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# Exposure to volatile organic compounds: Comparison among different transportation modes

Duc Hoai Do, Herman Van Langenhove, Stephen Izuchukwu Chigbo, Abebech Nuguse Amare, Kristof Demeestere, Christophe Walgraeve*

*Research Group EnVOC (Environmental Organic Chemistry and Technology), Department of Sustainable Organic Chemistry and Technology, Faculty of Bioscience Engineering, Coupure Links 653, B-9000 Ghent, Belgium*

## HIGHLIGHTS

- Comparison among three modes of transportation (tram, bike, car) in Ghent, Belgium.
- The aromatic compounds are the most abundant class (41–72% of the TVOC).
- TVOCs concentration levels observed in the tram are the highest.
- The inhaled dose for benzene for the commuter taking the bicycle is the highest.

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## ABSTRACT

The increasing trend of promoting public transportation (bus tram, metro, train) and more environmental friendly and sustainable non fossil-fuel alternatives (walking, cycling etc) as substitutes for auto vehicles brings forward new questions with regard to pollutant levels to which commuters are exposed. In this study, three transportation modes (tram, auto vehicle and bicycle) are studied and concentration levels of 84 volatile organic compounds (VOCs) (hydrocarbons, aromatic hydrocarbons, oxygen containing hydrocarbons, terpenes and halogenated compounds) are measured along a route in the city of Ghent, Belgium. The concentration levels are obtained by active sampling on Tenax TA sorbent tubes followed by thermal desorption gas chromatography mass spectrometry (TD-GC-MS) using deuterated toluene as an internal standard. The median total VOC concentrations for the tram mode (33 $\mu g/m^3$) is 1.7 times higher than that of the bicycle mode (20 $\mu g/m^3$) and 1.5 times higher than for the car mode (22 $\mu g/m^3$). It is found that aromatic hydrocarbons account for a significant proportion in the total VOCs concentration (TVOCs) being as high as 41–57%, 59–72% and 58–72% for the tram, car and bicycle respectively. In all transportation modes, there was a high ($r > 0.6$) degree of correlation between BTEX compounds, isopropylbenzene, n-propylbenzene, 1,3,5-trimethylbenzene and 1,2,4-trimethylbenzene. When comparing time weighed average concentrations along a fixed route in Ghent, it is found that commuters using the tram mode experience the highest TVOCs concentration levels. However, next to the concentration level to which commuters are exposed, the physical activity level involving the mode of transportation is important to assess the exposure to toxic VOCs. It is proven that the commuter using a bicycle ($4.3 \pm 1.5$ μg) inhales seven and nine times more benzene compared to the commuter using the car and tram respectively, when the same route is followed.



## 1. Introduction

Implementation of more stringent regulations with regard to car emissions leads to decreased emissions of air pollutants in Flanders, Belgium even when the number of cars increases (MINA-4, 2011–2015). The car fleet in Flanders of around more than three millions in 2010 has increased with around 36 000 cars per year during the last decade. Diesel- powered cars represents a major

* Corresponding author.
*E-mail addresses:* Christophe.Walgraeve@UGent.be, christophe.walgraeve@gmail.com (C. Walgraeve).

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proportion in the fleet at 61% in 2010 (MORA, 2014). Emissions from the traffic sector in Flanders were 100 kton $NO_x$, 29 kton non-methane volatile organic compounds (NMVOC), 6 kton $PM_{2.5}$ and 3.4 kton $SO_2$ for the year 2000 and have decreased to 75 kton NO*x*, 7 kton NMVOC, 3.3 kton $PM_{2.5}$ and 1.4 kton $SO_2$ by the year 2010, or a reduction of 25%, 75%, 46%, 58% respectively (MIRA-T, 2012). This reduction has clearly reduced the observed ambient concentration levels of toxic VOCs. The data from the Flemish environmental agency, obtained from ten measuring stations in Flanders, shows a decrease in the benzene concentration from the year 2003–2011 (1.03–0.76 μg/m$^3$ in rural regions; 1.98–0.95 μg/m$^3$ in urban regions). These benzene concentrations are well below the limit of 5 μg/m$^3$ specified in the Directive 2008/50/EC of the European Parliament (Legislation, 2008). However, it should be noted that real life exposure could be higher than those measured at fixed air quality stations (Batterman et al., 2002; Huang et al., 2012). Indeed, people spend up to 85–90% of their time indoors (houses, offices, gyms, clubs, bars etc), and a significant amount of time (5%) in traffic while commuting to and from work (Dudzinska, 2011). The close proximity to sources of pollutants in the latter emphasizes their importance. Within these microenvironments, concentration levels are sometimes higher than outdoors (Batterman et al., 2002; Chan et al., 2003; Ballesta et al., 2006). It has been shown that the level of commuter exposure is dependent on the transportation mode, including privately owned vehicles, public motorized transportation (bus, tram, train) and non-motorized transportation (bicycle, pedestrian). The difference in concentration levels between these different transportation modes are explained by several authors to be mainly related to (i) engine evaporative emissions, (ii) fuel type (Diesel Gasoline, liquefied petroleum gas (LPG)) and fuel composition, (iii) selection of the driving lane (Ongwandee and Chavalparit, 2010) (iv) vehicle height, since exhaust is generated near the surface of the road (Lau and Chan, 2003), (v) emissions from interior materials (Yoshida et al., 2006), (vi) traffic intensity (Ongwandee and Chavalparit, 2010), (vii) ventilation rate (Fedoruk and Kerger, 2003), (viii) smoking behavior (Leung and Harrison, 1999) and (ix) meteorological conditions (Parra et al., 2008).

(Chan et al., 2003) investigated benzene, toluene, ethylbenzene, and xylenes (BTEX) concentration levels in four public transportation modes in Guangzhou, China, and found that benzene concentration levels in taxi (34 μg/m$^3$) were the highest when compared to air-conditioned buses (14 μg/m$^3$), non air conditioned busses (11 μg/m$^3$) and the subway (8 μg/m$^3$). In Hong Kong, benzene levels ranging from 4.8 to 6.1 μg/m$^3$ in roadway transport, 3.0–3.8 μg/m$^3$ in railway transports and 2.1 μg/m$^3$ in ferry were observed (Lau and Chan, 2003). For the TEX compounds (toluene, ethylbenzene and xylene isomers) higher concentrations were found in air conditioned buses and trains and could be explained from the solvent related emissions from the interior construction materials. Zhang et al. (2008) have investigated the air quality in parked cars and found that concentration levels were 1.1 (formaldehyde) to 1.6 (toluene) higher in new cars compared to the older ones.

It can be concluded from the literature survey that studies have been mainly focused on a limited number of target organic compounds, with the BTEX compounds most often studied (Gomez-Perales et al., 2004; Balanay and Lungu, 2009; Hsu and Huang, 2009; Ongwandee and Chavalparit, 2010; Chen et al., 2011; Jo and Lee, 2011; Tran Thi Ngoc et al., 2013). Among the different commuter modes, cycling has only been considered by few studies (Kingham et al., 1998; Panis et al., 2010; Kendrick et al., 2011; de Nazelle et al., 2012; Weichenthal et al., 2012; Elen et al., 2013). It has been found that the bicycle lane characteristics have an effect on the exposure of cyclists to ultrafine particles (UFP), as the UFP number concentrations in a typical bicycle lane (next to road) are significantly higher than on a bicycle track that is separated from the road by a row of parked cars (Kendrick et al., 2011). A study conducted in Copenhagen found that car drivers experience 3 to 4 times higher BTEX concentrations and two times higher exposure of particles when compared to cyclists (Rank et al., 2001). Elen et al. (2013) have designed a special bicycle, Aeroflex, equipped with compact air quality measurement devices to monitor UFP number counts, particulate mass and black carbon concentrations in Belgium.

Within Belgium, there is strong encouragement from the government to increase the use of bicycles. For example, a bicycle highway network consisting of 400 km routes, called “FietsGEN” will be constructed in cities surrounding the capital, Brussels, in order to increase the use of bicycles for traveling distances up to 15 km. Also, in the region of Flanders a bicycle network is constructed (so called BFF) and in the province East Flanders, the Long Distance Bicycle network (so called LAF) will provide cycle lanes along canals, rivers and (old) train tracks. The city of Ghent (248 242 inhabitants in 2012; province of East Flanders), where the sampling was conducted, can be considered as a bicycle city.

The objective of this study is to collect new data on the pollutant levels to which cyclists are exposed and how these levels relate to those experienced by commuters using other transportation means. Therefore, three transportation modes including tram, car and bicycle are studied and concentration levels of 84 VOCs (belonging to hydrocarbons, aromatic hydrocarbons, oxygen containing hydrocarbons, terpenes and halogenated compounds) are measured along a fixed route in Ghent, Belgium. In order to make a direct comparison possible among the modes of transportation, sampling was conducted simultaneously from the same starting point to the same finishing point (fixed route). This allows for a sampling under identical atmospheric and traffic conditions. To support the comparison, extra data is also obtained from a fixed site located on the fixed route.

## 2. Experimental

### 2.1. Chemicals

Target compounds were purchased as the EPA 502/524.2 VOC mix (200 μg/ml in methanol) at Sigma–Aldrich (Bornem, Belgium) or as individual LC–MS grade VOCs, having a purity of at least 99.8% at Sigma–Aldrich (Bornem, Belgium) or Acros Organics (Geel, Belgium). The individual compounds are then volumetrically taken by a micropipette and dissolved and further diluted in methanol (LC–MS grade, 99.95%, Biosolve, Valkenswaard, The Netherlands) to obtain the final concentrations of ±50 μg/ml for each individual target compound. The solutions are then used to calibrate the mass spectrometer. The target compounds consist of 84 compounds belonging to 5 different groups of organic compounds ((cyclo)-alkanes, aromatic compounds, oxygenated compounds, halogenated compounds and terpenes) and are listed in Table 1.

[$^2H_8$]Toluene (Tol-d8; 99.5 + atom%D; Acros Organics, Geel, Belgium) is used as an internal standard. Clean and dry nitrogen and helium gases ([$H_2O$] <3.0 $ppm_v$; [$O_2$] <2.0 ppmv; [$C_xH_y$] <0.5 $ppm_v$) were provided by Air Liquide (Luik, Belgium).

### 2.2. Sampling

In order to assess the exposure to 84 VOCs among commuters using the tram, bicycle and vehicle, a route is selected within the city of Ghent, Belgium. The selected route is from the Southern part of the city (Flanders expo located in the suburb of Sint-Denijs) towards the North (Brielken located in the suburb of Evergem). The