



Emission of Volatile Organic Compounds from Consumer Products

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ABSTRACT

The total volatile organic compound (VOC) content and VOC composition of 12 consumer products is determined using the headspace method and chamber testing. Several hazardous or toxic VOC's are present in abundance. Some consumer products from the same category vary significantly in terms of the total VOC content and VOC species. Spray and adhesive products for this study have high total VOC contents.

The results show that three spray products and three adhesives have low moisture (0–35.87 wt.%) and a high total VOC content (63.41–99.52 wt.%) but the other six consumer products with a high moisture content (72.51–96.92 wt.%) have lower total VOC content (0.75–19.43 wt.%). Three adhesives and one car cleaner (spray product) emit significant amounts of VOC's, including large amounts of hazardous organic solvents and some toxic substances. Therefore, direct contact should be avoided in the household environment.

The total VOC content that is determined by this study can be used to calculate the total emissions and to establish an emissions inventory. All detectable VOC emission factors for each product are in the range of 6.77–924 mg g⁻¹. The emission factor for an individual VOC is used to better characterize consumer products as sources of hazardous material. The chamber test results that pertain to indoor air quality can be used to determine the risk of exposure.

Keywords: Volatile organic compounds (VOCs), Consumer products, Household environment, Chamber test

1 INTRODUCTION

Human activity patterns in the United States and the WHO European Region are similar, in that more than 90% of time is spent indoors (Sarigiannis, 2013). To increase energy efficiency, buildings are also more airtight so air pollutants accumulate in indoor air (Jones, 1999). Therefore, the exposure of humans to toxins in an indoor environment is of concern. Most studies determine the VOC emissions from industrial processes and facilities (Chen *et al.*, 2020; Lu *et al.*, 2020; Li *et al.*, 2021) and their effect on ambient air quality (Gao *et al.*, 2020; Guan *et al.*, 2020; Wang *et al.*, 2020; Wu *et al.*, 2021) and the increase in risk to human health but consumer products that are used indoors have a more direct effect on the human inhalation (Even *et al.*, 2020; Moxon *et al.*, 2020; Palmisani *et al.*, 2020). Consumer products contain biogenic VOCs and their emission can be the precursor to the emission of ozone and secondary organic aerosols (Martinsson *et al.*, 2020; Ahn *et al.*, 2021).

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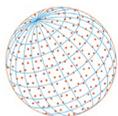
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Modern lifestyle choices mean that consumer products such as personal care and household cleaning products are widely used in indoor environments to improve hygiene. However, specific chemicals in consumer products, such as biocidal active ingredients, preservatives, odorants, additives and solvents, can be harmful (Peter and Andrew, 2003). These additives often contain volatile organic compounds and many studies identify consumer products as a major source of VOC's in indoor air.

Household cleaners release large amounts of VOCs during use and affect the respiratory pathway. Household cleaners that are used in many consumer products contain terpenes and terpenoids. These terpenes are released into an indoor environment and are transported after photochemical reactions that promote the formation of ozone (Nazaroff and Weschler, 2004; Steinemann, 2009; Martinsson *et al.*, 2020).

In addition to household cleaners, body spray products such as deodorants and hair sprays contain a variety of ingredients that can have a toxic effect on the respiratory tract (Rothe *et al.*, 2011). A previous study determined the effect of exposure to harmful volatile pollutants that are released from 10 common household spray products. The most common indoor VOCs, such as benzene, toluene, styrene, methyl ethyl ketone and butyl acetate, are contained in most spray products at concentrations of 5.3–125 mg L⁻¹. If the amount of spray product that is released into the air reaches a level of 0.3 mL, there is a considerable carcinogenic risk (Rahman and Kim, 2014).

Many studies concern VOC emissions from consumer products but there are currently no emissions testing or evaluation standards for consumer and personal care products. Testing protocols and results vary between laboratories because testing conditions and objectives differ, so comparisons are difficult (Petry *et al.*, 2013).

Using essential oils with aromatic compounds indoors can affect air quality. A study of five popular essential oils showed that the main VOC in the evaporating gas from essential oils at 40°C are toluene, 1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene, n-undecane, p-diethylbenzene and m-diethylbenzene. The emission factors for 52 VOCs range from 137 to 173 mg g⁻¹ (Chiu *et al.*, 2009). Steinemann *et al.* (2011) studied the VOCs that are emitted by 25 common fragrant consumer products and showed that more than 80% of products contain limonene, alpha-pinene and beta-pinene. Limonene is also the most common VOC in many fragrant consumer products.

To determine the role of consumer products in anthropogenic VOC emissions, qualitative and quantitative assessments of their levels are necessary, so this study pertains to four categories of consumer products: household cleaners, car cleaners, hairdressing agents and adhesives. These are widely used and are easily accessed by children. These products are tested for VOC composition and emissions. The results are used to construct emission inventories to better characterize consumer products as sources of pollution.

2 EXPERIMENTAL

2.1 Selection of Consumer Products

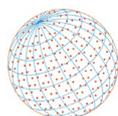
Sales records are used to study the constituents and VOC emissions for household cleaners, car cleaners, hairdressing agents and adhesives. A total of twelve samples of four categories of consumer products are used, including household cleaners (dish cleaner, toilet cleaner and laundry detergent), car cleaners (wiper washing, anti-rust lubricant and carburetor cleaner), hairdressing agents (hair care cream, hair styling spray and hair styling gel) and adhesives (power glue, super glue and instant glue) (Table 1). These products were purchased from a local market (in Taiwan) and are widely used. Anti-rust lubricant, carburetor cleaner and hair styling spray are spray products. All experiments for each consumer product were performed in triplicate.

2.2 Liquid and Gel Consumer Products

2.2.1 Determination of total VOC content

For liquid and gel consumer products (nine in total), the percentage by weight of total VOCs was determined using U.S. EPA Method 24 (U.S. EPA, 1995) and ASTM D2369-01 (ASTM, 2001).

An amount of sample was weighed and heated in an air oven at 110°C for 60 minutes. Total VOC and moisture are calculated using the difference in the weight of the sample before and after heating, from which the moisture content is subtracted to obtain the total VOC content

**Table 1.** The studied consumer products.

Category	Product name	Code	Capacity
Household cleaners	Dish cleaner	DC	1000 g
	Toilet cleaner	TC	650 g
	Laundry detergent	LD	3150 g
Car cleaners	Wiper washing	WW	1000 g
	Anti-rust lubricant	AL	600 mL (spray type)
	Carburetor cleaner	CC	473 mL (spray type)
Hairdressing agents	Hair care cream	HCC	80 g
	Hair styling spray	HSS	180 g (spray type)
	Hair styling gel	HSG	200 g
Adhesives	Power glue	PG	18 g
	Super glue	SG	2 g
	Instant glue	IG	20 g

(wt. %-product) in the consumer product. The moisture in products was measured using the Karl Fischer (KF) titration method that is described in ASTM D4017-96a (ASTM, 1996). An amount of the sample was diluted with 1-methoxy-2-propanol (MPA) and heated in an oven. Moisture was collected from the oven into the titration vessel using an inert carrier gas stream. The moisture in the titration vessel was continuously titrated to the end point using KF reagent, in order to determine the moisture content.

2.2.2 VOC constituents and emissions

Approximately 100 μL of the original sample was introduced into a headspace vial (20 mL) containing 5.0 mL of 10% water/polyethylene glycol 400 (as a dispersant). The vial was then sealed and equilibrated to 80°C. An aliquot of the headspace gas was removed using a syringe and introduced into an adsorbent tube (Tenax TA). The adsorbent tube was connected to a thermal desorption and a pre-concentrated unit (Entech 7100 instrument) to introduce the VOC into a gas chromatograph (GC, HP-6890) that is equipped with a mass spectrometer detector (MSD, HP 5973N Mass Spectrometer).

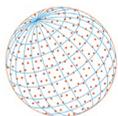
The GC is equipped with a fused silica capillary column (DB-624, 60 m at 0.25 mm i.d. with 1.4 μm film) and connected to the MSD. Ultrapure helium was passed through the column as a carrier gas at a flow rate of 1.0 mL min^{-1} . The initial temperature of the column was maintained at 35°C for 8 min and the column was then heated to 250°C at 5°C min^{-1} and that temperature was maintained for 10 min. The mass detector temperature is 280°C. Mass scanning is in the 30–350 m z^{-1} range.

Fragmentation patterns and the relative retention time for reference compounds in the mass spectrum library are used to qualitatively identify chemical species using the GC-MSD peaks. Using a semi-quantitative method, the peak areas are normalized and the relative content of VOC constituents is expressed as a percentage. The relative content of individual VOC's (wt. %-total VOC) is converted to an emission factor (mg g^{-1} -product) using the previously determined total VOC content (wt. %-product).

2.3 Spray Products

2.3.1 Total VOC content

The three spray products are aerosol products so the propellant (mainly liquefied petroleum gases) part is the VOC content (by weight). The aerosol propellant was separated from the non-propellant portion of the product and its weight was obtained by subtracting the weight before from that after separation. The products in glass and metal containers were respectively separated using ASTM D 3063-94 (ASTM, 1994a) and ASTM D 3074-94 (ASTM, 1994b) methods. The remaining non-propellant fraction was poured from the container and weighed and the VOC content was measured according to "Section 2.2.1". The total VOC content (wt. %) in the entire spray product was calculated using the weight of the VOCs in the non-propellant fraction and the entire propellant weight.



The VOC emissions for the non-propellant fraction were also measured using the semi-quantitative method that is described in "Section 2.2.2". This addresses the error in the quantification of some VOC species for chamber testing.

2.3.2 Conditions for chamber testing

The VOC emissions from spray products were tested in a chamber. The test chamber is made of stainless steel and has a volume of 0.036 m³ (36 L). Prior to testing, the materials were thoroughly mixed by shaking the spray bottle vigorously and the chamber was purged with clean air (individual VOC < 2 µg m⁻³ and TVOC < 20 µg m⁻³) for 2 h. The ambient temperature and relative humidity of the test chamber were respectively maintained at 25°C ± 2°C and 45%. The consumer product in the spray bottle was tested using an automatic sprayer in the test chamber and the product was sprayed (approximately 2–3 seconds) into the chamber after the door was closed. A small fan in the chamber disturbed the air for 30 min to avoid adsorption of VOCs on the walls and to promote volatilization. The VOCs were then assumed to have been completely released and aeration and sampling were performed.

The duration of the full test was 6 hours. The air exchange rate (ACH) was 1 h⁻¹ and the gas sampling time was 6 min. During each test, the supply air flow was checked to ensure that the deviation between the exhaust flow and the intake flow was < 5%. The individual VOC and TVOC concentrations in the supply air were respectively less than 1 and 10 µg m⁻³. Sampling was conducted after 12 min (i.e., 6th–12th min) and 30 min and at 1, 2 and 6 h. A Tedlar bag was placed in a rigid airtight container (SKC-Vac-U-Chamber) and the outlet gas was sampled using U.S. EPA Method 18 (Integrated Bag Method) (U.S. EPA, 1997). The spray bottle was weighed before and after spraying and the difference is the product load weight.

2.3.3 Determination of VOC constituents in a gas sample

Gas samples in a 5-L Tedlar bag were analyzed using U.S. EPA Method 18 (U.S. EPA, 1997). Three duplicate analyses were performed for each VOC sample. The gas sample bag was connected to a purge-and-trap system (Entech 7100 instrument) and VOC species were pre-concentrated and analyzed in a GC-MSD (HP-6890 Gas Chromatograph and HP 5973N Mass Spectrometer).

The GC is equipped with a fused silica capillary column (nonpolar RTx-1, 105 m at 0.25 mm i.d. with 1.0 µm film). The temperature was maintained at 35°C for 5 min and then increased to 250°C at 8°C min⁻¹. The injection and MSD are 250°C and 270°C, respectively. Calibration standards were produced by diluting the certified standard gas (56 Enviro-Mat Ozone Precursor, Matheson, USA) with ultrahigh-purity nitrogen in dilution bottles. Acetone, ethanol, linalool and d-limonene have been detected in many consumer product studies and are included in this VOC analysis due to their hazardous nature. These liquid pure chemicals (Merck, UV or GR) were weighed, mixed and heated in a gasifier and passed through high-purity nitrogen to carry the concentrated VOC gas into a thermal bottle. Calibration standards were produced by diluting the concentrated VOC gas with high-purity nitrogen in gas collecting tubes.

The performance of the GC-MSD was evaluated using perfluorotributylamine for quality control. The relative standard deviation for all VOCs is < 15%, the accuracy ranges from 87.7% (propane) to 104.12% (p-ethyltoluene) and the method detection limit varies from 0.02 (n-decane) to 0.14 (n-butane) ppb.

3 RESULTS AND DISCUSSION

3.1 Total VOC Content in the Studied Consumer Products

The total VOC content for twelve consumer products is shown in Fig. 1. Household cleaners (DC, TC and LD) have the lowest total VOC contents (0.93–9.94 wt.%). In terms of car cleaners, the total VOC content for AL (81.73 wt.%) and CC (99.52 wt.%) is much higher than that for WW (0.75 wt.%). In terms of hairdressing agents, the total VOC content for HCC (5.92 wt.%) and HSG (19.43 wt.%) is much lower than that for HSS (63.41 wt.%). These results show that products in the same category have a widely different total VOC content.

The total VOC content in the three spray products AL, CC and HSS, is greater because the spray product contains propellant, which contributes to the VOC content. The total VOC content for

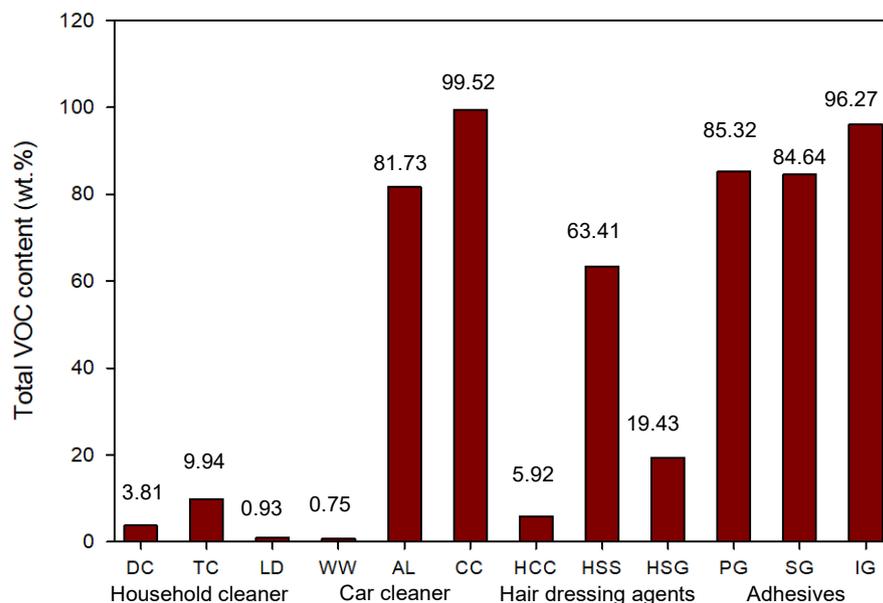
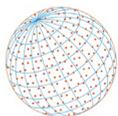


Fig. 1. Total VOC content in the studied consumer products.

products in the adhesive category is 85.32–96.27 wt.%, which is not less than that for spray products. However, few studies measure VOC emissions from products that are adhesives.

The results show that of the 12 consumer products, 3 spray products (AL, CC and HSS) and 3 adhesives (PG, SG and IG) have low moisture content (0–35.87 wt.%) and a high total VOC content (63.41–99.52 wt.%) but the other 6 consumer products with a high moisture content (72.51–96.92 wt.%) have a lower total VOC content (0.75–19.43 wt.%).

3.2 Emissions of VOC Constituents in Liquid and Gel Products

The emission factors for VOC species for each liquid and gel product are shown in Table 2. The VOC composition for these products varies widely, even for products in the same category. Previous studies show similar results. *Kwon et al. (2007)* studied the VOC emissions for all-purpose cleaning products and showed that decane, d-limonene, β -myrcene, octane, α -pinene and β -terpinene are present in one product, but not in the other 2 products. The 34 detectable VOC's are C2–C13, according to carbon number (Table 2). In household cleaners, DC, TC and LD have VOC species in the C8–C13, C2–C10, and C10–C13 ranges, respectively. WW in car cleaners has 2 VOC's with carbon numbers C6 and C10. In terms of the hairdressing agents, HCC has two VOCs with a carbon number of C3 and HSG has two VOCs with a carbon number of C6 and C10. In terms of the adhesives, PG, SG and IG have VOC species in the C6–C8, C2–C6 and C2–C6 ranges, respectively.

Zhu et al. (2001) studied consumer products using the headspace method and showed that 2-butoxyethanol, camphene, d-limonene, β -myrcene and β -pinene are emitted from all-purpose cleaning products. Other VOC emissions studies show that acetone, 2-butoxyethanol, decane, ethanol, ethylbenzene, hexane, d-limonene, tetrachloroethylene, phenol, 1-propanol, toluene and o-xylene are also frequently present in consumer products (*Kwon et al., 2008*). Specifically, d-limonene is the most common VOC in fragranced consumer products (*Rastogi et al., 2001; Singer et al., 2006; Jo et al., 2008*).

Steinemann (2015) studied 37 consumer products using the headspace method, 28 of which were laundry products, cleaners and personal care products. The VOCs in the products were determined by focusing on specific substances that are defined as toxic or hazardous by one or more U.S. federal laws. In the 28 products, terpenes d-limonene, α -pinene and β -pinene and ethanol, benzyl acetate and acetone are frequently detected in high concentrations. 2-butoxyethanol was detected in 2 of the 28 products, iso-propanol was detected in 8 and linalool was detected in 4.

The properties and types of DC, TC, LD, WW, HCC and HSG are similar to those of the 28 products in the study by *Steinemann (2015)*. The toxic or hazardous VOC species that are listed in the *Steinemann (2015)* study can be targeted to determine the VOC emissions from the products

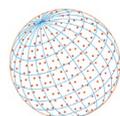


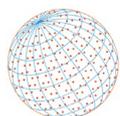
Table 2. The emissions values for VOC constituents in liquid and gel products.

Compounds		Emission factors of VOCs (mg g ⁻¹ -product)								
		DC	TC	LD	WW	HCC	HSG	PG	SG	IG
Dimethyl ether	C ₂ H ₆ O	-	-	-	-	-	-	-	68.55	63.07
Ethanol	C ₂ H ₆ O	-	-	-	-	-	86.76	-	-	-
iso-Propanol	C ₃ H ₈ O	-	-	-	-	21.55	-	-	-	-
Propylene glycol	C ₃ H ₈ O ₂	-	-	-	-	29.61	-	-	-	-
Acetone	C ₃ H ₆ O	-	-	-	-	-	-	-	-	144.14
Acetic acid	C ₂ H ₄ O ₂	-	10.25	-	-	-	-	-	-	-
2,2-Dimethoxypropane	C ₅ H ₁₂ O ₂	-	-	-	-	-	-	-	90.14	-
Methyl cyanoacrylate	C ₅ H ₅ NO ₂	-	-	-	-	-	-	-	-	48.93
Benzene	C ₆ H ₆	-	-	-	-	-	-	4.03	-	-
2-butoxyethanol	C ₆ H ₁₄ O ₂	-	-	-	3.93	-	-	-	-	-
Hexanoic acid	C ₆ H ₁₂ O ₂	-	7.47	-	-	-	-	-	-	-
Triethyl phosphate	C ₆ H ₁₅ O ₄ P	-	-	-	-	-	-	-	86.91	53.42
Ethyl cyanoacrylate	C ₆ H ₇ NO ₂	-	-	-	-	-	-	-	515.92	614.87
2-Ethylpentane	C ₇ H ₁₆	-	-	-	-	-	-	0.54	-	-
Toluene	C ₇ H ₈	-	-	-	-	-	-	773.18	-	-
Norbornane	C ₇ H ₁₂	-	-	-	-	-	-	1.35	-	-
Cyclohexylmethane	C ₇ H ₁₄	-	-	-	-	-	-	3.62	-	-
Heptanoic acid	C ₇ H ₁₄ O ₂	-	12.93	-	-	-	-	2.57	-	-
Benzaldehyde	C ₇ H ₆ O	-	24.91	-	-	-	-	-	-	-
o-Xylene	C ₈ H ₁₀	-	-	-	-	-	-	4.54	-	-
Phenoxyethanol	C ₈ H ₁₀ O ₂	15.63	-	-	-	-	-	-	-	-
Octanoic Acid	C ₈ H ₁₆ O ₂	-	-	-	-	-	-	3.51	-	-
Dimethoxymethylbenzene	C ₉ H ₁₂ O ₂	-	19.17	-	-	-	-	-	-	-
1-Decanol	C ₁₀ H ₂₂ O	-	-	-	2.84	-	-	-	-	-
Dihydromyrcenol	C ₁₀ H ₂₀ O	-	-	0.24	-	-	-	-	-	-
Linalool	C ₁₀ H ₁₈ O	-	-	0.16	-	-	-	-	-	-
2-Propyl-1-heptanol	C ₁₀ H ₂₂ O	-	5.76	-	-	-	-	-	-	-
d-Limonene	C ₁₀ H ₁₆	3.22	-	-	-	-	-	-	-	-
1-Chloroundecane	C ₁₁ H ₂₃ Cl	12.21	-	4.55	-	-	-	-	-	-
1-Undecene	C ₁₁ H ₂₂	0.54	-	-	-	-	-	-	-	-
2-Butyloctanol	C ₁₂ H ₂₆ O	1.53	-	1.12	-	-	-	-	-	-
Nonylcyclopropane	C ₁₂ H ₂₄	-	-	-	-	-	77.95	-	-	-
Dodecamethylcyclhexasiloxane	C ₁₂ H ₃₆ O ₆ Si ₆	-	-	-	-	-	4.92	-	-	-
1-Tridecene	C ₁₃ H ₂₆	0.36	-	-	-	-	-	-	-	-
N,N-Dimethyl-1-undecanamine	C ₁₃ H ₂₉ N	1.64	-	2.44	-	-	-	-	-	-
Sum of emissions (mg g ⁻¹)		35.13	80.49	8.51	6.77	51.16	169.63	793.34	761.52	924.43
Sum of VOCs contents (wt.%)		3.51	8.05	0.85	0.68	5.12	16.96	79.33	76.15	92.44

Note: “-” means not detected.

that are tested for this study. d-limonene has low acute toxicity but it can cause skin irritation and allergies. There is no relevant evidence to suggest that d-limonene has a chronic health effect in humans (Wolkoff and Nielsen, 2001; Anderson *et al.*, 2013). Table 2, shows that d-limonene, linalool, 2-butoxyethanol, iso-propanol and ethanol are respectively present in DC, LD, WW, HCC and HSG. Compared to all detectable VOCs in each product, 2-butoxyethanol in WW, isopropanol in HCC and ethanol in HSG produce significant emissions, with emission factors of 3.93, 21.55 and 86.76 mg g⁻¹, respectively.

TC has a different VOC composition to that for other products and emits a high amount of the hazardous substance, benzaldehyde (24.91 mg g⁻¹). Dodecamethylcyclhexasiloxane is also present in HSG, which is a hair styling product. However, research has shown that octamethylcyclotetrasiloxane, decamethylcyclopentasiloxane and dodecamethylcyclhexasiloxane are the VOC's that are associated with hair styling products (Wang *et al.*, 2009).



In the adhesive category, the main ingredients of PG are different to those for SG and IG, so there is a wide variety in the VOC constituents of the two (Table 2). The main ingredients of PG are toluene and rubber and SG and IG are mainly made of ethyl cyanoacrylate. PG emits a large amount of toluene (773.18 mg g^{-1}) and a small amount of benzene (4.03 mg g^{-1}) and o-xylene (4.54 mg g^{-1}). SG and IG contain high levels of ethyl cyanoacrylate and dimethyl ether, which two compounds account for more than half of emissions of the detectable VOCs for each product. IG also emits high levels of acetone (144.14 mg g^{-1}), which is not present in SG.

Dimethyl ether and acetone are also hazardous organic solvents. Table 2 shows that the sum of the VOC contents in an individual product is slightly less than the total VOC content that is shown in Fig. 1, so some VOC species cannot be identified using headspace sampling and GC-MSD analysis.

Benzene has low acute toxicity but it is readily absorbed if it is inhaled or ingested orally. Some acute conditions are caused by the systemic toxicity of benzene, such as myeloid leukemia (Snyder, 2012) so potential indoor exposure to benzene is a concern. Benzene is also classified as a human carcinogen (WHO, 2010). Toluene has low acute toxicity, but it has a significantly deleterious effect on the central nervous system. The available evidence does not show that toluene is carcinogenic and it is not known to be genotoxic (U.S. EPA, 2005).

Acute and chronic exposure to xylene can affect human health, the most significant of which is central nervous system depression, followed by symptoms such as headache, dizziness and nausea (Kandyala et al., 2010). Therefore, care is necessary when using the studied adhesives in a household environment and direct contact should be avoided because these products contain hazardous organic solvents (dimethyl ether and acetone) and toxic substances (benzene, toluene and xylene).

3.3 VOC Emissions from Spray Products

The VOC constituents and their emissions for three spray products are shown in Table 3. Chamber testing results show that the VOC emissions for three spray products are mainly liquefied petroleum gases (LPG), propane, n-butane and iso-butane. Other VOC species also account for a significant proportion of emissions, such as 2-methylhexane, ethanol, toluene and xylene.

LPG has similar characteristics and accounts for the majority of VOC emissions, so Figs. 2–4 only show VOC emissions per time interval for each spray product other than LPG. The gas was

Table 3. The emissions values for VOC constituents in spray products using chamber testing.

Compounds		Emission factors of VOCs (mg g^{-1} -product)		
		AL	CC	HSS
Ethanol	$\text{C}_2\text{H}_6\text{O}$	-	-	45.58
Propane	C_3H_8	23.22	421.73	96.26
iso-Butane	C_4H_{10}	185.54	16.71	117.41
n-Butane	C_4H_{10}	328.65	16.62	192.83
iso-Pentane	C_5H_{12}	1.66	-	1.45
Acetone	$\text{C}_3\text{H}_6\text{O}$	-	1.28	-
Benzene	C_6H_6	-	0.27	-
2,4-Dimethylpentane	C_7H_{16}	1.25	-	-
2-Methylhexane	C_7H_{16}	6.44	-	-
2,3-Dimethylpentane	C_7H_{16}	3.93	-	-
3-Methylhexane	C_7H_{16}	2.67	-	-
Heptane	C_7H_{16}	5.46	-	-
Toluene	C_7H_8	5.71	392.32	1.78
Ethylbenzene	C_8H_{10}	-	3.35	-
m+p-Xylen	C_8H_{10}	0.52	13.36	-
o-Xylene	C_8H_{10}	-	2.34	-
d-Limonene	$\text{C}_{10}\text{H}_{16}$	-	-	13.16
Sum of emissions (mg g^{-1})		565.05	867.98	468.92
Sum of VOCs contents (wt.%)		56.51	86.80	46.89

Note: “-” means not detected.

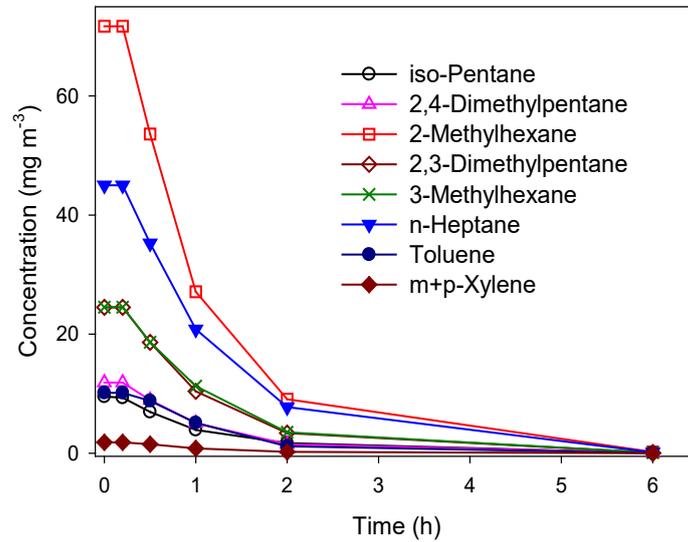
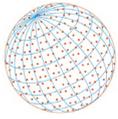


Fig. 2. VOC emissions from AL using chamber testing.

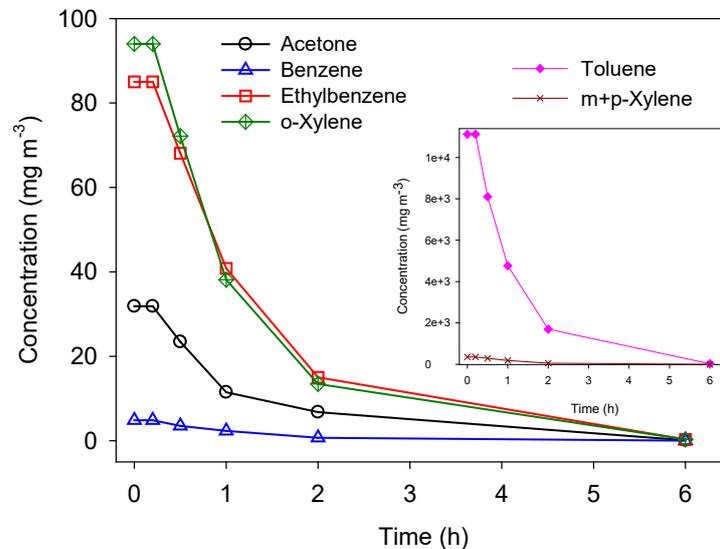


Fig. 3. VOC emissions from CC using chamber testing.

sampled earlier so it is assumed that the initial concentration (at time = 0 min) for each VOC is the same as the concentration at 0.2 h. The area under the plotted curve is used to calculate the emissions for each VOC component for the duration of the test (including LPG, although they are not shown in Figs. 2–4). For the test, the emissions (mg) for each VOC component are calculated as $\text{area} \times \text{ACH} \times \text{chamber volume}$. Therefore, the emission factor for each VOCs from a spray product (shown in Table 3) is determined by dividing the emission by the load weight.

This study uses a relatively small test chamber, with a volume of only 0.036 m^3 . This does not reflect reality. Bartzis *et al.* (2015) compared VOC emission in test chambers with three different volumes ($0.26\text{--}20 \text{ m}^3$) and concluded that any variability is independent of the chamber volume but is dependent on the test environment.

Table 3 shows that AL emits a large amount of LPG and a small amount of toluene, xylene (m- and p-xylene), methylhexane isomers and dimethylpentane isomers. Toluene and xylene are toxic compounds. CC emits a variety of hazardous or toxic substances, including large amounts of toluene (392.32 mg g^{-1}) and small amounts of benzene, ethylbenzene, xylene (o-, m- and p-xylene) and acetone. CC is a car cleaning product that is used outdoors, but it is used indoors in car paint shops, which creates a health problem.

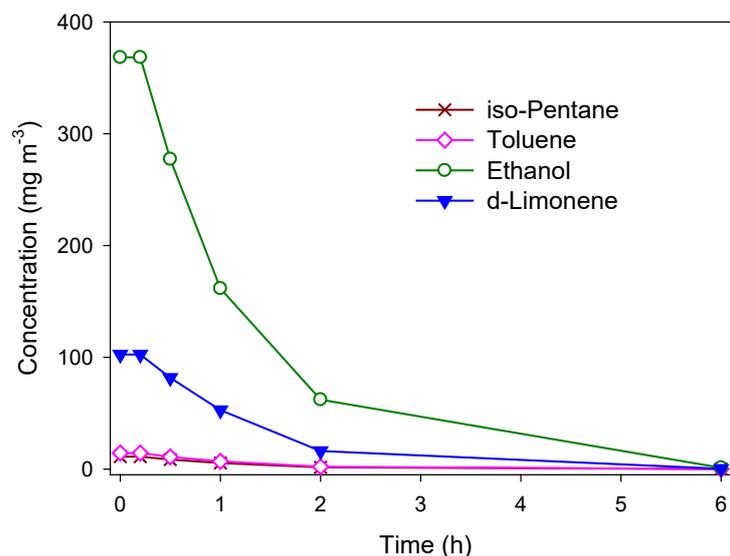
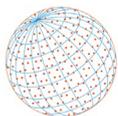


Fig. 4. VOC emissions from HSS using chamber testing.

Dinh *et al.* (2015) studied the emission of 22 target VOCs from consumer and commercial products. For 3 hair spray products, the VOC's are propane, iso-butane, n-butane and ethanol. The ethanol content is 30.5–42.7%. In contrast to the results of the study by Dinh *et al.* (2015), HSS (a hair spray product) is shown to emit ethanol, toluene and d-limonene, which are hazardous or toxic substances (Table 3).

Table 3 shows that the sum of the VOC contents in an individual product is slightly less than the total VOC content that is shown in Fig. 1. This difference may be due to the adsorption of some VOC onto the chamber walls and the limitations of the analytical method (56 + 4 target VOCs).

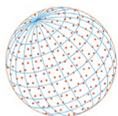
The results for non-propellants (GC-MSD semi-quantitative method) show that many VOCs that are present in compounds differ from those that are emitted during the chamber test. AL non-propellant contains undecane, methylundecane isomers, dodecane, 2,5-dimethylundecane, 4-methyldodecane, farnesane, tridecane and ethylhexyl chloroformate, which together account for about 21.16 wt.% of AL. However, the VOC emissions for AL in a chamber are 56.51 wt.%, undetectable emissions are 21.16 wt.% and the total VOC content is 81.73 wt.%, so there is a small difference that may be attributable to the adsorption of some VOCs onto the chamber walls. Similarly, 1-ethyl-4-methylcyclohexane (10.04 wt.%) and ethylhexyl chloroformate (7.83 wt.%) are only respectively emitted from CC and HSS non-propellants, so the VOC emissions from CC and HSS in the chamber (Table 3) are also slightly less than the total VOC content (Fig. 1) due to adsorption and analysis limitations.

4 CONCLUSIONS

The total VOC content and VOC constituents for twelve consumer products are determined using the headspace method and chamber tests. Several hazardous or toxic VOCs are present in significant amounts. The experimental results also show that consumer products in the same category can have significantly different total VOC contents and VOC species.

Three spray products (AL, CC and HSS) and three adhesive (PG, SG and IG) products have low moisture content and a high total VOC content, but three household cleaners (DC, TC and LD), one car cleaner (WW) and two hairdressing agents (HCC and HSG) have a high moisture content and a low total VOC content. The results of this study show that 2-butoxyethanol in WW, iso-propanol in HCC and ethanol in HSG produce significant emissions of all detectable VOC's for each product, with respective emission factors of 3.93, 21.55 and 86.76 mg g⁻¹.

Three adhesives (PG, SG and IG) and one car cleaner (CC) emit a large amount of VOC's. PG emits toluene (773.18 mg g⁻¹), benzene (4.03 mg g⁻¹) and o-xylene (4.54 mg g⁻¹). SG and IG contain



ethyl cyanoacrylate and dimethyl ether, which constitute more than half of the detectable VOCs. IG also emits high levels of acetone (144.14 mg g^{-1}), which is not present in SG.

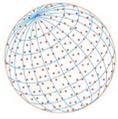
Using the annual product consumption data, the total VOC content for this study is used to calculate the total emissions and then establish an emissions inventory. The emission factor for an individual VOC is used to better characterize consumer products as sources of hazardous material. However, the chamber test results show that VOC emissions from the household environment can be used to determine the quality of indoor air and the risk that is created by exposure.

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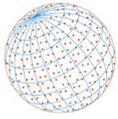
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REFERENCES

- Ahn, J., Rao, G., Vejerano, E.P. (2021). Dependence on humidity and aerosol composition of the gas-particle partitioning of weakly and moderately polar VOCs. *Aerosol Air Qual. Res.* 21, 210094. <https://doi.org/10.4209/aaqr.210094>
- Anderson, S.E., Khurshid, S.S., Meade, B.J., Lukomska, E., Wells, J.R. (2013). Toxicological Analysis of Limonene Reaction Products Using an in Vitro Exposure System. *Toxicol. Vitro.* 27, 721–730. <https://doi.org/10.1016/j.tiv.2012.11.017>
- ASTM International (ASTM) (1994a). ASTM D 3063-94 Standard Test Method for Pressure in Glass Aerosol Bottles. ASTM International.
- ASTM International (ASTM) (1994b). ASTM D 3074-94 Standard Test Methods for Pressure in Metal Aerosol Containers. ASTM International.
- ASTM International (ASTM) (1996). ASTM D 4017-96a Standard Test Method for Water in Paints and Paint Materials by the Karl Fisher Titration Method. ASTM International.
- ASTM International (ASTM) (2001). ASTM D 2369-01 Standard Test Method for Volatile Content of Coatings. ASTM International.
- Bartzis, J., Wolkoff, P., Stranger, M., Efthimiou, G., Tolis, E.I., Maes, F., Norgaard, A.W., Ventura, G., Kalimeri, K.K., Goelen, E., Fernandes, O. (2015). On organic emissions testing from indoor consumer products' use. *J. Hazard. Mater.* 285, 37–45. <https://doi.org/10.1016/j.jhazmat.2014.11.024>
- Chen, G.F., Lai, C.H., Chen, W.H. (2020). Principal component analysis and mapping to characterize the emission of volatile organic compounds in a typical petrochemical industrial park. *Aerosol Air Qual. Res.* 20, 465–476. <https://doi.org/10.4209/aaqr.2019.07.0365>
- Chiu, H.H., Chiang, H.M., Lo, C.C., Chen, C.Y., Chiang, H.L. (2009). Constituents of volatile organic compounds of evaporating essential oil. *Atmos. Environ.* 43, 5743–5749. <https://doi.org/10.1016/j.atmosenv.2009.08.002>
- Dinh, T.V., Kim, S.Y., Son, Y.S., Choi, I.Y., Park, S.R., Sunwoo, Y., Kim, J.C. (2015). Emission characteristics of VOCs emitted from consumer and commercial products and their ozone formation potential. *Environ. Sci. Pollut. Res.* 22, 9345–9355. <https://doi.org/10.1007/s11356-015-4092-8>
- Even, M., Hutzle, C., Wilke, O., Luch, A. (2020). Emissions of volatile organic compounds from polymer-based consumer products: Comparison of three emission chamber sizes. *Indoor Air* 30, 40–48. <https://doi.org/10.1111/ina.12605>
- Gao, Q., Yan, Y., Li, R., Xu, Y., Niu, Y., Liu, C., Xie, K., Chang, Z., Hu, D., Li, Z., Peng, L. (2020). Characteristics of volatile organic compounds during different pollution periods in winter in Yuncheng, a typical city in North China. *Aerosol Air Qual. Res.* 20, 97–107. <https://doi.org/10.4209/aaqr.2019.08.0402>
- Guan, Y., Zhang, Y., Zhang, Y., Wang, X., Han, J., Song, W., Hou, L., Duan, E. (2020). Pollution characteristics and key reactive species of volatile organic compounds in Beijing-Tianjin-Hebei area, China. *Aerosol Air Qual. Res.* 20, 1886–1897. <https://doi.org/10.4209/aaqr.2019.11.0595>



- Jo, W.K., Lee, J.H., Kim, M.K. (2008). Head-space, small-chamber and in-vehicle tests for volatile organic compounds (VOCs) emitted from air fresheners for the Korean market. *Chemosphere* 70, 1827–1834. <https://doi.org/10.1016/j.chemosphere.2007.08.021>
- Jones, A.P. (1999). Indoor air quality and health. *Atmos. Environ.* 33, 4535–4564. [https://doi.org/10.1016/S1352-2310\(99\)00272-1](https://doi.org/10.1016/S1352-2310(99)00272-1)
- Kandyala, R., Raghavendra, S.P., Rajasekharan, S.T. (2010). Xylene: An overview of its health hazards and preventive measures. *J. Oral Maxillofac. Pathol.* 14, 1–5. <https://doi.org/10.4103/0973-029X.64299>
- Kwon, K.D., Jo, W.K., Lim, H.J., Jeong, W.S. (2007). Characterization of emissions composition for selected household products available in Korea. *J. Hazard. Mater.* 148, 192–198. <https://doi.org/10.1016/j.jhazmat.2007.02.025>
- Kwon, K.D., Jo, W.K., Lim, H.J., Jeong, W.S. (2008). Volatile pollutants emitted from selected liquid household products. *Environ. Sci. Pollut. Res.* 15, 521–526. <https://doi.org/10.1007/s11356-008-0028-x>
- Li, Z., Li, W., Zhou, R., Miao, X., Lu, J., Wang, Z., Yang, Z., Wu, J. (2021). Process-based VOCs source profiles and contributions to ozone formation in typical organic solvent-used industries in Hangzhou. *Aerosol Air Qual. Res.* 21, 210008. <https://doi.org/10.4209/aaqr.210008>
- Lu, Y., Shao, Y., Qu, R., Zheng, C., Zhang, Y., Lin, W., Wu, W., Feng, Y., Gao, X. (2020). Component characteristics and emission factors of volatile organic compounds from dyestuff production. *Aerosol Air Qual. Res.* 20, 108–118. <https://doi.org/10.4209/aaqr.2019.09.0474>
- Martinsson, J., Sporre, M.K., Pédehontaa-Hiaa, G., Azeem, H.A. (2020). On the relationship of biogenic primary and secondary organic aerosol tracer compounds on the Aethalometer model parameters. *Aerosol Air Qual. Res.* 20, 2654–2668. <https://doi.org/10.4209/aaqr.2020.01.0035>
- Moxon, T.E., Li, H., Lee, M.Y., Piechota, P., Nicol, B., Pickles, J., Pendlington, R., Sorrell, I., Baltazar, M.T. (2020). Application of physiologically based kinetic (PBK) modelling in the next generation risk assessment of dermally applied consumer products. *Toxicol. in Vitro* 63, 104746. <https://doi.org/10.1016/j.tiv.2019.104746>
- Nazaroff, W.W., Weschler, C.J. (2004). Cleaning products and air fresheners: Exposure to primary and secondary air pollutants. *Atmos. Environ.* 38, 2841–2865. <https://doi.org/10.1016/j.atmosenv.2004.02.040>
- Palmisani, J., Nørgaard, A.W., Kofoed-Sørensen, V., Clausen, P.A., de Gennaro, G., Wolkoff, P. (2020). Formation of ozone-initiated VOCs and secondary organic aerosol following application of a carpet deodorizer. *Atmos. Environ.* 222, 117149. <https://doi.org/10.1016/j.atmosenv.2019.117149>
- Peter, G., Andrew, J.M. (2003). Potential impact of increased use of biocides in consumer products on prevalence of antibiotic resistance. *Clin. Microbiol. Rev.* 16, 189–208. <https://doi.org/10.1128/CMR.16.2.189-208.2003>
- Petry, T., Cazelle, E., Lloyd, P., Mascarenhas, R., Stijntjes, G. (2013). A standard method for measuring benzene and formaldehyde emissions from candles in emission test chambers for human health risk assessment purposes. *Environ. Sci. Pollut.* 15, 1369–1382. <https://doi.org/10.1039/c3em00011g>
- Rahman, M.M., Kim, K.H. (2014). Potential hazard of volatile organic compounds contained in household spray products. *Atmos. Environ.* 85, 266–274. <https://doi.org/10.1016/j.atmosenv.2013.12.001>
- Rastogi, S.C., Heydorn, S., Johansen, J.D., Basketter, D.A. (2001). Fragrance chemicals in domestic and occupational products. *Contact Derm.* 45, 221–225. <https://doi.org/10.1034/j.1600-0536.2001.450406.x>
- Rothe, H., Fautz, R., Gerber, E., Neumann, L., Rettinger, K., Schuh, W., Gronewold, C. (2011). Special aspects of cosmetic spray safety evaluations: principles on inhalation risk assessment. *Toxicol. Lett.* 205, 97–104. <https://doi.org/10.1016/j.toxlet.2011.05.1038>
- Sarigiannis, D.A. (2013). Combined or multiple exposure to health stressors in indoor built environments. World Health Organization for Europe, Copenhagen, Denmark.
- Singer, B.C., Destailats, H., Hodgson, A.T., Nazaroff, W.N. (2006). Cleaning products and air fresheners: Emissions and resulting concentrations of glycol ethers and terpenoids. *Indoor Air* 16, 179–191. <https://doi.org/10.1111/j.1600-0668.2005.00414.x>



- Snyder, R. (2012). Leukemia and benzene. *Int. J. Environ. Res. Public Health* 9, 2875–2893. <https://doi.org/10.3390/ijerph9082875>
- Steinemann, A.C. (2009). Fragranced consumer products and undisclosed ingredients. *Environ. Impact Assess. Rev.* 29, 32–38. <https://doi.org/10.1016/j.eiar.2008.05.002>
- Steinemann, A.C., MacGregor, I.C., Gordon, S.M., Gallagher, L.G., Davis, A.L., Ribeiro, D.S., Wallace, L.A. (2011). Fragranced consumer products: Chemicals emitted ingredients unlisted. *Environ. Impact Assess. Rev.* 31, 328–333. <https://doi.org/10.1016/j.eiar.2010.08.002>
- Steinemann, A. (2015). Volatile emissions from common consumer products. *Air Qual. Atmos. Health* 8, 273–281. <https://doi.org/10.1007/s11869-015-0327-6>
- U.S. Environmental Protection Agency (U.S. EPA) (1995). Determination of Volatile Matter Content, Water Content, Density, Volume Solids, and Weight Solids of Surface Coatings-Reference Method 24. Code of Federal Regulations, Part 60, Appendix A.
- U.S. Environmental Protection Agency (U.S. EPA) (1997). Measurement of Gaseous Organic Compound Emission by Gas Chromatography-Method 18. Code of Federal Regulation, Part 60, Subpart TTT. Government Printing Office, Washington, DC.
- U.S. Environmental Protection Agency (U.S. EPA) (2005). Integrated Risk Information System (IRIS) on Toluene. National Center for Environmental Assessment, Office of Research and Development, Washington, DC.
- Wang, R., Moody, R.P., Koniecki, D., Zhu, J. (2009). Low molecular weight cyclic volatile methylsiloxanes in cosmetic products sold in Canada: Implication for dermal exposure. *Environ. Int.* 35, 900–904. <https://doi.org/10.1016/j.envint.2009.03.009>
- Wang, Y., Yang, G., Wang, L., Zhao, L., Ji, S., Qi, M., Lu, X., Liu, Z., Tan, J., Liu, Y., Wang, Q., Xu, R. (2020). Characteristics and source apportionment of VOCs in a city with complex pollution in China. *Aerosol Air Qual. Res.* 20, 2196–2210. <https://doi.org/10.4209/aaqr.2019.11.0608>
- Wolkoff, P., Nielsen, G.D. (2001). Organic compounds in indoor air-their relevance for perceived indoor air quality. *Atmos. Environ.* 35, 4407–4417. [https://doi.org/10.1016/S1352-2310\(01\)00244-8](https://doi.org/10.1016/S1352-2310(01)00244-8)
- World Health Organization (WHO) (2010). WHO guidelines for indoor air quality: Selected pollutants. World Health Organization. Regional Office for Europe. <https://apps.who.int/iris/handle/10665/260127>
- Wu, X., Shi, G., Xiang, X., Yang, F. (2021). The characteristics of PM_{2.5} pollution episodes during 2016–2019 in Sichuan Basin, China. *Aerosol Air Qual. Res.* 21, 210126. <https://doi.org/10.4209/aaqr.210126>
- Zhu, J., Cao, X.L., Beauchamp, R. (2001). Determination of 2-butoxyethanol emissions from selected consumer products and its application in assessment of inhalation exposure associated with cleaning tasks. *Environ. Int.* 26, 589–597. [https://doi.org/10.1016/S0160-4120\(01\)00046-0](https://doi.org/10.1016/S0160-4120(01)00046-0)