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# Effects of anionic surfactant on n-hexane removal in biofilters

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## HIGHLIGHTS

- The biodegradability of 3 surfactants by biofilm microorganisms was evaluated.
- SDS could be biodegraded by and was not toxic to biofilm microorganisms.
- The optimal SDS concentration for enhanced n-hexane removal in biofilters was 0.1 CMC.

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## ABSTRACT

The biodegradability of three anion surfactants by biofilm microorganisms and the toxicity of the most readily biodegradable surfactant to biofilm microorganisms were examined using batch experiments, and the optimal concentration of SDS for enhanced removal of hexane was investigated using two biotrickling filters (BTFs) for comparison. Results showed that SDS could be biodegraded by microorganisms, and its toxicity to microorganisms within the experimental range was negligible. The best concentration of SDS in biofiltration of n-hexane was 0.1 CMC and the elimination capacity (EC) of 50.4 g $m^{-3}$ $h^{-1}$ was achieved at a fixed loading rate (LR) of 72 g $m^{-3}$ $h^{-1}$. When an inlet concentration of n-hexane increased from 600 to 850 mg $m^{-3}$, the removal efficiency (RE) decreased from 67% to 41% by BTF2 (with SDS) and from 52% to 42% by BTF1 (without SDS). SDS could enhance hexane removal from 43% (BTF1) to 60% (BTF2) at gas empty-bed residence time (EBRT) of 7.5 s and an inlet concentration of 200 mg $m^{-3}$.

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## 1. Introduction

Air pollution has recently been a main concern and become a crucial issue due to an increase of public consciousness about emissions of volatile organic compounds (VOCs). Governments and environmental agencies strictly regulate these VOC emissions (Muñoz et al., 2007). The development of viable and effective VOC emission control strategies has become a necessity. The most preferable option to control VOC emissions is an environment-friendly technology. Biofiltration systems designed and operated properly are considered a cost-effective and promising technique for VOC and odorous gases control. Additionally, comparing with conventional VOC control technologies, biofiltration systems are more suitable for VOC removal (Sorial et al., 1997; Cox and Deshusses, 2002; Dixit et al., 2012; Xue et al., 2013). The biofiltration process is based on the ability of microorganisms to convert VOCs into carbon dioxide, water and biomass (Devinny et al., 1999).

However, biological process performs poorly when treating hydrophobic VOCs, because the low solubility and transfer rates of hydrophobic VOCs from gas phase to biofilm phase inhibit microbial activity (Yang et al., 2010). As a result, low removal performance of hydrophobic VOCs such as n-hexane and styrene has been recorded in biofiltration systems (Lebrero et al., 2014; Kim et al., 2005). Therefore, increasing the bioavailability of VOCs in biofilm phase will help to enhance the biodegradability of these compounds (Zehraoui et al., 2012).

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To enhance the bioavailability of hydrophobic VOCs, one method is that surfactants are applied in biofilters. It is attributed to that the addition of surfactants reduce the surface tension and form micelles and thus improving the solubility of hydrophobic VOCs in liquid phase (Böttger et al., 2012). In this regard, surfactants have been extensively studied in contaminated soils and sediments (Mulligan et al., 2001). Moreover, most studies have reported that surfactants have a crucial effect on gas–liquid mass transfer of VOCs (Anderson, 1992; Cheng et al., 2009; Yang et al., 2010; Galindo et al., 2011). Zhou and Zhu (2007) and Li et al. (2011) reported that surfactants increased the solubility of hydrophobic organic compounds, leading to an enhancement of the biodegradation rate of these compounds in contaminated environments. In biofiltration systems, chemical surfactants have been introduced and researched as means for enhancing solubility of VOCs in water in recent years (Chan and You, 2009, 2010). Moreover, nonionic surfactants are used and studied more widely in biofilters (Wang et al., 2014; Tu et al., 2015). However, utilization of anionic surfactants such as sodium dodecyl sulfate (SDS) in biofiltration systems is rarely reported in literature. Zeng et al. (2007) reported that SDS could not be poisonous to microorganisms and could also be biodegradable, which avoided secondary contamination due to its discharge directly with waste solution from the bottom of a biofilter.

n-Hexane is well known for its high hydrophobicity and low bioavailability due to the restriction on mass transfer from gas phase to biofilm phase. Several investigations have reported on the n-hexane biofiltration under different operating parameters (Cheng et al., 2015). Other researchers used other methods to address the bioavailability of n-hexane, like introducing ionic surfactants or biosurfactants (Hassan and Sorial, 2008; Tu et al., 2015), providing favorable conditions for fungi (Spigno et al., 2003; Zehraoui et al., 2013), using two-phase reactors (Lebrero et al., 2014), and utilizing hydrophilic compounds (Zehraoui et al., 2012).

This study was to examine the bioavailability of n-hexane after introducing anionic surfactant into a biofilter and the potential of anionic surfactant for enhancing the degradation of n-hexane from contaminated air streams. In this work, batch experiments were conducted to evaluate the biodegradability of SDS, Tween 20 and Triton X-100 and the toxicity of SDS on microorganisms. The optimal concentration of SDS which effected n-hexane removal performance was investigated. Processes for continuous degradation of n-hexane vapor under different influent concentrations and gas empty bed residence time (EBRT) have been carried out with BTF2 fed with SDS and BTF1 without SDS.

## 2. Materials and methods

### 2.1. Chemicals

n-Hexane ($C_6H_{14}$) with a purity of 99% was selected as the target contaminant to model hydrophobic waste gas. SDS was purchased from Acros Organics, with purity 98%. Triton X-100 and Tween 20 were obtained from Sigma Chemical Company. Their structure and properties are listed in Table 1.

The mineral salt medium used for batch experiments and BTFs was reported by Chen et al. (2012).

**Table 1**
Critical Micelle Concentration (CMC) of surfactants.

| Surfactant | Molecular formula | MW | CMC (mg $L^{-1}$) | HLB |
|---|---|---|---|---|
| Triton X-100 | $C_8H_{17}C_6H_4O(OCH_2CH_2)_{9.5}H$ | 628 | 116.4 | 13.5 |
| Tween 20 | $C_{58}H_{113}O_{26}$ | 1225 | 60 | 16.7 |
| SDS | $C_{12}H_{25}SO_4Na$ | 288 | 1580 | 40.0 |

### 2.2. Experimental setup and operation

#### 2.2.1. Batch reactor

After the successful start-up of the biofilter, the removed biofilms from the medium bed second from the top were carried out for the batch experiments. The removed biofilm was put into a 250 mL glass flask with a 100 mL of the nutrient solution sterilized and shaking well. The cell concentration of suspension liquid is measured and calculated using protein content (unit: mgprotein $L^{-1}$). The detailed determination method for the protein concentration is provided by Zhong et al. (2014).

Biodegradability tests of surfactants (SDS, Triton X-100 and Tween 20) were carried out in duplicate in 135 mL glass flasks with a certain volume of the mineral salt medium, surfactants (prepared in water, at different concentrations of 0.1CMC and 1.0 CMC) and 1.0 mL of biofilms at 38 mgprotein $L^{-1}$. The total volume of the solution was 20 mL. The glass flasks were closed with butyl rubber stopper and tightened screw caps. Subsequently, these flasks were put on a rotary shaker at 150 rpm and 30 °C to incubate. Conditions of control flasks were similar to samples except not supplying with ether SDS, Triton X-100 or Tween 20 solution. A gas chromatograph was used to measure the headspace $CO_2$ concentrations of flasks every three days by extracting 100 μL gas samples from these flasks with a 100 μL gas syringe. If $CO_2$ content in control flasks without surfactants was lower obviously than that of flasks provided with surfactants, surfactants were considered to be biodegradable (Arriaga et al., 2006; Galindo et al., 2011).

Toxicity tests of the surfactant were conducted and the operating process was described as above. The difference was that easily available sources of carbon and energy (per liter in deionized water): 1.0 g glucose, 0.02 g yeast extract and 0.02 g peptone, respectively were applied in this experiment. However, control flasks were supplied with the nutrient solution lacking SDS. The produced $CO_2$ in the headspace of flasks were used for evaluating the toxicity of SDS to microorganisms and determined by a gas chromatography as described above. The SDS was considered to be toxic to microorganisms when produced $CO_2$ in flasks with SDS was apparently lower than that of control flasks.

#### 2.2.2. Biofilter

The two equally BTFs (BTF1 and BTF2) were carried out in parallel in this work. Both biofilters were made of a closed plexiglas column containing an internal diameter of 10 cm and a total height of 78 cm. Four similar cylindrical polyurethane sponge media were packed in both BTFs. The property of packing medium had been reported in our previous work (Wang et al., 2014). Total bed volume of each biofilter was 3.14 L. Packing meida before packed in both BTFs were soaked into the activated sludge taken from a wastewater treatment plant as seed source (Cheng et al., 2015) to inoculate BTFs. Nutrient sprayed on the filter bed at 4.5 L $d^{-1}$ from the top of the biofilter periodically and automatically using the timer to maintain the humidity of packing media. Both BTFs were fed with gas mixtures of n-hexane and the humidified air. The gas flow rates were adjusted by flowmeters. The gas flow was co-current with the nutrient. The schematic of the BTF setup is illustrated in Fig. 1 and had been previously provided (Cheng et al., 2015).

After successful start-up of both BTFs, SDS was added into the nutrient solution for BTF2 while the BTF1 fed without SDS. An average n-hexane inlet concentration of 200 mg $m^{-3}$ and an EBRT of 30 s were set as a reference condition. To obtain an optimal concentration of SDS, experiments were conducted by varying concentration of SDS (0.05 CMC, 0.1CMC, 0.3 CMC and 0.5CMC) at a continuous hexane feeding of 72 mg $m^{-3}$ $h^{-1}$. Subsequently, effects of n-hexane concentration (600 and 800 mg $m^{-3}$) and EBRT (30, 15, 7.5 s) on BTF performance were also examined in presence of

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