**ISSN**: 1231-4005
**e-ISSN:** 2354-0133
**DOI:** 10.5604/12314005.1216394

# RISK EVALUATION OF DRIVER EXPOSURE TO EXHAUST FUMES INSIDE THE PASSENGER CAR CABIN IN URBAN TRAFFIC CONDITIONS

**Maria Skrętowicz**

*Wroclaw University of Technology, Division of Automotive Engineering*
*Braci Gierymskich 164, 51-640 Wroclaw, Poland*
*tel./fax: + 48 71 3477918*
*e-mail: maria.skretowicz@pwr.edu.pl*

**Antoni Jankowski**

*Institute of Aviation*
*Krakowska Avenue 110/114, 02-256 Warsaw, Poland*
*tel.:+48 22 846 0011, fax: +48 22 846 4432*
*e-mail: ajank@ilot.edu.pl*

**Piotr Haller, Joanna Woźniak, Mateusz Janas**

*Wroclaw University of Technology, Division of Automotive Engineering*
*Braci Gierymskich 164, 51-640 Wroclaw, Poland*
*tel./fax: + 48 71 3477918*
*e-mail: piotr.haller@pwr.edu.pl*
*joanna.wozniak@pwr.edu.pl, mateusz.janas@pwr.edu.pl*

***Abstract***

*Nowadays, with the current dynamic development of the automotive industry, we spend more and more time indoors, including in vehicles. The air used for ventilation of the vehicle's cabin comes from the outside. Pollution enters into the vehicle. This research presents the results of tests conducted to assess the exposure of the driver and passengers to volatile organic compounds entering the vehicle with atmospheric air. The simulation researches were conducted on a chassis dynamometer at the Department of Vehicle Engineering at the Faculty of Mechanical Engineering Technical University of Wroclaw and the tests under real conditions, i.e. traffic urban conditions, were taken as well. The measurements were conducted in the centre of Wroclaw during peak hours, when the traffic jam is the most frequent. The measurements were taken in order to organic compounds analysis, which includes gas chromatography. The analysis results were averaged from three measurements to get these studies more reliable. Results show that during mobile tests the vehicle was exposed to much more pollution than in the stationary tests in the simulated conditions of traffic congestion. Therefore, the studies present that the pollution in the traffic congestion is the real danger to drivers.*

***Keywords:*** *vehicles, road transport, air pollution, car cabin, volatile organic compounds (VOCs)*

## 1. Introduction

Road transport is one of the main sources of air pollution, especially in urban conditions. In addition, it creates a source of so-called low emission, which means the exhaust gases are emitted at the height of human habitation. The exhaust gases emitted by vehicles are harmful to not only pedestrians and residents, but also to other road users, including those staying inside their vehicles. Especially unfavourable conditions occur in city traffic, especially when the traffic slows down (a large number of vehicles, pedestrian safety), in case of traffic congestion, as well in poorly ventilated areas due to the effect of the so-called city canyons (urban development) [1]. Modern lifestyle together with very rapid development of the automotive industry make people spend more time in their vehicles. Exhaust gases entering the vehicle through ventilation system at the height of a driver and passenger's heads create a serious threat for people inside the vehicle [2, 3].

Much of the scientific research focuses on the impact of motorization on the outside air quality. That's justified, as studies in Warsaw have shown a close link in between the quality of air and the traffic congestion [4]. Considering that the air ventilating the inside of vehicle comes from the outside, quality of atmospheric air is very important for microclimate inside the vehicle. The problem of air toxicity inside of a new vehicle has been addressed by Janicka [5]. In her research, vehicle interior parts (upholstery, adhesives used for finishing, etc.) were the main source of toxins emitted as volatile organic compounds; these turn out harmful to people occupying the vehicles' space.

Subject of this research was to measure the amount of volatile organic compounds getting into the interior of a vehicle together with air used for ventilation. The emphasis was put on Volatile Organic Compounds (VOCs) due to carcinogenic or mutagenic influence of most of these compounds on human organisms. Volatile organic compounds, as a group of hydrocarbons, are produced primarily as a result of incomplete combustion of fuel process, which causes interruption in elementary chain reactions. The main representatives of the VOCs are the so-called groups BTX (benzene, toluene, xylenes). They occur most frequently in the exhaust gas, and have the most negative effect on the human body [2, 6].

## 2. Material and methods

Research carried out within the scope of this study was to investigate the amount of volatile organic compounds getting into the interior of the vehicle when driving in conditions of road congestion. The study was divided into two phases: stationary and mobile. Research of background inside of the tested vehicle was conducted every time before taking the major measurements, allowing determining the amount of pollutants getting into the vehicle. Concept studies are shown in Fig. 1.

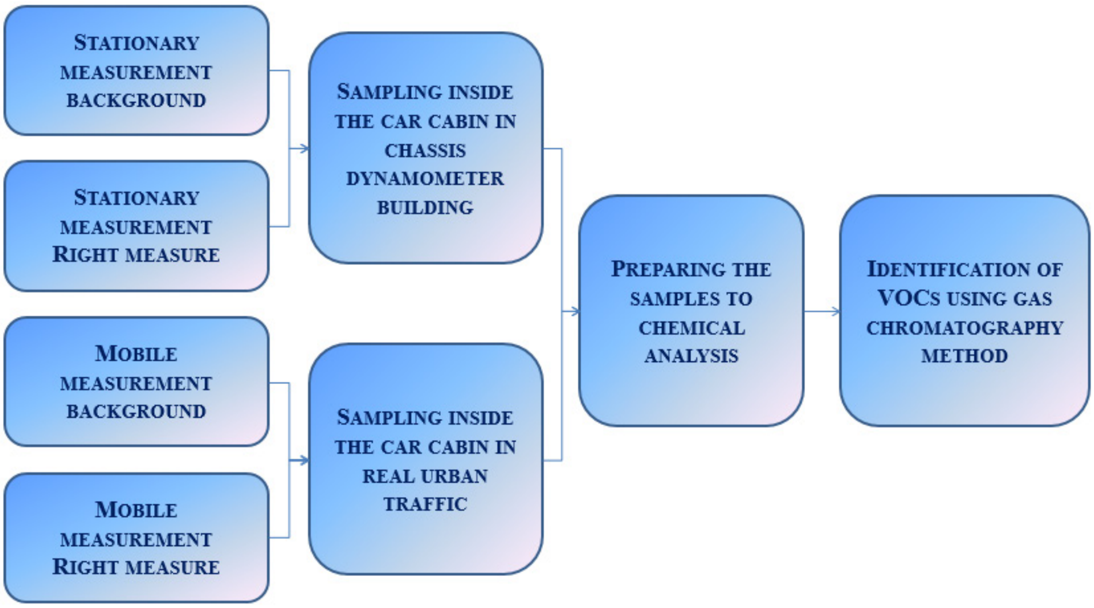


*Fig. 1. Study concept*

The study was conducted on a passenger car Ford Mondeo with a diesel engine. Tab. 1 shows the main parameters of the tested vehicle.

*Tab. 1. Parameters of the tested vehicle*

| | |
|---|---|
| Make and type of vehicle | Ford Mondeo |
| Production Year | 2003 |
| Fuel type | Diesel |
| Engine Capacity, $cm^3$ | 1998 |
| Engine Horsepower, hp | 140 |
| Vehicle type | Passenger car |

Samples of contaminants were always collected in two places: on the outside of the vehicle near the air intake for ventilating system (the control samples), and inside the cabin. Location of the air sampling in the cabin of the vehicle is a very important factor of research, as it allows assessing the exposure of the driver to contamination present in the cabin. According to the ISO / DIS 12219-1: 3 draft of the European Standard, the sample should be taken as shown on Diagram 2 [7]. The location where the samples were gathered inside the vehicle are justified by computer simulations using Computational Fluid Dynamics (CFD) carried out by Zawiślak and others, according to which the most pollution accumulates at the height of the driver's head.

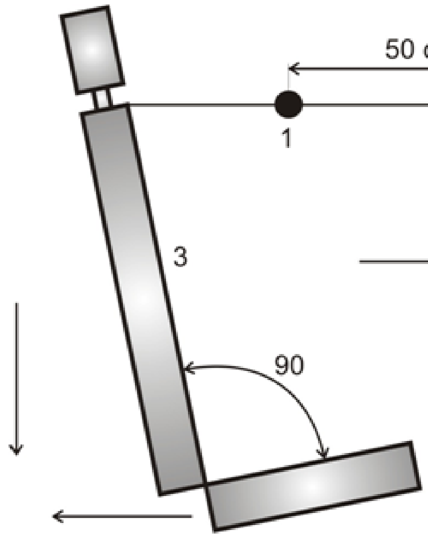


*Fig. 2. Location of sampling in the tested passenger car: 1 – sampling point, 2 – steering wheel, 3 – driver's seat [7]*

Simulation tests were conducted on a chassis dynamometer at the Department of Vehicle Engineering at the Faculty of Mechanical Engineering Technical University of Wroclaw. The vehicle emitting exhaust fumes was situated at 60 cm mark in front of the vehicle (an estimated distance between vehicles involved in road congestion). The aim of the measurements was to assess the fixed amount of exhaust gas getting into the cabin in contact with the single emitting vehicle. The next stage was to carry out tests under real conditions, i.e. Traffic in urban conditions. The measurements were carried out in the centre of Wroclaw during peak hours, characterized by the traffic congestion. As the indispensable presence of the driver in mobile conditions made it impossible to install the sample on a driver's seat, the sample inside the vehicle in this measurement was similarly located on the front passenger seat.

The samples were taken with a use of a semi-automatic, 2-channel aspirator – ASP-2 II, using sorbent tubes with active carbon (SKC_lot 120) for both stationary and mobile tests. Sampling time to determine the reference air composition serving as the baseline was the same or very similar to that of the collection of relevant measurement, and was typically 3 hours. Samples for establishing the baseline for the contamination inside the car were taken immediately before the actual tests. The airflow in the aspirator was set at 30 $dm^3$/hour. Tab. 2 shows the parameters of the test measurements for the stationary and mobile tests.

*Tab. 2. Sampling parameters*

| | Stationary measurement | | Mobile measurement | |
|---|---|---|---|---|
| | Background | Measurement | Background | Measurement |
| Date of sampling | 19.03.2016 | | 15.04.2016 | |
| Date of samples' analysis | 21.03.2016 | | 18.04.2016 | |
| Airflow, $dm^3/h$ | 30 | | 30 | |
| Time of sampling, h | 3 | | 3 | |
| Volume, $dm^3$ | 90 | | 90 | |

The next step after sampling was qualitative and quantitative analysis of chemical concentrations of VOCs. Chemical analyses were performed by gas chromatography (GC), which is the best-known method for the identification and measurement of concentrations of organic compounds. Chromatographic analyses were performed at the Laboratory of Research in the Department of Emissions.

The step preceding the chromatographic analysis was to prepare samples for analysis, consisting of desorption of hydrocarbons adsorbed into activated carbon with a solvent, carbon disulphide ($CS_2$). Chromatographic analysis was carried out using a gas chromatograph Varian 450GC equipped with a flame ionization detector (FID), a capillary column and a system of automatic feeding of samples (autosampler). The column used was Varian VF-WAXms (30 m x 0.25 mm ID DF: 0.25 μm) and the determination of concentrations of volatile organic compounds in the solutions was carried out under the following conditions:

- oven temperature (column) – 110°C for 10 minutes,
- injector temperature – 250°C,
- split (flow split) – 1:20,
- FID detector temperature – 250°C,
- carrier gas – helium,
- injection volume – 1 μl.

## 3. Results

Qualitative and quantitative composition (concentration levels) of volatile organic compounds identified in the vehicle in the form of so-called chromatograms was obtained as a result of the chromatographic analysis of samples. Gas chromatography, like any other analytical method, is subject to measurement error. Therefore, the analysis of each sample was performed three times and the final result of the concentration of individual compounds was derived as a mean value from executed repetitions. Additionally, a map was put together for the mobile measurement, allowing illustrating the route and traffic congestion (Fig. 3).

The results of the chromatographic analysis obtained directly from the chromatograph are expressed in ppm in 2 ml of carbon disulphide, used as a solvent to carry out the desorption of VOCs out of the activated carbon. Then, with knowledge of the absorption rate of the sample, a conversion was then applied to arrive with values for compound concentrations in the exhaust gas. The calculation was performed according to equation (1). Thus yielded concentrations of the respective compounds expressed in $mg/m^3$.

$$C_{mg/m^3} = \frac{2 \cdot S_{ppm} \cdot 1.26 \cdot 10^{-3}}{0,8} \cdot \frac{1000}{V}, \tag{1}$$

where:

2 – volume of the solvent used in desorption, $cm^3$,
$S_{ppm}$ – compound concentration read out from the chromatograms, ppm,
1.26 – concentration of the solvent used in desorption, $g/cm^3$,
0.8 – error of desorption,
V – volume of airflow, $dm^3$.

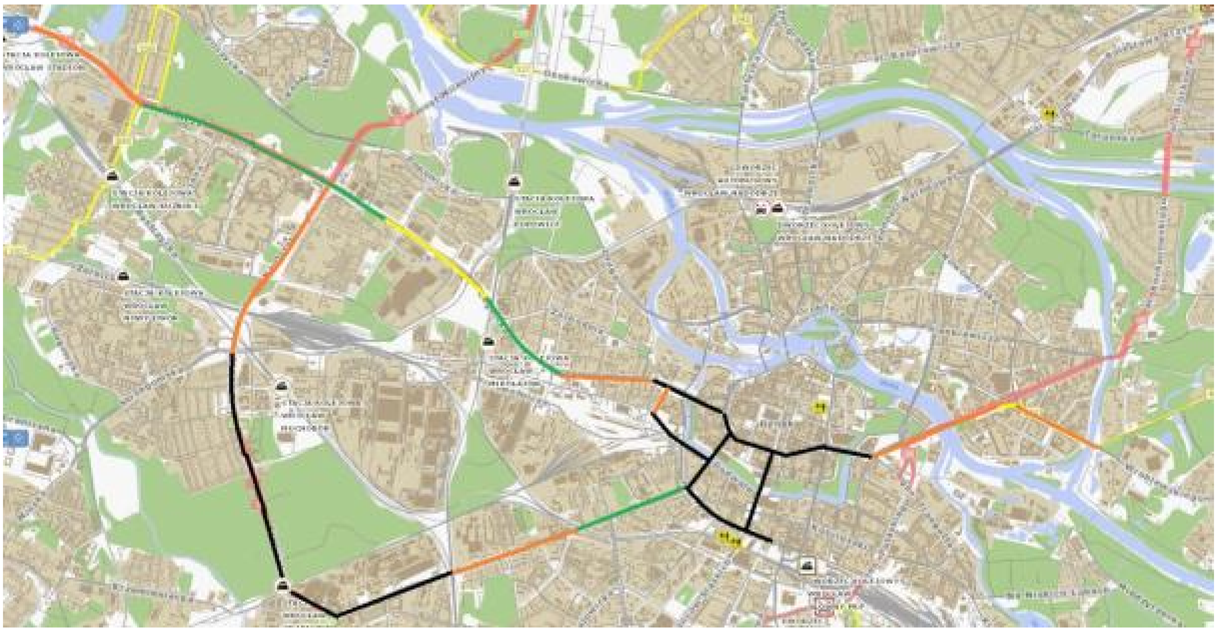

*Fig. 3. The route in mobile testing in Wroclaw, together with the characteristics of the flow of traffic (in black – the complete road blockage across the width of the road, the car stopped for more than 30 minutes – the average traveling speed in the road section not exceeding 5 km/h; in orange colour – partial blockage of the road, vehicle stoppage for approx. 20-30 minutes – the average traveling speed on the road section up to 10 km/h; in yellow – the road passable, but the movement is gradual; in green – the no road congestion)*

The next step was to calculate the amount of VOCs getting into the vehicle cabin in case of traffic jam conditions based on the actual measurement and the measured background values. The resulting calculation subtracted the background concentration value measured earlier from the concentration measured inside the test vehicle in motion according to the Equation (2).

$$C_{VOC} = C_{background} - C_{reading}, \tag{2}$$

where:

$C_{voc}$ – the increased amount of volatile organic compounds concentration during the test, mg/m$^3$,

$C_{background}$ – concentration of volatile organic compounds identified in the background contamination test, mg/m$^3$,

$C_{reading}$ – concentration of volatile organic compounds, which were measured during the stationary or mobile study, mg/m$^3$.

Table 3 presents the results of analyses and calculations of concentrations of identified volatile organic compounds, while Fig. 4 shows the number of individual compounds that have been introduced into the interior of the vehicle during stationary and mobile testing.

As it is apparent from Fig. 4, in the mobile measurement of the real-traffic conditions, a lot more compounds volatile organic entered the vehicle cabin than in stationary conditions.

## 3. Summary and discussion

The scope of the study included measurements of concentration of volatile organic compounds entering into the cabin of a passenger car in the conditions of a traffic jam in city traffic. There were two types of tests conducted with a use of the vehicle Ford Mondeo: stationary testing (simulation of a traffic jam) in the room of chassis dynamometer and mobile testing in real traffic conditions. The analysis with a use of gas chromatography identified a total of 12 different VOCs inside of the vehicle cabin. These were alcohols, (based on the n- pentane), 2- propanol, benzene, 2-butanol, toluene, and ethylbenzene, a mixture of para- and meta-xylene, cumene, ortho-xylene, propylbenzene and p-cymene.

*Tab. 3. The results of the chromatographic analysis together with the results of calculations (BS – stationary background, MS – stationary measurement, BM – mobile background, MM – mobile measurement)*

| | Concentration, ppm in $CS_2$ | | | | Concentration, mg/m$^3$ | | | | difference, mg/m3 | |
|---|---|---|---|---|---|---|---|---|---|---|
| COMPOUND | BS | MS | BM | MM | BS | MS | BM | MM | BS-MS | BM-MM |
| n-pentane | 0.578 | 2.403 | 1.290 | 1.487 | 0.020 | 0.084 | 0.045 | 0.052 | -0.064 | -0.007 |
| 2-propanol | 1.898 | 1.840 | 1.323 | 1.027 | 0.066 | 0.064 | 0.046 | 0.036 | 0.002 | 0.010 |
| benzene | – | 0.350 | 0.090 | 0.097 | – | 0.012 | 0.003 | 0.003 | -0.012 | 0.000 |
| 2-butanol | 0.373 | – | 0.480 | 0.220 | 0.013 | – | 0.017 | 0.008 | 0.013 | 0.009 |
| toluene | 0.155 | 0.427 | 0.627 | 0.657 | 0.005 | 0.015 | 0.022 | 0.023 | -0.010 | -0.001 |
| 1-butanol | 0.288 | – | 0.150 | 0.367 | 0.010 | – | 0.005 | 0.013 | 0.010 | -0.008 |
| ethylbenzene | 0.045 | 0.147 | 0.250 | 0.153 | 0.002 | 0.005 | 0.009 | 0.005 | -0.004 | 0.003 |
| m,p-xylene | 0.070 | 0.260 | 0.260 | 0.227 | 0.002 | 0.009 | 0.009 | 0.008 | -0.007 | 0.001 |
| cumene | 0.148 | 0.130 | 0.210 | 0.107 | 0.005 | 0.005 | 0.007 | 0.004 | 0.001 | 0.004 |
| o-xylene | 0.205 | 0.057 | 0.177 | 0.023 | 0.007 | 0.002 | 0.006 | 0.001 | 0.005 | 0.005 |
| propylbenzene | – | – | – | 0.103 | – | – | – | 0.004 | – | -0.004 |
| p-cymene | 0.313 | 0.270 | 0.597 | 0.123 | 0.011 | 0.009 | 0.021 | 0.004 | 0.001 | 0.017 |

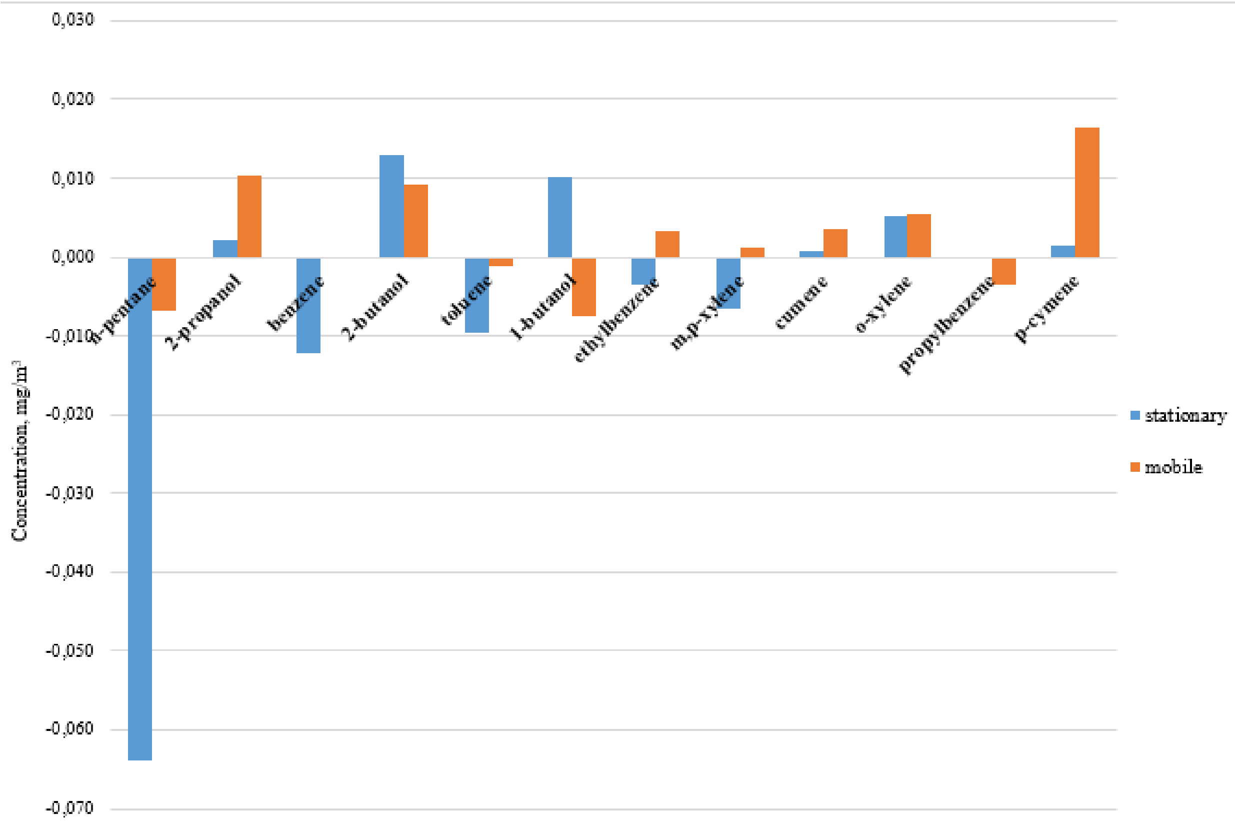


*Fig. 4. The amount of volatile organic compounds getting into the cabin of the vehicle in the stationary and mobile tests*

The following observations have been made and the following conclusions drawn based on the test results:

1. The measured concentrations of VOCs identified inside the cab vehicles are in most cases low, do not cause immediate reaction to the human body. None of the concentrations exceeded the maximum admissible concentration or the maximum instantaneous concentration, as defined in the Regulation of the Minister of Labour and Social Policy of 6 June 2014 about the maximum permissible concentration and intensity of harmful factors in the work environment [9]. However, it should be noted that long-term exposure to even low concentrations of organic compounds belonging to the group of VOCs could pose a threat to the driver and passengers' health.
2. In the real traffic tests, the exhaust gases emitted from the vehicle located in front of the tested vehicle were diluted by the movement of air (in the dynamometer based testing of stationary conditions, the distortion was not as impactful). In addition, the number of vehicles involved in a real city traffic exposes the vehicle to much more pollution than in stationary conditions, where the fumes were emitted by only one vehicle.

The studies should be considered as pilot-testing study. In the future, the mentioned topics will be expanded on, among other things: testing in a real city traffic with route tracking and traffic characteristics tracking with the use of Geographic Information Systems (GIS) will be conducted, which will allow for a detailed analysis of road conditions; similar studies will be performed for other vehicle types, other than passenger cars, to examine the impact of various external factors (e.g. meteorological conditions, traffic intensity) on the amount of pollutants getting into the cab. It will require the use of other tools, including GIS modelling of road emissions or mathematical models of pollution.

**Acknowledgments**

*The results presented in the paper was provided and developed during the POIG.01.04.00-02-154/13 and POIG.04.05.02-00-030/12-00 projects realization.*

**References**

[1] Prashant Thaker, Sharad Gokhale: *The impact of traffic-flow patterns on air quality in urban street canyons*, Environmental Pollution, Part A, Special Issue: Urban Health and Wellbeing, Vol. 208, pp. 161-169, 2016.

[2] Merkisz, J., *Ekologiczne problemy silników spalinowych, Tom 1*, Wydawnictwo Politechniki Poznańskiej, Poznan 1998.

[3] Golubic, J., Vogrin, Z., *Analysis of harmful emissions generated by road traffic in the city of Zagreb and proposals of measured*, Transport Problems, Vol. 8, Is. 2, pp. 73-82, 2013.

[4] Badyda, A. J., *Wpływ ruchu drogowego na poziom zanieczyszczeń powietrza oraz ryzyko chorób układu oddechowego, Cz. I, Opis zależności poziomów zanieczyszczeń od natężenia ruchu i innych wybranych parametrów z wykorzystaniem modeli statystycznych*, Modelowanie Inżynierskie, 37, pp. 11-18, Gliwice 2009.

[5] Janicka, A., *Ocena toksyczności mikroatmosfery środowiska wnętrza pojazdu samochodowego*, Oficyna Wydawnicza Politechniki Wrocławskiej, Wroclaw 2013.

[6] Su, J. G., Apte, J. S., Lipsitt, J., Garcia-Gonzales, D. A., Beckerman, B. S., de Nazelle, A., Texcalac-Sangrador, J. L., Jerrett, M., *Population potentially exposed to traffic-related air pollution in seven world cities, Environment International*, 78, pp. 82-89, 2015.

[7] Draft International Standard ISO/DIS 12219-1:3 Indoor air of road vehicles – Whole vehicle test chamber, Specification and method for the determination of volatile organic compounds in cabin interiors, 2011.

[8] Janicka, A., Matanovic, A., Michniewicz, D., Zawiślak, M., *Numerical analysis of impact of new BTX-removal method application in vehicle interior on user exposure*, Transport Przemysłowy i Maszyny Robocze, Nr 2, suppl., pp. 180-182, 2014.
[9] Rozporządzenie Ministra Pracy i Polityki Społecznej z dnia 6 czerwca 2014 r. w sprawie najwyższych dopuszczalnych stężeń i natężeń czynników szkodliwych dla zdrowia w środowisku pracy, Dz. U. 2014, poz. 817.