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EVALUATION METHODS OF THE IMPACT OF MOTORIZATION ON THE QUALITY OF THE ATMOSPHERIC AIR

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Abstract

The automotive industry is one of the fastest developing branches in the world. From year to year on the roads appear more and more cars. In the modern vehicles, better and more efficient technologies reducing exhaust emission are applied. However, the cars are still the leading source of air pollution, especially in towns and cities. Car exhaust gases have adverse effect on the human health, because they form so-called "low emission". It means that they are released into the troposphere at the people living height. As a result, people are exposed to the direct and long-lasting contact with the fumes. Therefore, precise assessment is very important to the vehicles' impact on the quality of the atmospheric air. The review of the evaluation methods of the impact of vehicles on the air quality was presented in the paper, with special regard to the mathematical dispersion modelling of the exhaust gases.

In particular, NOx emission by sector in Poland, changing NOx emissions from road transport in Poland in the years 2000-2009 with regard to the change in the number of cars, vertical cross-section of a typical symmetric urban street canyon are presented in the paper.

Keywords: *vehicles, exhaust emission and ecology, road transport, combustion engines, air pollution*

1. Introduction

Air pollution is one of the most important problems of modern civilization. A lot of pollutants have significant influence of human health, environment and climate. The overall composition of clear air in Tab. 1 is given. Air pollution occurs when natural components are more or, most often, when air contains un-natural ingredients.

Tab. 1. The natural components of clear air

Ingredient	Content (% vol.)	Ingredient	Content (% vol.)
Nitrogen	78.09	Carbon dioxide	0.03
Oxygen	20.95	Others	0.0001
Argon	0.93		

Generally, the air pollution sources are divided into natural and artificial (manufactured). Natural sources include volcanic eruptions, windblown dust, sea-salt spray and emissions of volatile organic compounds from plants. The most meaning man-made pollutants are generated by burning of fossil fuels in electricity generation, transport, industry, households, industrial processes and solvent use (for example in the chemical and mining industries), agriculture, waste treatment [1]. The second division of air pollution sources due to spatial dimensions of them. In this way, there are point, line, surface and volume emission sources [2, 3].

Engine vehicles are one of the main air pollution sources in urban area. Road transport is the example of line emission source. It means that pollutants are emitted to the atmosphere along a straight or curve line of considerable length [3]. In addition, pollutants from road transport are emitted at the people living height. It makes them extremely dangerous for human health, especially in cities, where buildings and infrastructure make up the street canyons, where the air pollutants are cumulated because of weak ventilation.

2. Emission from the vehicles and human health effects

The vehicles could be divided for following categories: passenger cars, light commercial vehicles, heavy-duty vehicles and buses, mopeds and motorcycles [4]. In cities the most serious problem are passenger cars because of their amount. The most important pollutants emitted by road vehicles include: ozone precursors (CO, NO_x, non-methane volatile organic compounds NMVOCs), uncombusted hydrocarbons (HC), greenhouse gases (CO_2, CH_4, N_2O), acidifying substances (NH_3, SO_2), particulate matter mass (PM), carcinogenic species (polycyclic aromatic hydrocarbons PAHs and persistant organic pollutants POPs), toxic substances (dioxins and furans) and heavy metals [4, 5]. In Fig. 1 percentage of NOx, emission rate by sectors is presented. The number of cars from year to year is growing, but in the modern vehicles, various after-treatment devices to reduce pollutant emissions (such as catalytic converters and diesel particle filters) are installed. It causes a decrease of emission rate from the single cars. However, the fast increase in number of cars causes' growth emission rate as it is shown in Fig. 2.

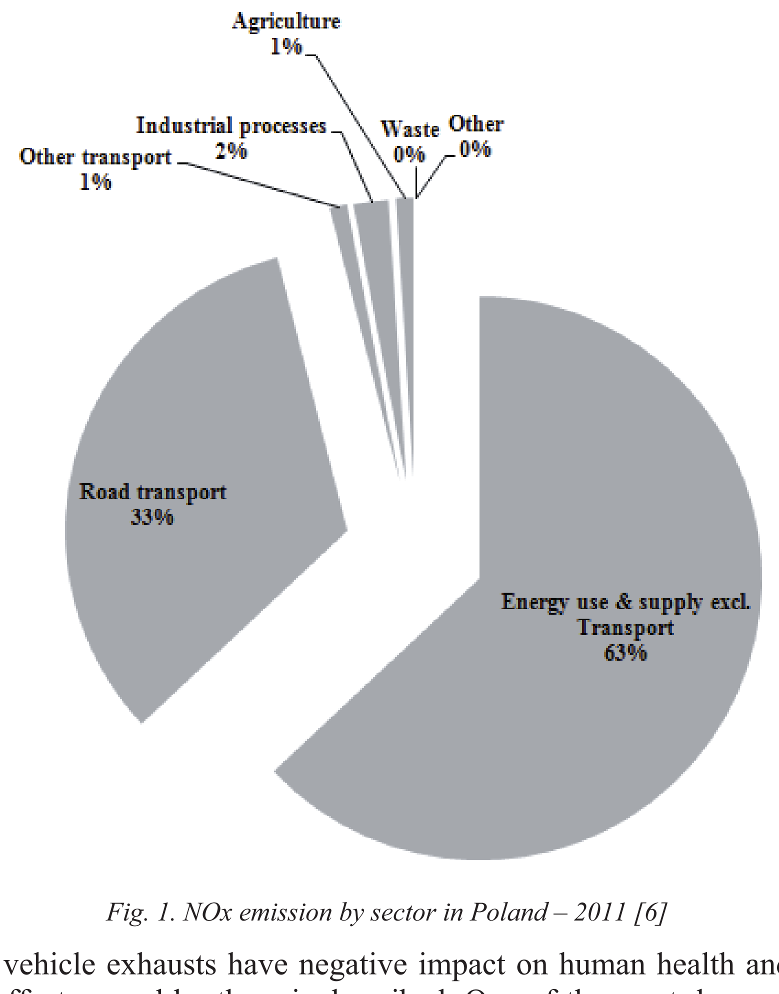

Fig. 1. NOx emission by sector in Poland – 2011 [6]

As it was said, vehicle exhausts have negative impact on human health and the environment. Below the health, effect caused by them is described. One of the most dangerous components of the fumes is particulate matter mass (PM). This substance is emitted especially from diesel engines. In people, it could cause or aggravate cardiovascular and lung diseases, heart attacks and arrhythmias, affect the central nervous system [1]. Very fine parts of PM could accumulate in the lung and in effect cause shortness of breath and breathing problems. In addition, on the PM heavy metals are deposited. It may cause even cancer. NO_2 can affect the liver, lung, spleen and blood. It can also aggravate lung diseases leading to respiratory symptoms and increased susceptibility to respiratory infection [6]. CO can cause heart disease and problems with the nervous system. In addition, it could be the reason of headache, dizziness and fatigue. Exposure to SO_2 could aggravates asthma, reduce lung function and inflame the respiratory tract. Also, like CO may result headache, general discomfort and anxiety.

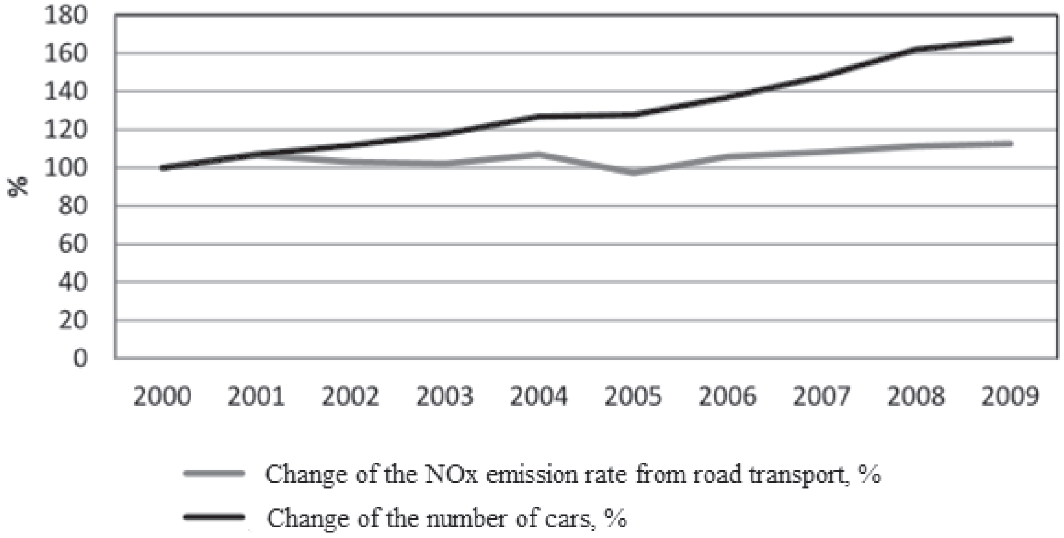

Fig. 2. Changing NOx emissions from road transport in Poland in the years 2000-2009 with regard to the change the number of cars [7]

It follows that in urban areas people are exposure to a lot of toxic substances from vehicle exhausts, which have significantly negative impact on their health and well-being day by day. It is considered to be very important to make a reliable evaluation of the emission rate from fossil fuel combustion and the impact that emission on the people.

3. Methods of the impact engine vehicles on the atmospheric air

The first action connected with the air quality control is legislation, which conduct to reduce air pollution and influence of them. In Europe, there are two main regulations on air quality and emission rate of fumes. The main legal act concerning air quality is Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. The Directive requires Member States of European Union to reduce emissions into the atmospheric air. These restrictions also apply to emissions from the fuel combustion in car engines. The Directive determine first of all [8]:

- methods and criteria of assessing the ambient air quality in Member States,
- improving the air quality or, if it is already good maintain that status,
- using modelling techniques where it's possible,
- the allowed values of the levels of concentration of air pollutants.

In direct relation to emissions from the road, vehicles corresponding EU regulation is applied [9]. That regulation establishes technical requirements for the type approval of motor vehicles and replacement parts, such as replacement pollution control devices, with regard to their emissions. Regulation also lays down rules for in-service conformity, durability of pollution control devices, on-board diagnostic (OBD) systems, measurement of fuel consumption and accessibility of vehicle repair and maintenance information. It means, that every new vehicle has to comply with the requirements of that regulation. The act imposes the obligation to use the measures limiting exhaust emissions from vehicles and the use of exhaust control systems during the vehicle movement. In Tab. 2 emission limits for chosen fumes, components in according to Euro 5 are presented. Actions to reduce pollutants emission from the vehicles could be divided into internal and external [5]. Internal actions include optimization of combustion chamber, high injection pressure, injection start optimization, optimization of the quantity of fuel injected, etc. To reduce the exhausted emission oxidation catalyst, diesel particulate filter, exhaust gas recirculation (EGR) or NOx catalyst can be used. Every new car is provided with a diagnostic system, on-board diagnostic (OBD). That system diagnoses engine control system (injection and ignition), exhaust system (catalyst and lambda probe work) and fuel system. All of those operations lead to reduce fumes emission what reduces the negative effects on ambient air.

Tab. 2. Euro 5 emission limits for passenger cars, mg/km [9]

CO		NOx		PM	
PI	CI	PI	CI	PI	CI
1000	500	60	180	5	5

The next way of the impact of vehicles on air quality assessment is evaluation of the emission rate of fumes. Generally, two methods to assess the emission rate could be used. First, one refers to single vehicle and relies on the chemical analysis of exhausts. It could be carried out in several ways. The most popular is sampling the fumes (while engine is working) to the special bags. Sample could be directly or indirectly and continuous or random. Next, the exhausts are applied to fumes analyser or to chromatograph. Before measuring exhausts may be cleaned and dried. By that devices the fumes emission rate from the single car is measured.

However, to study the influence of vehicles on the atmospheric air in a chosen area the impact of the whole traffic should be determined. This is more complicated process than measuring fumes emission rate from single car. To evaluate whole road emission it is important to know not only emission rate from individual vehicles. In addition, the others road transport parameters should be determine, especially traffic flow and distribution of different types of vehicles, fuel and age of them. It would be impossible to analyse every single car. To determine the exhausts emission rate from the road, emission factors are used. There are a lot of sources including emission factors from vehicles. However, in Europe EMEP/CORINAR database is the most often used. That base includes not only emission factors, but also information about methodology of emission factor rating and emission measuring and controlling [4]. The database is built on the basis on emission inventory and related to Euro standards in [9]. The methodology and emission factors can be also applied in countries not following the Euro standards, provided that a correspondence between the national technological classification and European legislation classes can be approximated. The document contains emission factors for almost all of exhausts ingredients. The values of emission factors are presented depending on the fuel (in g of the substance per kg of the fuel) or vehicle category with typical fuel consumption (in g of the substance per km of the distance). Example of mean values of emission factors for NOx and PM depending on the vehicle and fuel type in Tab. 3 are presented. Similar emission factors database US Environmental Protection Agency or UK government developed [10, 11]. Germany, Austria and Switzerland developed The Handbook of Emission Factors for Road Transport (HBEFA) [12]. This database was originally developed on behalf of the Environmental Protection Agencies of Germany, Switzerland and Austria, but with time, HBEFA start to be supported the other countries like Sweden, Norway and France. The first version (HBEFA 1.1) was published in December 1995, and the newest version, HBEFA 3.2 is planned on 2014. Emission factors in the HBEFA model are determined by PHEM model [13].

In literature, a lot of methods of determining and tests for validation of emission factors could be found. It could be done by simulations in road tunnel or by road traffic emission models. One of those models is PHEM model. Hausberger et all validated emission factors contained in HBEFA (1995) for heavy-duty vehicles by tunnel measurements [14]. The measurements of more than 100 engines have already have been made available was done. Methodology of elaboration of the emission factors was based on interpolations from steady-state emission maps. That

Tab. 3. Emission factors for NOx and PM, g/kg fuel [4]

Category	Fuel	NOx	PM
passenger cars	gasoline	8.73	0.03
	diesel	13.96	1.1
	LPG	15.2	0
light commercial vehicles	gasoline	13.22	0.02
	diesel	14.91	1.52
heavy-duty vehicles	diesel	33.37	0.94
	CNG (buses)	13	0.02
Two-wheel	gasoline	6.64	2.2

database was used in the emission model. With a given driving cycle and road gradient the engine power was calculated second per second according to the driving resistances and losses in the transmission system. Passenger car and heavy-duty emission model (PHEM) was used in researches. The model offers a routine to convert the measured points into this standard format by interpolation from all measured values. By this standard a simple averaging of single engine maps, independent of the engine size is available. With the used of these tools, emission factors have been elaborated. In the next step evaluated emission factors was validated by the road tunnel measurements. The research has demonstrated that emission from heavy-duty vehicles contained in HBEFA (1995) was underestimated. The simulations results showed correlation between the data measured in the tunnel and elaborated emission factors. Emission factor validation with using tunnel measurements and statistical model was also done by Colberg et all for light- and heavy-duty vehicle [15]. Evaluated in studies emission factors were compared with the emission factors included in the HBEFA model.

Based on emission factors and other road traffic parameters (like traffic activity and distribution of different types of vehicles, fuel, etc.) determine of emission rate from road transport in chosen area are available. When emission rate is known, dispersion pollutants in ambient air could be evaluated. Therefore, the next step in determination of the impact of motorization on the quality of atmospheric air could be spatial distribution of pollutants concentration with used mathematical modelling. Dispersion models are extensively used for assessing roadside air quality by predicting current and future pollution levels, as well as their temporal and spatial variations.

All deterministic mathematical models, in which linear emission sources could be entered, can be applied for modelling dispersion of the road pollutants. For example, in Poland Gaussian plume model, Pasquille formula is used [16]. Although model is dedicated for point emission sources, it can be used for linear ones. In this model, the chosen road is shared on several segments and point equivalent emitters are made. This solution causes significant calculation errors, but the estimation of pollutants concentration level in air is this model is possible.

However, there are also more complicated models, developed especially for the pollution from road vehicles. Many of them allows to modelling in urban area, where evaluation of the influence of cars is extremely important. Those models are suitable for calculations air pollution in street canyons. These are the models for micro-scale modelling and require very detailed description of air mass flows in street canyons. Therefore, this is important to know meteorological conditions on considered area. At Fig. 3, vertical cross-section of a typical symmetric urban street canyon is presented. One of those models is Danish Operation Street Pollution Model (OSPM), which contains a simplified description of flow and dispersion conditions in urban roads [17].

Concentrations of exhaust emissions are calculated using a combination of two types of dispersion models: a plume model and box ones. The plume model is used for the direct contribution. In the box model, the recirculation pollution part in the street is determining.

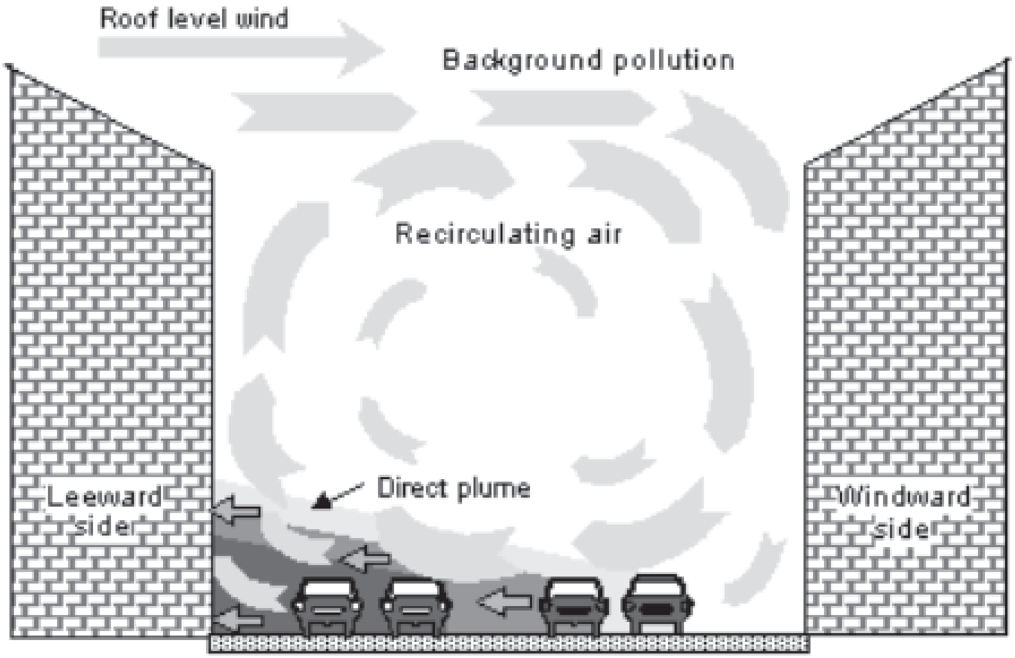

Fig. 3. Vertical cross-section of a typical symmetric urban street canyon [18]

Kaplan et all. used Lagrangian Particle Dispersion Model (LPDM) to calculate concentrations at street level in France. The model describes emission of NOx from traffic into a constant background of ozone BO_3. Model also includes chemical reaction scheme and traffic induced turbulence. Results of mathematical modelling were compared with measurements at two monitoring stations in Paris. The results of researches showed that urban-scale model can be used stand-alone if the background ozone concentration and also be coupled with meso-scale chemistry transport model. Sathe Yogesh V. in India applied STREET and STREET Box models, which used for calculating the dispersion of pollutants generated from a city [20]. Models take into account the mass flux balance between a horizontal convective flux, a turbulent diffusive vertical flux and a continuous road transport emission source to determine the pollutants concentration in the street. This is important to well known the canyon geometry. He noted that STREET Box model provides a good estimation of pollutant concentration while STREET model underestimates the concentrations. But both of the models provide a quick estimate of pollutant concentrations, which will be very useful in urban air quality assessment.

4. Summary

Although automotive companies are still working at low-emission engines, pollution caused by road vehicles have still significantly negative impact of the ambient air. There are many tools, but evaluation of impact of road traffic on the atmospheric air is not easy to determine. But this is very important to assess it, because of air quality and human health. Emission from road vehicles is especially adverse in urban area, in city centres. Car emits pollutants at human living height and is the reason of 'low-emission'. It means, that a lot of toxic substances go directly to human organism. Many cities have air pollution monitoring network. The level of pollutants concentration is measured constantly by devices included in the network. But, for example in Wroclaw, there are only 3-air pollution monitoring stations. In addition, limits of a lot of substances are still highly exceeded. To improve air quality in the streets canyon (which is directly connected with road traffic) it is needed at first, to very reliable evaluate the emission rate and impact of the cars and next, take the actions for reduce influence of road traffic. It could be done by getting better systems to reduce pollutants emission from engines, improving the traffic organization in cities, the promotion of alternative fuels and not using the cars in city centres, etc.

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