Development of a Novel Bioreactor System for the Treatment of Gaseous Benzene

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Abstract

A novel, continuous bioreactor system combining a bubble column (absorption section) and a two-phase bioreactor (degradation section) has been designed to treat a gas stream containing benzene. The bubble column contained hexadecane as an absorbent for benzene, and was systemically chosen considering physical, biological, environmental, operational and economic factors. This solvent has infinite solubility for benzene and very low volatility. After absorbing benzene in the bubble column, the hexadecane served as the organic phase of the two-phase partitioning bioreactor, transferring benzene into the aqueous phase where it was degraded by *Alcaligenes xylosoxidans* Y234. The hexadecane was then continuously recirculated back to the absorber section for the removal of additional benzene. All mass transfer and biodegradation characteristics in this system were investigated prior to operation of the integrated unit, and these included: the mass transfer rate of benzene in the absorption column, the mass transfer rate of benzene from the organic phase into the aqueous phase in the two-phase bioreactor, the stripping rate of benzene out of the two-phase bioreactor, etc. All of these parameters were incorporated into model equations, which were used to investigate the effects of operating conditions on the performance of the system. Several experiments were conducted to show the feasibility of this system. This process is believed to be very practical for the treatment of high concentrations of gaseous pollutants.

Introduction

Volatile aromatic compounds such as benzene, toluene and xylene (BTX) are major products of petroleum and fine chemical industries and among the most frequently used organic solvents [1)]. However, since they are suspected as carcinogens and produce offensive odours, their release to the environment is strictly controlled and they are classified as priority environmental pollutants by the Environmental Protection Agency in the USA. Biological treatment using microorganisms has the potential of not producing secondary effluent problems. Also, in general, biological treatment processes may be the most cost-effective technique for treating aqueous waste streams containing organic compounds [2)]. Biofilters has been considered to be one of the most promising methods for the treatment of volatile compounds .However it can treat only low concentration of volatile pollutants[3)]. Maintaining proper

temperature, pH and moisture are also challenging problems [4].

In this study, we combined an absorption column with the two-phase bioreactor to remove and degrade high concentration of benzene from a gas stream. In the absorption column hexadecane (which was selected because of its favorable physical properties for capturing benzene) was used to scrub a gaseous benzene. The solvent, which also had to meet various biological criteria for use in such a system, was then pumped to the two-phase bioreactor where *Alcaligenes xylosoxidans* Y234 in the aqueous phase consumed the contaminant. The hexadecane was then recirculated back to the stripper for re-use. Prior to experimentally demonstrating the effectiveness of this concept, it was necessary to quantify the mass transfer rates between the various phases as well as microbial kinetic coefficients. These were used in a mathematical model to identify appropriate operating conditions (e.g. concentrations, flow rates) to be used. Several experiments were then undertaken to show the validity of this process concept.

Materials and Methods

Microorganism

Alcaligenes xylosoxidans Y234 isolated from oil-contaminated soil was used in this study. It can degrade benzene, toluene and phenol [5].

Absorber/Bioreactor Configuration

The central feature of this arrangement consisted of a 2 L New Brunswick Scientific Bioflo fermentor, with a 1 L aqueous volume, and 500 mL organic volume. In addition, a means of generating a constant composition benzene-in-air stream was required, and this was achieved by manipulating the ratio of the air flow rate to a 1 L flask containing pure benzene, and a make-up air flow stream. The system also made use of a glass cylindrical absorption column (with an inner diameter of 6.5 cm and a working volume of 1.0 L) to scrub the benzene gas stream with the solvent. A sintered glass sparger was used to introduce the gas stream into the absorber. The solvent was circulated in a closed loop in this system, with benzene being picked up in the absorber, and being "delivered" to the cells in the two-phase bioreactor, with subsequent return to the absorber. The entire system was maintained at 30 °C by means of water baths, heating coils, and internal temperature control on the fermentor.

Results and Discussion

Solvent selection

The solvent must be biocompatible, nonbiodegradable, nontoxic, inexpensive, have a high partition coefficient and selectivity as well as low volatility and density. By means of a systematic solvent selection strategy as previously described [6], hexadecane was chosen as the solvent for the treatment of benzene in this two-phase system.

Mass transfer measurements in the system

A bubble column was used in this study to remove benzene from air by contacting with hexadecane. While the effect of influent gaseous benzene concentration on mass transfer coefficient of benzene into the liquid phase is almost negligible, that of gas flow rate on the mass transfer coefficient of benzene was significant and could be correlated linearly. Saturated liquid phase benzene concentration which is in equilibrium with benzene in the bulk gas phase was linearly proportional to inlet gaseous benzene concentration. The mass transfer rate of benzene from the organic phase to the aqueous phase in the two-phase partitioning bioreactor was increased with an increase in the agitation rate but decreased with an increase in aeration rate. By aerating the bioreactor it was anticipated that some benzene would be continuously stripped out of the two-phase system. The coefficient for benzene stripping from the organic phase was also correlated linearly.

Mathematical formulation for simulation of the system

Mathematical model equations were formulated to determine the effect of each operating parameter on the performance of the system. Parameter sensitivity was determined as the difference in removal efficiency at the steady state. Five parameters were considered: the agitation rate, aeration rate, hexadecane circulation rate (HCR), aqueous feed rate (AFR) and initial cell concentration. Since HCR and AFR were thought to be the most critical operating parameters from the sensitivity analysis, their influences on the removal efficiency of benzene were investigated by simulation. With this in mind, the optimal condition was determined by grid search.

Verification experiments

In the first (non-optimal) experiment, the aeration rate in the two-phase bioreactor was chosen arbitrarily as 500 ml/min (0.5 vvm on the basis of aqueous phase volume) and HCR and AFR were set at 3.0 L/h and 0.2 L/h, respectively. The removal efficiency of benzene at steady state from both the simulation and the experiment was about 69 %.

In the second experiment, the optimal operating conditions were adopted from the simulation. The aeration rate was decreased to 0.25 vvm and the AFR was also decreased to 0.12 L/h. The other conditions were the same as those in the first experiment. The predicted removal efficiency in this experiment was 84 % and the actual measured value was 75 % as shown in Fig. 1.

In the former two experiments, the inlet gas flow rate and benzene concentration were set to be 120 L/h and 4.2 mg/L, respectively. To treat much higher benzene concentration, bubble column was replaced with packed-bed column which has more mass transfer unit. More than 90 % of 20 mg/L benzene with 60 L/hr was removed with this system when aeration rate was 0.25 vvm as shown in Fig 2.

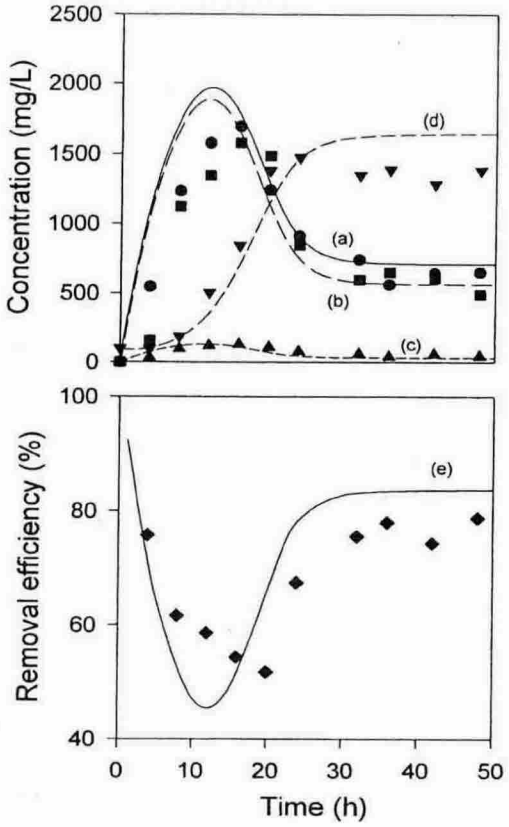

Fig. 1 Operation with 4.2 mg/L benzene concentration and 120 L/hr gas flow rate.

● : cell mass, ■ : benzene in the bubble column, ▲ : benzene in organic phase, □ : benzene in aqueous phase, ◆ : removal efficiency.

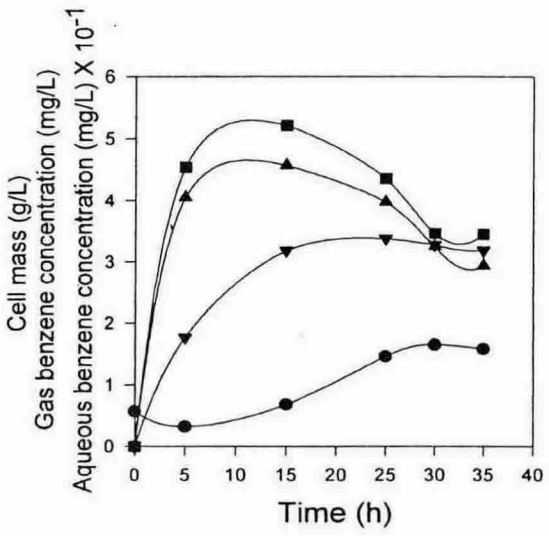

Fig. 2 Operation with 20 m/gL benzene concentration and 60 L/hr gas flow rate.

● : cell mass, ■ : emitting benzene from absorber, □ : emitting benzene from bioreactor, ▼ : benzene in aqueous phase.

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