Development of Parallel Trickling Biofilter for the Treatment of Gas-phase Trichloroethylene

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Abstract

A parallel TBF system that is consisted of two TBFs was developed for the long-term treatment of gas-phase trichloroethylene (TCE). Each TBF was operated for TCE degradation or reactivation in a parallel mode, and the effect of switching time and operation variables between the two reactors was investigated. Within 12 hr after switching from TCE degradation to reactivation mode, the MO activity increased up to the initial level. More than 50 % of TCE was degraded for feed concentrations ranging from 5 to 17 ppm_v, and completely 100 % removed at concentration of less than 5 ppm_v, while TCE removal decreased severely over 28 ppm_v. In various empty bed retention times (EBRTs), ranging from 5.2 to 10.7 min, the optimal EBRT was 10.7 min that TCE conversion achieved more than 50 %. For the inlet loading below 23.4 mg TCE/L/day, TCE was entirely removed. The maximal TCE elimination capacity in this system was about 66.63 mg TCE/L/day. During the continuous treatment of TCE over 3 months, TCE removal efficiency was maintained at the range of about 50 %. In these results, the parallel TBF system can be available for the continuously TCE biodegrading operation.

Introduction

Trichloroethylene (TCE) has been widely used as industrial solvents and degreasing agents. Because of extensive use and improper disposal, it has become a widespread contaminant in air, soil, and underground water (1). Since TCE is a suspected carcinogen and constitutes public health concerns, many treatment systems have been investigated to remove this hazardous waste (2). Microbial degradation is a promising method for the remediation of TCE, where TCE can be completely mineralized into harmless end products by enzymes (3). Since TCE itself is not a growth substrate, it can be degraded *via* cometabolism, in which oxygenase, the corresponding enzyme for initiating growth substrate oxidation, fortuitously transforms TCE. One of the most promising reactor systems for the microbial degradation of TCE is trickling biofilter

(TBF), in which TCE is degraded by a microbial film (4, 5). TCE, however, is not easily treated by simple biofiltration. This is mainly due to the toxicity of TCE to microbial cell. TCE itself and its degradation products can react unspecific way, resulting to the deactivation of enzyme and cell. The removal efficiency of TCE in simple trickling biofilter normally decreases with time. The intermittent feeding of low concentration of carbon substrate was considered to prevent this deactivation of biofilm. This approach, however, could not be successful for the long-term stable treatment of TCE. In this presentation, we developed and operated the parallel TBF system consisting of two unit of TBF in parallel mode, one for TCE biodegradation and the other for biofilm reactivation, to evaluate the potential of this system for the long-term continuous treatment of TCE.

Materials and methods

Microorganism and culture medium

Burkholderia cepacia G4 was employed in this study and M9 medium supplemented with phenol as a sole carbon source was used to culture the cells and develop biofilm.

Analytical methods

TCE concentrations were determined by analysis of 30 $\mu\ell$ of inlet and outlet gas-phase samples on a gas chromatography (Hewlett Packard 5890 II plus, USA) equipped with an electron capture detector (ECD) and HP-5 capillary column (Alltech Inc., USA). The nitrogen of 30 $m\ell$/min was used as a carrier gas, and the temperatures of oven, detector and injector were 100 ℃, 200 ℃ and 250 ℃, respectively. The activity of toluene monooxygenase (TMO) was analyzed by modified naphthalene oxidation assay.

Parallel trickling biofilter (TBF) system

The TBF unit consists of a 1.4-L glass cylinder (diameter: 5 cm, height: 70 cm) and ceramics as supporter matrix packed to a depth of 50 cm. All fittings and connectors were gas-tight and the temperature of TBF was controlled using water circulator.

Results and discussion

Parallel TBF system development

In order to overcome the decrease in the removal efficiency observed in single-stage TBF, parallel TBF system consisting of two TBF in a parallel mode was developed. One TBF unit was used for TCE degradation and the other TBF unit for reactivation of

the deactivated biofilm. When the biofilm activity in the TCE degradation TBF was deactivated down to a certain level, the reactor operation mode of the degradation unit is switched to a reactivation mode and the corresponding reactivation unit to reactor operation mode for TCE degradation, and *vice versa*. This system was proposed for the long-term stable treatment of gas-phase TCE.

Deactivation and reactivation of biofilm

To determine the growth substrate requirement for the biofilm in the reactivation TBF unit, the effects of phenol concentrations on bacterial cell growth were investigated based on the fact that the maximal reactivation of biofilm could be normally obtained at the optimal growth condition. The specific growth rates were calculated from the data of early exponential phase of growth curve obtained from the cultures on various initial phenol concentrations, and the phenol concentration for the biofilm under reactivation conditions was determined to be 3 mM. In the outlet of liquid stream from reactivation TBF unit, hardly any phenol could be detected by modified colorimetric assay. The phenol concentration of 1 mg/L was also fed to the TCE transformation reactor for the enhanced TCE degradation based on the previous results that TCE degradation rate could be improved by the supply of appropriate amount of phenol.

The patterns of deactivation of biofilm activity in the TCE transformation operation mode and reactivation in the reactivation operation mode were analyzed. The MO activity in the TCE degradation mode decreased down to about 30 % of the initial level after 24 hr operation. The TBF operation mode was switched to a reactivation mode by supplying the growth medium supplemented with optimal concentration of phenol as the carbon source. When the reactivation medium was supplied, the activity of MO rapidly increased. Within 12 hr after switching from TCE degradation to reactivation mode, the MO activity increased up to the initial level value. These results clearly represented that the possibility of long-term stable operation of TBF could be achieved by a parallel TBF system.

Effects of operation variables on the performance of the parallel TBF system

The effects of inlet TCE concentrations on TCE conversion and degradation rate were investigated at concentrations ranging from 5 to 30 ppm_v to evaluate the performance of the parallel TBF system. The flow rate of buffer containing 1 mg/L phenol, empty bed retention time (EBRT), and the temperature of TBF were 0.86 mL/min, 10.7 min, and 30℃, respectively. The inlet TCE concentrations were raised step-by-step, and then the system was allowed to reach equilibrium. TCE removal efficiency and degradation rate decreased with increase in inlet TCE concentration due to the toxic effect of TCE degradation products. More than 50 % of TCE was degraded for feed concentrations ranging from 5 to 17 ppm_v and almost 100 % removal was achieved when TCE was introduced at concentration of less than 5 ppm_v. It appeared

that the TCE degradation decreased drastically after the introduction of high concentration of TCE above 28 ppm_v, which showed that the TBF system consisting of pseudomonads biofilm could be applied for low TCE concentration below 20 ppm_v.

The experiments for the effects of gas flow rates on TCE degradation were also investigated with the conditions of 11 ppm_v of inlet TCE concentration, buffer flow rate of 0.86 mL/min, and TBR temperature of 30℃. The EBRT was varied from 10.7 to 5.2 min, and inlet and outlet TCE concentrations were analyzed. TCE removal efficiency was decreased with increase in EBRT. The low removal efficiency of 25 % was obtained at 5.2 min of EBRT. The TCE elimination capacity expressed as the amount of TCE degraded per reactor volume per time was calculated at the range of TCE inlet concentrations of 25 - 240 mg TCE/L/day. For the inlet loading below 23.4 mg TCE/L/day, 100 % removal of TCE could be achieved. The maximum TCE elimination capacity of parallel TBR system was calculated to be 66.63 mg/L/day.

Long-term operation of parallel TBF

To evaluate the possibility of long-term continuous TCE degradation, the removals of TCE in the parallel TBF system were monitored by gas chromatography. TCE was degraded with the removal efficiency above 50 % by the parallel operational mode with 12 hr-switching period. When parallel TBF was operated for the long-term removal of TCE, semi-continuous supply of growth substrate led to the increase of large quantities of biomass, which clogged the system. Therefore, the method for the biomass reactivation under non- or limited-growth condition needs to be investigated.

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