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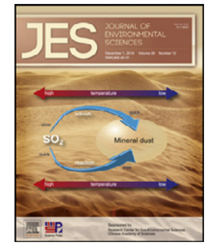


# Enhanced removal of ethylbenzene from gas streams in biotrickling filters by Tween-20 and Zn(II)

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ABSTRACT

The effects of Tween-20 and Zn(II) on ethylbenzene removal were evaluated using two biotrickling filters (BTFs), BTF1 and BTF2. Only BTF1 was fed with Tween-20 and Zn(II). Results show that ethylbenzene removal decreased from 94% to 69% for BTF1 and from 74% to 54% for BTF2 with increased organic loading from 64.8 to 189.0 g ethylbenzene/($m^3$·hr) at EBRT of 40 sec. The effect of EBRT (60–15 sec) at a constant ethylbenzene inlet concentration was more significant than that of EBRT (30–10 sec) at a constant organic loading. Biomass accumulation rate within packing media was reduced significantly.


## Introduction

Ethylbenzene, the monocyclic, volatile organic compound (VOC) which was listed as a priority pollutant by the US Environmental Protection Agency (USEPA), was typically found in petroleum products, like diesel fuel and gasoline (Es'haghi et al., 2011). It is commonly used as an intermediate or solvent in the manufacture of such organic synthesis, and during these manufacturing processes, exposure to ethylbenzene may occur. This pollutant has major influences on central nervous systems and it has been found to cause many serious side-effects to human health (e.g., respiratory problems, skin and sensory irritation, cancer, leukemia, and some disturbance of the liver, kidney, and blood systems) (Aivalioti et al., 2010).

Considerable efforts regarding liquid ethylbenzene removal from wastewater and soil have been devoted in the past years, and several methods have been proposed and successfully applied (Yuan and Weng, 2004; Mohamed and Ouki, 2011; Santos et al., 2012), while few reports were available on gas-phase ethylbenzene removal from waste gas streams (Álvarez-Hornos et al., 2008). In some areas where industries are highly developed, air pollution by ethylbenzene is a real problem, so it would be a benefit if an effective technology could be implemented in such regions. Conventional chemical and physical treatment techniques, however, suffer from great technical limitations for their hazardous byproducts, so, biologically-based technique, which offers lots of advantages such as low capital costs and innocuous byproducts, is turning into an extremely attractive alternative for gas pollutant removal (Cox and Deshusses, 2002; Sercu et al., 2005; Cheng et al., 2011). Biotrickling filter (BTF) is one of these biologically-based techniques.

Although biotrickling filtration of ethylbenzene provides a promising alternative to other conventional technologies, the poor performance for hydrophobic volatile pollutants removal,

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especially under a higher concentration, has intrinsically limited its large scale applications (Sempere et al., 2008). This can be explained that the hydrophobic contaminants are very recalcitrant to undergo biodegradation within the BTF reactor because it can penetrate only a small way into the filter bed (Kraakman et al., 2011). That is to say, transportation of ethylbenzene from the gas phase to the liquid and biofilm phase might be the main rate limiting factor (Hassan and Sorial, 2010; Yang et al., 2010a). Hence, some hydrotropic agents should be added into the reactor to lower the mass transfer limitations.

The non-ionic surfactant Tween-20 and the metal ion Zn(II) were selected as the suitable addition materials in this work. Volkering et al. (1998), Park et al. (2008) and Bilé et al. (2011) have indicated that surfactants can lower the surface tension as well as the interfacial tension for their amphiphilic property, thereby improving the wettability of the gas-phase VOC, making them more bio-available in the BTF reactor. And this solubilization process may be enhanced when the metal ion exists (Wu et al., 2008; Yang et al., 2010a). Ramirez et al. (2012) have devoted some efforts to discuss the possibility of applying hydrotropic agents in bioreactors for a better abatement of VOC. However, studies on combining two materials, such as surfactant and metal ion, for improved VOC removal are very insufficient.

In the previous study, the remarkable enhancement of BTF performance for ethylbenzene removal has been proposed and discussed, which was performed by providing the reactor with different concentrations of Tween-20 and Zn(II) (Wang et al., 2013). Results indicated that the reactor performed with 11.76 mg/L Tween-20 and 1 mg/L Zn(II) could show the maximum removal efficiency, and these hydrotropic agents could also significantly reduce the biomass accumulation in packing media and promote the recovery of microbial activity (Wang et al., 2013).

Therefore, the objective of this study was to make an improvement of the previous research. In this study, processes for continuous degradation of ethylbenzene gas under different organic loading rates and empty-bed residence times (EBRTs) (EBRT at a constant organic loading rate and EBRT at a constant ethylbenzene inlet concentration) have been conducted with BTF1 fed with Tween-20 and Zn(II) while BTF2 without them. The effects of the two additives on promoting the recovery of microbial activity and inhibiting excessive biomass accumulation were also studied in this article.

## 1. Materials and methods

### 1.1. Biofilters

Experiments were carried out using two identical BTFs named BTF1 and BTF2. Fig. 1 illustrates one of these experimental units. The main part of BTF was a closed plexiglas column (Guangda Machinery Manufacturing Co., Ltd., Changsha, China) with an inner diameter of 10 cm and a total height of 78 cm in which four sections were equally divided. A perforate plexiglas plate (Guangda Machinery Manufacturing Co., Ltd., Changsha, China) with a diameter of 10 cm was fixed at the end of each section with a layer of packing medium putting on it. There was a 4 cm plenum located between two sections to allow for sampling and re-distribution of the waste gas streams. Simulative waste gas was generated by mixing two separate air streams, with one stream bubbling directly into the flask containing ethylbenzene reagent, and the other delivered into a humidifier to be water saturated (Bailón et al., 2009). Nutrient solution supplied periodically (spray 3 sec every 3 min, 4.5 L/day) into the reactor in a downward mode without recirculation. Both BTF1 and BTF2 were operated in a temperature controlled chamber with a constant operating temperature of (25 ± 1)°C.

### 1.2. Chemicals

#### 1.2.1. Model VOC

Analytical reagent grade ethylbenzene (Sinopharm Chemical Reagent Co., Ltd., Shanghai, China) ($C_8H_{10}$, 99%) was used as the test substance in this work. The ethylbenzene-contained waste gas streams were introduced into the bioreactor by using a vortex air pump (Wuxi Guangming Pump industry Co., Ltd., Wuxi, China) in a downward flow mode.

#### 1.2.2. Tween-20 and Zn(II)

Reagent grade Tween-20 (Bo Mei Biotechnology Co., Ltd., Hefei, China) (purity of more than 99%) was used as one of the additives in this study and Zn(II) (obtained by dissolving solid zinc chloride into distilled water) was used as another additive.

#### 1.2.3. Nutrient

Nutrients fed into the BTFs should consist of macronutrients (nitrate and phosphate), vitamins, and buffers (Chen et al., 2012). Table 1 gives the chemical composition of the nutrient solution.

### 1.3. Packing media

Open-pore reticulated polyurethane sponges (Shenzhen Jiechun Filter Material Corporation, Guangdong, China) have good permeability and higher mechanical strength, making them suitable bioreactor packing media for long-running removal processes (Moe and Qi, 2004; Ramírez et al., 2009). The polyurethane sponge with a pore size of 10 pores per cm has a porosity of 95.3% and an apparent density of 28 kg/m$^3$. Before being inserted into the reactor column, the sponges were cut into cylinders with a diameter of 10 cm and a height of 10 cm.

### 1.4. Seeding microorganisms

The activated sludge used to inoculate the bioreactors was originated from Changsha Jinxia Wastewater Treatment Plant, Hunan, China. No enrichment procedures were applied before its utilization.

### 1.5. Analytical methods

The performance of BTFs was analyzed in terms of daily determination of removal efficiency (RE), elimination capacity (EC), and pressure drop for the whole bed (it is an indicator of biomass accumulation within the packing media).

Ethylbenzene concentration was analyzed by gas chromatograph (GC) using an Agilent GC 6890 apparatus equipped with a capillary column type HP-VOC (60 m × 320 μm i.d. × 1.8 μm film thickness) and a flame ionization detector (FID), according to Yang et al. (2010a). It was operated with a split ratio of 1:20 (*V/V*) and a split flow of 60 mL/min. Nitrogen (purity ≥ 99.99%) was used as the carrier gas at a constant flow rate of 30 mL/min and hydrogen gas (purity ≥ 99.999%) together with purified air was used as the feed gas. The temperatures of the injector, oven and detector were set at 120, 120 and 250°C, respectively.