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Review article

Fate, behavior and effects of surfactants and their degradation products in the environment

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Abstract

Surfactants are widely used in household and industrial products. After use, surfactants as well as their products are mainly discharged into sewage treatment plants and then dispersed into the environment through effluent discharge into surface waters and sludge disposal on lands. Surfactants have different behavior and fate in the environment. Nonionic and cationic surfactants had much higher sorption on soil and sediment than anionic surfactants such as LAS. Most surfactants can be degraded by microbes in the environment although some surfactants such as LAS and DTDMAC as well as alkylphenols may be persistent under anaerobic conditions. LAS were found to degrade in sludge amended soils with a half-lives of 7 to 33 days. Most surfactants are not acutely toxic to organisms at environmental concentrations and aquatic chronic toxicity of surfactants occurred at concentrations usually greater than 0.1 mg/L. However, alkylphenols have shown to be capable of inducing the production of vitellogenin in male fish at a concentration as low as 5 μg/L. More toxicity data are needed to assess the effects on terrestrial organisms such as plants.

Keywords: Surfactants; Behavior; Biodegradation; Toxicity; Water; Soil; Sediment

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1. Introduction

Surfactants are a diverse group of chemicals that are designed to have cleaning or solubilisation properties. They generally consist of a polar head group (either charged or uncharged), which is well solvated in water, and a nonpolar hydrocarbon tail, which is not easily dissolved in water. Hence, surfactants combine hydrophobic and hydrophilic properties in one molecule. Synthetic surfactants are economically important chemicals. They are widely used in household cleaning detergents, personal care products, textiles, paints, polymers, pesticide formulations, pharmaceuticals, mining, oil recovery and pulp and paper industries. The world production of synthetic surfactants amounts to 7.2 million tons annually (Di Corcia, 1998).

Surfactants consisted mainly of three types: anionic, nonionic and cationic (Table 1). Linear alkylbenzene sulphonates (LAS), alkyl ethoxy sulphates (AES), alkyl sulphates (AS), alkylphenol ethoxylates (APE), alkyl ethoxylates (AE), and quaternary ammonium compounds (QAC) are the commonly used commercial surfactants. Especially, LAS, APE, and QAC are the most extensively studied surfactants. In the following, we use abbreviations for each class of surfactants, for example, C12EO9 (EO=ethylene oxide unit) having nine EO units and an alkyl chain of 12 carbon atoms, C14LAS having an alkyl chain of 14 carbon atoms, NPE9 or NPEO9 for nonylphenol ethoxylates with 9 EO units.

Table 1
Acronyms of the most widely used surfactants

Class	Common name	Acronym
Anionic surfactants	Linear alkyl benzene sulphonates	LAS
	Secondary alkane sulphonates	SAS
	Alcohol ether sulphates (Alkyl ethoxy sulphates)	AES
	Alcohol sulphates (Alkyl sulphates)	AS
Nonionic surfactants	Alkylphenol ethoxylates	APE (or APEO)
	Nonyl phenol ethoxylates	NPE (or NPEO)
	Octyl phenol ethoxyales	OPE (or OPEO)
	Alcohol ethoxyaltes	AE (or AEO)
Cationic surfactants	Quaternary ammonium-based compounds	QAC
	Alkyl trimethyl ammonium halides	TMAC
	Alkyl dimethyl ammonium halides	DMAC
	Alkyl benzyl dimethyl ammonium halides	BDMAC
	Dialkyl dimethyl ammonium halides	DADMAC
	Dihydrogenated tallow dimethyl ammonium chloride	DHTDMAC or DTDMAC
	Ditallow trimethyl ammonium chloride	DTTMAC
	Diethyl ester dimethyl ammonium chloride	DEEDMAC

Linear alkylbenzene sulphonates (LAS) are the most popularly used synthetic anionic surfactants. It has been extensively used for over 30 years with an estimated global consumption of 2.8 million tons in 1998 (Verge et al., 2000). Commercially available products are very complex mixtures containing homologues with alkyl chains ranging from 10 to 14 carbon units (C10–C14LAS). Furthermore, since the phenyl group may be attached to any internal carbon atom of the alkyl chain, each homologue contains 5–7 positional isomers.

Alkylphenol ethoxylates (APE) constitute a large portion of the nonionic surfactant market. The worldwide production of APEs was estimated at 500,000 tons in 1997 with 80% of nonylphenol ethoxylates (NPE) and 20% of octylphenol ethoxyalyes (OPE) (Renner, 1997). Concern has increased recently about the wide usage of APE because of their relatively stable biodegradation products nonylphenol (NP) and octylphenol (OP). NP and OP have been demonstrated to be toxic to both marine and freshwater species (Comber et al., 1993; McLeese et al., 1981), and to induce estrogenic responses in fish (Jobling and Sumpter, 1993; Purdom et al., 1994).

Quaternary ammonium-based surfactants (QAC) are molecules with at least one hydrophobic hydrocarbon chain linked to a positively charged nitrogen atom, the other alkyl groups being mostly short-chain substituents such as methyl or benzyl groups. The major uses of this group of cationic surfactants are as fabric softeners and antiseptic agents in laundry detergents as well as other industrial uses. The most widely used active ingredient in fabric softeners has been dihydrogenated tallow dimethyl ammonium chloride (DTDMAC) until recently. However, the replacement of DTDMAC by ester cationic surfactants such as diethyl ester dimethyl ammonium chloride (DEEDMAC) has recently begun in Europe (Giolando et al., 1995).

After use, residual surfactants and their degradation products are discharged to sewage treatment plants or directly to surface waters, then dispersed into different environmental compartments. Due to their widespread use and high consumption, surfactants and their degradation products have been detected at various concentrations in surface waters, sediments and sludge-amended soils. In order to assess their environmental risks, we need to understand the distribution, behavior, fate and biological effects of these surfactants in the environment. There have been some detailed research papers and review articles on the occurrence of various surfactants and their degradation products in the environment (e.g., Fendinger et al., 1995;