Starch Wastewater Treatment in a Three Phase Fluidized Bed Bioreactor with Low Density Biomass Support

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ABSTRACT: Aerobic digestion of starch industry wastewater was carried out in an inverse fluidized bed bioreactor using low density (870 kg/m^3) polypropylene particles. Experiments were carried at different initial substrate concentration of 2250, 4475, 6730 and 8910mg COD/L and for various hydraulic retention time 40, 32, 24, 16 and 8h. Degradation of organic matter was studied at different organic loading rate by varying the hydraulic retention time and initial substrate concentration. From the results it was observed that the maximum COD removal of 95.6% occurs at an organic loading rate of 1.35 kg COD/m^3/d and a minimum of 51.8% at an OLR of 26.73 kg COD/m^3/d. The properties of biomass accumulation on the surface of particles were also studied. It was observed that a constant biomass loading was achieved over the entire period of operation. @JASEM

Nomenclature

σ - Biofilm thickness, cm
r_p - Support particle radius , cm
ρ_p - Density of the particle, g/cc
d_p – Diameter of the particle, cm
d_b – Diameter of the bioparticle, cm

M_s – Mass of the support particles, g
A – Surface area of particles, cm^2
H – bed height, cm
ρ_b – Bio particle density, g/cc
ρ_{bw} – Biofilm Density considered as 1g/cc

During the past few years the application of fluidization has increased considerably in the field of chemical, biochemical engineering and in wastewater treatment. It has many advantages over fixed bed reactors (Sokol, 2001). 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. The maximum biofilm thickness at which no diffusional limitation is observed is usually around 100 μm. Therefore to operate the bioreactor efficiently, the biofilm thickness should be approximately 100 μm. In order to maintain a constant biofilm thickness, the particles are taken out and the excess biofilm is removed and particles are sent to the reactor. The use of IFBBR can solve this problem (Karamanev and Nikolov, 1996).

The inverse fluidization is a multiphase gas-liquid-solid system. The difference between ordinary fluidization and inverse fluidization lies in the density of solid particles used in the reactor. If the density of the particles used is greater than the fluid, it is ordinary fluidization; if it is less than fluid it is called as inverse fluidization. The use of low-density particles has some advantages and overcomes the problem, which occurs during conventional fluidization. Low-density particles require low fluid velocity for their expansion and hence low power requirement. In IFBBR, the control of biofilm thickness is achieved within a narrow range (Karamanev, 1987). The particle-particle and particle wall collision maintains a constant biofilm thickness (Sokol, 2001). The present study aims to investigate the feasibility of an inverse fluidized bed bioreactor for the treatment of starch industry wastewater.

MATERIALS AND METHODS

The experimental set up of the inverse fluidized bed bioreactor (IFBBR) was shown in Figure 1. Reactor was made up of Perspex column and has the dimensions of 9.6 cm internal diameter, 220 cm height and a wall thickness of 0.4 cm. The bottom was conical in order to facilitate easy removal of solids settled in the reactor. The total volume of the reactor was 16 L. A vent was provided at the middle of the reactor for the easy loading and unloading of the particles from the reactor. Meshes were placed 30 cm from both top and bottom of the reactor to prevent the elutriation of particles and to retain the particles during shut down periods. A hand woven nylon mesh was used for this purpose. The supporting particles used in this study were made of polypropylene with a density of 870 kg/m^3. It is

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irregular in shape with a diameter of 10 mm and surface area of $390mm^2/mm^3$.

The reactor was filled with the supporting material to give 80 cm initial bed height from the supporting mesh. The substrate was starch industry wastewater. The inoculum was prepared from the sludge taken from the starch industry effluent treatment plant. It was introduced into the reactor along with the support particles and substrate, to start the growth of microorganisms on the surface of supporting materials. Since the wastewater was deficient of phosphorous and nitrogen small quantity of potassium phosphate and ammonium chloride are

added to the wastewater as per requirement (Nehru Kumar, 2001). Air is supplied at the rate of 11.11 cc/s, which is sufficient for biomass growth and pH was maintained between 5.9 and 6.1. It was found that a pH value of 6 is optimum for the better degradation of starch wastewater using the sludge (Rajasimman and Karthikeyan, 2004). The set up was left for 20 days with aeration in order to enhance microbial film formation on the low-density support particle. After the completion of biofilm formation, the liquid medium inside the reactor was withdrawn leaving the biomass-laden particles. Then the substrate was pumped into the reactor and air was supplied at the same rate.
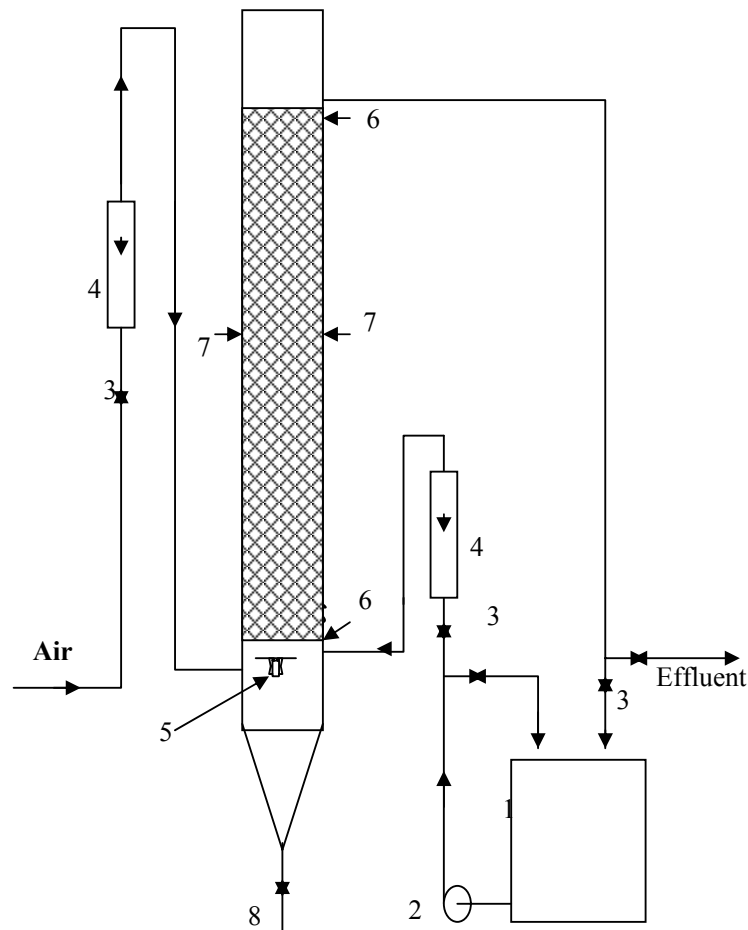
Fig.1 Inverse Fluidized Bed Bioreactor
1.Storage tank. 2.Centrifugal pump. 3.Valves. 4.Rotameter. 5.Air Sparger. 6.Supporting mesh. 7.Fluidizing section. 8.Discharge valve.

Biomass growth on the low-density particles, in the reactor was continuously monitored. The particles covered by biofilm were taken out and the attached volatile solid (dry weight) was found out. The

difference between two weights was considered as the attached volatile solid that corresponds to the biomass weight (Garcia-Calderon *et al.*, 1998). Bioparticles samples were withdrawn from top,

middle and bottom of the reactor, because at the bottom of the reactor the density of the particles were found to be more when compared with the middle and top section of the reactor. This is due to the growth of biofilm on the surface of the particles and it is also an added advantage because the substrate concentration is more at the bottom. The biofilm thickness is calculated by the equation (Nikolov and Karamanev, 1990)

$$\sigma = \left| \frac{\left[\dfrac{M_S}{4\pi r_p^2} - \dfrac{r_p \rho_p}{3} \right]}{\rho_{bw}} \right| \qquad .....1$$

Bioparticle diameters are calculated according to Setiadi, (1995)

$$d_b = \sqrt{\frac{d_p^3 (1-\varepsilon)}{\left(\dfrac{M_s}{\rho_b HA} \right)}} \qquad .....2$$

Biofilm thickness and bio particle density are determined based on the equations (Sheikh *et al.,* 1981)

$$d_b = d_p + 2\sigma \qquad .....3$$

$$\rho_b = \rho_m \left(\frac{d_p}{d_b} \right)^3 + \rho_{bw} \left[1 - \left(\frac{d_p}{d_b} \right)^3 \right] ..4$$

Degradation of starch wastewater in IFBBR was carried out continuously in different stages by varying initial substrate concentration (2250, 4475, 6730 and 8910 mg COD/L) and hydraulic retention time (40, 32, 24, 16 and 8h). Degradation was started with an initial concentration of 2250 mg COD/L and a HRT of 40 h. The reactor was monitored continuously by measuring effluent COD values. When the reactor reaches steady state, the HRT was reduced to 32 h and reduction in COD was monitored. Experiment was continued with various HRT (24, 16 and 8h). The performance of the reactor was studied based on COD removal efficiency. Experiment was repeated for various initial substrate concentrations at five different HRT by maintaining an optimum bed height and air flow rate. The pH of the influent to the reactor was maintained at 6.0

RESULTS AND DISCUSSION
The performance of the IFBBR for the biodegradation of starch industry wastewater was studied in this work. All the studies were carried out at a bed height of 80 cm and at constant air flow rate of 62.50 cc/s, which is optimum for the maximum degradation rate (Rajasimman and Karthikeyan, 2006). The influent and effluent concentration of the

reactor for the average initial substrate concentration of 2250 mg COD/L was shown in Figure 2. Initially the reactor was started with an organic loading rate (OLR) of 1.35 kg COD/m^3/d. During the initial stage, percentage COD reduction was found to be low due to the fact that microbes need longer time for acclimatization. The maximum COD reduction of 95.6% occurs at the thirteenth day from the experiment start up period. The effect of OLR was investigated by varying HRT while maintaining the concentration of the influent constant. The HRT were varied from 40 h to 8 h. Organic loading rate was increased to 1.69 kgCOD/m^3/d by reducing HRT from 40 h to 32 h on fourteenth day and the reactor performance was monitored regularly by measuring effluent COD from the reactor. The reactor reached steady state within seven days of operation and the reduction in COD was found to be 94.7%.

After reaching the steady state, the OLR was increased to 2.25 kgCOD/m^3/d by reducing the HRT to 24 h and the percentage COD reduction was found to be 93.9% after 34 days. Then the HRT was decreased to 16 h and the maximum degradation of 87.5% was occurred at the 46th day. Although there is an instantaneous increase in the OLR while decreasing the HRT, a low effluent COD level is recovered in a short period of time. Then the HRT was decreased to 8 h and the maximum percentage removal of COD was found to be 72.8%. It was inferred that at lower HRT the percentage COD reduction was found to be low. This may be due to inadequate time for the degradation of waste by the biomass. With decrease in HRT the percentage COD reduction is found to decrease. However a significant drop in percentage COD reduction occurs for the HRT between 16 h and 8 h. It was also seen that there is no significant improvement in the degradation of organic matter above 24 h HRT. This is well in agreement with the findings of Choi *et al.*, 1995. When the organic loading rate is increased, sudden decrease in COD removal efficiency is observed and recovers at relatively in short period of time.

In the next stages, the average initial substrate concentration of the influent was increased to 4475, 6730 and 8910 mg COD/L and the reactor performance was observed. The degradation trend observed for the other initial substrate concentrations were similar to low concentration effluent. During final stage of operation, for the shock load condition of 26.73 kg COD/m^3/d with the HRT of 8 h, the percentage removal was found to be very low (51.8%). It was observed that a high amount of suspended matter present in the effluent leaving the reactor. The reactor exhibits a good stability to the variations in OLR and HRT (Arnaiz *et al.,*2005).
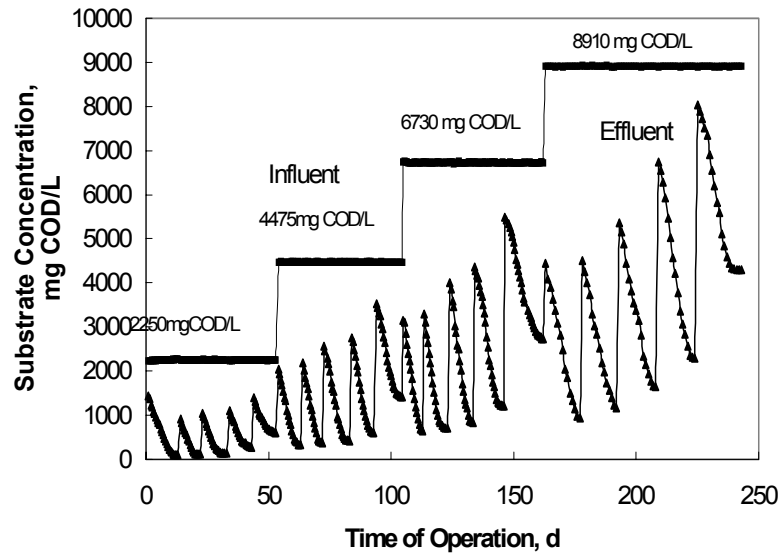
Fig.2 Variation of the effluent COD concentrations in response to the influent
COD concentrations resulted by the variation of HRT and organic loading rate

Figure 3 shows the relationship between the organic loading rate and the COD removal efficiency for overall performance of the reactor. During the initial stages, at low organic loading rate, the removal efficiency was found to be high (> 90 %). It was also observed that IFBBR has an excellent ability to overcome sudden disturbance in input organic loading. Some immediate decrease in COD removal efficiency is followed, but the high removal efficiency is recovered in a short period of time. In the Figure, for the same organic loading rate, a difference in percentage COD reduction was observed and it is due to the fact that the reactor is operated at different initial substrate concentrations.
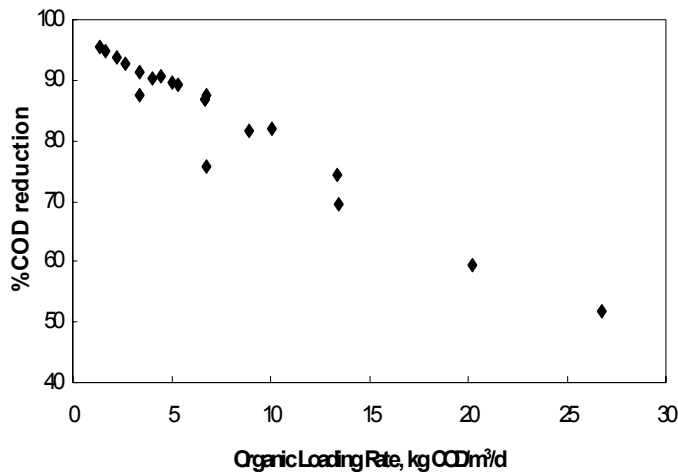

Fig.3 Effect of Organic Loading Rate on %COD reduction

Biomass accumulation was measured by the increase of the attached volatile solids on polypropylene particles. Samples were taken at different heights of the reactor. At the upper part of the fluidized bed, the attached volatile solids concentration was always lesser than in the lower levels of the bed. Particles with thicker biofilm were found at the lowest level of the reactor, because particle terminal velocity decreases with biofilm accumulation. It was shown in Figure 4. Al-Dibouni and Garside (1979) considered particle dispersion in a fluidized bed to be influenced by several parameters: overall porosity, liquid superficial velocity, particle size, density, and shape. Figure 5 shows the biofilm development (average of the sample points), as well as the particle density at different organic loading rates. The biofilm formed was constant over the entire period of operation. The irregular surface of polypropylene particle allowed an increased biomass hold-up and the biomass accumulation modified the particle characteristics. As diameter increases due to the formation of the biofilm on the

surface of the particle the density increases. Hermanovicz and Ganczarzyk (1983) and Setiadi (1995) considered that the biofilm-wet density is equal to 1000 kg/m^3. Average specific density of biocovered particles was found to be increased from 870 to 960 kg/m^3 with increasing biofilm thickness.
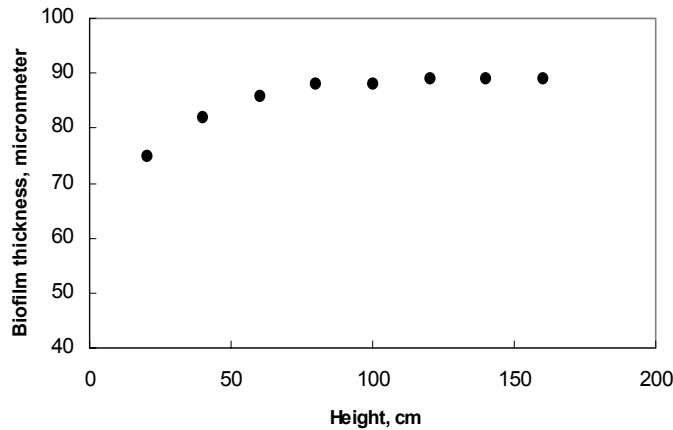

Fig. 4 Profile of the biofilm thickness by reactor height, h = 0 at top of the bed.
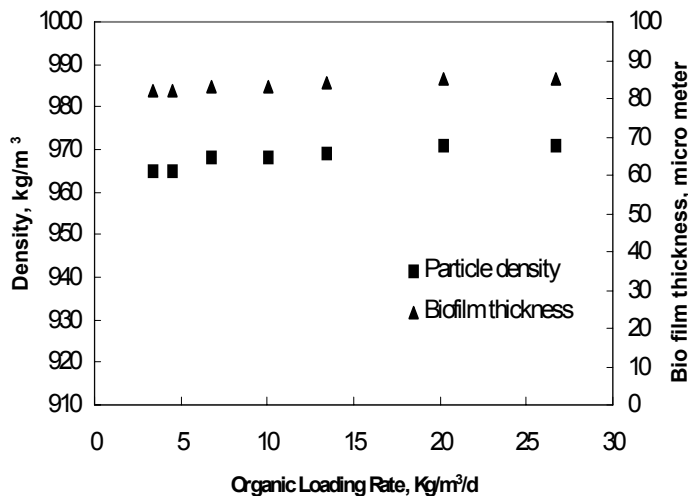

Fig.5 Biomass on the surface of particles at different OLR

Particles without biofilm presented the lowest bed expansion rate. At the same air velocity, bed expansion increased as biofilm thickness increased. This may be attributed to (i) Biofilm accumulation enlarges particles, and thus, original bed expansion is modified; and (ii) Terminal settling velocity decreases as particle density increases which means that microbial growth attachment would provoke a greater bed expansion rate at the same fluidization velocity (Garcia – Calderon *et al.*, 1998).

Conclusion: The experiments were conducted in a fluidized bed reactor with low-density biomass support at various hydraulic retention time and for different initial substrate concentrations. From the present study, it was found that the bioreactor with low-density particles can be utilized for the treatment of starch industry wastewater. The results were summarized as follows.

▪ The continuous degradation study was carried out at an optimized bed height and air flow rate. The parameters varied were initial substrate concentration (2250, 4475, 6730 and 8910 mg COD/L) and hydraulic retention time (40, 32, 24, 16 and 8h).

▪ The performance of the reactor was studied at various organic loading rates. At low OLR (< 5KgCOD/m^3/d), the efficiency of the reactor was found to be greater than 90%.

▪ At higher OLR, greater than 20 kg COD/ m^3/d, the COD removal efficiency was found to be less than 60%.

▪ The biofilm thickness was found to be constant thought the study.

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