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Review

Fate and transport of fragrance materials in principal environmental sinks

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HIGHLIGHTS

- How fragrance materials could impact human health is addressed.
- A complete frame of where fragrances enter and end up in environment is provided.
- Fate of fragrances in water, wastewater, wastewater sludge, and soil is discussed.

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ABSTRACT

Fragrance materials are widely present in the environment, such as air, water, and soil. Concerns have been raised due to the increasing utilization and suspected impact on human health. The bioaccumulating property is considered as one of the causes of the toxicity to human beings. The removal of fragrance materials from environmental sinks has not been paid enough attention due to the lack of regulation and research on their toxicity. This paper provides systematic information on how fragrance materials are transferred to the environment, how do they affect human lives, and what is their fate in water, wastewater, wastewater sludge, and soil.

Contents

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1. Introduction

Fragrance materials (FMs) are generally semi-volatile organic compounds (SOCs) that are used to deliver preferred odor in consumer products including cosmetics, detergents, fabric softeners, household cleaning products, fine fragrances, and air fresheners. They are complex combination of natural and synthetic substances. Fragrances have been utilized for thousands of years, and hundreds of the same are created every year, in countries all over the world. FMs are added in more and more products due to their attractive scent to customers. According to the survey of 1995–1996, FMs used with less than 1% in volume had global industry volumes of around 4000 metric tons per year, while over the decade, it dramatically grew at a rate of 3–5% per year (Simonich et al., 2000; Simonich, 2005). North America and Europe alone account for almost two-thirds of global consumption (Global Flavor & Fragrance Market Report, 2011). The large amount of FMs consumed ultimately enters into environment through disposal of consumer products, and has grabbed huge attention. Although FMs industries have addressed the fact that FMs are safer to skin of the product users, still they leave many blind points, such as effect on indoor air quality, health, and environment. It has been reported that FMs can trigger or cause allergic, asthma, non-allergic rhinitis, chronic respiratory disease, and central nervous system disorders (http://www.anapsid.org/cnd/mcs/bridges.html). Moreover, the awareness has become a particular concern that FMs are persistent in the environment and bioaccumulate in the fatty tissue of aquatic organisms. Hence, the management of FMs has become very important.

The physical and chemical properties of FMs determine their management strategy. Volatilization, biodegradation, sorption, and/or oxidation are frequently applied methods of FMs removal (DiFrancesco et al., 2003; Joss et al., 2005; Janzen et al., 2011). As FMs are normally semi-volatile organic compounds, volatilization occurs during the treatments as there is the contact between air and water.

Tonalide 7-acetyl-1,1,3,4,4,6-hexamethyltetrahydronaphthalene (AHTN) and galaxolide 7-acetyl-1,1,3,4,4,6-hexahydro-4,6,6,7,8,8-hexamethylcyclopenta(g)-2-benzopyrane (HHCB) are two of the most often used low-cost FMs present in wastewater with a large concentration range from 1 to 25 μg L^{-1} (Artola-Garicano et al., 2003; Santiago-Morales et al., 2012). It was found that their removal is significantly associated with the degradation ability which is the primary mechanisms of the removal from wastewater (Simonich et al., 2002; Artola-Garicano et al., 2003). It leads to the preference of the utilization of macrocyclic musk which has high biodegradability, over nitro- musk and polycyclic musk. Macrocyclic, nitro-, and polycyclic musk are artificially synthesized aromachemicals with musk-like smells. Macrocyclic musk consists of a single ring normally with around 10–15 carbons such as habanolide and muscone. Nitro-musk is a group of nitrated benzenes. Musk xylene, musk ketone and musk ambrette are three most popular nitro-musk. Polycyclic musk has multiple rings in the structures such as celestolide, tonalide, and galaxolide. Some of the commonly used FMs are listed in Table 1 with acronyms, commercial trade names, and chemical names.

Hydrophobic FMs are easily removed by sorption. It was reported that activated sludge and activated carbon showed higher efficiency in FMs removal which was up to 90% (Serrano et al., 2010). FMs widely exist in water, wastewater, wastewater sludge, and soil, while there are only very few studies on the fate and effect of FMs in principal environmental sink.

This review discusses the sources and toxicity of FMs, and provides the insight on the mode of entry of FMs, their transport, and removal mechanisms in the relative environment.

2. Sources and toxicity of fragrance materials

FMs have become a key factor of the products sold in market as they deliver pleasant smell to the users. Consumer research reveals that FMs is leading the people's preference for the products, which indicates that the use of FMs would increase rather than decrease in the future. Fragrances are identified as natural and synthetic semi-volatile substances. The former are made from essential oils extracted from plants or animals, and the latter are man-made substances mostly referring to petroleum-based chemicals. In the early period of the utilization of fragrances, natural ones were dominating, while synthetic ones took over due to increased

Table 1
Commonly used fragrances in surface water and wastewater.

Commercial trade name	Chemical name	Acronyms	Conc. in surface water	Conc. in wastewater	Ref.
Cashmeran	1,2,3,5,6,7-Hexahydro-1,1,2,3,3-pentamethyl-4H-inden-4-one	DPMI	NA	<1.6 μg L^{-1}	(Zeng et al. (2007))
Celestolide	1-[6-(1,1-Dimethylethyl)-2,3-dihydro-1, 1-dimethyl-1H-inden-4-yl]-ethanone	ADBI	<50 ng L^{-1}	<30 μg L^{-1}	Zeng et al. (2007), Clara et al. (2011), Villa et al. (2012)
Galaxolide	7-Acetyl-1,1,3,4,4,6-hexahydro-4,6,6,7,8,8-hexamethylcyclopenta(g)-2-benzopyrane	HHCB	<300 ng L^{-1}	<25 μg L^{-1}	Bester (2005), Lee et al. (2010), Rosal et al. (2010))
Habanolide	(12E)-1-oxacyclohexadec-12-en-2-one	–	NA	<1.6 μg L^{-1}	(Vallecillos et al., 2012)
Methyl dihydrojasmonate	Methyl 2-(3-oxo-2-pentylcyclopentyl)acetate	MDJ	NA	<5.4 μg L^{-1}	Simonich et al. (2000)
Muscone	(R)-3-methylcyclopentadecanone	-	NA	NA	Posada-Ureta et al. (2012)
Musk ambrette	4-tert-Butyl-2,6-dinitro-3-methoxytoluene	MA	ND	ND	Yang and Metcalfe (2006)
Musk ketone	1-(4-Tert-butyl-2,6-dimethyl-3,5-dinitrophenyl)ethanone	MK	<30 ng L^{-1}	<420 ng L^{-1}	Sumner et al. (2010), Gómez et al. (2012)
Musk moskene	1,1,3,3,5-Pentamethyl- 4,6-dinitroindane	MM	ND	ND	Yang and Metcalfe (2006)
Musk tibetene	1-Tert-butyl-2,6-dinitro-3,4,5-trimethylbenzene	MT	ND	ND	Yang and Metcalfe (2006)
Musk xylene	1-Tert-butyl-3,5-dimethyl-2,4,6-trinitrobenzene	MX	<7 ng L^{-1}	<260 ng L^{-1}	Sumner et al. (2010), Gómez et al. (2012)
Patchouli ethanone	1-(2,3,8,8-Tetramethyl-1,3,4,5,6,7-hexahydronaphthalen-2-yl)ethanone	OTNE	<30 ng L^{-1}	<1.9 μg L^{-1}	Bester (2005), Lee et al. (2010), Rosal et al. (2010), Sumner et al. (2010)
Phantolide	6-Acetyl-1,1,2,3,3,5-hexamethylindane	AHMI	<5.5 ng L^{-1}	<50 ng L^{-1}	Clara et al. (2005), Zeng et al. (2007), Pedrouzo et al. (2011)
Tonalide	7-Acetyl-1,1,3,4,4,6-hexamethyltetrahydronaphthalene	AHTN	<60 ng L^{-1}	<1.9 μg L^{-1}	Rosal et al. (2010)
Traseolide	5-Acetyl-3-isopropyl-1,1,2,6-tetramethylindane	ATII	<2.5 ng L^{-1}	<32 ng L^{-1}	Zeng et al. (2007), Clara et al. (2011)

NA: not available; ND: not detected.