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Aerobic digestion of starch wastewater in a fluidized bed bioreactor with low density biomass support

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Abstract

A solid–liquid–gas, multiphase, fluidized bed bioreactor with low density particles was used in this study to treat the high organic content starch industry wastewater. The characteristics of starch wastewater were studied. It shows high organic content and acidic nature. The performance of a three phase fluidized bed bioreactor with low density biomass support was studied under various average initial substrate concentrations, by varying COD values (2250, 4475, 6730 and 8910 mg/L) and for various hydraulic retention times (8, 16, 24, 32 and 40 h) based on COD removal efficiency. The optimum bed height for the maximum COD reduction was found to be 80 cm. Experiments were carried out in the bioreactor at an optimized bed height, after the formation of biofilm on the surface of low-density particles (density = 870 kg/m^3). Mixed culture obtained from the sludge, taken from starch industry effluent treatment plant, was used as the source for microorganisms. From the results it was observed that increase in initial substrate concentration leads to decrease in COD reduction and COD reduction increases with increase in hydraulic retention time. The optimum COD removal of 93.8% occurs at an initial substrate concentration of 2250 mg/L and for the hydraulic retention time of 24 h.

Keywords: Fluidized bed; Starch wastewater; Low density particles; Three phase

1. Introduction

During the last few years the application of fluidization in the field of biotechnology has increased considerably [1]. The main application of fluidization principle is in the field of environmental biotechnology. Fluidized bed bioreactor has several advantages over other conventional reactors for the treatment of wastewater. The limitation of the fluidized bed reactor in wastewater treatment is the biofilm thickness. There is a problem of increase in biofilm thickness when the microorganisms in the biofilm multiply. This limits diffusion of oxygen and/or the organic substrate to the deeper layers of the biofilm. Starvation of the microorganisms at the base of the biofilm causes pieces of the biofilm to detach and leads to ineffective bioreactor operation. In the fluidized bed bioreactor with low-density particles, the control of biofilm thickness is achieved within a narrow range and it was found that this bioreactor is more efficient when used for biological aerobic wastewater treatment [2].

There were several studies on hydrodynamics [3–5] and mass transfer aspects of this kind of reactor [6,7]. This bioreactor is successfully used for ferrous iron oxidation by *Thiobacillus ferrooxidans* [2]. A few research works deal with the application of fluidized bed bioreactor with low density particles on wastewater treatment [8–12].

Cassava is one of the world's most important staple food crops. The industrial uses of starch and starch products are numerous. In the international trade cassava enjoys a good position as raw material for compound animal feed, mostly in two basic forms of processing, namely cassava chips and cassava pellets. The wastewater generated from cassava industries are highly organic and acidic in nature. Several authors have reported the physical methods, chemical methods of treatment and anaerobic digestion of starch industry wastewater [13,14]. Only a few research works [15,16] are available on degradation of starch effluent by aerobic microbes and hence this work focuses on the treatment of the starch industry wastewater by aerobic microorganisms in a fluidized bed bioreactor with low density biomass support. The objective of this study is to characterize the starch wastewater and to treat it in this reactor by varying the hydraulic retention time and initial substrate con-

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centration. Experiments were also conducted to find out the optimum bed height and to study the behavior of air holdup.

2. Materials and methods

2.1. Experimental setup

The schematic diagram of the fluidized bed bioreactor is shown in Fig. 1. The column was made of Perspex had the dimensions of 0.092 m internal diameter, 1.7 m height with a conical bottom and a wall thickness of 3 mm. The air was introduced by means of a sparger, located just below the supporting mesh, which helps in uniform mixing. Airflow rate is measured by a rotameter and a valve is used to control the flow rate. The reactor is monitored for pH and it is maintained by the addition of acid or alkali. The low density biomass support particles were made of polypropylene of density 870 kg/m^3 and irregular in shape with more surface area (390 m^2/m^3). It requires a low gas velocity for being expanded.

2.2. Reactor inoculation and startup

Hydrodynamic studies were carried out to find out the air holdup for various air flow rate and bed heights. The reactor was filled with the supporting material to give 80 cm initial bed height from the supporting mesh. Rajasimman and Karthikeyan [17] studied the effect of bed height on COD removal and found that a bed height of 80 cm was found to be optimum for starch industry wastewater in this reactor. The substrate is an industrial starch wastewater without any minerals. The inoculums were prepared from the sludge taken from the starch industry effluent treatment plant. It was introduced into the reactor along with the biomass support particles and substrate, to start the growth of microorganisms on the surface of supporting materials. Air was supplied at a rate of 48.64 cm^3/s, which is sufficient for biomass growth, and pH is maintained between 5.9 and 6.1. It was found that a pH value of 6 was found to be the optimum for the better degradation of starch wastewater using the sludge [17]. The set up was left for 20 days with aeration in order to enhance microbial film formation on the low density support material. After the completion of film formation, the liquid medium inside the reactor is withdrawn leaving the biomass-laden particles. Then the substrate was pumped into the reactor and air was supplied at the same rate.

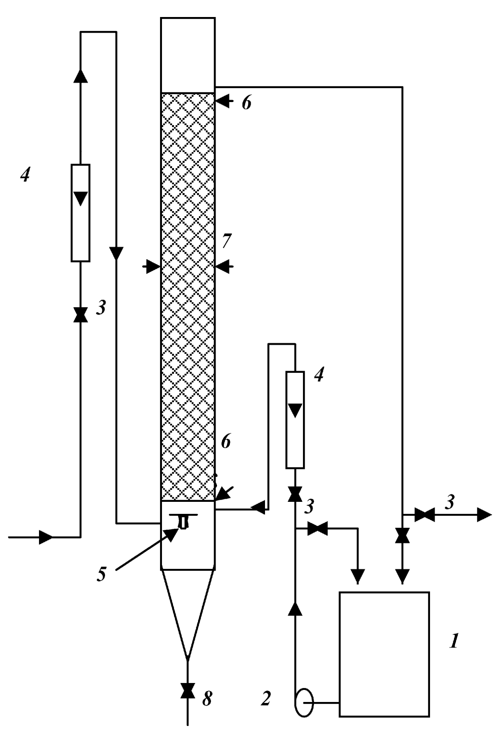

Fig. 1. Schematic diagram of fluidized bed bioreactor: (1) storage tank; (2) centrifugal pump; (3) valves; (4) rotameter; (5) air sparger; (6) supporting mesh; (7) fluidizing section; (8) discharge valve.

Table 1
Characteristics of starch industry wastewater

Parameter	Values
pH	4.5–4.8
Chemical oxygen demand (mg/L)	8560–8910
Biological oxygen demand (mg/L)	5810–6020
Total solids (mg/L)	7275–7815
Volatile solids (mg/L)	5000–5230
Total dissolved solids (mg/L)	6035–6120
Total suspended solids (mg/L)	1240–1695
Volatile suspended solids (mg/L)	900–1005

2.3. Experimental procedure

The characteristics of starch wastewater are given in Table 1. All the analysis were made according to the procedures given in APHA [18]. In this study, co current mode of operation was carried out, i.e. both gas and liquid were introduced at the bottom of the reactor. Experiments were carried out in a semi continuous mode, i.e., air was supplied continuously and liquid was introduced into the reactor in batch mode during the startup of the reactor. After attaining constant biomass loading, the wastewater was pumped into the reactor. Air was supplied with a flow rate equal to that of the aeration used for the growth of microbes. The performance of the reactor was studied by measuring COD values at regular intervals of time. Then the flow rate of air was varied and COD reduction was observed for all the flow rates. The above procedure is repeated for various initial concentrations of the starch industry wastewater (2250, 4475, 6730 and 8910 mg/L) and for various hydraulic retention time i.e. for 8, 16, 24, 32 and 40 h.

3. Results and discussion

3.1. Wastewater characterization

Table 1 shows the characteristics of starch industry wastewater. The high COD and BOD value shows that the wastewater has high organic content and pH value of 4.5 indicates acidic nature of the wastewater. The acidic nature is due to release of acid from roots and also use of acids during final stage operations. The ratio of BOD to COD was 0.67, which indicates that starch

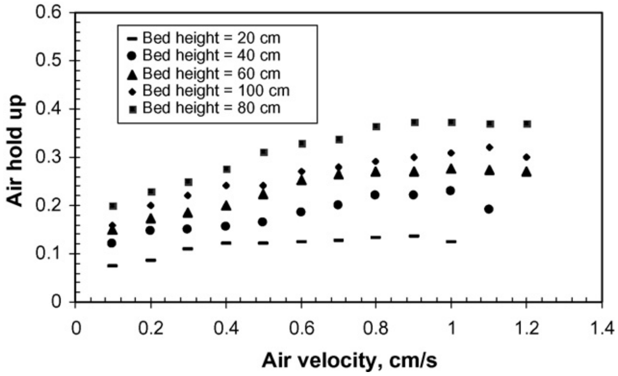

Fig. 2. Effect of air velocity on air holdup for various initial bed heights.

wastewater is biologically degradable. From Table 1 it was also observed that the wastewater has higher solid content.

3.2. Air holdup and bed height optimization

The hydrodynamics studies are important in designing the reactor for application of wastewater treatment. From Fig. 2, it was inferred that the air holdup increases with increase in air flow rate and decreases after reaches the critical velocity. Air holdup also increases with increase in bed height and then decreases after reaches a bed height of 80 cm. These results are well matched with the findings of Rajasimman and Karthikeyan [19].

The variation of COD reduction with initial bed height was shown in Fig. 3. It was inferred that the reduction in COD increases with increase in bed height and then decreases after reaches an optimum bed height of 80 cm. The increase in COD reduction with bed height was due to increase in volume of biomass support particles which lead to increase in biomass concentration for the degradation of wastewater. Further increase in bed height leads to the decrease COD reduction due to the reduction in air holdup. This observation is consistent with the results obtained by Ocheing et al. [11] in which it was observed that the particle loading affects phase mixing and affects the mass transfer characteristics. Hence all the experiments were carried out at a fixed bed height of 80 cm, which was found to be the optimum for the maximum degradation of starch industry effluent [17]. These findings are well supported by Ochieng et al. [11] and Sokol [20].

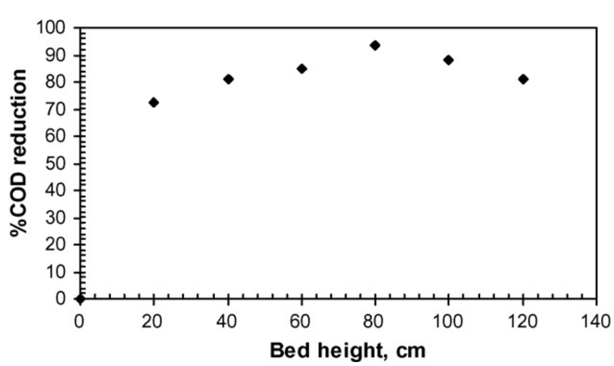

Fig. 3. Effect of initial bed height on COD reduction.

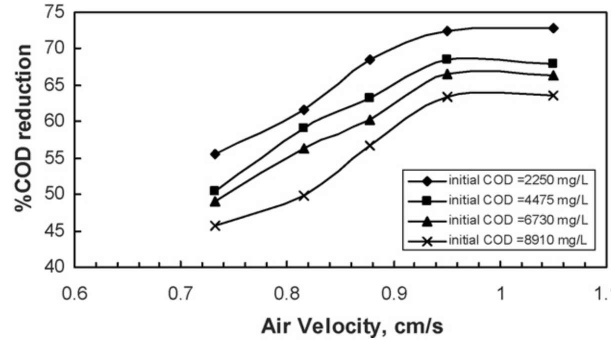

Fig. 4. Effect of initial substrate concentration on %COD reduction-HRT of 8 h.

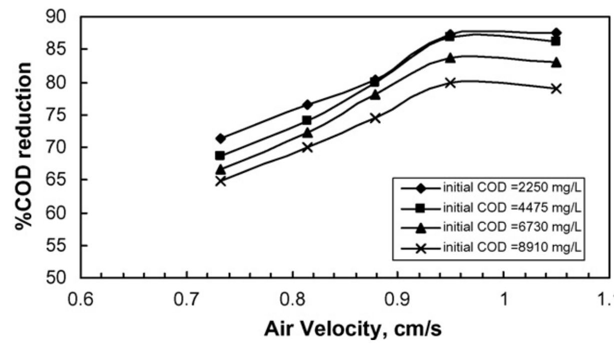

Fig. 5. Effect of initial substrate concentration on %COD reduction-HRT of 16 h.

3.3. Initial substrate concentration

The results obtained for various initial concentration and hydraulic retention times were shown in Figs. 4–8. Fig. 4 shows the percentage of COD reductions for the hydraulic retention time of 8 h at various initial concentration of the starch wastewater. The maximum COD removal of 72.8% was observed at an initial concentration of 2250 mg/L and a minimum of 63.6% for 8910 mg/L for the air flow rate 69.77 cm^3/s. It was inferred that as the initial concentration of the substrate increases, the percentage reduction of COD decreases and at low substrate concentration the degradation occurs at a faster rate than at

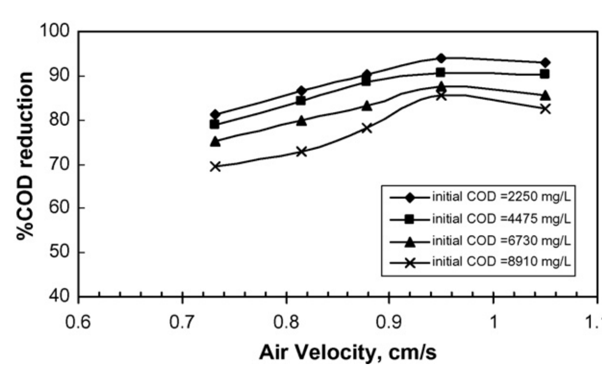

Fig. 6. Effect of initial substrate concentration on %COD reduction-HRT of 24 h.

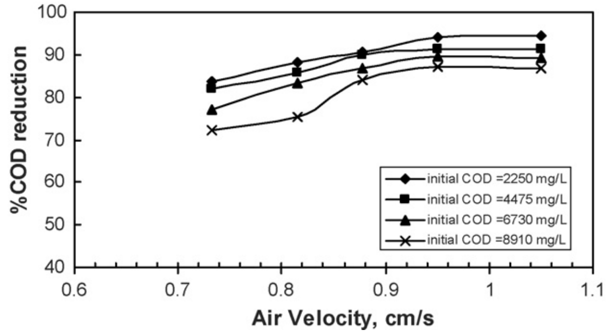

Fig. 7. Effect of initial substrate concentration on %COD reduction-HRT of 32 h.

higher concentrations. This may be due to presence of low level of organics present in the wastewater and the lesser resistance offered by them. With increase in concentration of effluent, the quantity of pollutants and organics to be treated were found to increase which in turn was found to inhibit the degradation rate. It was also observed that as the flow rate increases the COD reduction increases and then decreases after reaches a velocity called critical velocity. This may be due to, the air holdup starts decreasing after the critical velocity and also the retention time of gas was also found to be low. This is in agreement with the findings of Sokol [20]. Figs. 5–8 show the percentage reduction for various hydraulic retention time of 16, 24, 32 and 40 h. The same trend was observed for the treatment at various hydraulic retention time.

3.4. Hydraulic retention time

Hydraulic retention time is an important parameter in the application of wastewater treatment for any reactor. Fig. 9 shows the effect of hydraulic retention time on the percentage reduction of COD. From Fig. 9, it was observed that the degradation efficiency increases with increase in HRT for all the initial substrate concentrations. The maximum removal of 95.6% occurs at 40 h for the initial concentration of 2250 mg/L and for the initial concentration of 8910 mg/L, a reduction of 89.4% was observed. However a removal efficiency of 93.8% was achieved when HRT is 24 h, after that there was no significant reduction in COD values. Hence the optimum value was found to be 93.8% which occurs at a HRT of 24 h.

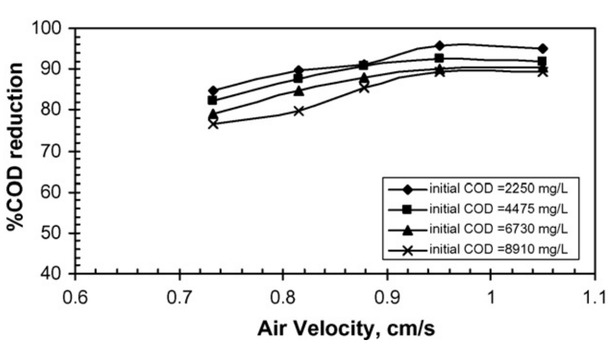

Fig. 8. Effect of initial substrate concentration on %COD reduction-HRT of 40 h.

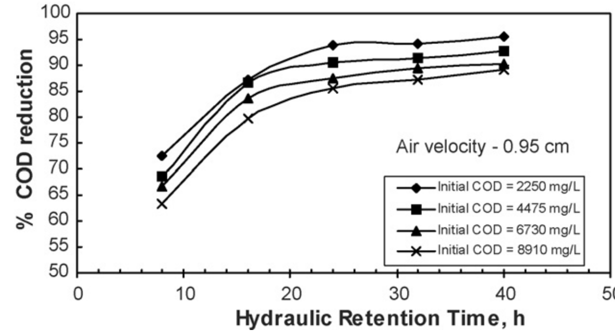

Fig. 9. Influence of HRT on %COD reduction.

4. Conclusions

The experiments were conducted in a fluidized bed reactor with low-density biomass support at various HRT and for different initial substrate concentrations. From the present study, it was found that this bioreactor with low-density particles could be utilized for the treatment of starch industry wastewater. From this work the following conclusions were drawn:

- The characteristics of starch wastewater show high organic content and acidic nature. It also has high solid content.
- From the hydrodynamic studies it was observed that the air holdup increases with increase in air velocity and then decreases after reaching the critical velocity. Similarly air holdup increases with increase in initial bed height and decreases after critical bed height.
- Reduction of COD is depends on the initial substrate concentration, hydraulic retention time and air flow rate for a fixed bed height.
- The percentage reduction of COD increases with increase in HRT but decreases with increase in initial substrate concentration. An optimum COD removal of 93.8% occurs at an initial substrate concentration of 2250 mg/L for the airflow rate 63.12 cm^3/s.

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