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Evaluation of inverse anaerobic fluidized bed reactor for treating high strength organic wastewater

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ABSTRACT

Inverse fluidization particles having specific gravity less than one are carried out in the reactor. The carrier particles chosen for this study was perlite having specific surface area of 7010m^2/m^3 and low energy requirements for fluidization. Before starting up the reactor physical properties of the carrier material were determined. 1mm diameter perlite particle is found to have a specific density of 295kg/m^3. It was used for the treatment of distillery waste and performance studies were carried out for 85 days. Once the down flow anaerobic fluidized bed system reached the steady state, the organic load was increased step wise by reducing Hydraulic Retention Time (HRT) from 2 days to 0.19day, while maintaining the constant feed of COD concentration. Most particles are covered with a thin biofilm of uniform thickness. This system achieved 87% COD removal at an Organic Loading Rate (OLR) of 35 kg of COD/m^3/d.

KEYWORDS

Anaerobic digestion;
Inverse anaerobic fluidized bed;
Start up;
Organic loading rate;
Hydraulic loading rate;
Volatile fatty acid.

INTRODUCTION

Among the different anaerobic process available, an anaerobic down flow fluidized bed reactor emerge as a good alternative for the treatment of wastewater. In the classic case of fluidized systems, the solid particles have a higher density than the fluid. In down-flow (or inverse) fluidization, the liquid specific density is higher than the particle specific density, and the bed is expanded downward by the liquid flow.

The down flow fluidized bed reactor or inverse fluidized bed reactor has been described for application in anaerobic treatment of wastewater[1]. In their description, of down-flow fluidization, particles with a specific gravity smaller than the liquid are fluidized downward by a concurrent flow of liquid. The paper described the application of the downflow(or inverse) fluidization technology for the anaerobic digestion of red wine distillery wastewater. The carrier employed was ground perlite, an expanded volcanic rock.

The biofilm formation and its effect on hydrodynamics of the reverse fluidized bed reactor has been

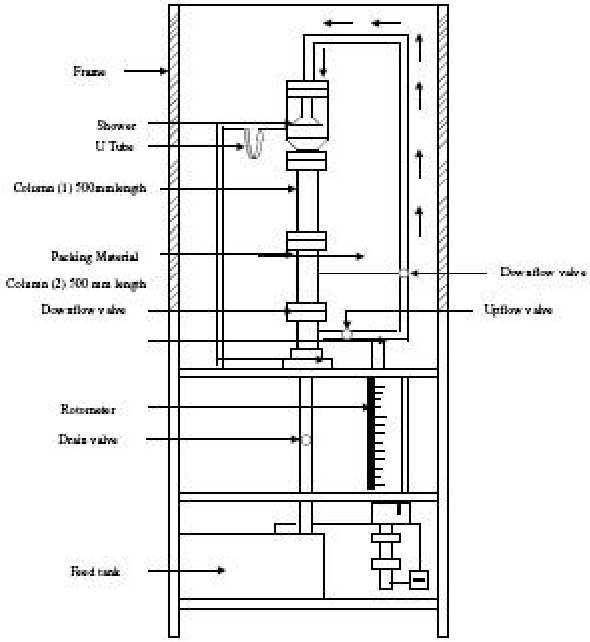

Figure 1 : Anaerobic fluidized bed reactor

TABLE 1 : Composition of synthetic wastewater

Glucose	1000mg/l,
K_2HPO_4	1070mg/
KH_2PO_4	527mg/
Urea	227mg/l
$CaCl_2$	0.06mg/
$FeCl_3$	0.008mg/l

described[1]. The application of inverse fluidization in wastewater treatment from laboratory to full-scale bioreactors has been described[2]. The biofilm, growing on the surface of support particles, increases the overall bioparticle(support particle plus biofilm) diameter. It results in bed expansion and very slow movement of the lower bed level downward until the lower bed level reaches the lower draft tube opening and some of the bioparticles enter the draft tube with the liquid flow. The inverse fluidized bed biofilm reactor designed so that the biofilm thickness can be controlled to avoid the intrabiofilm diffusion limitations.

Under the fluidized state, each media provides a large surface area for biofilm formation and growth. It enables the attainment of high reactor biomass hold-up and promotes the system efficiency and stability. This provides an opportunity for higher organic loading rates and greater resistance to inhibitors. Fluidized bed technology is more effective than anaerobic filter technology as it favours the transport of microbial cells from the bulk to the surface and thus enhances the contact between microorganisms and the substrate. Further it enhances higher organic loading rate in terms of kg/cu.m/d over any other bioreactor.

Objectives

- To determine the effect of operating variables like Organic Loading Rate (OLR), Hydraulic Retention Time (HRT), Particle size, fluidization velocity on COD, TSS, TDS removal efficiencies and biogas yield.
- To determine Biokinetic coefficients.
- To improve knowledge and to recognize design criteria for the development of microbial process for the decomposition of effluent streams containing high strength organic matter.
- To develop basic research with laboratory experiments to simulate the behavior of the systems and the establishment of kinetic parameters of their scaling

MATERIALS AND METHODS

Experimental set-up

The reactor consisted of column with a total volume of 5.03 lits(0.08m in diameter, 1m in height). The flow distributor and the gas outlet are placed at the removable cap covering the top section. The gas outlet was connected to gas meter. The pH in the reactor was adjusted to 7 with NaOH during the start up period, and then it was naturally maintained between 7 and 7.5 without addition of NaOH. Figure 1 shows a schematic diagram of the experimental set-up. The substrate is an industrial distillery wastewater with a concentration of 10-30.16kg/m^3.

Reactor inoculation and start-up

The reactor was filled with the solid carrier material up 55% of its active volume. This material is a light mineral granular material mainly composed of silica and alumina. The reactor was fed with a synthetic wastewater containing glucose as a carbon substrate(TABLE 1). The reactor was monitored for temperature, flow rate, pH and biogas production. The Total Suspended Solids(TSS), Total Dissolved Solids(TDS) and Volatile Fatty Acids(VFA) are routinely analysed. The influent Organic Loading Rate(OLR) was held initially at

TABLE 2 : Physical properties of the carrier material

S.No.	Properties	Values
1	Mean diameter (ϕ)	1 mm
2	Moisture content	43%
3	Specific gravity (G)	1.8
4	Specific dry density (ρ_d)	205kg/ m^3
5	Specific wet density (ρ_w)	295kg/ m^3
6	Specific surface area (S_a)	7030m^2/ m^3

6.11kg of COD/m^3/d with a constant Hydraulic Retention Time(HRT) of 2.0 days. The OLR was then increased by increasing the input flow rate. The OLR was calculated on the basis of the active volume. There was no sludge recycling.

Measurement and analysis

During the operation of the inverse fluidized bed reactor, temperature, pH, gas production rate are monitored daily. Feed and effluents are taken for the analysis of COD, Volatile Fatty Acids (VFA), and Total Suspended Solids (TSS) are carried out once per day. All determinations are performed according to Standard Methods[19]. The average biofilm size on particles was estimated from diameter measurements. The measurement was performed with an optical microscope. The diameter was determined for approximately 50 particles for each sample.

RESULTS AND DISCUSSION

Reactor start-up

The perlite particles are an irregular surface with sharp angles and crevices. These characteristics are suitable because biomass attachment and development are improved when particles present irregularities[18]. TABLE 2 presents the observed physical properties of perlite particles. Perlite is a interesting carrier when compared to others like cork, polyethylene or polypropylene. Minimum fluidization velocity for these materials are higher because surface phenomena(hydrophobic surface) their very low specific density(cork) and in the case of polyethylene or polypropylene, because of their size of particle. Indeed, in downflow fluidization, biomass accumulation makes the particles heavier, increasing particle density and bed expansion. If there is an excess of biomass accumulation, density of the particles can attain 1000kg /m^3 and particles can be washed out of the reactor. Another important parameter is particle size, because it indicates the available surface for biofilm attachment and growth[20]. Particle size also affected hydrodynamics: shear, fluidization velocity, flow behavior of the gas bubbles and flow regime[21]. In this case, 0.968mm size particles enabled a high biomass concentration at low liquid fluidization velocities. Nevertheless, particles are irregular and nonspherical, thus comparisons with other studies become difficult, because most available correlations are made for spheres.

Over the first 15 days, very few changes occurred in the reactor concerning the aspect of the carrier particles. The adjunction of trace elements and nitrogen source in the influent mixture quickly modified the aspect of the reactor. First the colour of the particles obviously turned from almost white to intense gray. Microscopic observations confirmed the presence of biomass on the carrier, either as local outgrowth colonies, either as uniform covering of the particles. The biomass coverage on the particle is very uniform. A large number of particles are covered regularly by a thin biofilm of constant thickness. This may be due to their perfectly spherical shape and to the friction effects enhanced by turbulence.

In 70 days of operation, the first 15 days can be considered as "lost" for the process start-up, because of the nutrient deficiency in the wastewater used and the poor resulting biomass growth. The start-up period is divided into two parts. From day 1 to 33, the influent wastewater was taken from the feed tank without addition of nutrients, but very few microbial growth occurred and input OLR load had to be kept as 6.11kg of COD/m^3/d. From day 33, a mixture of trace elements was added to the inlet together with a nitrogen source. Within 10 days, the reactor had recovered an excellent COD removal efficiency. This increased from 6.11-35.09kg COD/m^3/d over the two months of operation. During this period the COD removal reached 87%. From day 46 to day 70, the input loading rate could be increased from 15 to 35 without any noticeable change in the measured control parameters. The figure 2 is the plot of input organic load(kg COD/m^3/d) and COD removal efficiency. On 21-st day VFA was dropped down and continues up to 43rd day and reached the less than 0.5g/l and VFA amount slightly rose up to 3.5g/l. The figure 3 is the plot of Volatile Fatty Acid

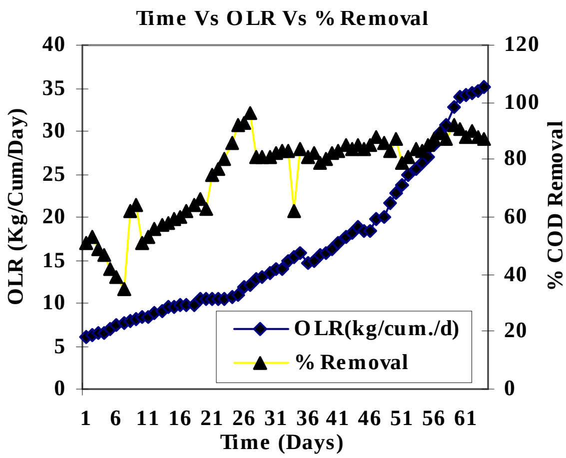

Figure 2

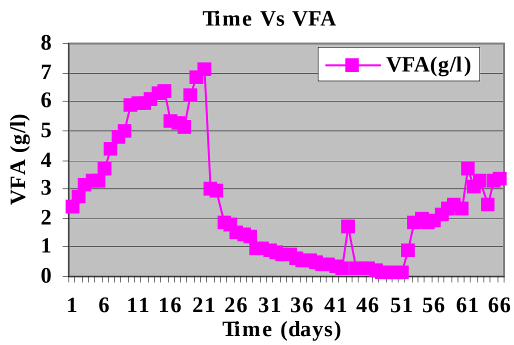

Figure 3

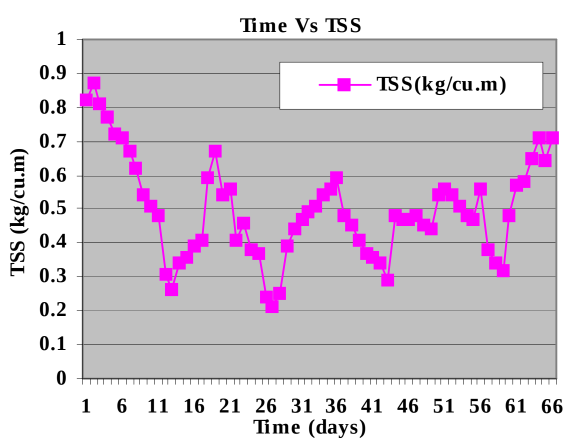

Figure 4

(VFA) production and figure 4 represents the Total Suspended Solids (TSS) removal.

A comparison with previously studied reactors treating the same kind of effluents can be made. The initial start-up is similar to what observed with a classical up-flow fluidized bed working with 384mum pozzolana particle[1,3,4,13]. In the experiment, the OLR was increased from 2 to 18kg/m^3/d in 70 days, and the carbon removal varied between 92 and 75%. In an inverse fluidized bed with a downflow liquid fluidization with perlite as biomass carrier, the OLR was increased from 3 to 15 in 60 days, but the reactor was destabilized and the carbon removal was only 55% at the end of the experiment and the input load to be decreased[1]. In an inverse turbulent bed with upflow current of gas using Extendosphere as biomass carrier, the OLR was increased from 2 to 23.2kg/m^3/d[1]. The removal of total BOD and COD from the wastewater were generally very good(80-92% COD removal and 90-96% BOD removal). The best performance was observed with a HRT of 4days(OLR of 2.37kg /m^3/d).When detention time was decreased to 2days the efficiency of the GRABBR(Granular Bed Anaerobic Baffled Reactor) dropped, but the removal rated were still comparing good[22]. In another study, during the start-up period, OLR was maintained at approximately 1.5 kg TOC/m^3/d. When the system reached the steady state, organic load was increased by reducing HRT. It attained 85% of carbon removal with 4.5kg TOC/m^3/d (approximately11.3kg COD/m^3/d) without pH regulation[1]. Other distillery waste studies have been reported using other anaerobic process such as anaerobic filers[15] and UASB reactor[16] with 80% and 83% COD removal at organic loads of 12.0 and 13.2kg/m^3/d and HTR of 1.4 and 2.4 days respectively.

Further investigations could be done on this kind of reactors. For instance, the amount of solid to be used in the reactor has been fixed here at 55% of the working volume. Other workers report that a correct fluidized state can be obtained for filling rates as high as 70-80%, all the more since the minimal fluidization velocity is lower for high solids amount[12]..

CONCLUSION

This work intended to test a new kind of anaerobic with attached biomass, the inverse turbulent bed. The application to the treatment of distillery wastewater presented satisfactory results compared to other reactors. The input organic loading rate could be increased from 6.11 to 35.09kg COD/m^3/d with in less than 75days, despite 15days delay due to a nutrient deficiency problem. The COD removal was kept around 87% and the hydraulic retention time could be reduced down to

0.19day. The inverse anaerobic fluidized bed reactor appeared to be a good option for anaerobic treatment of distillery wastewater. The system attained high OLR with good COD removal rates and exhibited a good stability to the variations in OLR and HRT.

The carrier material was found to be a very important parameter, because biomass accumulation brings about changes in particle volume and density, affecting the whole system. Perlite was found to be good carrier for the anaerobic digestion of distillery wastewater in inverse fluidized bed.

List of symbols and abbreviations

COD : Chemical Oxygen Demand (kg/ m^3); BOD : Bio-chemical Oxygen Demand (kg/ m^3); OLR : Organic Loading Rate (kg of COD/m^3/d); HRT : Hydraulic Retention Time (d); TOC : Total Organic Carbon (kg TOC /m^3/d); UASB : Upflow Anaerobic Sludge Blanket Reactor; ϕ : Mean diameter (m); m : Moisture Content(%); G : Specific Gravity; ρ_d: Specific dry density(kg/ m^3); ρ_w : Specific Wet density (kg/m^3); S_a : Specific Surface area (m^2/m^3)

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