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Effect of oxygen transfer limitations in phenol biodegradation

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Abstract

Activated sludge acclimatized to 400 ppm phenol was used for the biodegradation of phenol in a batch reactor system and a Rotating Biological Contactor (RBC). Phenol degradation in the batch reactor was studied in relation to supply of oxygen, in addition to the effect of biomass concentration. An aeration pump and oxygen concentrator were used to supply oxygen. It was confirmed that the performance of system improved with increased availability of oxygen, as determined from the phenol degradation rate. Alternatively increasing stirring speed proportionally, increased the mass transfer coefficient of oxygen and also resulted in improved phenol degradation. However, in all the above cases the dissolved oxygen (DO) was zero in the presence of phenol. Studies using the RBC led to amelioration/improvement in DO levels, thus overcoming the limitations of oxygen supply to the process during phenol degradation in the batch mode.

Keywords: Phenol biodegradation; Activated sludge; Dissolved oxygen (DO); Rotating Biological Contactor (RBC); Oxygen concentrator

1. Introduction

There has been much concern with the environment being made vulnerable to enormous quantities of organic and inorganic toxic discharges on account of human activities. Phenol and phenolic compounds are common constituents of aqueous effluents from operations such as polymeric resin production, petrochemical plants, ceramic plants, oil refining, cooking plants and stainless steel production [1]. Phenol is a troublesome contaminant causing irritation to skin and also contributes to off flavours in drinking and food processing waters. Due to the toxic nature of some of these compounds the Environmental Protection Agency has set a water purification standard of less than 1 part per billion (ppb) of phenol in surface waters [2]. To achieve this level of phenol removal special systems are required. Although a variety of physicochemical techniques are available for the clean up of surface water, interest in the use of microbial degradative ability is growing [3]. Microbial degradation of phenolic wastewaters has been documented [4]. Although both aerobic and anaerobic organisms are able to degrade phenol and its derivatives, aerobic processes may be preferred [5]. Many aerobic bacteria are capable of using aromatic compounds as the sole source of carbon and energy. A typical pathway for metabolizing an aromatic compound is to dihydroxylate the benzene ring to form a catechol derivative and then to open the ring through *ortho* or *meta* oxidation [6]. Most of these studies have involved single microbial species which may have limitations in field application due to the variety of contaminants in the waste. The activated sludge is considered as a natural microbial consortium and appears as a more attractive solution because of its various advantages [7]. In the present study we thus chose to work with activated sludge. Most of the work that has been carried out and reported has invariably related the rate of degradation with respect to biomass concentration and phenol concentration. Since activated sludge is an highly aerobic system, it was thought desirable to study the rate of phenol degradation with dissolved oxygen levels.

2. Material and methods

The sludge was brought from a waste water treatment plant of a local petrochemical complex where one of the waste water ingredients was phenol. Most of the chemicals used were AR grade and were obtained from standard sources.

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2.1. Culture conditions/acclimatization

The seed inoculation (sludge) was acclimatized to phenol as the sole source of carbon with other salts like $MgSO_4 \cdot 7H_2O$, 25; $FeCl_3 \cdot 6H_2O$, 1.2; $CaCl_2 \cdot 2H_2O$, 1.9; $MnSO_4 \cdot H_2O$, 2.5; $(NH_4)_2SO_4$, 1000; KH_2PO_4, 1320 and K_2HPO_4, 2680 added in the concentration (mg/l) to the basal medium. Enrichment of the sludge microbial population was carried out by taking a part of the seed inoculum into a 5 l beaker with aeration arrangement. Each day a part of the aerating fluid was discarded. The system was brought back to its original volume with tap water and concentrated stock solution of carbon source and nutrients in appropriate amounts sufficient to provide the desired final concentration in the feed (phenol concentration in the final mixture was 50 ppm). The phenol concentration was maintained at this level for a week. The phenol concentration was increased to 400 ppm in increments of 50. The sludge was said to be acclimatized when phenol from the system was completely degraded in repeated uses in fixed time intervals.

2.2. Estimation of phenol

Phenol concentration was estimated using the 4-amino-antipyrine method as described in standard methods for the examination of water and waste waters [7,8].

2.3. Determination of mother liquor suspended solids (MLSS)

Sludge (25 ml) was filtered through a pre weighed Whatman filter paper no. 1. The paper was dried in oven at 105 °C for 30 min. Difference in weight was reported as sludge solid in mg/l.

2.4. Estimation of dissolved oxygen (DO)

Winkler's method was used for estimating the dissolved oxygen in the system [9].

2.5. Batch reactor

Studies were conducted in a batch reactor to investigate the rate of phenol degradation and also the levels of dissolved oxygen present in the system. A glass beaker of 5 l capacity was used as the reactor. Sludge acclimatized to 400 ppm phenol was taken and phenol was added to a final concentration of 400 ppm at the start of the experiment. The working volume of the reaction liquid was maintained at 3 l Overhead stirrer was used at 80 rpm to keep the organism in suspension and to ensure mixing of air bubbles. Oxygen was supplied using fish tank aeration pump or as otherwise mentioned. Samples were collected at definite time intervals to estimate the phenol concentration, MLSS, and DO. After taking samples, water was added to the system to make up the volume of the reactor. During analysis appropriate corrections was made to take into account the dilution due to water addition.

2.6. Effect of biomass concentration

The kinetics of phenol degradation by the sludge was assessed in a batch reactor using three different concentrations of biomass (MLSS) and keeping starting phenol concentration same (400 ppm) and also under similar conditions for oxygen supply (air flow 4 l/h).

2.7. Effect of increased oxygen supply

To study the effect of increased oxygen availability for phenol degradation in the batch system, various aeration modes were investigated. A fish tank aeration pump that supplied air at two different flow rates (2 and 4 l/h) were used in conjunction with the basic setup described earlier. To increase the oxygen supply further, an oxygen concentrator (AIRSEP Corp., NY, USA) was used to supply oxygen at flow rate of 2 l/h. An oxygen concentrator is able to deliver oxygen concentrated to 95% on the principle of Pressure Swing Adsorption (PSA) wherein synthetic Zeolites are used to adsorb impurities from air. In the case of the control system no external aeration was supplied, but the suspension in the reactor was mixed with an overhead stirrer at 80 rpm.

2.8. Rotating Biological Contactor

A single stage bench scale RBC reactor was fabricated using 2 mm thick stainless steel discs of 0.09 m diameter. Nine such discs were mounted on a horizontal shaft at 0.01 m distance from each other. The shaft containing the discs were placed in a trough such that the discs are partly submerged in water and partly exposed to air. At 50% submergence the working volume was 500 ml. The desired rotational speed of discs was obtained using a motor with a gearbox. The trough was fitted with two nozzles for the inflowing and out flowing solution. Flow of phenol solution through the RBC was controlled using a peristaltic pump.

2.9. Immobilization of activated sludge on RBC

The discs were made with holes so that flannel cloth could be stitched on either surfaces of the disc. Acclimatized sludge (500 ml) was then poured in the trough, with both the nozzles clamped. When the discs were rotated the sludge adhered to the cloth surface. After 1 h, the inlet nozzle was connected to a reservoir containing the growth medium, which was perfused till a healthy growth of the biofilm was seen on all the plates. The outlet was let into a drain.