

Assessment of the impact of the traffic situation in urban area on the amount of volatile organic compounds getting into the cabin of the car on the road

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Abstract. In the paper the levels of concentrations of volatile organic compounds getting into car cabin during the driving have been measured. Three series of the tests have been performed. Each series has been carried out in different road situation in terms of traffic intensity. For the tests exploited passenger car, Subaru Impreza was used. Before every series the background measurements was carried out and directly after that, the correct the correct tests were performed. Inside the cabin 14 different organic compounds have been identified. To analyse the change of the concentrations levels between the correct and background test have been calculated. The results indicate that the longer time of travel caused that the driver and passengers are more exposed to highest concentrations of VOCs.

1 Introduction

Traveling is the part of everyday human life. People spend several hours in a car every day driving to work and back home, shopping or attending to other matters. Spending this amount of time in the car makes microatmosphere of the vehicle specific environment with a significant influence on human health and well-being. Air pollution getting into the interior of the vehicle, both the necessary tightness of the vehicle affects negatively the quality of the atmosphere inside the passenger car. Depending on the length of the route, congestion and other components of the road traffic, the vehicle user is exposed temporarily or for a long time to such harmful pollution components as carbon dioxide, hydrocarbons from the VOCs group (e.g. benzene, toluene, xylenes) or particulate matters. The choice of proper ventilation or recirculation of the air plays a very important role. It largely influences the air quality in the car's microenvironment and the air humidity level

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[1]. In order to determine the relationship between the pollution of the microatmosphere of the vehicle and the road traffic, appropriate road traffic components that may affect the amount of pollution during the journey should be defined. In the paper traffic in urban conditions will be investigated.

Road components in urban conditions include physical and mathematical elements. The physical components include: road infrastructure, user or group of users (e.g. vehicle driver and passenger), while the mathematical: traffic description (algorithms describing the motion) [2].

Physical components can be relatively easily determined as follows:

- The road infrastructure is created by building structures (roads, streets, bridges, tunnels, etc.). They form intersections and interstitial sections. While intersections are a relatively problematic element of road infrastructure because of the decision-making by user at this facility, other tools are taken into account, such as road signs, speed limits, traffic light and traffic regulations. Road infrastructure is the reason for road traffic and it is the basis for traffic analysis.
- Road traffic is created by users, such as driver, passengers or group of users (students). Their goal is to move to a different location by choosing the appropriate mean of transport (car, bicycle, public transport or on foot, also counted as a means of transport).

Mathematical component of road transportation is defined by:

- Motion description – the parameters characterizing description of the movement are the speed and its changes, the length of the route and the time of movement. This is very important element of the road traffic characteristics – the data obtained from the traffic description enable the analysis and the traffic assessment. Different calculation methods and algorithms (e.g. regarding traffic lights) are used to describe the motion. The calculation methods include theoretical, simulative, empirical and forecasting methods.

In addition to the above components, the road traffic characteristics are strongly influenced by other factors that should be taken into account. Therefore, other important data to be included is the reason for traffic generation (e.g. business meeting), urban traffic model (e.g. morning rush hours) and the way to achieve the goal (e.g. minimum travel time). Additionally, the perception of a person influences the description of the movement. Decisiveness, errors, speed of human reaction or lack of information can lead to a significant change in the description of vehicle movement. In this case probability calculations should be defined.

The above factors indirectly affect pollution inside vehicles. The direct factors are mainly combustion products of fuels and engine oils (especially in traffic where street congestions often occur), leaks of operating fluids, dust on the surface and tribological processes occurring during vehicle operation, as well as upholstery elements made of plastics [3]. The above mentioned road traffic components also have a significant impact on the environment. Road infrastructure and physical road traffic components have a major impact on the level of ecosystem pollution. In addition to the exhaust gases in the air, toxic pollution also have an impact on the environment, which from roads and streets penetrate a larger area and triggered by weather conditions or surface disturbance (e.g. during pedestrian crossing on the outskirts of streets) [4]. In addition to this, the type of vehicle, the volume of its cabin, age and technical condition and the type of power unit affect the pollution

inside the vehicle. Such a large number of factors affecting the amount of pollution entering the interior of the vehicle causes researches on this subject very broad and the relationships are constantly being discovered.

2 Methodology

2.1 Selection of the optimal measuring route

The right measuring route was the main component of this research. The measurement route was chosen to best reflect the conditions of everyday driving in the city under different conditions. The test scenario predicted various elements of city traffic, such as large, moderate and small traffic intensity with maximum speed allowed and during street congestions. The test also required continuous driving for one hour, due to the type of measurement of volatile pollutants.

Five types of measuring routes with different lengths and different traffic volume have been selected to extract an optimal route that will meet all requirements (Table 1). The korkowo.pl program was used to identify traffic congestion [5].

Table 1. Selected routes to carry out the tests.

Route number	The length of the route, km
Route No. 1	24.25
Route No. 2	33.69
Route No. 3	27.93
Route No. 4	28.80
Route No. 5	27.44

After consultation and careful analysis of the routes, route No. 2 was chosen. This route provided varied traffic conditions, such as maximum permitted speed in places with an increased number of traffic lanes, as well as the presence of traffic congestions from overlapping public transport routes with passenger cars. In addition, a long route No. 2 provided the required time needed to collect the appropriate samples. In order to verify the assumptions a four tests run was carried out. The first ride was made to confirm the time needed to perform the tests. Three more were made in three variants of urban traffic intensity (small, moderate and large traffic congestion). After performing the tests, the route No. 2 was modified and established to make the proper measurement. Route No. 2 after modifications is shown in Figure 1.

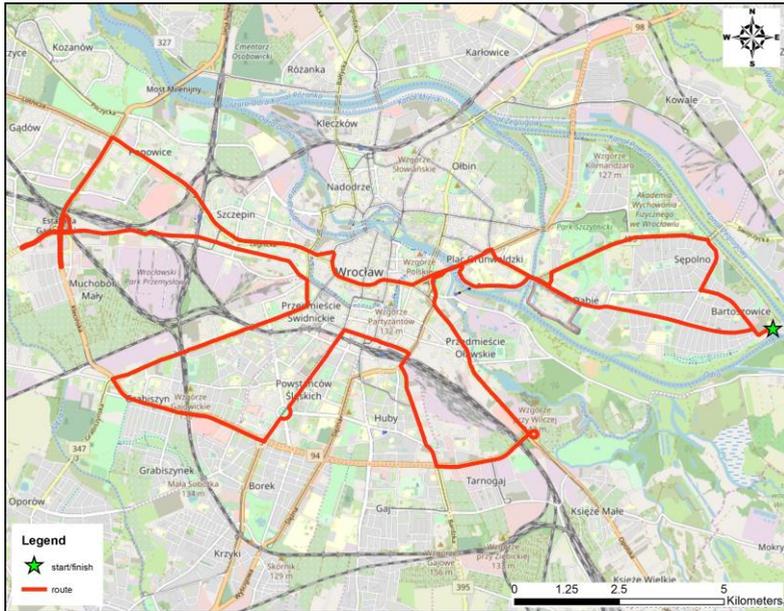


Fig. 1. Selected measuring route No. 2 after modifications (43 km) [6].

2.2 Vehicle characteristics and boundary conditions

The Subaru Impreza passenger car was used to test the air quality in the car cabin (Figure 2). This version is a type of station wagon and its cabin interior volume is 2.56 m^3 [7]. The vehicle was equipped with a ventilation system with air conditioning with a manually controlled 4-stage airflow. The ventilation system was equipped with a pollen filter, which at the time of testing was not replaced. The vehicle's age was 13 years. The interior of the vehicle is equipped with various upholstery elements, made of such materials as: plastics (dashboard, middle channel, door panels), sponges (seats, rear seat and parts of door panels) and textiles (upholstery, roof linings).



Fig. 2. Presentation of the vehicle used for the tests (source <https://www.edmunds.com/subaru/impreza/2004/>).

The boundary conditions were the appropriate settings of ventilation in the vehicle cabin. In order to maintain repeatable measurement conditions, fixed parameters of the ventilation system were established:

- closed windows,
- air conditioning switched off,
- fan speed set to level 2,
- the air temperature is set to cold,
- direction of blowing air directed to the head and legs.

2.3 Air quality measurement methodology

2.3.1 Measuring station

In order to collect air samples, an ASP II aspirator with two measurement channels was used. The tubes filled with active carbon was used as the carrier of the collected organic pollutants (VOCs). The test included sampling outside the vehicle and inside to obtain information on the amount of contaminants present in the cabin compared to the air pollution outside the vehicle. Measuring points were installed in the following places: the first one was mounted in the vehicle cabin at the height of the passenger's head and the second measuring point was located outside the vehicle near the air inlet to the cabin at the bottom of the windshield.

2.3.2 Plan of measurements

To perform the tests were provided three series of rides respectively at the low (series 1), moderate (series 2) and large (series 3) traffic intensity. In the first place before each test during the vehicle movement a stationary measurement was taken (background measurement). The background test was performed in order to obtain outside sample as a reference for later measurements. Background measurement was performed for three hours to collect 90 litres of air and adsorb them on active carbon in the aspiration tube. The air flow was set at 30 l/h. During the measurement, the car was closed to separate the ambient air in the cabin. After the completion of the background sample collection the aspiration tubes were replaced and the correct measurement started. The boundary conditions were retained as above for the period of actual measurement. The air flow in the aspirator has remained unchanged, but the time of the measurement was different, depending on the travel time. In Table 2 parameters for each of sampling series are presented.

Table 2. Sampling parameters.

Parameter	Series 1	Series 2	Series 3
Air flow, dm ³ /h	30	30	30
Time of sampling, min	85	80	134
Air volume, dm ³	43.6	43.6	66.8
Temperature inside the cabin, °C	38.4	42.3	44.4
Outdoor temperature, °C	21	25	26.5

2.3.3 Chromatographic analysis

After sampling, the tubes with active carbon have been moved into the laboratory and chromatographic analysis were made. VOCs adsorbed on the active carbon have been extracted in carbon disulphide (CS₂), the solution has been cleaned and next given on the gas chromatograph Varian 450-GC with capillary column and autosampler. As the results of chromatographic analysis were concentrations of separated organic compounds such as benzene, toluene, ethylbenzene, etc. in ppm of the pollutant in 2 ml of CS₂. It was needed to calculate the concentrations of VOCs in the air in µg/m³, taking into account the amount of air collected during the sampling.

3 Results and discussion

In Table 3 the obtained concentrations values (in µg/m³) of identified in chromatographic analysis VOCs are presented. Two isomers of xylene (*para*- and *meta*-) are presented together, because their retention time overlap. The shorts used in the Table 3 mean: BI – background sampled inside the cabin, BO – background sampled outside the car, MI – correct measurement conducted inside the cabin, MO – correct measurement conducted outside the car. Due to destroyed in the laboratory the tube in series 3 BO, the concentrations in that sample have been not obtained.

Table 3. The results of the measurements.

Compound	Series 1				Series 2				Series 3			
	BI	BO	MI	MO	BI	BO	MI	MO	BI	BO	MI	MO
n-pentane	18.9	34.8	24.9	39.9	15.3	52.2	28.0	34.8	16.5	-	15.7	19.1
2-propanol	64.5	15.4	29.3	-	51.1	76.0	26.7	123	24.0	-	0.5	0.7
Benzene	2.6	-	4.0	-	1.0	13.1	3.6	5.9	1.3	-	5.6	0.2
2-butanol	36.6	1.0	0.9	-	35.9	-	-	-	17.3	-	-	-
Toluene	13.8	0.9	2.7	3.0	7.2	-	0.7	-	2.8	-	4.0	0.7
1-butanol	6.8	-	-	2.9	5.9	-	1.2	-	1.5	-	0.3	0.6
Ethylbenzene	1.7	-	6.0	-	-	-	-	-	-	-	-	-
p,m-xylene	2.1	-	-	2.8	1.9	-	4.3	-	0.6	-	2.6	-
Kumene	9.8	-	-	-	7.4	-	-	-	3.1	-	0.3	-
o-xylene	42.6	-	-	0.7	31.7	-	-	-	9.5	-	-	-
Propylbenzene	-	-	0.3	-	-	-	0.4	-	-	-	2.8	-
Mezitylene	73.8	-	0.9	-	58.1	-	1.1	-	33.6	-	1.8	-
p-cymene	7.7	-	0.5	-	7.7	-	-	-	2.8	-	0.4	-
Butylbenzene	6.5	-	-	1.3	17.3	-	0.6	-	0.9	-	0.9	0.9

In total, in all measurements 14 different organic compounds have been identified. The largest amount of VOCs have been detected in tests conducted inside the car cabin, both in background and correct measurements. As it can be seen, concentrations values of n-pentane (n-pentane represents the mixture of the lightest hydrocarbons) in each series are higher in samples taken outside than in samples taken inside the car cabin. generally, the highest concentrations inside the car cabin were received for n-pentane, 2-propanol, benzene, 2-butanol, toluene and propylbenzene.

To analyse how the concentration levels of the pollutants change during the route, it was needed to calculate the difference between concentrations measured in correct tests (MI) and background (BI). In Figure 3 the differences for each series have been shown.

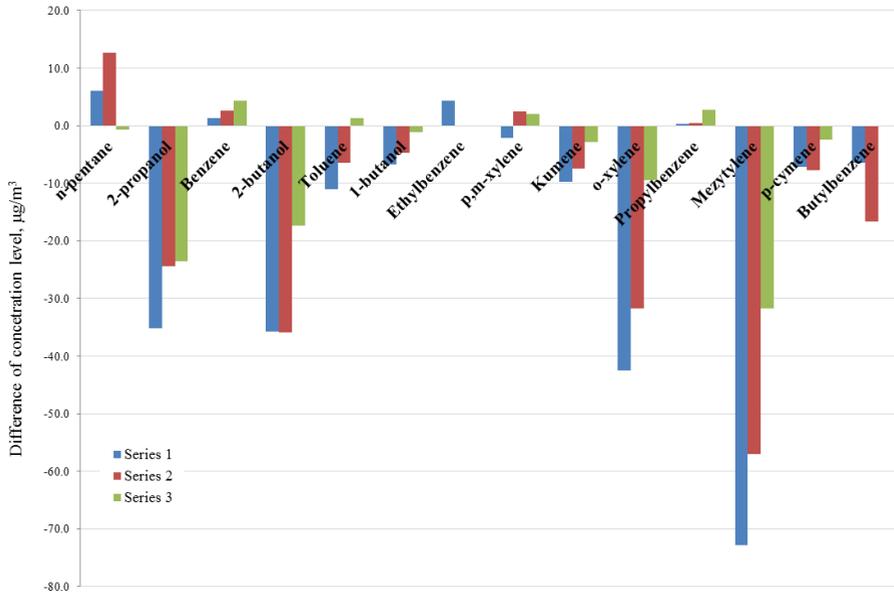


Fig. 3. Difference of concentration levels between correct and background measurements in each series.

For more pollutants levels of concentrations was lower in correct measurements than in background, therefore value of the difference of that pollutants was negative. It is caused by the methodology used during the background and correct measurements. In background tests ignition of the vehicle was switched off, so the fan wasn't working. In turn, during the correct measurement the fan was working with speed set to level 2. Therefore pollutants cumulated inside the cabin have been dispersed.

In the series 1 concentrations of four of identified organic compounds have grown during the route: n-pentane, benzene, ethylbenzene and propylbenzene. Worth attention is fact, that propylbenzene haven't been identified in background and appeared only in correct test, what means that it got into the cabin in traffic with ventilation air. In the series 2 pollutants, the concentration of which was increased were almost the same as in series 1 except ethylbenzene and p,m-xylene. In that series propylbenzene also haven't been identified in background test. In the series 3 the concentration of benzene, toluene, p,m-xylene and propylbenzene increased. What is important, difference in case of benzene between concentration level measured in correct and background test was positive in each series and the highest concentration was measured in series 3, when the traffic intensity was the largest. Generally, along with the increase of travel time (increase of traffic intensity), the negative difference decreases. For the toluene, the negative difference in series 2 is smaller than in series 1, in turn in series 3 the growth of concentration occurred. It indicate that despite dispersion of pollutants caused by turning on the fan on the

beginning of correct measure, during the route organic compounds have got into the interior. In series 3 the temperature inside the cabin was the highest, therefore emission from the cabin equipment could take place, but tested car has been in operation for many years, so share of that type of emission was negligible.

4 Summary

In the paper measurements of volatile organic compounds inside the car cabin depending on the traffic intensity have been performed. Permanent route has been established and three measuring series have been carried out. Different road situations have been chosen, characterized by low, moderate and high traffic intensity. Due to the route haven't been changed in each series, with growth the traffic, the time of travel increased too. For the tests exploited passenger car, Subaru Impreza was used. Before every series the background measurements was carried out and directly after that, the correct the correct tests were performed.

Inside the cabin 14 different organic compounds have been identified. To analyse the change of the concentrations levels between the correct and background test have been calculated. The results indicate that the longer time of travel caused that the driver and passengers are more exposed to highest concentrations of VOCs. Although the fan switched on at the beginning of the correct tests caused the dispersion of cumulated pollutants, it is significantly visible the influence of the traffic intensity on the amount of the pollutants getting into the interior.

In the future, it is needed for conducting additional tests taking into account weather conditions, various settings of the vehicle's ventilation system or the state of the cabin air filter. That will allow to obtain comparative results, specify the reasons for increases and decreases in the concentration of harmful compounds and the development of methods to minimize their impact on the driver and passengers.

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