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Operational Condition and Temperature Study for Ethylbenzene Treating Biofilter

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Abstract : Biofiltration can effectively remove both organic and inorganic air pollution compounds from both industrial and public sources. However, for the optimal biofiltration performance, it is necessary to gain a better understanding of the inner environment and destruction mechanisms within a biofilter. The effects of operational factors on removal efficiency was studied. Generally, removal efficiency decreases as the loading rate increases. Temperature, as one of the key factors that affect biofiltration design and performance, was also investigated. Conceptually, the biofilter reactor of this paper was divided into five different consecutive stages. The more ethylbenzene COD degraded at each stage, the higher the temperature increases observed compared to the temperatures of the previous stages. It was observed that for every 1 kg of ethylbenzene COD degraded per cubic meter of biofilter media, there was generally a 0.41°C increase in the temperature of that stage.

Keywords : biofilter, ethylbenzene, temperature, loading rate, degradation

Introduction

Biofiltration is an emerging and promising air pollution control technology. Both organic and inorganic air pollution compounds that are toxic to humans and volatile organic compounds from a variety of industrial and public sector sources have been effectively removed with biofiltration[1-4]. The objective of this paper is to investigate the effects of loading rate and fluctuation of temperature in a ethylbenzene treating biofilter.

The relationship between loading rate and removal efficiency was investigated by many researchers[1,3,5-11]. According to previous studies, removal efficiency decreases as the loading rate increases. Determination of maximum loading rate is an essential part of full-scale biofilter design. Devinny and Hodge[12] experienced a GAC biofilter upset when the biofilter was overloaded with ethanol. According to Devinny and Hodge, biofilter upset caused by overload can result in the reactor performance being degraded and toxic intermediates being carried out of the biofilter.

A pulse test to biofilters was performed by Wani *et al.*[13] and Deshusses *et al.*[14]. Wani *et al.* studied hydrogen sulfide (H_2S) treatment under pulse loading lasted about thirty minutes at a concentration of approximately twice the baseline load level. It took about 1.5-2.5 hours for the biofilters to reach the original removal capacity after the H_2S pulse. Deshusses *et al.*[14] performed methyl-ethyl-ketone (MEK) pulse tests which lasted 2 minutes at a loading rate of 1.28 g/m^3 which was approximately 1.5 times the baseline load level. It took about an hour for the biofilter to achieve the original removal capacity after the MEK pulse. A methyl-isobutyl-ketone (MIBK) pulse test by Deshusses *et al.*[14] showed similar results. Based on different loading rates and duration of a pulse, different recovery times are expected for a biofilter to achieve original removal capacity after the pulse input.

Sorial *et al.*[7] investigated the temperature effects on toluene removal in a peat biofilter. The toluene loading rate was 0.45 kg COD/m^3-day and EBRT was 2 minutes. The biofilter achieved removal

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efficiencies as high as 99% at 32.2°C. In contrast, at 11.1°C, the removal efficiency was 58%.

Wright *et al.*[15] operated four identical compost biofilters to treat gasoline vapor. During the summer months, two out of four biofilters were shaded from solar heating and two were not shaded. Often, outlet gas temperatures from the unshaded biofilters were 10°C warmer (up to 38°C) than the outlet gas temperatures from the shaded ones. Biofilters with higher outlet gas temperatures achieved higher removal efficiencies (89% and 92%) than with lower outlet gas temperatures, which had removal efficiencies of 64% and 67%.

Lackey *et al.*[9] also reported higher styrene removal efficiencies during the summer. The average temperature of inlet air stream to biofilter was 32.2°C for the summer season, and only 13.8°C for the winter season. Lackey *et al.* reported the optimum inlet gas temperature was between 20 and 40°C.

Swanson and Loehr[16] recommended 35°C for the aerobic microorganisms in biofilters. Cox *et al.*[8] reported that styrene degradation rates at biofilter were similar between 22.5 and 33°C. However, a rapid decrease was observed at higher temperatures. More research is needed to determine the optimum temperature range for various biofilter operating conditions. The impacts of the temperature and its relationship to moisture contents also need to be studied.

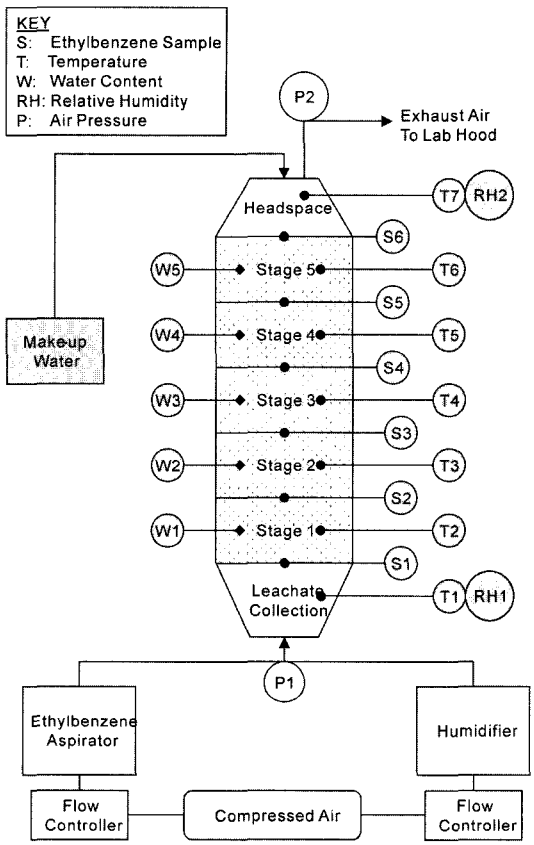

Fig. 1. Schematic of the biofiltration system.

Experimental Methods

Biofilter media

Composting material was mainly used as the biofilter media for the experiment. Two different types of hardwood saw dust and municipal wastewater sludge are used for the raw material of the compost. The pH of the compost was 7.2 (±0.1).

Biofilter design

A schematic of the biofiltration system is shown in Fig. 1. The biofilter was constructed from an acrylic tube with an internal diameter of 14.0 cm. The Biofilter consisted of the following sections, from top to bottom.

1) A headspace for housing the water spray nozzle.
2) A section containing biofilter media. The height of the biofilter media was one meter. Conceptually, the biofilter was divided into five different consecutive stages. The height of each stage was 20 cm.
3) A bottom space to collect leachate from biofilter.

Inlet and outlet relative humidity ($R.H._1$ and $R.H._2$) and temperature (T_1 and T_7) were measured using a HMI41 humidity and temperature indicator and a HMP42 probe (Vaisala Inc., Woburn, MA). Inlet air stream relative humidity was maintained over 95% for the entire experimental period. The humidifying water chamber was constructed from an acrylic tube with an internal diameter of 11.7 cm, and a height of 80 cm. Water level inside the chamber was maintained at about 65 cm, which gives a water volume of approximately 7 liters. An air stream was aspirated into water inside the chamber through the four sets of fine air bubblers.

Temperatures of the biofilter media at five different consecutive stages (T_2, T_3, T_4, T_5, and T_6) were measured using a model 865F thermistor meter and model OL-710-PP probes (Omega Engineering Inc., Stamford, CT). Inlet and outlet air pressure ($A.P._1$ and $A.P._2$) was measured with Ashcroft type 1084 pressure gauges (Dresser Instrument, Stratford, CT). Using ThetaProbe soil moisture sensors (type ML2, Delta-T Devices Ltd., Cambridge, U.K.), water content of the biofilter media at each stage ($W.C._1$, $W.C._2$, $W.C._3$, $W.C._4$, and $W.C._5$) was measured. After termination of the experiment, five samples of biofilter media at each stage of the reactor were carefully collected. Water content of all the collected samples was measured using standard method 2540B (American Public Health Association *et al.*, 1989) and the average of the water content of these collected samples was used for the calibration of the moisture sensor probes.

The air used for creating the synthesized contaminated gas stream was taken from the laboratory air compressor. Before use, the air was purified by an activated carbon trap, catalog number 2-4564 (Supelco Inc., Bellefonte, PA). A small amount of the air stream was separated out of the purified main stream to pass through the ethylbenzene aspirator, catalog number 657750-5023 (Kimble Glass Inc., Vineland, NJ). In the aspirator, liquid ethylbenzene was volatilized into the air stream. The other air stream passed through the humidifying water chamber and then the two air streams were combined together before entering the biofilter. Using flowmeters (Key Instrument, Trevose, PA), the flow rates of the two air streams were varied to adjust the total airflow rate and the concentration of ethylbenzene. The combined air stream moved upward through the media bed and was exhausted through the top of the biofilter.

For an initial irrigation of the biofilter, twelve liters of distilled water were sprayed through the nozzle in the headspace of the reactor. The leachate in the bottom of the reactor was recycled until the whole biofilter media was thoroughly saturated. After the initial water irrigation of the biofilter media, no water was added to the reactor for the remainder of the each experimental period.

Ethylbenzene analysis

Inlet and outlet air samples from each stage of the biofilter (S_1, S_2, S_3, S_4, S_5, and S_6) were analyzed using a Rosemount NGA 2000 series flame-ionization detector (FID) (Rosemount Analytical Inc., La Habra, CA). Premixed 40% hydrogen and 60% helium standard gas was used as the fuel gas. House air was used as burner and purge air. Air samples from each stage of the biofilter were individually transferred to the FID with an air pump (catalog number M01310TC, Air Dimensions Inc., Deerfield Beach, FL) at a sample flow rate of 600 ml/min using a heated transfer line at 150 C. Other operating conditions follow the standard operating method of Rosemount NGA 2000 series FID.

Retention time and loading rate to the biofilter

Two experiments were performed based on different biofilter loading rates. Before each experiment, water irrigation was performed to saturate the biofilter media. A two minute retention time was used for experiment 1 and a one minute retention time was used for the experiment 2. Influent concentration of ethylbenzene applied to

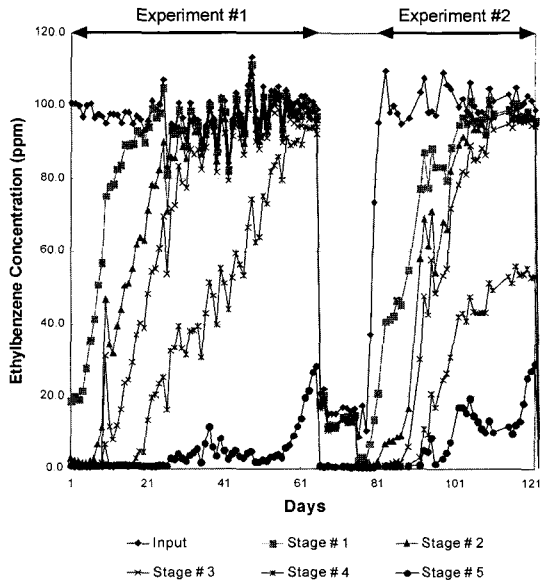

Fig. 2. Applied ethylbenzene concentration (ppm) to each stage.

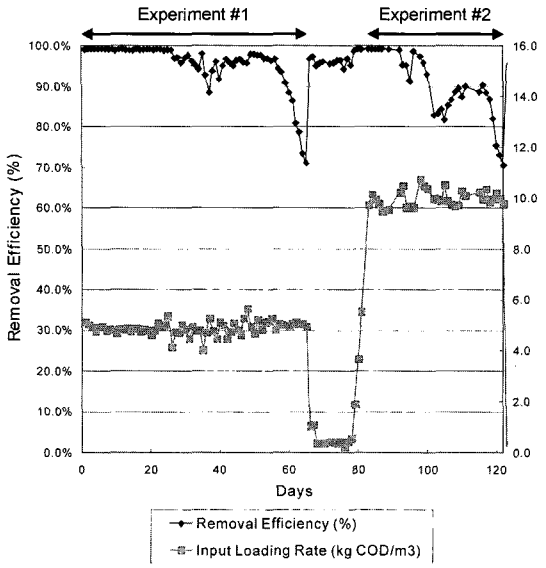

Fig. 3. Applied input stage loading rate (kg COD/m^3) and total removal efficiency (%).

Table 1. Operating conditions for the biofilter

	Experiment 1	Experiment 2
Stage Biofilter Bed Volume (Liter)	3.07	3.07
Ethylbenzene Conc. (ppm)	100	100
Air Stream Flow Rate (Liter/min)	7.65	15.30
Stage Empty Bed Retention Time (min)	0.4	0.2
Stage Loading Rate (kg COD/day/m^3)	5.0	10.0

the biofilter are also shown in Fig. 2. The period for experiment 1 was 65 days and the period for experiment 2 was 40 days (from consecutive day 83 to day 122). The ethylbenzene COD loading rate (kg COD/m^3) to the biofilter was calculated based on the individual stage volume (3.07 Liter). Relatively constant COD loading rates to the biofilter were applied during each experiment (Fig. 3). For the experiment 1, loading rate to stage #1 (or input loading rate) was maintained at 5.0 kg COD/m^3, and for the experiment 2, it was maintained at 10.0 kg COD/m^3 respectively. Other operating conditions are shown in Table 1.

Results and Discussion

Ethylbenzene degradation in a multiple stage biofilter

The degradation of ethylbenzene in the air stream is shown in Figs. 2 from bottom of the biofilter (stage #1) to the top (stage #5). Figs. 2 and 3 shows the level of COD loading rate (kg COD/m^3) and ethylbenzene concentration (ppm) applied to each stage during the experiment. As each stage removes a certain amount of ethylbenzene, smaller and smaller amounts of COD loading rates and concentrations were continually applied to the following stage. Ethylbenzene was not equally degraded over the depth of the biofilter. Instead, each stage of the biofilter was dominant in degrading ethylbenzene for a given experimental time period. As time progressed, the most dominant stage in ethylbenzene degradation or primary active stage (PAS) shifted consecutively from stage # 1 to stage # 5.

Removal efficiency

Removal Efficiency of the biofilter for experiment 1 was greater than 90 percent for 59 days and greater than 80 percent for 62 days. For experiment 2, removal Efficiency of the biofilter was greater than 90 percent for 18 days and greater than 80 percent for 37 days.

As mentioned previously, after an initial irrigation at the beginning at each experimental period, water was not added to the reactor during the remainder of each experimental period, 1 and 2. Therefore, since target removal efficiency of the biofilter was 80 percent, without any addition of nutrient solution or water to the reactor, the biofilter was successfully operated for 62 days for experiment 1, for 37 days for experiment 2 (Fig. 4).

Temperature correlation with stage activity

Temperatures of each stage of the biofilter media were also investigated. The more ethylbenzene COD degraded at each stage, the higher the temperature increases observed compared to the temperatures of the previous stages. Fig. 5 shows the fluctuation of the temperature difference (or increase) of stage 3, compared to the previous stage (stage 2) for the entire experimental period,

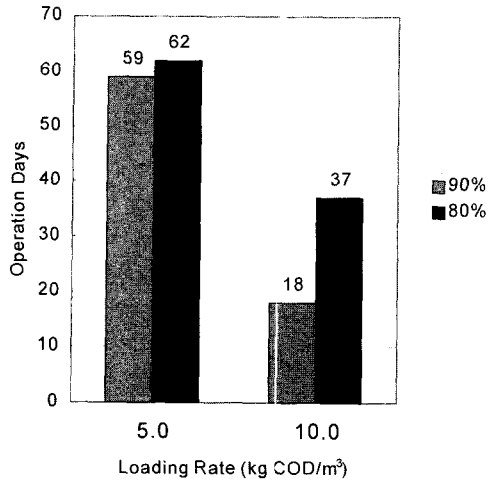

Fig. 4. Biofilter operational days with different target removal efficiency (%) and loading rate (kg COD/m^3).

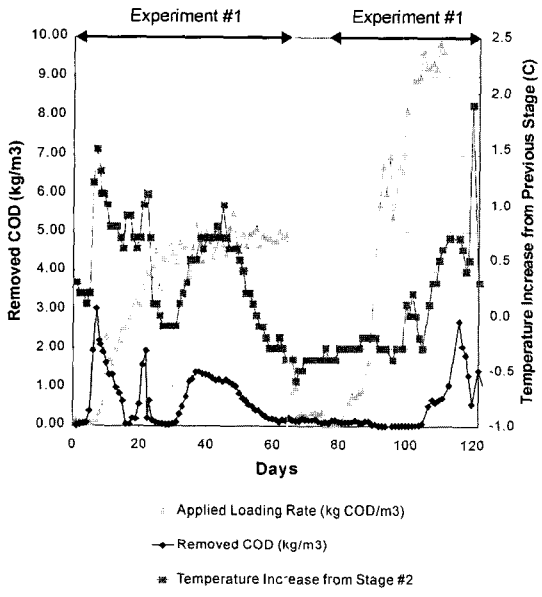

Fig. 5. Relationship at Stage # 3 between the amount of COD removed and temperature increase from previous stage.

applied ethylbenzene COD loading rate (kg COD/m^3), and the corresponding amount of COD removed (kg COD/m^3). In general, when the temperature difference of stage 3 increased, the amount of COD removed (kg COD/m^3) at the stage also increased. In the same way, when the temperature difference decreased, the amount of COD removed (kg COD/m^3) also decreased. This trend was also observed at stage 3, 4, and 5.

It was observed that for every 1 kg of ethylbenzene COD degraded per cubic meter of biofilter media, there was generally a 0.41°C increase in the temperature of that stage. Bio-oxidation of an organic compound is an exothermic reaction. When ethylbenzene is biodegraded inside the biofilter, heat is generated and steadily released into the biofilter. Thereafter, this produced and released heat from the biodegradation process increases the temperature of the biofilter media. Leson and Smith[5] similarly reported that elevating the loading rate to the biofilter increased the temperature of the exhausted gas from the biofilter.

Conclusion

Ethylbenzene was successfully removed continuously in a biofilter. However, ethylbenzene was not equally degraded over the depth of the biofilter. Instead, each stage of the biofilter was dominant in degrading ethylbenzene for a given experimental time period. As target removal efficiency of the biofilter was 80 percent, the biofilter was successfully operated for 62 days for experiment #1 (under the loading rate of 5.0 kg COD/m^3) without any addition of nutrient solution or water to the biofilter. Under the increased loading rate of 10.0 kg COD/m^3, the biofilter was successfully operated for 37 days during the experiment #2.

The more ethylbenzene COD degraded at each stage, the higher the temperature increases observed compared to the temperatures of the previous stages. It was observed that for every 1 kg of ethylbenzene COD degraded per cubic meter of biofilter media, there was generally a 0.41°C increase in the temperature of that stage. When ethylbenzene is biodegraded inside the biofilter, heat is generated and steadily released into the biofilter. Thereafter, this produced and released heat from the biodegradation process increases the temperature of the biofilter media.

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