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Volatile Organic Compounds from Unexpected Sources: Fabric Softener-Initiated Emissions

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Abstract

A fabric softener is usually applied to laundry during a rinse stage. It is composed of surfactants, solvents and others, which can escape into the air and cause adverse effects. Emissions of volatile organic compounds (VOCs) from fabrics conditioned with liquid fabric softener were measured and compared with those unconditioned and conditioned with water. Undyed, naturally- and chemically-dyed silks, cotton, polyester, Tetron cotton (T/C) and rayon fabrics were tested. The test fabrics were cut into 15×40 mm rectangles and equilibrated for 24 hr at 30 °C in 20 ml vials. The emitted VOCs in the vial air were sampled, using a solid phase microextraction technique and then analyzed by a gas chromatograph-mass spectrometer. Alkanes and toluene were mostly detected from the unconditioned fabrics. Toluene was emitted from machine woven fabrics – cotton, polyester, T/C and rayon - but not detected in the hand-woven silk. The fabrics emitted total VOCs per unit projected surface area in the range of 1-9 μg/m^2 as toluene equivalent. Water-washing reduced emissions by 4 - 55%, whereas the fabric softener treatment increased emissions by 10 - 163% from the water-treated ones, except for the undyed silk. The most commonly emitted VOCs, from the fabrics treated with the fabric softener, were ethyl 2-methyl butyrate, nonanal, d-limonene and eucalyptol – compounds used to enhance fragrance. This demonstrated that fabric softeners contribute to the release of several VOCs mixtures that did not originate from the fabric itself.

Keywords: Emission; Total volatile organic compounds; Fabrics; Fabric softener; Sorption

1. Introduction

The daily laundering of clothing includes washing with a detergent, a dry cleaning solution and a fabric softener. Several studies have reported that clothing accumulates organic chemicals on the clothing surface, e.g. surfactants, solvents and other active ingredients (Noble, 2000; Chien *et al.,* 2011; Morrison *et al.,* 2015; Morrison *et al.,* 2016; Saini *et al.,* 2016; Saini *et al.,* 2017; Eftekhari *et al.,* 2018). These compounds can irritate a wearer's skin and cause eye/airway irritation (Morrison *et al.,* 2015; Anderson and Anderson, 2010). Fabric softeners are widely used laundry products: 390,000 tons were consumed in 2005 (Wahle, 2002). They are usually applied to laundry, during a rinse stage, to soften fabrics, reduce static electricity buildup and impart a fresh fragrance (Mather and Wardman, 2015; Mishra and Tyagi, 2007). Three types of fabric softeners are normally available in the market: liquid softeners, dryer sheets and dryer balls (Brains, 2020).

Fabric softeners usually contain cationic surfactants, long chain quaternary ammonium salts, as the main active ingredient, for example, ditallow dimethyl ammonium chloride, diethyl ester dimethyl ammonium chloride, dioctadecyl dimethyl ammonium chloride, distearyldimethyl ammonium chloride, dehydrogenated-tallow alkyl dimethylammoniumchloride and benzalkonium chloride etc. (Mather and Wardman, 2015; Mishra and Tyagi, 2007). These cationic surfactants adhere well to natural fibres (wool or cotton) and synthetic fibres (polyester or polyamide), as these fibres have negative charges (Wahle, 2002). Also, colloidal deposition of vesicles, mostly composed of lipids, have been used in fabric softening in order to distribute active ingredients like perfumes throughout the fibres (Kumar *et al.,* 2018).

Numerous chemicals emitted from fabric softeners have been detected in the air. Anderson and Anderson (2010) measured volatile organic compounds (VOCs) emitted from commercial fabric softener pads using sorbent tubes and gas chromatography-mass spectroscopy (GC-MS). They detected aromatics (toluene, 1,2,4-trimethyl benzene, m-xylene, styrene, isopropylbenzene, o xylene), alcohols (phenol, thymol, ethanol, linalool, alpha-terpineol, beta-citronellol) and as well as 2,2,3-trimethylpentane, benzyl acetate, limonene and other esters. Wallace *et al.* (1991) showed similar VOCs detected from fabric softeners, using canisters and GC-MS, e.g. benzyl acetate, limonene, linalool, alpha-terpineol and beta-citronellol. These VOCs were also identified in other consumer products containing fragrances.

Anderson and Anderson (2010) studied the toxic effects of fabric softeners, using a standardized toxicological test to measure biological effects of the airborne irritant chemicals using mice exposed to the VOCs emitted directly from the fabric softener pad for three exposures. Mild inflammation of interalveolar septal was seen. When mice were exposed to VOCs emitted from cotton T-shirts treated with the softener pads, they developed sensory irritation in 49% of breaths, versus 6% in untreated shirt exposure. This clearly demonstrated the adverse effects of human due to exposure to prolonged release of chemicals from clothes treated with fabric softener. This is important as clothing covers up to 85% of human bodies (Andersson *et al.,* 2002).

Sorption of the fabric softener compounds onto clothing surfaces depends on physical (e.g. weight, weave, pore size, etc.) and chemical (e.g. nature of the bonds in the fibres, the dye and the finishing chemicals with which the fabric is imbued) properties and treatment history (e.g. storage condition, laundering, etc.) (Mather and Wardman, 2015; Kumar *et al.,* 2018). All of these can affect the amount of chemicals accumulated on the fabric surface, which in turn can affect emissions of compounds, adsorbed on the fabric surface, into the air (Ongwandee *et al.,* 2016). There have been very few studies measuring VOC emissions from fabric softeners directly (Anderson and Anderson, 2010; Wallace *et al.,* 1991): to date, only Anderson and Anderson measured VOCs emitted from cotton T-shirts treated with softener sheets by sorbent tube sampling.

Thus, the emissions of the VOCs from a variety of fabrics, treated with a commercial fabric softener were measured and compared with those washed with deionized water (DI) using a solid-phase micro extraction (SPME) sampling technique. Air sampling with SPME has become widely used in indoor emission studies: it has many advantages over conventional techniques, using, for example, sorbent tubes, including reduced sampling time, potential for 'hot spot' sampling and on-site analysis (Koziel and Pawliszyn, 2001). The study fabrics included natural and synthetic fibres - silk, cotton, polyester, T/C (cotton 65%, polyester 35%) and rayon. Furthermore, we studied the physical and chemical properties of all fabric types to describe the character of fabric surface after treating by fabric softener.

2. Materials and Methods

2.1 Test fabrics and fabric softener

Five types of fabrics were chosen, including two natural fibres - silk (SU) and cotton (COT) – and synthetic fibres - polyester (POE) and rayon (RAY) - and a mixed fiber - 65% cotton and 35% polyester (T/C). Silk was bought from the MSU-OUTLET in Mahasarakham University, Thailand (16°14'29.9"N 103°15'03.5"E). The other fabrics were bought from a local market in Mahasarakham Province, Thailand (16°11'15.6"N 103°18'13.0"E). Table 1 summarizes the characteristics of the test fabrics.

Table 1. Test fabric characteristics

Fiber		Fiber composition*	Color	Dyeing	Code	Structure	Fabric count ($inch^2$)†		Density (mg/m^2)‡	BET area ($m^2 \cdot g$)ξ	BET area per projected areaϕ
							Warp	Weft			
natural	silk	protein	white	undyed	SU	plain	81	44	0.9×10^{-3}	4.22	380
	silk	protein	black	naturally dyed	SN	plain	81	44	-	-	-
	silk	protein	black	chemically dyed	SC	plain	81	44	-	-	-
	cotton	cellulose	white	undyed	COT	plain	148	83	1.3×10^{-3}	4.85	630
synthetic	polyester	polyester	white	undyed	POE	2/2 twill	97	44	1.1×10^{-3}	5.12	563
	T/C	65% cotton, 35% polyester	white	undyed	T/C	plain	111	55	1.1×10^{-3}	3.70	407
	rayon	reconstituted cellulose	white	undyed	RAY	sateen	37	70	1.2×10^{-3}	11.08	1330

Notes: *reference (Mather and Wardman, 2015); †manual counts referred to (Islam *et al.*, 2018); ‡weighing (a balance scale, Mettler Toledo, France); ξBrunauer-Emmett-Teller analysis (BEL, Japan); ϕm^2 BET surface area per 1-m^2 projected area

In Thailand, commercial liquid fabric softeners are most commonly sold in two formulations, i.e. ordinary or concentrated forms. They are distinguished by the amount of diethyl ester dimethyl ammonium chloride (DEEDMAC, CAS 888888-02-8) added to the liquid. The preliminary test indicated similar VOCs were identified from fabrics treated with ordinary and concentrated formulations, but the emitted amounts were higher in the concentrated form. Thus, the concentrated fabric softener was chosen to represent a worst case scenario of VOCs emitted from laundered clothes. One common fabric softener brand in Thailand was chosen as a representative, due to its over 50 percent market share (Brand Inside, 2019). It also provided a detailed list of active chemicals, whereas other brands did not specify them. This liquid fabric softener was labeled as a 'concentrated' softener, mainly containing 8% DEEDMAC (w/w).

2.2 Sample preparation

All fabrics were treated in three different ways. Firstly, fabric samples were carefully cut into 15 × 40 mm pieces. They were then kept in zip lock bags to avoid any contamination on the fabric surfaces and stored in an electronic dry cabinet at 27 ± 1 °C and 61 ± 1% RH. Note that all headspace vials used were cleaned with DI water twice and then dried at 160 °C for 4 hr before being used (Baimatova *et al.,* 2016). Figure 1 shows the experimental procedure sampling by SPME. The fabrics were conditioned in three different ways:

(a) Unconditioned fabrics: a fabric sample was hung in a 20-ml headspace vial by its yarn. The vial was then purged with high purity N_2. Then, the vial was capped with a magnetic screw-thread closure (SUN-Sri, USA), shaken at 80 rpm, using a shaking incubator at 30 °C for 24 hr, to allow the in-vial VOCs to reach a steady state. The headspace VOCs were sampled by a SPME technique, described in VOC sampling and analyzes

(b) Conditioned with DI water: cut fabric samples were immersed in deionized (DI) water in a 100-ml beaker, then horizontally shaken for 10 min. The conditioned fabric was dried by high purity N_2 in a clean stainless steel chamber for an hour. The dried fabric was hung in a 20-ml headspace vial. The vial was capped and followed the procedure in (a) above.

(c) Conditioned with a fabric softener: The conditioning procedure followed (b), except for the final step. The cut fabric was immersed in a mixture of DI water and the concentrated fabric softener and shaken for 10 min. The mixture concentration was 0.08% (calculated from the manufacturer's directions, for washing machine use on the package, i.e. 1 cap for a full load up to 52 L of water).

To identify VOCs from either the fibres themselves or the softener sorbed on them, we measured organic compounds released from the softener. 1 ml concentrated fabric softener liquid was introduced into a 20-ml headspace vial and then shaken at 80 rpm, 30 °C for 4 hr. The headspace VOCs were sampled

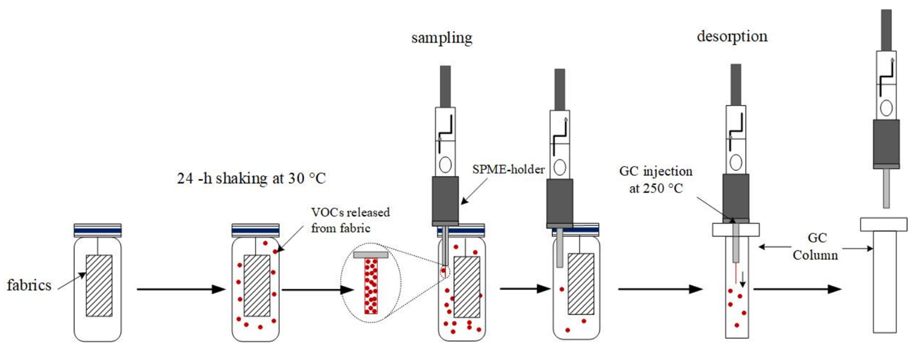

Figure 1. Experimental procedure for VOC emission from the study fabrics by SPME air sampling technique

by the SPME technique. Furthermore, the effects of natural and synthetic dyes on the VOC emissions from the silk fabrics were examined. A black dye from natural fresh eucalyptus leaves and a synthetic direct dye (Direct Black 28) - an anionic dye with multi-azo structures were tested. Direct dyes adhere to the fabric molecules, without help from other chemicals; they are used on cotton, silk, wool, and rayon. Expert staff of the Silk Innovation Center staff at Mahasarakham University, Thailand, dyed the silks. Organic compounds vaporized from the dye powder were measured to identify VOC sources. 0.1 g dye powder was added to a 20-ml headspace vial, then shaken at 80 rpm, 30 °C, using a shaking incubator, for 5 h. The headspace VOCs were sampled by the SPME technique.

2.3 VOC sampling and analyzes

The VOCs in the headspace vial were collected using an SPME-manual holder coupled with 50/30 µm SPME fibres of divinylbenzene/ carboxen/ polydimethylsiloxane (DVB/CAR/ PDMS) (Bellefonte, USA), and then analyzed by a GC-MS (Shimadzu, Japan). Our SPME efficiency test, to determine the optimum extraction and desorption times for the VOCs, showed that the highest efficiency at the 3-min extraction time at the headspace-vial temperature of 30 °C and the 3-min desorption time at the GC injector temperature of 250 °C. Thus, we used the SPME fiber extraction and desorption times for 3 min. Note that this sampling condition was optimum for SPME analysis of aromatics (Chatsuvan *et al.,* 2019). The GC-MS operation conditions were: Rtx®5-MS silica column with 0.25 µm df (film thickness) and 30 m length, injection temperature 250 °C, oven temperature - initially 40 °C, raised to 60 °C at 1 °C/ min and then raised to 80 °C at 20 °C /min. The MS was operated in a scan mode from 40 to 500 amu. VOC masses were measured by summing total ion current and calibrated relative to toluene as the reference species in terms of gaseous concentration. The toluene calibration curve, were based on 0, 0.15, 0.95, 3.80 and 7.59 ppmv concentrations, $R^2 \geq 0.96$ in all cases. GC-grade toluene was purchased from Sigma-Aldrich (Sigma-Aldrich, Singapore). An empty headspace vial was measured for TVOC twice. The average background value was subtracted from the sample values before fitting the standard curve in calculation of the sample TVOC concentration. After each sampling test, the SPME fibres were cleaned with the injector at 250 °C for 30 min. Duplicate samples for each test fabric type and treatment condition were analyzed. Differences between TVOCs from the duplicates were less than the 20% relative standard deviation (RSD) criterion (Baimatova *et al.,* 2016).

TVOC emission per unit projected surface area from the fabric at the equilibrium time of 24 hr, $E_{projected}$ (µg m^{-2}), was calculated:

$$E_{projected} = \frac{C_{fabric} \times V}{A_{projected}} \quad (1)$$

where C_{fabric} is the TVOC concentration measured in the sample vial at 24 hr (µg/m^3); V is the vial air volume (m^3); and $A_{projected}$ is the sum of the projected area of both sides of the test fabric hung in the vial (1.2×10^3 mm^2).

2.4 Surface characterization

The effects of physical and chemical fabric surface properties on the VOC emissions from the softener treated and dyed fabrics were measured. The accessible surface area of the fabrics or specific surface area was analyzed by N_2 Brunauer-Emmett-Teller (BET) analysis (BEL, Japan). A Universal Attenuated Total Reflectance Fourier Transform Infrared Spectrometer (UATR-FTIR), equipped with a KRS-5-diamond composite crystal accessory (Perkin Elmer, USA), was used to study surface interactions between the softener ingredients and dyes. The spectral range was 4000 - 400 cm^{-1}.

3. Results and Discussion

3.1 Identification of VOCs emitted from fabrics

Table 2a and 2b lists codes and identified VOCs in vial air that was emitted from original fabrics and fabrics with the two treatments, i.e. water cleansing and fabric softener treatment, and VOCs released from the liquid fabric softener. Duplicates were collected for each trial.

Table 2a. Codes for chemicals detected from the fabrics

Code	Chemical	CAS number
SIL	Silane, diethoxydimethyl	78-62-6
HEP	Heptane, 2,2,4,6,6-pentamethyl	13475-82-6
DEC	Decane	124-18-5
NON	Nonane	111-84-2
UND	Undecane, 5,5-dimethyl	17312-73-1
EHX	2-Ethylhexanol	104-76-7
NNN	Nonanal	124-19-6
MYR	β-Myrcene	123-35-3
EUC	Eucalyptol	470-82-6
EMB	Ethyl 2-methylbutyrate	7452-79-1
OCT	Octanal	124-13-0
BUT	1-Butanol	71-36-3
TOL	Toluene	108-88-3
TET	1-Tetradecanol	112 -72-1
ACA	Acetic acid, hexyl ester	142-92-7
LIM	d-Limonene	5989-27-5
BHB	Butyl 3-hydroxybutanoate	53605-94-0
MPP	1-Methoxy-2-propanol	107-98-2

Table 2b. VOCs emitted from the original fabrics, water- and fabric softener-treatment conditions*

silk -undyed (SU)											
original	SIL	HEP	DEC	NON	UND	EHX	-	-	-		
water	SIL	HEP	DEC	-	UND	EHX	-	-	-		
softener	SIL	-	-	-	-	EHX	NNN	MYR	EUC		
silk -naturally dyed (SN)											
original	SIL	HEP	-	-	-	-					
water	-	HEP	-	-	-	-					
softener	-	HEP	EMB	NNN	OCT	EUC					
silk -chemically dyed (SC)											
original	BUT	TOL	TET	SIL	HEP	EHX	-	-	-	-	-
water	BUT	TOL	TET	SIL	HEP	EHX	-	-	-	-	-
softener	-	TOL	TET	SIL	HEP	EHX	ACA	EMB	NNN	LIM	EUC
cotton (COT)											
original	BHB	MPP	TOL	SIL	HEP	-	-	-	-		
water	BHB	MPP	TOL	SIL	HEP	-	-	-	-		
softener	BHB	MPP	TOL	SIL	HEP	EMB	NNN	LIM	EUC		
polyester (POE)											
original	BHB	MPP	TOL	SIL	HEP	EHX	-	-	-		
water	BHB	MPP	TOL	SIL	HEP	EHX	-	-	-		
softener	BHB	MPP	TOL	SIL	HEP	EHX	EMB	LIM	EUC		
T/C											
original	TOL	HEP	EHX	-	-	-					
water	TOL	HEP	EHX	-	-	-					
softener-	TOL	HEP	EHX	EMB	NNN	EUC					
rayon (RAY)											
original	†	†	†	†	†						
water	TOL	SIL	HEP	-	-						
softener	TOL	SIL	HEP	EHX	LIM						

*Grey shaded cells indicate the presence of VOC species. Codes used in this table are defined in Table 2a.

† Data for the original rayon were excluded due to an error during the experiment.

'-' denotes not detected.

For the unconditioned fabrics, VOCs mostly detected were alkanes and toluene, similar to Chien *et al.* (2011). Toluene was found emitted from machine woven fabrics - cotton, polyester, T/C and rayon - but it was not detected in the hand-woven silk. Toluene is a solvent used to add fillers to coated fibres in textile finishing to enhance raw fibre properties (US EPA, 1994). Toluene can be released at room temperatures, so it is probable that toluene on fibres was released from fabric to vial air at 30 °C. We also detected silane compounds released from almost all fabrics. Silane coupling compounds are commonly used as antimicrobial growth in fabrics and other natural products, e.g. rubber toys (Aslanidou and Karapanagiotis, 2018; Oldertrøen *et al.,* 2016). Interestingly, the undyed silk emitted 10 times more than the dyed silks and the other fabrics. This is often introduced in sericulture stages, when an antifungal agent is scattered over silkworms regularly, before feeding them with mulberry leaves (Chaitungchit *et al.,* 2021), so it could accumulate in natural silk fibres.

Dyeing affected the quality of chemicals released from the silk into the vial air. The chemically dyed silk emitted a larger variety of VOCs than the naturally dyed silk. The solid black dye powder, 0.1 g in a 20-ml vial, was measured for the chemicals released into the vial air. The VOCs released from the solid dye powder are listed in Supplementary Information – Table SI1. The most commonly VOCs emitted were alcohols, which are usually used as solvents. 4-tert-butylcyclohexyl acetate, which is used as a binder of dye molecules to a surface (PubChem CID 36081), was also detected. The chemically dyed silk emitted some VOCs which may have originated from dye powder coated or accumulated on fibres after dyeing, i.e. butanol and toluene. Butanol (PubChem CID 263) and toluene (PubChem CID 1140) were often reported as dye components.

3.2 Fabric softener-initiated VOC emissions

Table SI2 lists 31 VOCs released from the liquid fabric softener into the vial air. The six major chemicals and their mass proportion emissions were: acetic acid, hexyl ester (hexyl acetate) – 32%; d-limonene – 23%; 2 butanol, ethyl 2-methylbutyrate (ethyl 2-methylbutyrate) – 12%; 1-hexanol – 9%; 2-propanol – 7%; linalool – 6% and others – 11%. Most of these compounds provide pleasant odors (US EPA, 2021).

When treating the fabrics with the fabric softener (Table 3), the emitted VOCs were similar to those released directly from the liquid fabric softener. Seven fabric softener-initiated VOCs from the fabrics were identified. Table 3 also shows a mass proportion of the softener-initiated VOCs in the vial air. The VOC mass ratios were determined from their corresponding total ion current (TIC) chromatograms by GC-MS.

All detected VOCs listed in Table 3 are often used in laundry and household cleaning agents to enhance fragrance (Steinemann *et al.,* 2011; Wallance *et al.,* 1991). They produce a variety of odors and last for a period of consumer use. Among these, four compounds – ethyl 2-methyl butyrate, nonanal, d limonene and eucalyptol - were mostly detected from both natural and synthetic fabrics. Interestingly, rayon emitted only d-limonene. This is likely due to the chemical properties of the rayon surface. FT-IR functional group analysis of the rayon surface found lower absorptions at ~1711cm^{-1}, ~1243 cm^{-1} and ~720 cm^{-1}, corresponding to low polarity C = Ocarbonyl groups, C - C aromatic groups and = C - H alkane groups , in contrast to the polar amine, amide, alcohol and phenol groups, found in the natural fibres - silk and cotton. Hence, rayon appears to have lower sorption ability for the components in fabric softener than silk and cotton. Petrick *et al.* (2010) reported that cotton fabrics had highly polar surfaces and absorbed nicotine better than synthetic fibres - polyester and nylon, although they had similar BET-measured surface areas. Functional group analysis by FT-IR showed that cotton had a strong absorption at 3333 cm^{-1}, corresponding to stretching of the O - H group, present in cellulose. This corresponds to a cotton surface with predominant alcohol, phenol and carbonyl groups: these groups can strongly interact with fabric softener components.

Table 3. Fabric softener-initiated VOCs from the fabrics and their mass ratios

VOCs	Odor type	Pub Chem CID	Softener-treated fabric (VOC mass ratio, %)†						
			SU	SN	SC	COT	POE	T/C	RAY
Nonanal	rose-orange	31289	51	40	30	32		63	
β-Myrcene	pleasant	31253	13						
Eucalyptol	mint-like	2758	36	15	26	21	61	21	
Ethyl 2-methyl butyrate	green-fruity	24020		31	13	10	27	16	
Octanal	fruity	454		14					
Hexyl acetate	mind sweet	8908			25				
d-Limonene	lemon-like	440917			6	37	12		100

'†' denotes the VOCs detected.

Clothing usually covers up to 85% of the total skin area of the body (Andersson *et al.,* 2002). These VOCs, for example toluene, 2-ethyl hexanol, 1-butanol and chemicals in fragrances - eucalyptol and d-limonene, can cause skin irritation, dryness, redness, and, after inhalation, nausea, headache and dizziness (Kim *et al.,* 2015). Interestingly, 2-ethyl hexanol emitted from most unconditioned fabrics and d-limonene initiated from the fabric softener had low threshold limit values (TLVs) for sensory irritation (Wolkoff *et al.,* 2005). Similarly, Wallance *et al.* (1991) reported some people have chemical sensitivity to odorous chemicals like alcohols, aldehydes, esters and ketones, resulting in complaints of eye, nose and throat irritation.

3.3 TVOC emissions from fabrics

Table 4 presents the TVOC emissions from unconditioned fabrics and two treated with water and with fabric softener. The emissions are reported relative to the projected area of the fabric.

The fabrics emitted TVOCs in the range of 1 - 9 µg/m² toluene equivalent for all conditions. Water-washing reduced emissions by 4 - 55%, whereas the fabric softener treatment increased emissions by 10 - 163% from the water-treated ones, except for the undyed silk. Fabric softener application reduced the TVOC emission of the undyed silk by 65%. The softener could sorb or coat the original fibre surface, thus lowering the silk-originated VOCs (a silane compound and hydrocarbons) by 6 times. The fabric softener-originated VOCs, i.e. nonanal, myrcene and eucalyptol, contributed to 44% of the TVOC emission of the treated undyed silk.

The cotton, polyester and T/C treated with fabric softener released twice the amount of TVOC as those treated with water, whereas the emissions of the untreated- and treated-rayon were similar. According to the FT-IR analysis, cotton exhibited predominant alcohol, phenol and carbonyl groups. These groups can strongly interact with fabric softener components. For T/C (mixed 65% cotton and 35% polyester), the proportion was similar to cotton; it had polar amine, amide and carbonyls groups on the surface, thus it attracted the fabric softener well, similar to cotton. Polyester and rayon showed the similar FT-IR spectrum including aromatic, carbonyl, aliphatic and alkane groups with lower polarity than cotton. Both fabrics sorbed well d-limonene, particularly the polyester emitted d-limonene at highest among the studied fabrics. Its emission was twice higher than the cotton. Limonene is classified as a weak electron donor; thus, its sorptive interaction is mainly via van der Walls forces with low-polarity polymers (Ongwandee *et al.,* 2016).

Table 4. TVOC emissions from the fabrics treated with water and fabric softener

Fabric	TVOC emission (μg/m^2 of toluene equivalent)		
	Unconditioned	Treated with water	Treated with fabric softener
SU	4.8	4.6	1.6
SN	0.7	0.8	1.4
SC	9.0	4.0	4.8
COT	3.2	2.7	4.2
POE	3.7	2.4	4.2
T/C	1.9	1.1	2.9
RAY	-	1.0	1.1

'-' Data for rayon was excluded due to an error during the experiment.

Typically, a medium-size T-shirt has an average area of both sides of 1.5 m^2 (UNIQLO, 2021). Thus, treating a new cotton shirt with a fabric softener could release ~6 μg of TVOC into the air surrounding a wearer. These released VOC molecules are expected to reside near the wearer's skin and then partially partition between the skin and the air or they are transported by air flow or molecular diffusion to the breathing zone. Anderson and Anderson (2010) showed complex concentration-response relationships of the fabric softener-initiated TVOCs from bioassays with the VOC mixtures. They attributed the adverse effects, i.e. sensory irritation, pulmonary irritation and airflow limitation, to the emission mixtures.

4. Conclusion

The laundering of clothing using a fabric softener during a rinse stage affected the type of VOCs emitted. Numerous VOCs emitted not only from the original surface fabrics, but also from the fabric softeners, accumulated on or coated the fibres, treated with fabric softener. Natural fabrics, e.g. cotton, emitted more chemicals from fabric softener than synthetic ones. Some emitted VOCs also have low threshold limit values based on sensory irritation. People who have chemical sensitivity to odorous chemicals may consider avoiding using fabric softeners. Moreover, the sorbed softener compounds on the fabrics modified the original surface properties, so that the surface, when exposed to airborne indoor pollutants, led to different sorption behaviour. This phenomenon can alter the pattern of occupants exposed to airborne organic pollutants in indoors.

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