network of public transit or a properly developed road infrastructure.

The sequence of actions for the development of a transport system may be as follows [2]:

1. Analysis of the existing transport system,
2. Determination of the requirements for the new system,
3. Selection of the transport combination.

The analysis of the existing system is a starting point for the actions aiming at the improvement of the current situation. The analysis must comprise current flows in the transport system, future demand for carriage o passengers and goods and the consequences of the functioning of the current system in the form of e.g. congestion, noise and exhaust emission level or number of road accidents. In the next step the objective to be achieved must be defined e.g. the level o admissible exhaust emissions at a given flow of exhaust gases must be determined.

The selection of the transport combination covers the identification of the admissible solutions e.g. those related to the modifications of the traffic organization (new transport nodes, modification of the traffic lights pattern, limits in the flow of a given type of vehicles on selected roads) and the assessment of the consequences of their implementation. At the final stage of the process a decision is made as to which solution meets, the expectations i.e. the decision maximizes the function of benefits at assumed limitations (e.g. budget).

Particularly difficult is the development of transport systems where the fundamental requirements of the new system are connected with the environment protection. The consideration of the environmental aspects is always connected with a limitation of the development of a transport system that, somewhat naturally, has negative environmental impacts. The priority of the investors and decision makers is, most frequently, maximizing the throughput of the new system at given limitations related to the investment expenditure or, possibly, building infrastructure at a minimum cost to obtain the assumed network efficiency. The reduction of the negative impact of transport on the environment either increases the expenditure for the system development or leads to a traffic limitation (system throughput).

3. The exhaust emission measurements under actual conditions of operation

When developing sustainable road transport systems that take into account the environmental issues, reliable vehicle exhaust emission data are extremely important. In the currently applicable homologation tests in the vehicle category of PC and LDV the parameters of operation of the engines are much different from the actual in–traffic parameters. For example, the FTP test used in the U.S. was developed using data on the traffic rate of the cities of Los Angeles and New York from the 1970s of the last century [6]. During the measurement and analysis of the exhaust emissions from road transport, the key factor is the specialized measurement equipment from the PEMS group (Portable Emission Measurement System). For the measurement of the exhaust emission rate engineers use SEMTECH DS, by Sensors Inc. (Fig. 2). The measurement of the concentration of the individual exhaust gas components is performed using analysers that are frequently used in homologation tests (tab. x). In order to determine the on-road or unit exhaust emissions we must know the mass flow rate of the exhaust gases. For this purpose exhaust, mass flow meters are used. These are mostly equipment components dedicated to a specified model of the measurement system. There are also portable particulate matter analyzers that can measure such PM properties as: mass emission rate (Micro Soot Sensor by AVL), size distribution (Engine Exhaust Particulate Sizer by TSI) or particle number (Particle Counter by AVL).

Fig. 2. View of the portable exhaust emission measurement system (SEMTECH DS)

Tab. 1. Exhaust emission analyzers used in SEMTECH DS

Parameter	Measurement method	Accuracy
CO HC NOx = (NO + NO_2) CO_2 O_2	NDIR analyzer, range 0-10% FID analyzer, range 0-10 000 ppm NDUV analyzer, range 0-3000 ppm NDIR analyzer, range 0-20% Electrochemical analyzer, range 0-20%	±3% of the range ±2% of the range ±3% of the range ±3% of the range ±1% of the range
2. Exhaust gas flow	Mass flow rate T_{max}: 700 °C	±2.5% range ±1% range
3. Warm up time	900 s	
4. Response time	T90 < 1 s	
5. Diagnostic systems	ISO, CAN, VPW, PWM	

Figure 3 presents the results of the exhaust emission tests from Euro 4 and Euro 5 compliant Diesel passenger vehicles carried out under actual traffic conditions. The measurements were performed using portable exhaust emission measurement systems (exhaust emission analyser – Semtech DS by Sensors Inc.). The output parameter from the measurement system is the emission rate of the individual exhaust components. Having such data, we can compare the emission level of different vehicles on the same test route. In order to facilitate the comparison of the on-road tests with the homologation tests emission indexes of the individual exhaust components are determined that can fall into the following categories:

– instantaneous values – characterized by a great deal of fluctuation as they are calculated in each second of the test,

– values incrementing while the test is being performed, calculated as on-going on-road emission of a given exhaust component (from the onset of the test until the current moment) compared to the normative value,
– values related to the whole test as a ratio of the on-road emission in an on-road test (carried out under actual traffic conditions) to the normative value.

The vehicle emission index (given exhaust component) has been defined as:

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

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

$$E_{rzecz,j} = \sum_a \sum_v u(a,v) \cdot e_j(a,v). \tag{2}$$

The on-road emission index of a given exhaust component can assume values from the range $\langle 0, \infty)$. This means that if the on-road emission from a vehicle does not exceed the normative values, the index has a value less than 1 and when the normative value is exceeded the index is greater than 1 and when the actual emissions are equal to the normative one the index equals 1 [11].

The graphs in Fig. 3 show the extent of changes of the emission index for which the normative limit is met for each exhaust component (dotted line). Despite high momentary variability of the emission index its ‘incrementing value’ is characterized as follows:

– for carbon monoxide – a very abrupt growth during engine start and then a reduction of its value; under actual operation, in a short term, a satisfactory reduction of the emission is obtained within the limits of the required standard for both the Euro 4 and Euro 5 vehicles; the index values are comparable for the tested vehicles,
– for hydrocarbons – the course of the index changes is similar to carbon monoxide, yet the Euro 4 vehicle needed a shorter distance (approximately 2 km) to reach the index value below 1. For the Euro 5 vehicle this distance was approximately 10 km,
– for nitric oxides – no normative requirements have been met – this mainly results from the difference of the engine operation in the NEDC test and that under actual traffic conditions; for the tested vehicles the emission index value is greater than 1.

The values of the exhaust emission indexes for passenger vehicles were determined based on the performed tests under actual traffic conditions. For the determination of the emission, indexes for the outstanding categories the authors adopted the results of earlier works carried out by the research team with the Chair of Combustion Engines at Poznan University of Technology [7-10]. For the category of low emission vehicles, the emission indexes assume values much greater than 1 in the initial driving phases but then they decrease to a value of several per cent of the value set forth in the emission standard (this dependence is the case for the emission of carbon monoxide and hydrocarbons). Contrary to the presented scheme is the course of the emission index for nitric oxides: it decreases its value, but it does not reach the level set forth in the emission standard. For this reason under actual traffic conditions the emission of nitric oxides is several times above the admissible limit – this dependence was confirmed in the tests of heavy-duty vehicles and city buses. For the rest of the vehicles of different emission categories the emission index curves k = f(S) were determined as dependent on the distance covered by the vehicles (Fig. 4, Tab. 2).

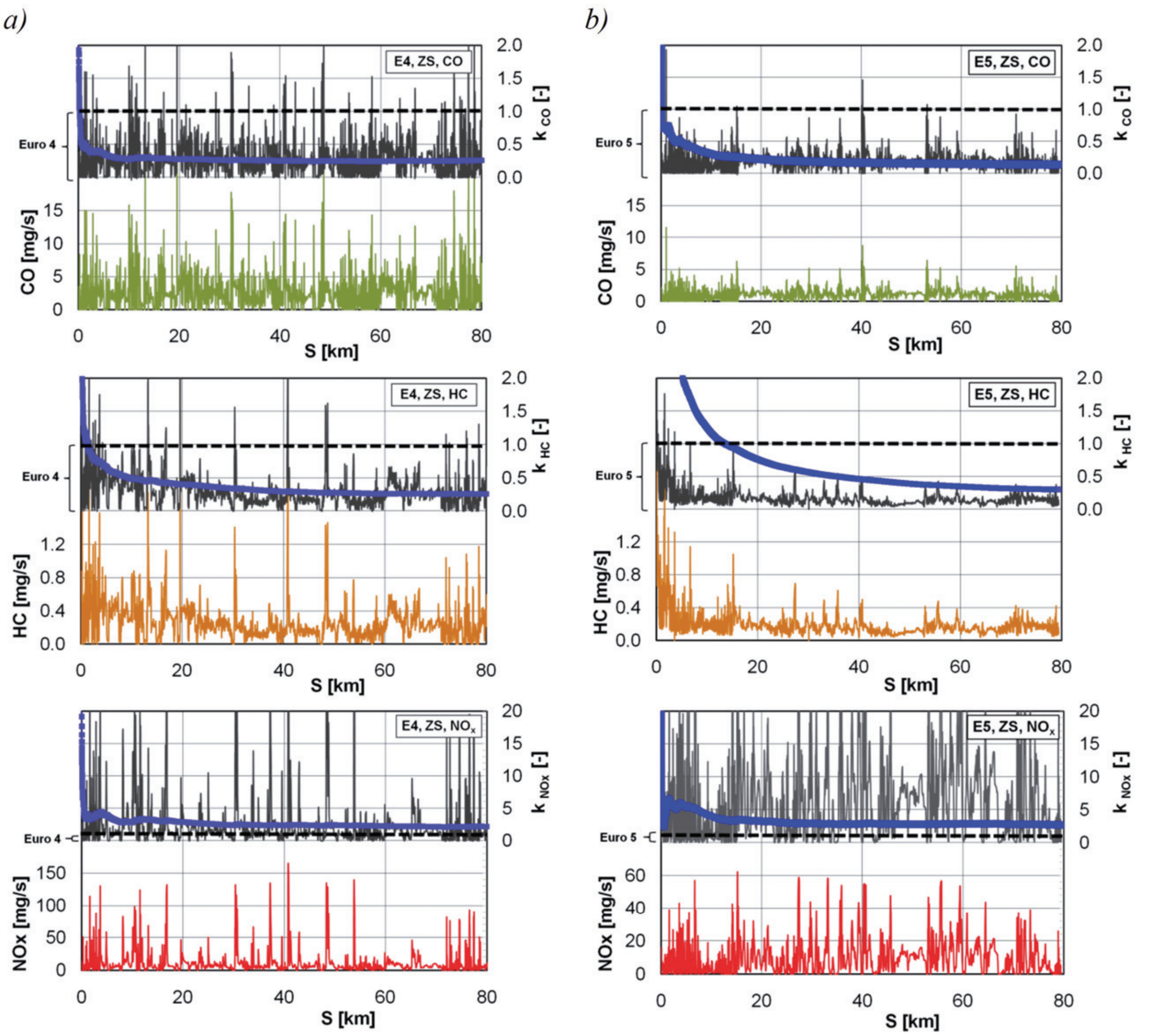

Fig. 3. The values of the emission rate and indexes of on-road emission for passenger vehicles compliant with Euro 4 emission standard, and Euro 5 emission standard

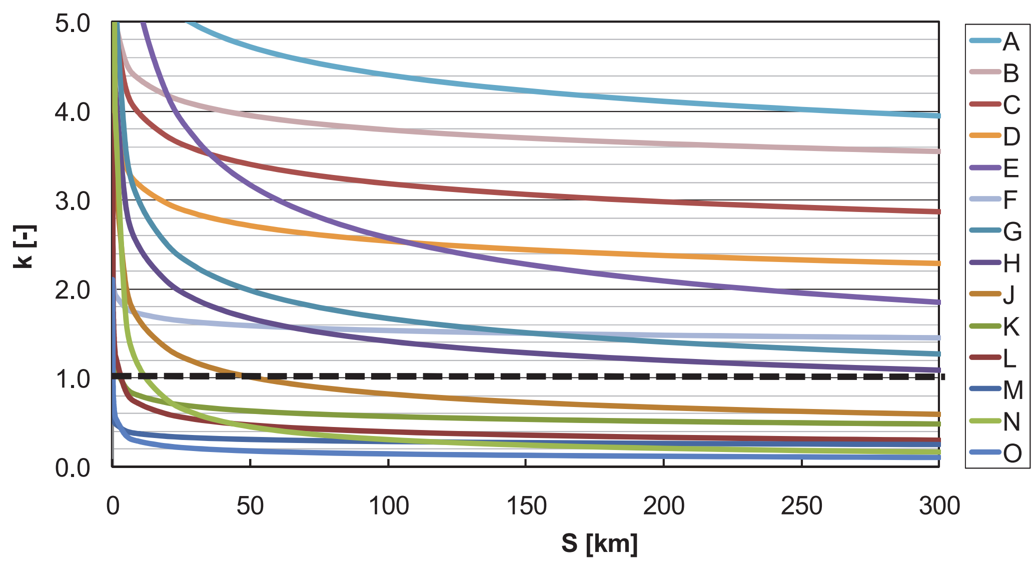

Fig. 4. Curves of the exhaust emission indexes

Tab. 2. Courses of the exhaust emission index curves assigned to individual vehicle types and corresponding emission categories

Vehicle	Engine		Exhaust emission index							
			E0	E1	E2	E3	E4	E5	E6	E7
PC	Petrol	CO	A	B	H	J	O	O	O	O
		HC	A	B	H	J	O	O	O	O
		NO_x	A	D	G	J	M	N	N	N
	Diesel	CO	A	D	H	J	L	M	O	O
		HC	A	D	H	J	N	M	O	O
		NO_x	A	F	G	E	J	C	B	D
LCV	Petrol	CO	B	C	E	G	M	N	O	O
		HC	B	C	E	E	M	N	O	O
		NO_x	E	G	G	J	K	K	L	L
	Diesel	CO	F	H	J	K	L	N	O	O
		HC	F	H	J	K	L	N	O	O
		NO_x	J	H	G	E	D	C	B	D
HDV	Diesel	CO	A	C	J	K	L	N	O	O
		HC	B	C	J	K	L	N	O	O
		NO_x	F	E	E	E	D	B	B	D
Bus	Diesel	CO	A	B	D	K	L	M	O	O
		HC	B	B	D	K	L	M	O	O
		NO_x	F	E	C	E	D	B	B	D
Motorcycle	Petrol	CO	A	A	H	J	O	O	O	O
		HC	A	A	H	J	O	O	O	O
		NO_x	E	G	G	J	N	N	N	N

4. Conclusions

The consequences resulting from constant advancement of the transport system have been presented in the paper. Ways of minimization of the negative impact of the automotive industry on the environment have also been discussed. At the current and future level of advancement of the road network, special attention should be drawn to the creation of a sustainable transport system. An important issue in this area is the assessment of the current impact of motor vehicles on the natural environment. For this reason exhaust, emission tests under actual operating conditions are a necessity. This type of tests is necessary because such tests enable an obtainment of reliable results in comparison to the homologation tests in which the engine work areas are limited and the vehicle is temperature-conditioned prior to the tests.

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