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Biodegradation of phenolic wastewater in a bubble column bioreactor with internal draft tube

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In the present study, phenol present in synthetic wastewater has been biodegraded in a bubble column bioreactor using ***Pseudomonas putida*** (NCIM-2650). Experiments have been carried out at various feed flow rates of synthetic wastewater, at a feed concentration of 250 mg/L and air flow rate of 2 Lpm. The effect of internal draft tube height on biodegradation of phenol has also been studied. It is observed that with increase in draft tube height, better performance of the reactor is obtained. Volumetric oxygen mass transfer coefficient and gas holdup have been found to increase when draft tube is used.

Keywords: Biodegradation, Bioreactor, Bubble column, Draft tube, Phenol, Wastewater

Phenol is one of the major organic pollutants found in the wastewaters from process industries such as petroleum refineries, coal carbonization units, gas and coke industries and fibreglass units. Phenol is irritating and corrosive. Consumption of water containing phenol leads to health problems[1]. Phenol has usually been removed by physicochemical methods, such as adsorption, ion exchange or chemical oxidation. However, biological treatment of wastewater has been reported to be promising as it produces innocuous end products. Treatment of phenolic wastewater in different types of bioreactors, such as packed beds and fluidized beds[2-4] has been reported. Bubble column reactors have been receiving increased attention because of the inherent advantages. Bubble columns are simple to construct and operate. They consist of vessels, which are usually cylindrical, in which gas is sparged into a liquid. They have no moving parts, as adequate levels of mixing can be achieved with the sparged gas. In bubble column bioreactors (BCRs), all the energy needed for agitation, as well as the oxygen required for the culture, is provided by sparged air.

Bubble column reactors owe their wide application area to a number of advantages they provide both in design and operation as compared to other reactors. They have excellent heat and mass transfer characteristics, meaning high heat and mass transfer coefficients. Little maintenance and low operating costs are required due to lack of moving parts and compactness. Bubble columns have been investigated for gas holdup studies[5-8], bubble characteristics[9-11], flow regime investigations and computational fluid dynamics studies[12-14], local and average heat transfer measurements[15,16] and mass transfer studies[17,18].

An important application area of bubble columns is their use as bioreactors in which microorganisms are utilized in order to produce industrially valuable products such as enzymes, proteins, antibiotics, etc[19]. Bubble columns are intensively utilized as multiphase contactors and reactors in chemical, petrochemical, biochemical and metallurgical industries[12]. They are used especially in chemical processes involving reactions such as oxidation, chlorination, alkylation, polymerization and hydrogenation, in the manufacture of synthetic fuels by gas conversion processes and in biochemical processes such as fermentation and biological wastewater treatment[9,20].

Draft tubes have been used as inserts in bubble columns[21,22], airlift bioreactors[23-25] and fluidized bed bioreactors[2,4] to improve the circulation of the reactor contents, thereby improving the performance of the process. Reports of biodegradation of phenol in bubble column bioreactors have been found scanty. In this study, biodegradation of phenolic wastewater in a bubble column bioreactor has been carried out. The effect of draft tube height on the (i) biodegradation of phenol (ii) gas holdup and (iii) volumetric mass transfer coefficient has been investigated.

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Experimental Procedure

Experimental set-up

The experimental set-up is shown in the Fig.1. The bubble column bioreactor is made of glass. A sparger made of glass has been provided at the bottom of the reactor through which air can be sparged into the reactor. The active volume of the reactor is about 3.54 L. The top of the glass reactor is closed with a plate through which all the probes and sensors are inserted into the reactor. An overflow line has been provided at the top, so that the reaction medium flows out of the reactor in continuous operation. The reactor is provided with a glass jacket to maintain the temperature of the reactor system above or below the ambient temperature. Depending on the temperature set for the reactor operation, controller switches on either the heating or refrigeration circuit. Separate tanks made of stainless steel have been provided for supplying the feed, medium, acid and base solutions for pH control. Two types of connecting tubing are used in the set-up. One is silicon tubing and the other is PVC.

Oxygen will be consumed in the degradation of phenol by microorganism. Oxygen required for the process was supplied in the form of air from a compressor. The flow rate of air was measured using rotameter, with a range of 1–10 Lpm. To maintain the pH of the system, a ***p***H meter and a controller were provided. ***p***H was maintained by addition of acid or base from the tanks.

Culture preparation

Pseudomonas putida (NCIM-2650), reported to be capable of using phenol as carbon source, was collected from National Collection of Industrial Microorganisms (NCIM) of National Chemical Laboratory (NCL), Pune, India. The culture was maintained by periodic subculture on nutrient agar and stored in a refrigerator. The reaction medium was prepared from this strain by growing the bacteria on 3.54 L of 50 ppm (mg/L) phenol solution containing growth medium of the composition KH_2PO_4 420 mg/L, K_2HPO_4 375 mg/L, $(NH_4)_2SO_4$ 240 mg/L, NaCl 15 mg/L, $CaCl_2$ 15 mg/L, and $MgSO_4.H_2O$ 30 mg/L. Sterilization of the phenol solution was done before inoculation of the organism. This has been done to selectively grow the microorganism. After the inoculation, the bacteria was allowed to grow in incubator at 30°C for 24 h. The bacteria was

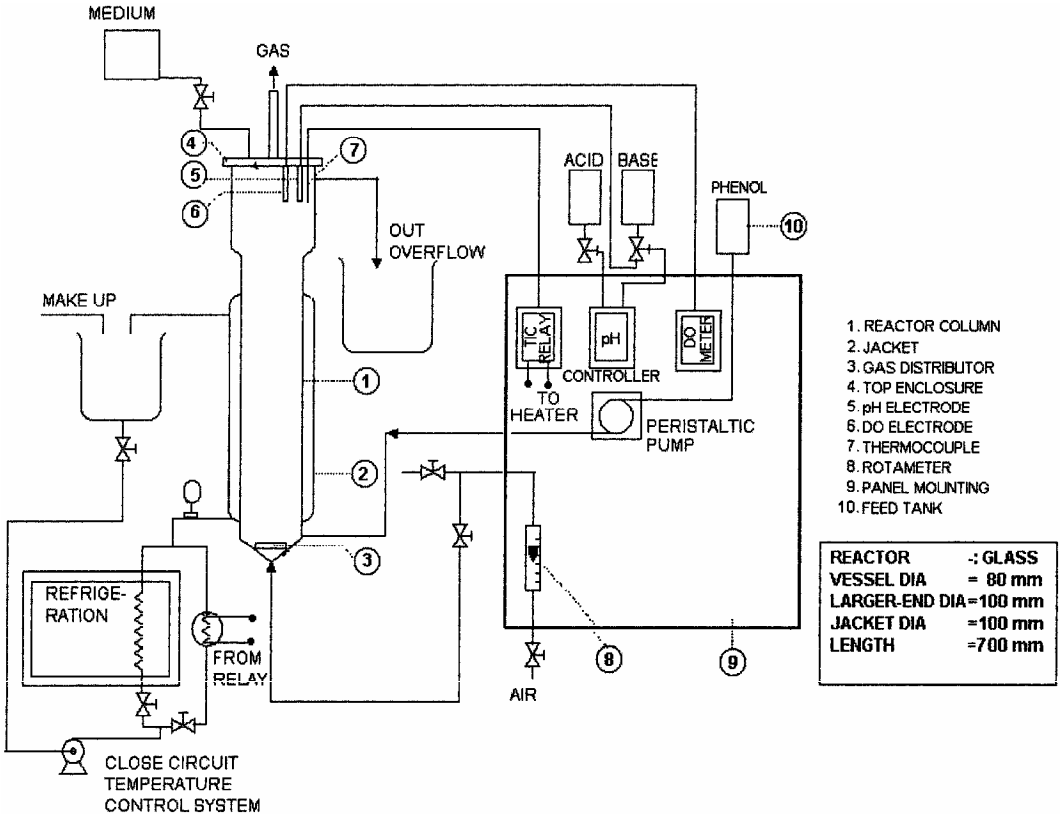

Fig.1 ─ Experimental setup

subcultured (100 mL of nutrient broth/agar) once in a month by preparing slants using nutrient agar of composition beef extract 1.0 g, NaCl 0.5 g, peptone 1.0 g and agar-agar 2.0 g. Sterile conditions were not maintained during the continuous operation of the reactor.

Start-up of the equipment

The 3.54 L of reaction medium after 24 h of inoculation was transferred to bioreactor. In the first run thereafter, the bioreactor was put in continuous operation with a feed flow rate of 390 mL/h. Synthetic wastewater containing phenol was used as feed. Synthetic wastewater was prepared by distilling phenol to obtain pure phenol and dissolving it subsequently in water. Phenol concentration in feed was 250 ppm (mg/L). The ***p***H in all the runs was maintained at 7.0 using 0.1 N HCl and 0.1N NaOH. The reaction temperature was maintained at 30°C in all the runs using the temperature controller provided with a heating/cooling circuit.

Biodegradation studies

Experiments have been carried out in bubble column bioreactor for biodegradation of phenolic wastewater in continuous mode at feed concentration of 250 mg/L, feed flow rates of 390, 450, 510, 570 and 630 mL/h and air flow rate of 2 Lpm. Three draft tubes of different sizes have been used in the study. The details of the draft tubes are given in Table 1. The arrangement of the draft tube inside the bioreactor is shown in Fig.2. The draft tube rests on the bottom of the bioreactor vessel. Phenol concentration has been determined using iodometric method[26].

Determination of volume fraction of gas phase (gas holdup)

In all the runs, air has been used to maintain dissolved oxygen concentration in the reactor. To find the volume of the gas phase in the reactor, the air supply to the reactor was suddenly shut off when the reactor was operating in steady state. As a result of this, the level of the reaction medium in the reactor would fall by an amount equal to the volume of the gas phase present in the reactor when it is in steady state operation. This volume was determined by measuring the volume of the liquid required to fill the reactor to the previous level. This measured volume was divided by the total reactor volume to obtain the volume fraction (gas holdup) of the gas phase in the reactor.

Table 1—Dimensions of draft tube

Parameter	Inside diameter, cm	Height, cm
Draft tube 1	4.5	47
Draft tube 2	4.5	39
Draft tube 3	4.5	27.5

Oxygen mass transfer coefficient

The dynamic method has been used to determine the volumetric oxygen mass transfer coefficient (***k_La***). The method is based on the response of the dissolved oxygen concentration to changes in the oxygen concentration in inlet gas phase[27].

Results and Discussion

Biodegradation of phenolic wastewater with a feed concentration of 250 ppm (mg/L) at various feed flow rates (390, 450, 510, 570 and 630 mL/h), for three different draft tubes has been studied. Figure 3 shows the effect of feed flow rate on biodegradation of phenol for draft tube 1. It is observed that as the feed

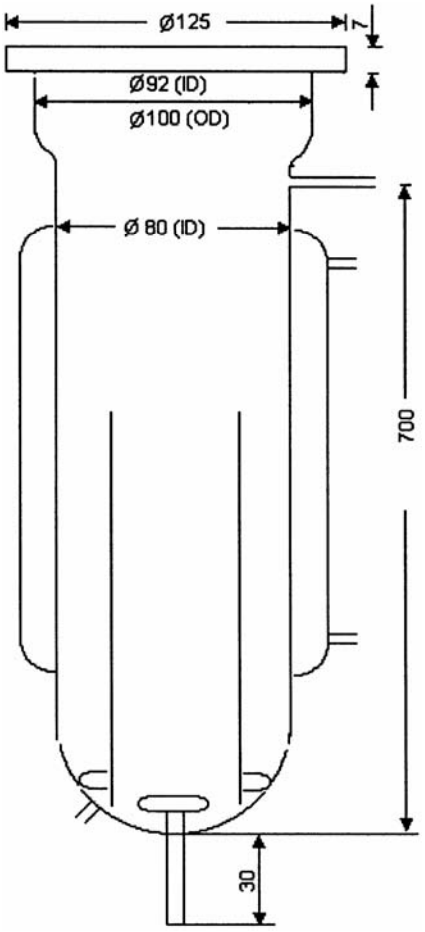

Fig.2—Bioreactor and draft tube (all dimension in mm)

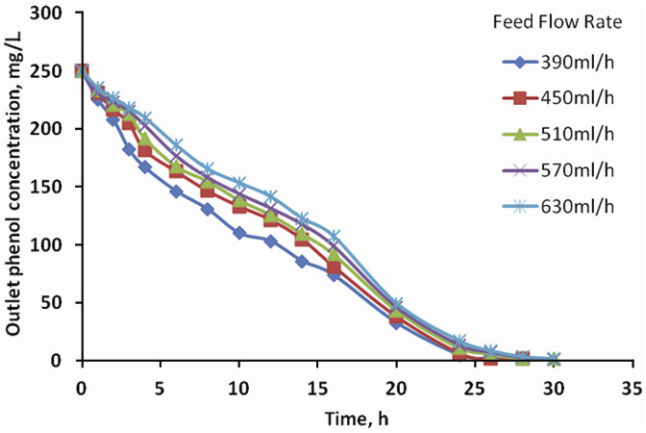

Fig.3—Outlet phenol concentration as function of time for draft tube 1

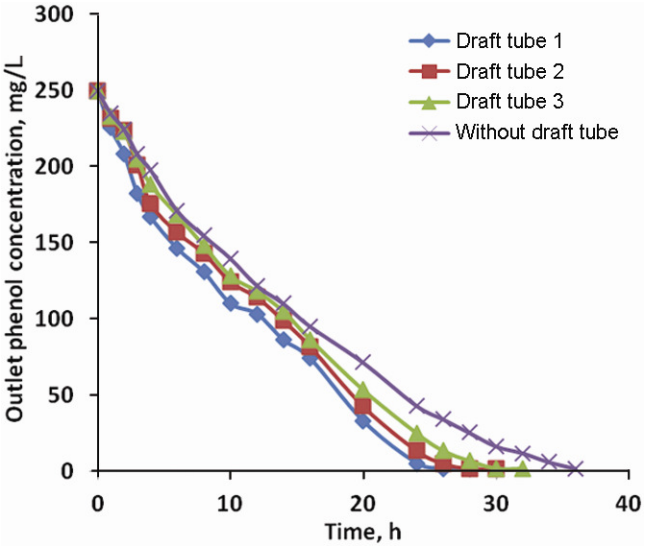

Fig.4—Outlet phenol concentration as function of time (feed flow rate 390mL/h)

flow rate increases the time required to reach steady state increases. A similar trend was obtained for draft tubes 2 and 3. Figure 4 shows the performance of the reactor with and without draft tube, for feed flow rate 390 mL/h. The performance of the reactor is better when the draft tube is used. Further, with the increase in draft tube height, the performance of the reactor improves. This can be seen from the lower time required to reach steady state as the draft tube height is increased. This can be attributed to the improved circulation of the contents in the reactor, leading to better performance of the reactor when draft tube is used. A similar trend was obtained for other feed flow rates.

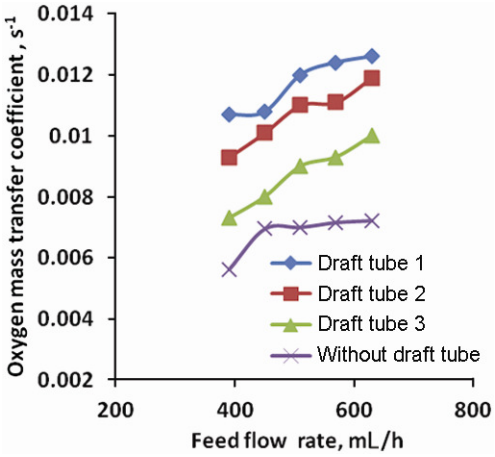

Fig.5—Oxygen mass transfer coefficient

The results of the study for the volumetric oxygen mass transfer coefficient are shown in Fig.5. The values of the mass transfer coefficient obtained are in the range of 0.00562 – 0.00723s^{-1} when study is carried out without draft tube, and in the range of 0.0073 - 0.0126 s^{-1} when the draft tubes are used. It is observed that the mass transfer coefficient increases with the increase in feed flow rates. Use of draft tube has increased the mass transfer coefficient for oxygen from gas phase to the liquid phase, which results in higher mass transfer rates. As the microorganism is aerobic, this increased supply of oxygen results in better biodegradation as observed in the previous figures. The values of the mass transfer coefficient give an idea of resistance to oxygen mass transfer from gas phase to liquid phase in the biodegradation of phenol in bubble column bioreactor. The values obtained in the present study are found to be more than the values reported for biodegradation of phenol in fluidized bed bioreactors. Worden and Donaldson[28] in their study on dynamics of a fluidized bed bioreactor (FBR) treating phenol obtained $\boldsymbol{K_L a}$ (overall coefficient) in the absence of reaction in the range 0.005 – 0.01 s^{-1}. They used deoxygenated water in the experiments to transfer oxygen from gas phase to liquid (water) phase.

The results of the study for gas holdup are shown in Fig.6. It is observed that gas holdup is more when draft tube is used. Further, as the height of the draft tube is increased, the gas holdup is found to increase. When draft tube is used for a given flow rate, the gas velocity is more compared to the operation without draft tube, as the draft tube has smaller cross-sectional area.

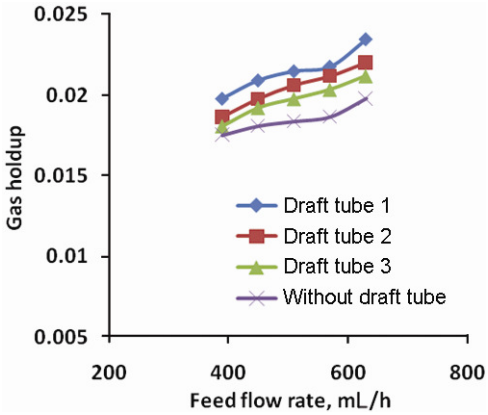

Fig.6—Variation of gas hold-up (fraction) with feed flow rates and with draft tubes 1, 2 and 3 without draft tube

Conclusion

The performance of bubble column bioreactor has been evaluated with three draft tubes of different heights, using the microorganism ***Pseudomonas putida***. It is found that the biodegradation is better when draft tubes are used. The performance of the bubble column bioreactor has improved with increase in draft tube height. The volumetric oxygen mass transfer coefficient and gas holdup are also found to increase with increase in draft tube height.

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