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EVALUATION OF INTERIOR AIR QUALITY IN TERMS OF VOLATILE ORGANIC COMPOUNDS EMISSION INSIDE A NEW PASSENGER CAR CABIN DEPENDING ON THE TEMPERATURE

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Abstract

The new passenger car, BMW 225 XE was tested. The results of measurements of concentration of VOCs carried out inside the car cabin depending on the temperature were presented. The investigation was carried out in a special climatic chamber isolated from external factors such as outside air pollutants and weather conditions. The following temperature values have been set: 17ºC, 20ºC, 35ºC and 50ºC. The samples were located inside and outside of the vehicle's cabin. As expected, the concentrations of each compound increased with increasing temperature (volatility of VOCs increases with the temperature). Values of concentrations obtained in the measurements have been compared with the values of highest acceptable concentration specified in polish law. The article describes the investigation, which was provided in a special climatic chamber. The chamber was isolated from external weather conditions and pollutants. Before each sampling interior of car cabin was ventilated to remove all pollutants from inside. Concentrations of BTX measured in different temperatures were converted to temperature of 20ºC.

Keywords: *vehicles, road transport, materials, VOCs, air pollution, car cabin*

1. Introduction

The advantages of plastics such as mechanical properties, weight, cost of obtaining or ease of forming, have made them the basic materials used to build the interior of vehicles. In turn, the leather is often used as the material for elements such as seats or door panels. During the production and processing of vehicle interior, organic volatile compounds (VOCs) are formed and emitted during their operation. Emission of VOCs from materials in vehicle cabins is one of the main reasons for poor inside air quality.

Volatile organic compounds are a group of hydrocarbons that is characterized by a toxic effect on living organisms. They have in temperature 293.15 K vapour pressure not less than 0.01 kPa and thus high volatility [1]. Among the most significant anthropogenic sources are combustion processes (power industry), production and use of solvents, paints, varnishes, etc., road transport, mining and distribution of fossil fuels, and many others [2]. There are two main sources of VOCs inside the car cabin. The first are the materials, which are elements of equipment of interior. The second one is the ventilation system – VOCs are taken from ambient air to ventilation the cabin. In new cars, VOCs emitted from the materials dominate, while after even one year the external source may become more and more significant [3]. Except that VOCs are toxic, they also could cause odour nuisance, because many of them have a characteristic smell [4].

Many researches around the world focus in their investigations on the problem of pollution of in-cabin air by VOCs in different ways. The tests carried out in new vehicles mainly concern VOC emissions from inside the cab. Different sources give different number of VOCs identified in the interior of the vehicle. Some researchers have identified over 60, another around 200 or even 300 different VOCs [5, 6]. The most frequently identified and most important in terms of health hydrocarbons are benzene, ethylbenzene, xylene with isomers, toluene and light aliphatic hydrocarbons [7]. Brodzik and others provided tests of emission VOCs from elements of interior equipment before montage [8]. They identified more than 250 compounds and confirmed more than 160 by mass spectrometry method.

Considering that the overall concentration of VOCs inside the vehicle cabin consists of both: the emissions inside the cabin, as well as those introduced from the environment with atmospheric air, the concentration of these compounds in the vehicle may be higher not only than the concentration in ambient air, but also than concentrations in the ordinary room. Two factors have an impact on this: firstly, the vehicle's cabin has a relatively small cubage, and secondly, by direct sunlight inside the vehicle usually is higher temperature than outside [9, 10]. VOC concentrations in the summer can be up to 40% higher than in winter. The tests also showed that inside the cabin, VOC concentrations are higher than in the outside of the vehicle, which proves that these compounds accumulate in the cabin.

2. Material and methods

The new, not used, passenger car, BMW 225 XE (C-segment) produced in February 2017 was tested (Fig. 1). That plug-in type hybrid achieves nominal power 224 horsepower. It consists of a combustion engine located in front and an electric motor on the rear axle. Both engines can operate depending on the situation and the state of charge of the high voltage battery, individually or together. When only the internal combustion engine is running, the front wheels are driven. In turn, the electric motor drives the rear wheels. According to the manufacturer's data, on the battery it can drive up to 41 km without any emission. In Tab. 1, technical data of the engines of tested car is presented. Among the main materials from which the interior of the vehicle was made were black perforated leather (seats and door panels), synthetic leather (central console) and plastics. Organics glues and paints were also used to finish the cabin.

Fig. 1. BMW 225 XE inside the climatic chamber

The investigation was provided in May 2017 in special climatic chamber. The chamber was isolated from external weather conditions and pollutants. Before each sampling interior of car cabin was ventilated to remove all pollutants from inside. Samples were taken in four different values of temperature: 17, 20, 35 and 50ºC. The temperature in chamber was set a few hours before sampling, which allowed for temperature equalization inside and outside the car cabin. The location of samples inside the vehicle was chosen according to European Standard ISO/DIS 12219-1 [11] (Fig. 2) and it was on the high of driver's head.

Tab. 1. Technical data of BMW 225 XE

Combustion engine	
Capacity, cm^3	1499
Power, HP	136 (at 4400 rpm)
Fuel consumption*, l/100 km	2
CO_2 emission*, g/km	46
Compression ratio	1:11
Battery	
Power, HP	88
Range, km	41

* In the mixed cycle

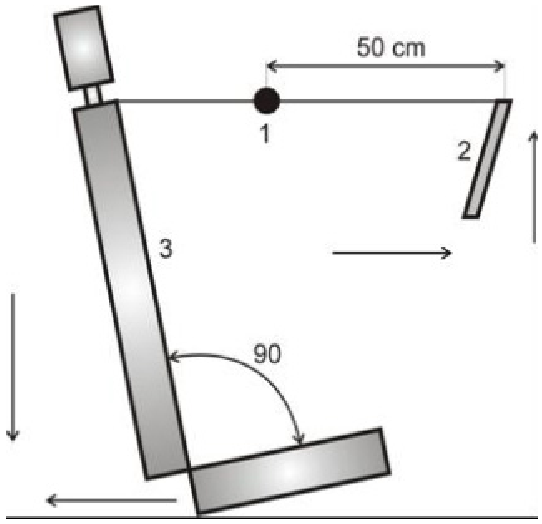

Fig. 2. Location of the sample inside the car interior (according to [11])

The samples were taken with used semi-automatic aspirator ASP-2 II into the special glass tubes filled by active carbon as solid sorbent. Sampling in each test was provided during 2 hours with flow 30 dm^3/h. Next, the samples were analysed in the laboratory using gas chromatography method.

3. Results

The results obtained directly from chromatograph were the concentrations of VOCs in ppm in 2 ml of carbon dioxide (CS_2), which was used as the solvent during preparation of samples to chemical analysis. It was necessary to make the calculations to present the VOCs concentrations in mg/m^3 in the air with the following equation:

$$C_{mg/m^3} = \frac{2 \cdot S_{ppm} \cdot 1.26 \cdot 10^{-3}}{0.8} \cdot \frac{1000}{V}, \quad (1)$$

where:
2 – the volume of solvent (CS_2), ml,
S_{ppm} – the concentration of VOCs in ppm in 2 ml of solvent,
1.26 – density of CS_2, g/cm^3,
0.8 – the error of the desorption,
V – volume of the air, dm^3.

In Tab. 2 concentrations of identified VOCs in different temperatures are presented.

Tab. 2. Concentrations of VOCs in mg/m³

Component	17ºC	20ºC	35ºC	50ºC
n-pentane	0.0210	0.0298	0.0179	0.0525
2-propanol	0.1017	0.1533	0.1577	0.2301
benzene	0.0042	0.0130	0.0180	0.0205
2-butanol	0.0173	0.0551	0.0560	0.1269
toluene	0.0054	0.0173	0.0212	0.0443
1-butanol	0.0056	0.0196	0.0247	0.0501
ethylbenzene	0.0040	0.0128	0.0191	0.0366
p, m-xylene	0.0053	0.0172	0.0205	0.0355
cumene	0.0105	0.0249	0.0424	0.0737
o-xylene	0.0007	0.0011	0.0023	0.0021
propylbenzene	0.0011	0.0014	0.0035	0.0053
1,3,5-trimethylbenzene	0.0016	0.0009	0.0053	0.0074
p-cymene	0.0028	0.0011	0.0068	0.0102
butylbenzene	0.0009	0.0007	0.0005	0.0005

The most important compounds of VOCs in terms of concentration in air and human health are compounds such as benzene, toluene and xylene with isomers (BTX group). These compounds have highly toxic properties and exhibit mutagenic and carcinogenic effects even in very low concentrations. The limits of concentration of the BTX in ambient and indoor air have been determined in the polish regulations. Acceptable values for atmospheric air are included in Minister of the Environment Regulation [12], in turn for indoor air are included in Regulation of the Regulation of the Minister of Labour and Social Policy as the highest acceptable concentration and the highest acceptable instant concentration [13]. The values in the regulation [3] are expressed in mg/m^3 in conditions: temperature 20ºC and pressure 101.3 kPa (Tab. 3). To compare the concentrations of BTX obtained in tests with acceptable values, it was needed to convert them into the conditions given in the regulation. In Fig. 3, concentrations of BTX converted to temperature 20ºC are presented.

Tab. 3. The highest acceptable concentration of BTX according to [13] in µg/m³

Component	The highest acceptable concentration, µg/m^3
benzene	1600
toluene	100000
p, m, o-xylene	100000

4. Summary and discussion

In the article, the tests of VOC content in the cabin of a new vehicle as a function of the temperature prevailing inside were presented. The BMW 225 XE vehicle was tested, which has

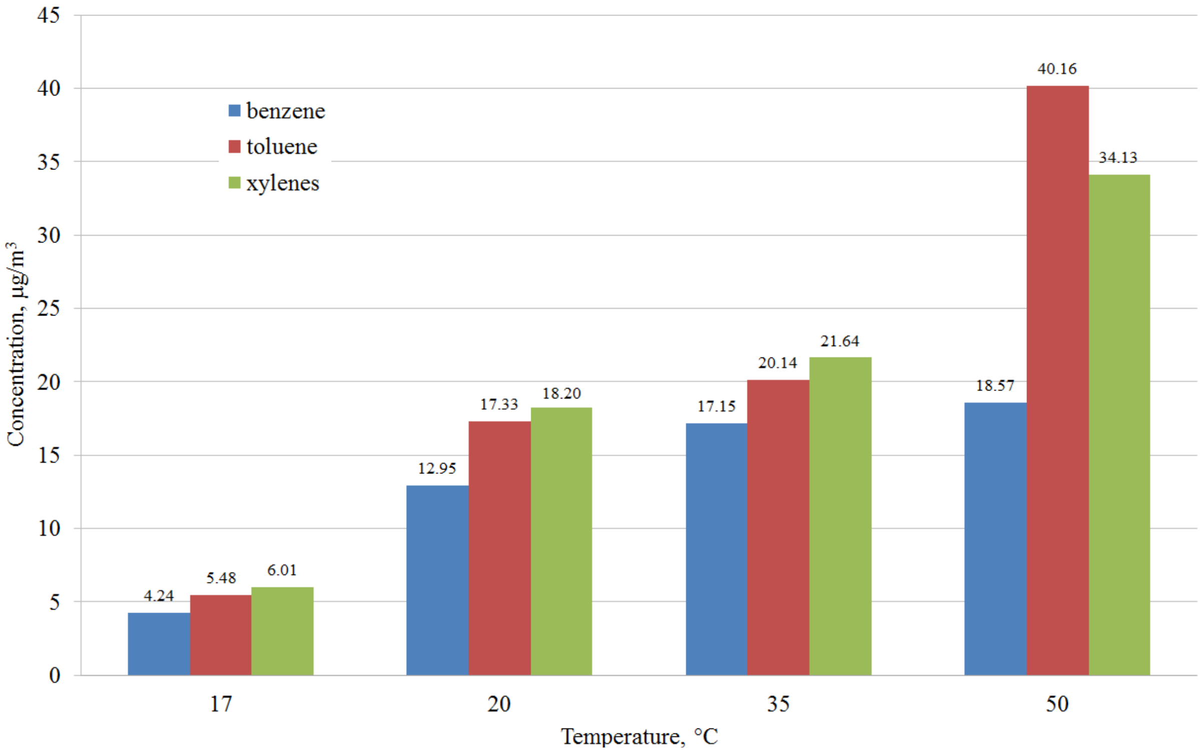

Fig. 3. Concentrations of BTX measured in different temperatures converted to 20ºC

not been operated. The interior of the vehicle was equipped with natural leather, synthetic leather and plastics. In addition, varnishes and glues were used for the finish, which are the trade secret of the manufacturer. The main objective of the research was to measure the VOCs concentrations emitted inside the vehicle by the equipment elements under different temperature conditions.

As it is presented in Tab. 2, the VOCs concentrations increased with increasing the temperature inside the vehicle cabin. This is a phenomenon justified by the characteristics of these compounds, whose volatility increases with increasing temperature. The most harmful to human health among all identified compounds (i.e. benzene, toluene and xylenes, BTX group) were extracted. Considering that, people spend more and more of their time in the car, the measured concentration values have been compared with the values of the highest acceptable concentrations that are related to the working environment. The results indicated that even in the worst of the analysed conditions (temperature 50ºC), the concentration values of BTX are below the limit values, which indicated the safety of the driver and passengers in terms of exposure to toxicity of these compounds.

As the vehicle would be operated, the VOCs concentrations emitted from the equipment elements should gradually decrease and share of the pollutants brought into the vehicle's cabin through the ventilation system from the outside air will be getting bigger and bigger. Therefore, it is important to regularly service the vehicle and observe the dates of replacement of filters, especially in this case the cabin filter.

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