Anaerobic treatment of low concentration waste water in an inverse fluidized bed reactor

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Abstract Low concentration synthetic and municipal wastewaters were treated at HRT as short as 3 and 0.6 h respectively in an anaerobic inverse fluidized bed. Both bioreactors showed gas hold up due to the liquid downflow pattern of the prototype. The bioreactor operated at 3 h had a removal efficiency of 83%, specific activity of 4.5 kg COD\text{removed}/kg IVS(d) and the gas hold up varied from 23 to 55%. The reactor treating municipal wastewater had a removal efficiency of 44% when operating at 0.6 h, the specific activity was 4.2 kg COD\text{removed}/kg IVS(d) and no biogas was detected apparently because an important fraction was dissolved in the liquid phase. The biomass concentration was 13.8 and 1.1 kg IVS/m³ for synthetic and municipal wastewater and the SEM microphotographs showed a bacterial diversity for the first run and only cocci cells for the second run. The system does not remove suspended solids, so a polishing posttreatment to improve water quality has to be implemented.

Keywords Biomass concentration; inverse fluidized bed; synthetic; municipal wastewater; specific loading rate; specific activity

Introduction

Biofilms provide longer biomass retention times than suspended growth but have an operational disadvantage due to the required time to develop the biofilm, typically 45 to 100 days, despite the natural tendency of the cells to attach to surfaces. The biofilm formation mechanism, the molecular structure that constitutes the biofilm and the microorganisms interactions between each other and the support has been extensively studied (Verrier et al. 1988; van Loosdrecht et al., 1990, Characklis, 1990).

Fluidized bed reactors (FBR) offer high biomass concentration over tiny inert support particles (<1 mm), compact biofilms and higher microbial activities. One of the most important aspects of the FBR is the biofilm formation, since the wastewater composition and the liquid superficial velocity are determinant for the biofilm microbial diversity, biomass concentration and consequently, density and thickness.

Immobilization of anaerobic bacteria in the inverse fluidized bed reactor (IFBR) has been recently reported (González et al. 1992; Meraz et al., 1995, 1996) and pointed out that the formation of very active and well adapted biofilm is necessary for a high conversion capacity.

The IFBR uses support media with densities lower than water, such as plastics (polyethylene, polypropylene, polystyrene) so the bed expands downwards due to the downflow liquid direction. By feeding gas the bed density diminishes so the liquid superficial velocity can be reduced (Fan et al., 1982). During the anaerobic treatment of wastewaters, the biogas produced into the reactor tends to rise countercurrent to the liquid direction remaining longer in the liquid phase. The operational restriction for this prototype when high strength wastewater is treated, is gas hold up due to the downflow pattern and biomass accumulation onto the support that changes bioparticles density (Meraz et al., 1997; García-Calderón et al., 1998; Buffière et al., 1999). When the designed loading rate is surpassed, and as biogas and biomass accumulation increases, the excessive bed expansion leads to reactive support displacement from the bed.
The present work shows a comparison between the results obtained from the treatment of synthetic and municipal wastewater in an anaerobic IFBR. In a first stage of the experimental work, the IFBR was fed with synthetic water. The obtained results were then used to establish the maximum achievable performance of the bioreactor. In a second stage, the IFBR was fed with municipal wastewater with lower concentrations than that of the synthetic wastewater. The results demonstrate the capacity of immobilized biomass in the IFBR to remove contaminants in an efficient fashion. In fact, it is obtained that IFBR can present high efficiency operation at low HRTs.

**Materials and methods**

**The Inverse Fluidized Bed Biofilm Reactor**

The bioreactor was a 2.5 L glass column (L/D 20) as shown in Figure 1, packed with low density polyethylene fine particles, 0.4 mm mean diameter and 267 kg/m³ apparent density. The system was tested for synthetic (SWW) and municipal wastewater (MWW) treatment.

**Analysis**

The routine analysis for influent and effluent streams were total and soluble COD concentration; total, fixed and volatile suspended solids (APHA, 1995); pH; alkalinity ratio (AR) that relates the produced bicarbonate to total alkalinity (Noyola, 1994). The biogas flow rate was measured with an electronic water displacement device and its composition by gas chromatography. The attached biomass expressed as immobilized volatile solids (IVS) and the SEM technique used to follow up the biofilm formation is described elsewhere (Meraz et al., 1995).

**Synthetic waste water (SWW) treatment**

The mineral synthetic feed (Balch et al., 1979) was supplemented with acetate and glucose in concentrations ranging from 0.5 to 2.0 g/L. The bioreactor was inoculated with 500 mg VSS/L anaerobic sludge from the malting and vinasses industries. Several hydraulic retention times (HRT) were tested: 6, 4, 3 h during 160 days. The superficial velocity varied from 7.3 to 1.6 m/h.

![Figure 1 IFBBR schematic diagram. (1) Influent line, (2) pump, (3) distributor and removable cap, (4) glass column, (5) liquid-solid-gas separator, (6) pump, (7) effluent line, (8) biogas exit](https://iwaponline.com/wst/article-pdf/41/4-5/245/427318/245.pdf)
Municipal waste water (MWW) treatment

The water used to feed the second run had a concentration of 266 (99 mg total COD/L; 59 (35 mg VSS/L and a pH 8.2±0.2. To inoculate the MWW bioreactor, an amount of immobilized particles were taken from the SWW run to an initial biomass concentration of 0.5 kg IVS/m³. It was operated at HRT of 3, 2, 1.3, 0.6 h during a year and the superficial velocity varied from 7.6 to 11.9 m/h.

Results and discussion

The bioreactor fed with SWW was used as a framework to compare the results to MWW treatment. The bioreactor had COD removal efficiency around 83% in the range of worked organic volumetric loads (see Figure 2(a)). This behavior may due to several factors: (1) the organic matter concentration was relatively low, such that the loading rate is below saturation for the given immobilized biomass concentration.

Since the concentration of contaminants in the MWW was lower than in the SWW, the IFBR was operated at very short HRT in order to increase the organic loads. Compared with the SWW treatment, the performance of the bioreactor was lower. In fact, the removal efficiency was in the range of 40–60%. Interestingly, the efficiency presented a decreasing behavior when the HRT was diminished and loading rates were increased (see Figure 2(a) and (b)). This behavior is due to the effect of the combination of these two variables on the bioreactor performance, suggesting that the short HRT allowed only dissolved organic matter to be removed.

As compared with standard anaerobic processes (e.g., UASB), the saturation limit is larger maybe due to the more intensive local mixing around bioparticles. This means that in the tested range of contaminant concentrations, the degradation kinetics is zeroth order. This result agree well with previous ones which states that immobilized biomass on plastic support display high organic load degradation capacity (Meraz et al., 1996). (2) Contrary to MWW, SWW has no suspended solids, which are hardly removed during the FBR anaerobic treatment. The behavior of the bioreactor when the HRT was varied was not conclusive, since the efficiency remains about 83% in the range of operated HRTs. Several hydrodynamics factors (e.g., mixing, convective mass transfer, etc.) may limit strongly the maximum achievable efficiency.

Regarding to specific activity (see Figure 3), it is interesting to note that it presented a linear behavior against specific load rate. This may be a possible confirmation that the
immobilized biomass is working near its saturation thresholds. In fact, the linearity relationship can be seen as an evidence of zeroth-order kinetic behavior.

It has to be pointed out that there is no enough contact time between the biofilm and the suspended organic matter contained in the MWW, besides the fact that this kind of wastewater contains non-degradable contaminants via anaerobic treatment, such as detergents. Based on the results obtained with the SWW case, it can be said that immobilized biomass in the IFBR is able to remove the dissolved group of contaminants with 90% efficiency, e.g. glucose and acetate, contrary to the MWW treatment. This motivates the usage of post-treatment process via aerobic bacteria, to obtain high total efficiencies. Therefore, the IFBR displays certain capacity to damp contaminants concentration peaks that are commonly found in municipal wastewaters.

The specific loading rates achieved in the reactor in both experiments were higher than those reported for standard anaerobic processes, particularly UASB reactors (Monroy et al., 1999), as can be seen in Figure 3. This is probably due to the intense mixing that the prototype provides, so the mass transfer limitations to the biofilm are minimized.

In the case of SWW, the specific activity was 4.5 kg COD$_{removed}$/kg IVS · d for the highest specific loading rate. For MWW, the highest achieved specific loading rate was 10.6 kg COD/kg IVS · d. These values are sensibly larger than those obtained with standard anaerobic processes (Meraz et al., 1996), thus demonstrating that IFBRs are an alternative technology to UASB reactors for low concentration wastewater treatment.

The operation at very short HRT led to the treatment of 92.0 L MWW/d in a device of 2.5 L nominal volume. The volume treated using SWW was 20 L/d in the same prototype. The limited organic loads achieved in this case was due to excessive bed expansion since the gas hold up in this run varied from 23 to 55% and expanded the bed in such extent that the superficial velocity was diminished to 1.6 m/h to avoid bioparticles displacement. Decrements in superficial velocity and increments in organic loads led to biomass accumulation, of about 13.8 kg IVS/m$^3$ reactor during the SWW treatment. This behavior is represented as a sudden increase in biomass concentration in Figure 4(a).

On one hand, increments in biomass concentrations due to increments in organic loading are expected, since the SWW contained essential nutrients for bacterial growth. On the other hand, the variations in superficial velocity present an interesting trade-off problem: while low superficial velocities promote high immobilized biomass concentrations as shown in Figure 4(b), high superficial velocities are needed for high rates of wastewater treatment (i.e. low HRTs). Furthermore, high superficial velocities are required to lowering mass transfer resistance, which improve organic matter degradation by enhancing local

Figure 3 COD removal efficiency related to specific loading rate during the treatment of SWW (n) and MWW (°) in the IFBR
mixing. However, this improvement in local mixing also promotes biomass detachment due to shear stress effects.

The IFBR treating MWW had no expansion problems and the methane composition in the biogas was 60%. The detected methane rate was about 10% of the theoretical expected value. On the other hand, the calculated dissolved biogas fraction in the liquid phase was about 21%. Compared to the SWW treatment, the biomass concentration achieved was very low still with increasing organic loads, but in this case was probably due to the water composition and the higher superficial velocity used for fluidization.

The produced biogas for SWW was 2.0 m$^3$ CH$_4$/m$^3$·d while for MWW varied from 0.2 to 0.8. The difference comes from the composition and concentration of both wastewaters tested, since the methane composition in the biogas found was of 85% for SWW and 62% for MWW, although not all the biogas was recovered. Probably a fraction was retained in the liquid phase, due to the downflow pattern, that favors and enhances the operation, since the bed density diminishes and consequently the liquid velocity can be lowered. In the case of low concentration wastewater, a fraction of the methane leaves the reactor with the effluent, as pointed out before by Noyola et al. (1989).

The SEM microphotographs showed that SWW biofilm was heavily colonized with a variety of bacteria, mainly cocci and rod cells embedded in the microbial mass and amor- phous exopolimeric substances (Figure 5(a)). At the contrary, MWW biofilm shifted to fermentative-like cocci cells only after 1 year of operation, covering all the support surface, as can be seen in Figure 5(b). This shows a bacterial selection due to the existing organic components and its concentration in the wastewater. Probably fermentative and anaerobic bacteria would breakdown only those organic components that are available and easily transported via local mixing to the biofilm. Suspended solids or large and complex macromolecules would not be degraded, because the hydrolysis time for these components is larger that the contact time allowed during the IFBR operation.

Comparing both treatments against the up-flow fluidized bed reactors reported by Heijnen et al. (1989), it can be seen that biomass concentration achieved in both treatments are low particularly for MWW treatment. The specific activities are higher because the biomass concentration is smaller so the prototype tolerates high specific loading rates since it was operated with low HRT. One of the main advantages of the IFBR is the low superficial velocity necessary to expand the bed.

It must be pointed out that the IFBR, as another fluidized beds, does not remove suspended solids. In fact, the mean concentration in the effluent was of 54.22 (44.54 mg/L, very similar to that of the influent. Probably neither pathogens nor parasites were also removed.

**Figure 4** Biomass accumulation during the IFBR operation with synthetic (n) and municipal () wastewater with increasing loading rates and superficial velocity
Deactivation of these microorganisms is of prime importance for wastewater reusing, so a post-treatment to polish the wastewater must be considered such as stabilization ponds, filtration and chlorination or UV treatments should be coupled with the IFBR wastewater treatment.

**Conclusions**

As compared to standard anaerobic technologies (e.g., UASB reactors), the IFBR presented higher efficiencies, which are explained as due to the stronger mixing induced by hydrodynamic patterns. Moreover, the results showed that, although IFBRs have inherent limitations in the maximum organic loading rates, these technologies are an efficient alternative to treat large volumes with very compact equipment.

When municipal wastewater is treated, low biogas and biofilm amounts are produced with the advantage that HRT needed for UASB reactors, may be reduced to less than an hour, achieving similar removal efficiencies (45 to 80%). In any case, a significant fraction of the total methane is dissolved in the liquid phase. Although in some cases the removal efficiency may be low, the treated water could be subjected to post-treatment via aerobic and physic-chemical processes to be reused. In this way, the low concentration wastewater treatment in the IFBR achieves great importance when the flow rates discharged surpass the possibility of treatment in conventional equipment and layouts.

It is then concluded that the IFBR is able to retain biomass on the support with a wide margin of robust operation (i.e. with a wide margin of contaminant degradation). An
efficient IFBR design must consider the optimization of superficial velocities under the restriction of maximal immobilized biomass retention and gas hold up.

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References