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The use of an oil–absorber–bioscrubber system during biodegradation of sequentially alternating loadings of 1,2-dichloroethane and fluorobenzene in a waste gas

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Abstract

This work seeks to improve the robustness of vapour phase bioscrubbing by applying an absorber prior to a bioscrubber during the dynamic treatment of sequentially alternating loads of inhibitory pollutants. *Rhizobiales* sp. strain F11 and *Xanthobacter autotrophicus* sp. GJ10, exhibiting specific degradation capabilities for fluorobenzene (FB) and 1,2-dichloroethane (DCE), respectively, were used as a compound-strain model system. The stability of a combined oil–absorber–bioscrubber (OAB) was compared to the stability of a bioscrubber only (BO) system, during sequentially alternating periods (duration 3–6 d) of FB and DCE in the gas feed. The OAB achieved $>66\%$ degradation of FB, while in the BO system the FB removal efficiency dropped to 0% upon restoring FB feed after a 3 d FB starvation period. Following 6 d of FB starvation the BO failed to recover within 10 d, while the OAB required only 2 d to recover. In contrast, during the DCE treatment periods the OAB system did not show any advantage over the BO system. Further investigation showed that the F^- (a main metabolic product from FB degradation) has a strong inhibitory effect on strain GJ10 even at concentrations below 50 mg L^{-1}. In the OAB system the inhibitory effect persisted for longer periods due to the absorber, which continued to supply FB to the system, and caused deterioration in the DCE removal efficiency. The inhibition of the microbial culture was confirmed by fluorescence *in situ* hybridisation (FISH), which showed that the activity of cells was reduced when only FB was fed. The results of this study have shown that in the presence of an inhibitory metabolic product the OAB system may not effectively improve the biological treatment of waste gas during sequential alternations in the feed of inhibitory pollutants.

Keywords: 1,2-Dichloroethane; Fluorobenzene; Absorption; Bioreactors; Environment; Molecular biology

1. Introduction

A critical characteristic of industrial waste streams is the random variations in the pollutants concentration profiles (Koutinas et al., 2006, 2007). Past studies have extensively described the responses of biological systems to changes in pollutant concentration. Furthermore, various bioreactor designs and control strategies have been proposed to enhance bioreactor stability, in most cases using absorption or adsorption materials contained within the bioreactor, or as a separate unit prior to the bioreactor. Granular activated carbon and solid polymers have been applied for the control of fluctuating pollutant loads (Weber and Hartmans, 1995; Abumaizar et al., 1998; Amsden et al., 2003; Daugulis et al., 2003). However, organic solvents or oils are expected to have higher capacities for most organic substrates (Daugulis, 1997; Daugulis et al., 2003). Recently, cost effective and environmentally friendly organic absorbents were exploited for the control of inhibitory concentrations of pollutants and starvation periods in bioscrubber systems, producing successful results (Oliveira and Livingston, 2003; Nielsen et al., 2005; Koutinas et al., 2006, 2007).

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However, there has been limited work performed to study responses during periodic switches in carbon source (Ferreira Jorge and Livingston, 2000a). The application of cost effective and environmentally friendly organic absorbents for the control of biological treatment of such waste streams would be an interesting approach. The scenario of sequential changes in the waste stream chemical composition is referred to in this work as 'sequentially alternating pollutants' (SAP), and describes cases in which the chemical composition is alternating sequentially from one set of compounds to another over cycle periods of days or weeks.

The first study introducing a SAP feeding scenario to bioreactors was performed by Goodall et al. (1998). Two immobilised cell airlift reactors were compared, during the biodegradation of an alternating sequence of meta- and para-nitrobenzoic acid by two specific microbial strains. The comparison showed that when the strains were co-immobilised, due to microbial interactions the system could respond faster to the re-introduction of each isomer, than when each strain was immobilised on different beads. In a separate study Goodall and Peretti (1998) developed a mathematical model to describe the co-immobilised configuration, predicting successfully the metabolic behaviour of the co-immobilised culture.

Ferreira Jorge and Livingston (2000a) investigated the biodegradation (by two specific microbial strains) of an alternating feed of monochlorobenzene (MCB) and DCE in a continuous stirred tank bioreactor (CSTB). Although the system required re-acclimation for the first few hours after DCE was re-introduced, re-acclimation was not observed when the feed was switched to MCB. The authors concluded that the strain degrading MCB was maintained in an active state in the CSTB when only DCE was fed, due to microbial interactions between the two species. To prevent undesirable DCE accumulation, a continuous flow of a 'maintenance feed' was introduced which enhanced the CSTB performance. However, it was not considered a feasible solution due to the excessive amounts of DCE required. Ferreira Jorge and Livingston (2000b) also investigated the performance of an extractive membrane bioreactor (EMB) challenged with SAP loads, using the same compound-strain model system. The physical retention of the biomass due to the biofilm improved the performance of the system, and both strains were retained active in the EMB. However, recent studies have shown that the response of bioreactors to SAP conditions is also dependent on the physicochemical properties of the pollutants fed (Kim et al., 2005; Cai et al., 2006).

The above studies indicate that the greater the variability of pollutants in the waste stream, the greater the constraints on bioreactors treating such waste streams. They also suggest two strategies to overcome loss of degradation during SAP conditions: (i) the physical retention of biomass in the system via immobilisation, which can reduce the response time of the system after the switch in the substrate feed, and (ii) the maintenance of the microbial culture activity with the addition of an external carbon source as a maintenance feed, which has been proven successful even during the pilot scale operation of biological plants (Bastos et al., 2003).

The smoothing effect of an absorber, as proven when dealing with variations in the process inlet concentration (Koutinas et al., 2006, 2007), might be a successful alternative in meeting the challenges offered by SAP conditions during treatment. The present work investigates the potential of an oil absorber placed upstream of a bioscrubber to stabilise the biological treatment of waste gas during sequentially alternating loads of FB and DCE. The stability of the OAB and the BO systems was compared under SAP treatment conditions and a mathematical model was used to describe the operation of the absorber. In parallel, the microbial culture dynamics were monitored using FISH.

2. Materials and methods

2.1. Cultivation of microorganisms

Subcultures of *Xanthobacter autotrophicus* GJ10 and *Rhizobiales* sp. strain F11 were used for bioscrubber inoculation, and were grown under mineral medium and conditions described by Koutinas et al. (2006).

2.2. Experimental set-up

The experimental set-up used is presented in Fig. 1. The total flow rate of air influent to the system was $0.3\,L\,min^{-1}$ and consisted of three different gas streams (G1–3), giving a volumetric gas flow rate per bioscrubber volume of $0.2\,min^{-1}$. Streams G1 and G2 were enriched with FB and DCE, respectively, by passing through two saturation vessels containing pure compounds, while stream G3 comprised air. Gas direction I was followed when the absorber was not used and the waste gas was introduced directly to the bioscrubber. The bioscrubber (SGI '30/SET002', SGE, France) was operated with 1.5 L working volume and at a dilution rate of $0.023\,h^{-1}$, controlled by a Watson Marlow 502S (Watson-Marlow Bredel Products, UK) peristaltic pump. The dissolved oxygen concentration was monitored via an Ingold oxygen probe (Mettler Toledo Ltd, UK), pH was controlled at 7 ± 0.05 with the addition of 2 M H_2SO_4 or 2 M NaOH and temperature was maintained constant at 30 °C. A stainless steel sparger was used to supply the inlet gas stream to the bioscrubber and two impellers rotating at 1000 rpm were used for gas dispersion. The bioscrubber was operated under non-sterile conditions during the experiments. The absorber was a glass column (50 cm height, 5 cm i.d.) divided into a packed section with a 27 cm high bed of pall rings, and an oil reservoir. The gas stream inlet was placed between the two sections, at 10 cm column height and the two streams (gas and oil) flowed in counter-current mode. A 0.52 L of sunflower oil (Pure Sunflower Oil, Tesco Stores Ltd, UK) was used. The oil was recirculated at a flow rate of $1\,L\,min^{-1}$ via a gear pump (130-000-110 model, Cole-Parmer Instrument Company Ltd, London, UK) through the column, in order to mix the oil with the gas phase in the packed section. A temperature controller was employed to maintain the column temperature constant at 27 °C, utilising a thermocouple and a heating coil.