environmental protection; road transport;
road vehicle; exhaust emission;

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SOME ISSUES OF ROAD EMISSION FOR PASSENGER CARS AND LIGHT DUTY VEHICLES SECTOR IN THE ASPECTS OF ENVIRONMENTAL PROTECTION

Summary. The article presents the results of studies and investigations concerning some aspects of exhaust emission and methods of assessment of its influence on the environment. Some issues related to the modelling of emission level and costs of environmental protection have been discussed. The results of investigations concerning vehicle durability have been presented in the context of the need to meet more restrictive emission standards.

NIEKTÓRE ZAGADNIENIA EMISJI DROGOWEJ DLA SEKTORA SAMOCHODÓW OSOBOWYCH I DOSTAWCZYCH W ASPEKCIE OCHRONY ŚRODOWISKA

Streszczenie. W artykule przedstawiono rezultaty studiów i badań dotyczących niektórych aspektów emisji spalin oraz metod oceny ich wpływy na środowisko. Omówiono niektóre problemy związane z modelowaniem poziomu emisji oraz kosztów ochrony środowiska. Przedstawiono rezultaty badań trwałości samochodów w kontekście spełniania wymagań bardziej restrykcyjnych standardów emisji spalin.

1. INTRODUCTION

It is a truism to say that transportation plays a crucial role in a development of the world economy. We can consider this area of human activity as the movement of people, goods and services, consumption of energy in terms of resource use efficiency as well as significant source of environmental pollution. Analysing transportation issues in the context of sustainable development, we must apply energy analysis to identify the work potential of resources, the loss of potential in the course of energy transformation and energy consumption in the process of removing the negative effects in the interaction with the environment. The transportation efficiency can be considered as energy transformation efficiency, financial efficiency and the impact on the environment. The aggregated costs of transportation include total costs of production, maintenance and operating of transport means, costs of transport infrastructure, labour costs and costs of environmental protection. The increase of the requirements for environmental protection imposes greater investment in developing new solutions for the construction of means of transport, their maintenance, the use of new fuels, maintenance and utilization of residues. Increasing expenditures of the environmental protection can have a significant impact on the financial efficiency of transportation and it has an important social significance. It significantly improves the quality of life but the costs affects the final customer.

The increase of these costs can be a significant barrier to the demand for transport services in some transportation sectors.

2. ESTIMATION OF EMISSIONS

2.1. Predictions of emission level

Predictions of the level of emission is important to determine the type of managements or emission control measures that must be implemented in order to maintain air quality at the acceptable level. Underestimation of emission may be the reason for the deterioration of health and living conditions. Overestimation increases unnecessary the costs related to environmental protection. Models of the road transport emission based on emission level regulations, taking into account the structure of a vehicle age, the average mileage in each group of vehicle types and the average fuel consumption, etc. New vehicles emitted less pollution than the old ones because of the need to meet the emission requirements but emissions may increase with the aging of vehicles because of degradation of engine performance and air pollution control equipment [2, 3, 6]. Total exhaust emission E for V_{is} depends on average fuel consumption by vehicle $F_{i,s}$ and emission factor for vehicles of i type and s age.

$$E(t) = \sum_i \sum_s V_{i,s}(t) F_{i,s} EF_{i,s} \quad (1)$$

The structure of vehicle age which is available in statistical data may be different from the structure of vehicles which run on the roads. For each year, the fuel consumption by existing vehicles may be lower than the consumption in the previous year because the older vehicles probably drive less.

Estimation of the dynamics of changes of vehicle age is a separate problems. Retirement rates which are appropriate for the maintenance system and the lifestyle, should be taken into account. The retirement rate R during a time period Δt that begins at t can be determined from the survival rate S_u:

$$R(t, \Delta t) = 1 - \frac{S_u(t+\Delta t)}{S_u(t)} \quad (2)$$

Survival rate is different for each type and age group of vehicles. It depends on the shape factor, lifetime, failure steepness and characteristic servicing history.

2.2. Evaluation of environmental protection

The introduction of new emission standards will reduce the level of emission in the future, but it generates the cost increase immediately. The prediction and evaluation of the correctness of the adopted standards is difficult. However it is possible after a long time. Seckin and colleges [5] propose the use of the exergy balance analysis to evaluate efficiency of transportation systems. The extended exergy content of a material or immaterial system product B_p is the sum of material exergy B_m, the physical exergy B_{phys}, the exergetic equivalent of the total net monetary influx into the system B_K, the exergetic equivalent of the sum of the labour contribution into a system B_L and environmental remediation equivalent exergy B_{Env} [5].

$$B_p = B_{phys} + B_m + B_K + B_L + B_{Env} \quad (3)$$

The EE_{Env} of each effluent is equal to the sum of the net exergy of material and energy carriers, exergetic equivalent of labour and capital requirements by the installation and operation connected with an environment remediation, minus extended exergy of possible products of the treatment that may be recycled or otherwise used.

Exergy balance can be also applied to solutions regarding environmental protection. In this case it is necessary to take into account environment exergy equivalent related to the environmental burden due to the introduction of new solutions.

3. EMMISSION LEVEL REQUIREMENTS

3.1. Regulations of emission level

The main challenges in the field of environmental protection concerning road transport are:

- the achievement of high reduction in transport-related CO_2 emissions, on full fuel cycle and vehicle lifecycle,
- the gradual replacement of petroleum by new alternative, more environmental friendly fuels.

These goals are related to the need of saving natural resources, reduction of total greenhouse gas emissions as well as energy independence increase of particular countries.

The global increase of emission of carbon dioxide, nitrogen oxides, hydrocarbons and particles by road vehicles is one of the main problems of environmental protection. The worldwide regulations for CO_2 have predicted significant reduction of emission level (Fig. 1).

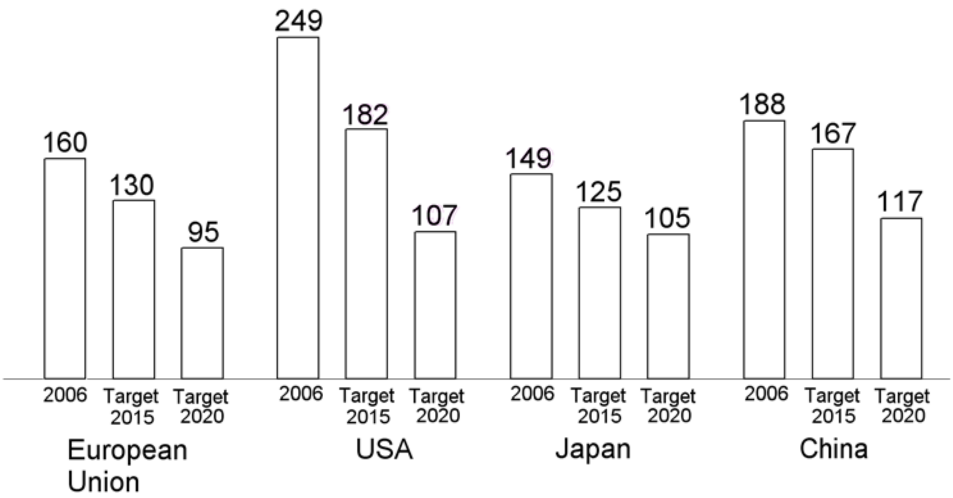

Fig. 1. Worldwide regulation for CO_2 reduction – emission targets [g/km] related to the New European Driving Cycle (NEDC)

Rys. 1. Regulacje redukcji poziomu CO_2 na świecie – poziom emisji [g/km] w odniesieniu do NEDC

Current and future regulations in this field require the new approach to the development of new design solutions and operating issues concerning vehicles.

3.2. Ways to achieve emission targets

The reduction of emission can be achieved through the reduction of the number of vehicles, the use of more restrictive legal regulations of emissions and it requires new trends of the development investigations, improvement of exhaust aftertreatment systems, reduction of fuel consumption by improving the engine efficiency and the use of new drive systems. In general, these long-term solutions face steep barriers in terms of technological risk. They are difficult to implement at needed scale. The introduction of new solutions for the reduction of fuel consumption or emission, results in the necessity of solving new problems, e.g. increasing the number of failures of cars or existence of difficult to utilize wastes, such as e.g. batteries.

The level of exhaust emission depends on fuel consumption. The main task in the field of engine development is the application of new solutions in order to increase the efficiency and to reduce harmful emissions. Increasing of the engine efficiency will be achieved through downsizing, turbocharging and direct injection. Estimated market share of different types of engines has been shown in Fig. 2. It can be assumed that the percentage share of diesel engines will be constant, while the share of the spark ignition engines will increase. Implementations of new solutions often create new challenges. For example, the application of direct injection system in spark ignition engine reduces carbon dioxide but solid particles increase. Particle and carbon dioxide emission limits have become stricter. Gasoline and diesel engine limits will merge. With a relatively high concentration of solid particles in the air it is necessary to introduce new solutions in filtering exhaust systems. The implementation of new solutions requires the development of new tests and other new systems. The total number of emitted particles in DI engines is much higher than that in MPI engines. There has been a problem of this type of pollution reduction. So far this problem affected only diesel engines. Different conditions of particle formation in diesel and spark ignition engines make it impossible to use the same solutions for exhaust filtration in various types of engines. Modification of exhaust aftertreatment systems may involve replacing the old systems with the new ones or adding new elements to the already existing. Solid particle filters can be added to the exhaust system behind the catalyst or they can be added to the catalyst. Each of the solutions requires the use of new materials.

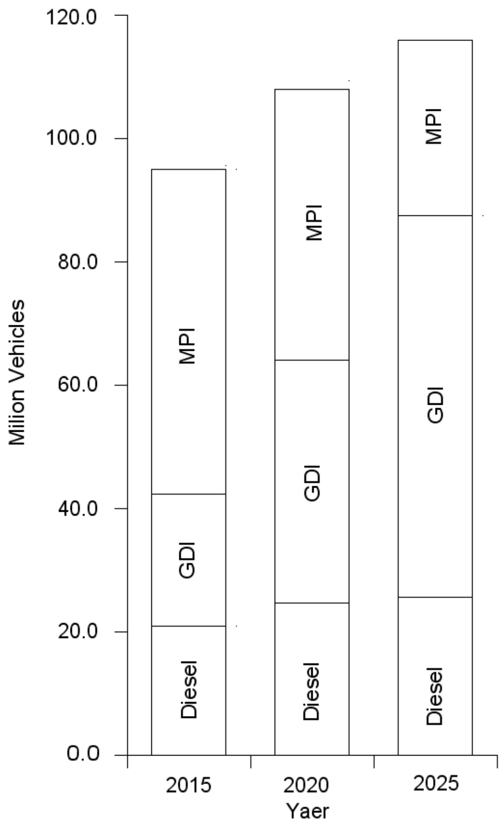

Fig. 2. Estimated market share of different internal combustion engines
Rys. 2. Przewidywany udział w rynku różnego rodzaju silników spalinowych

4. PROBLEMS ASSOCIATED WITH THE FULFILMENT OF THE EMISSION REQUIREMENTS

4.1. Influence of durability and maintenance of cars on the level of emission

The results of previous studies [2, 3] showed that the number of vehicles which have exceeded the level of emission increases as the vehicles become older. In order to determine the probability that the emission requirements are not fulfilled the measurements of exhaust emission for 850 vehicles were made in accordance with the methodology of periodical car inspection. The measurements provided information about the level of emission from each vehicle. The results of investigations concerning the level of exhaust emission were compared with the requirements of each model of a given year. Those investigations gave information about the number of vehicles which were faulty for each year of a car's production. The probability that a vehicle does not meet emission requirements *R(t)* were calculated according to the following formula:

$$R(t) = \frac{N(0) - n(t)}{N(0)} \tag{4}$$

where: *R(t)* – probability that a vehicle does not meet emission requirements after a given *t* operating time, *N(0)* – total number of investigated vehicles, n(t) – number of vehicles which meet emission requirements after *t* operating time.

The results of calculations have been shown in Fig. 3.

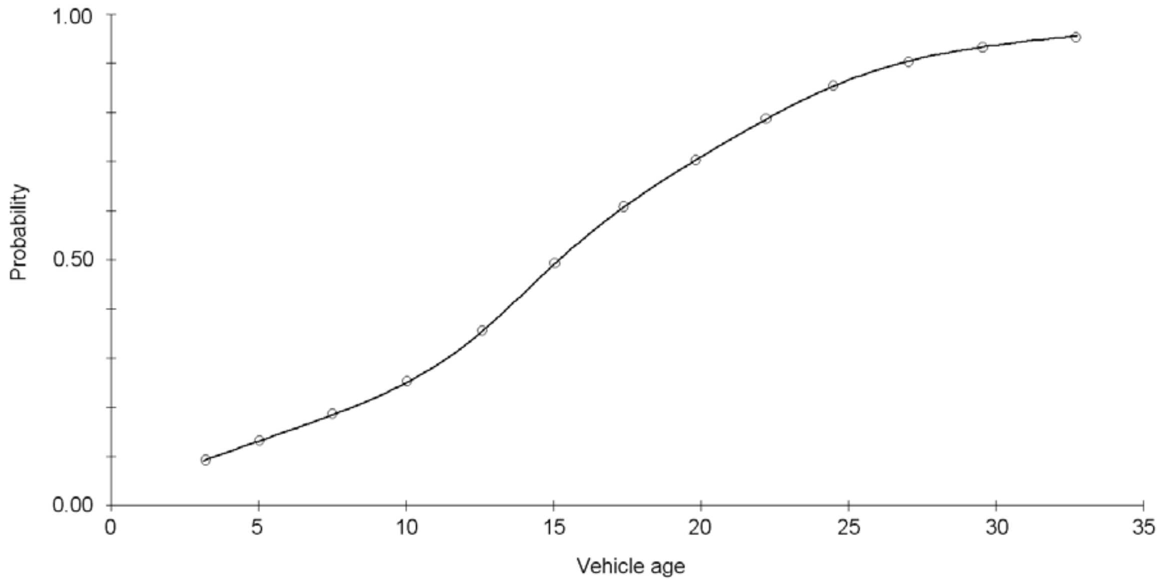

Fig. 3. Probability of excess emission level depending on vehicle age
Rys. 3. Prawdopodobieństwo przekroczenia poziomu emisji w zależności od wieku pojazdu

Technical condition of the vehicle can affect the fuel consumption as well as the level of harmful emission. The increase of harmful emission at the early stage may be masked by a catalytic system. Therefore, analysing the impact of the technical condition of the vehicle on greenhouse emissions measurement and fuel consumption should be included. The increase of fuel consumption can be caused by engine failure or faults of other systems.

4.2. Damages of car systems related to emission

Emission is closely related to the technical condition of vehicles. Faults of some car systems like engine or brake systems can have huge influence on the total emission level. Damages of engines result in increased harmful emission. During investigation, 20 types of damages which have a significant influence on emission and fuel consumption have been recognized (Tab. 1).

5. CONCLUSIONS

The timing of new standards introduction affects total emissions. For modeling the level of exhaust emission, many factors which are characteristic for a particular country region should be taken into account. The level of contamination of the environment by vehicle operating depends more on the average vehicle age and the age structure than the new more restrictive regulations.

Table 1

Types of damages which have a significant influence on fuel consumption

No	Type of faults	Reason of faults	Increase of fuel consumption [%]	Increase of harmful emission [%]
1	Increase of rolling resistance	Blocked piston in brake calliper of rear wheel	13 %	
2	Increase of rolling resistance	Wear of tear wheel bearing hub	12 %	
3	Increase of rolling resistance	Fault of shoe adjustment mechanism	18 %	
4	Increase of rolling resistance	Bad clearance adjustment in tapered roller bearing	18 %	
5	Loss of power, engine roughness	Fault of the control unit	22 %	
6	Engine roughness, overheating of engine	Fault of wastegate valve	28 %	
7	Engine roughness, loss of engine power	Fault of fuel high-pressure pump	25 %	
8	Loss of engine power, loss of compression pressure in the cylinder	Wear of cylinder liner	38 %	
9	Loss of engine power, loss of compression pressure in the cylinder	Cracked piston ring	18 %	
10	Loss of engine power	Incorrect installation of valve-gear mechanism	32 %	80, k
11	Uneven work of cold engine	Fault of thermostat in cooling system	16 %	
12	Uneven work of engine	Fault of air flow sensor	18 %	
13	Uneven work of engine	Fault of knock sensor	16 %	
14	Loss of engine power	Fault of lambda sensor	28 %	300, CO, 100, HC
15	Loss of engine power	Fault of spark plug	25 %	300, HC
16	Loss of engine power	Fault of gasoline injector	24 %	
17	Loss of engine power	Fault of diesel oil injector	22%	50, k
18	Loss of engine power, loss of compression pressure in the cylinder	Fault of head gasket	36%	
19	Uneven work of cold engine	Fault of coolant temperature sensor	12%	
20	Loss of engine power, loss of compression pressure in the cylinder	Fault of engine valve	42%	540, HC

The trend changes of emission level represents the combination of emission intensity and fuel consumption. The properly estimated emission level is important in assessing the impact of the introduction of new regulations, concerning environmental protection or assessing new solutions for road traffic. In the first case the impact of aging vehicles on the emission level and changes in the quantity of consumed fuel for different age groups of vehicles should be taken into consideration. The fuel consumption depends on the average mileage of a vehicle in particular age group. In the second case it is important to asses properly the age ranges of cars in a given traffic stream. In both cases changes of emission level which depend on different technical conditions should be taken into consideration.

It is possible to estimate the emission taking into account the vehicle age, but the problem lies in the mileage in different age groups.

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Received 12.03.2013; accepted in revised form 22.04.2015