

WASTE WATER MANAGEMENT IN A SUGAR BEET FACTORY: A CASE STUDY OF COMPARISON BETWEEN ANAEROBIC TECHNOLOGIES

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ABSTRACT

The ACOR-1 sugarbeet factory owns a waste water treatment plant which handles 2500 m³/d of medium strength wastewater (COD = 4000 mg/L). The system was designed to treat the excess wastewater from the beet transport circuit, some process streams, the sanitary waters and wastewaters from an alcohol distillery. The plant is based on two lagoons for equalization and pre-acidification of the waste, an Upflow Anaerobic Sludge Bed (UASB) reactor (efficiency > 97% soluble COD) and a small lagoon used for final polishing of the effluent.

A pilot-scale Fluidized Bed (FB) reactor was run in parallel with the UASB reactor to assess the capability of the FB system. There were two runs in consecutive campaigns, where results showed very good efficiency in spite of very high loading rates and low hydraulic residence times achieved in the FB system.

KEYWORDS

Wastewater treatment; anaerobic fluidized bed reactor; upflow anaerobic sludge blanket reactor; sugarbeet wastewater.

INTRODUCTION

The publication of the "Ley de Aguas" (Water Act) and its implementation in early 1986, and the incorporation of Spain to the European Community (E.C.) have changed drastically the pollution control requirements at the agroindustries in the country. Since January 1st 1986 all environmental directives of the E.C. are applicable in Spain and the implementation of the Spanish "Ley de Aguas" follows most of the requirements of those directives. Depending on the type of industry and the quality of the effluent, a tax is applied. All agroindustries are qualified as Class 3, which is the most taxed group. The amount paid can be greatly reduced if a decrease of volume and pollutant concentration is achieved. Strategies like water circuits reconfiguration, closer process control, and waste minimization and treatment are now steps which agroindustries should take into consideration.

Sugar beet factories use water for three main purposes: cooling circuits, wash and transport circuit, and process. In normal conditions, the main producer of pollution is the wash and transport circuit (usually closed), which carries out from the beet stock pile some sand and small pieces of beet and soluble chemicals, mainly sugars and some proteins and surfactants. Those sugars are acidified in the circuit, producing a decrease in pH, which is controlled with the addition of lime. The control strategies are different depending on the country (Nähle, 1986) and also between factories. This strategy makes a difference for the anaerobic treatment of the wastewater, due to the amount of calcium ions present in solution.

The anaerobic treatment used at the factory ACOR-1 (Valladolid) is a combination of old lagoons, now used as settlers and equalization/pre-acidification tanks, and an Upflow Anaerobic Sludge Blanket Reactor (UASB). Efficiency has been proved to be good enough to fulfil the legal requirements, eliminating the need for a secondary treatment.

As a part of a continued research effort at the University of Valladolid, a pilot scale fluidized bed reactor was built to study the behavior of this kind of anaerobic reactor and assess the applicability of the system to this wastewater. This reactor was operated during two consecutive working seasons in parallel with the full-scale plant. Results obtained permit us to evaluate the difference between these two anaerobic technologies.

EXPERIMENTAL FACILITIES

The ACOR-1 sugar beet factory is located at the city of Valladolid, near the Pisuerga river. The season starts at the end of September – when the flow of the river is near minimum – and lasts for three or four months, depending on weather conditions. This factory mills about 3000 tonnes beet per day. The beet stock pile is quite small and the average residence time is less than two days. Before stockpiling, beets are dry washed using vibrating screens. Later on, beets are washed and carried to the factory by a closed water circuit, where a thickener separates the sand and mud.

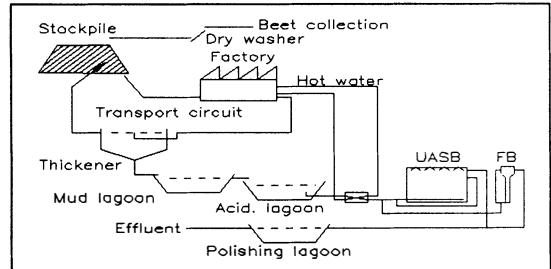


Figure 1 Simplified flow schematic

Lime is added to keep control of pH to a typical value of 7.0. Antifoaming agents are used when needed. The effluent from the thickener goes to a mud lagoon, and the supernatant flows by gravity to another lagoon, which serves as equalizing and pre-acidification tank. This lagoon, approximate volume 2400 m³, collects also some process and sanitary streams. Vinasses are not treated simultaneously with other streams. It was found that the solids capture in the lagoon affected the operation of the UASB reactor. This lagoon was remodelled in 1988 with a labyrinth structure and a pump well with a 2 mm sieve. These modifications greatly improved the influent characteristics. Water is introduced to a UASB reactor after heating with a plate heat exchanger, using excess hot water from the cooling system.

Characteristics of the system:

Reactor size:	Diameter:	18.5 m
	Height:	6.3 m
Active volume:		1200 m ³
Design parameters:	Load:	12 t COD/d
	Flow:	95 m ³ /d
	H.R.T.	12 h
	Temperature	35 °C

This reactor was started-up in 1984, and it has operated for the last five years. Only minor problems of heating capacity and reactor painting were found and solved. After the UASB reactor, a small lagoon is used to separate the easily settleable biomass which is washed out with the effluent. The mud collected at this lagoon has been used to inoculate new reactors in the area.

A pilot-scale fluidized bed reactor is located near the full-scale reactor, and operated in parallel. A full description of this set up can be found elsewhere (Iza, 1987). This reactor was started-up in 1986 and operated during 1987 and 1988. Major problems found were reactor heating and foam formation.

COMPARISON BETWEEN TECHNOLOGIES

Although UASB and FB reactors seem to be totally different, they are reactors based on the same formal principle: to keep inside the reactor active flocs of microorganisms.

Main differences are:

- * UASB reactors operate with suspended biomass, whereas FB reactors do it with fluidized bioparticles.
- * A dense carrier is added in FB reactors for promoting the bioparticle formation, whereas a natural granulation of flocculent biomass is the goal for UASB reactors.

Both granular UASB and small-diameter-bioparticle FB reactors have similar hydrodynamic behavior. Some differences, however, can be described for some control and design parameters.

Superficial velocity and recirculation. The UASB reactor should be designed taking into consideration that the sludge used for the start-up is a flocculent one. That means the liquid upflow velocity should be less than 0.5 m/h. Once the granulation of the biomass is obtained, this upflow velocity could be increased to more than 1 m/h. Our reactor operates with velocities less than 0.4 m/h. For a FB reactor the design upflow velocity is a function of particle diameter and density of the carrier material. Typical velocities range between 2 and 40 m/h. When the attached biofilm grows, the size and density of the bioparticles change and it is necessary to alter the upflow velocity—in most of the cases reduce it—to keep constant the expansion of the bed. Our reactor operates with upflow velocities ranging from 6 to 12 m/h.

Biomass. The UASB reactor can operate with flocculent and granular methanogenic biomass, and their characteristics are different. The biomass concentrations change from typ. 5 gVSS/L for a flocculent type to more than 40 gVSS/L for a granular sludge type. The UASB reactor was, until mid-season in 1988, a flocculent biomass reactor. Every season, the low hydraulic load of the system allowed the biomass to be kept inside the reactor until the third quarter of the season, when the reactor filled-up and some excess biomass was washed-out with the effluent. During the last season, granulation of biomass took place, increasing the overall density of biomass and reducing the wash-out.

The FBR is a bioparticle reactor. The evolution of the biomass concentration in a FB reactor is more lineal. Once the reactor is correctly started-up the volatile solid concentration from the bioparticles is relatively constant and bigger than in the flocculent UASB. Small pieces of detached biofilm are washed out continuously with the effluent, due to the higher upflow velocity and the difference in density. The quality of the effluent is, thus, poorer than in the UASB.

Recycle. The FB reactor uses a recycle line to provide the liquid upflow velocity needed for fluidization. The UASB, however, works without recirculation for most of the time. Long periods between working seasons help the biomass to settle down and compact inside the reactor. During the start-up and restart-up procedures, some recycle is needed to increase the mixing of the sludge and help to avoid short-circuiting of the bed. It is, thus, needed to provide recycle pumps for both type of reactors. For a full-scale FB reactor, the recycle ratio can be as low as 2:1, our pilot-scale operates between 1.8:1 and 30:1 recycle ratio. One of the operating characteristics of the reactors, the liquid flow model, can change if recycle is performed. The probable plug-flow behavior changes to a completely mixed flow model when recycle ratio increases.

COMPOSITION OF THE WASTEWATER

Characterization / Evolution. The waste water treated at the UASB and the FB reactor is analyzed daily during the season for COD (total and soluble), pH,

alkalinity, calcium concentration and settleable material; and periodically for solids concentration (total and volatile solids) following the recommended Standard Methods. The schedule of analysis is varied depending on the operative behavior of the system.

This is a medium-strength, highly acidified (70-95% acidification) waste water. It can be seen in Figure 2 that there is an increase in solids, and therefore, COD concentration. This trend is common to all years and is due to accumulation of solids and soluble compounds in the transport circuit. The amount of solids which enter the reactor is in direct relationship with the amount of solids collected in the last lagoon. In order to reduce the capture of non-biodegradable solids, mechanical screening and sieve filtration was provided during the last season, achieving a significant reduction in the solids concentration and decreasing the load of the system.

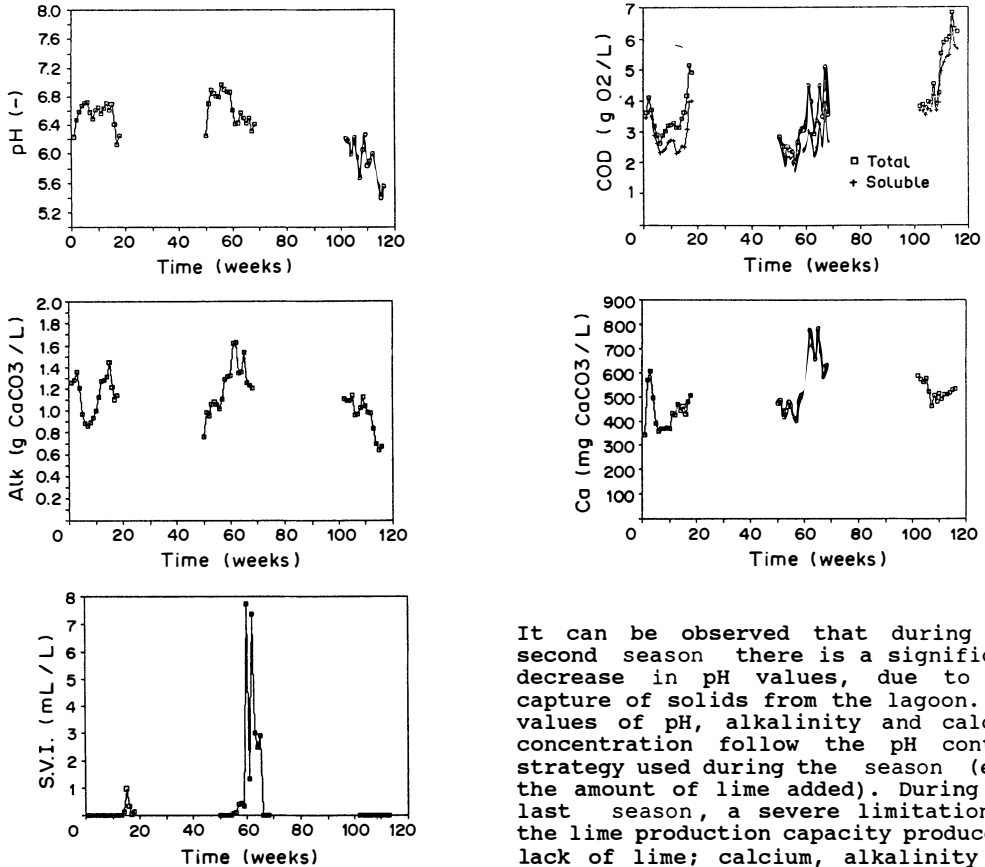


Figure 2. Wastewater characteristics: pH, COD, Alkalinity, Calcium concentration and settleable material.

acidification of the waste is almost complete, with acetic acid as a main component. The particulate COD is related to the amount of volatile solids in the influent. For this kind of wastewater, easily acidifiable, the main pretreatment precaution is the reduction of the concentration of non-biodegradable solids.

It can be observed that during the second season there is a significant decrease in pH values, due to the capture of solids from the lagoon. The values of pH, alkalinity and calcium concentration follow the pH control strategy used during the season (e.g. the amount of lime added). During the last season, a severe limitation in the lime production capacity produced a lack of lime; calcium, alkalinity and pH levels were decreasing during the season.

It can be seen from the COD plot, that a great percentage of the COD is soluble COD, mainly VFA-COD. The

soluble COD is related to the amount of volatile solids in the influent. For this kind of wastewater, easily acidifiable, the main pretreatment precaution is the reduction of the concentration of non-biodegradable solids.

RESULTS

In order to extract valuable information about stability and efficiency of the system, optimize the restart-up procedures, and assess the importance of the different parameters as control parameters, the experimental results for both pilot and full-scale reactors are shown.

Evolution of Main Parameters

Flowrate. This is the most important operation parameter, being one of the few for which we can have full control. It is easy to manipulate this parameter to react against perturbations produced for fed quality changes. The control devices for the FBR are a rotameter and a flow totalizer, and an electromagnetic flowmeter for the UASB reactor. Figure 3 is a plot of the flow rate for the FBR. During the first season flow was restricted to approx. 200 L/h until the pump was changed. Average values of 400 L/h were used for the rest of the season. The second season was dedicated to restart-up studies.

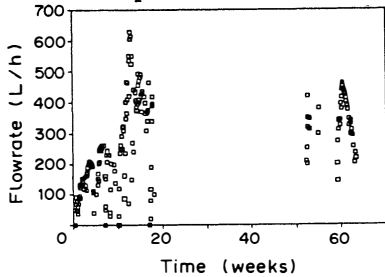


Figure 3. FBR flow rate.

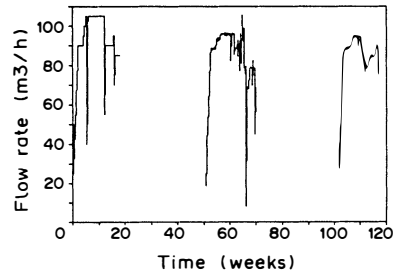


Figure 4. UASB reactor flow rate

The UASB reactor flow rate is presented in Figure 4. For the UASB reactor start-up during the first weeks of the season, the flow rate is increased step by step until the design flow rate is reached. This flow rate is kept constant during the season, and the only variations are due to temporary shut-downs promoted by heating problems, level alarms or sudden changes in influent organic load. If one of those situations occurs, the flow rate is reduced, and after solving the problem, a step by step strategy, similar to restart-up, is followed.

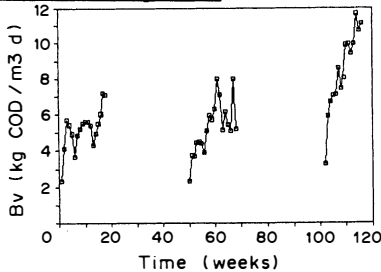
Organic loading rate.

Figure 5. Organic Loading Rate. UASB reactor.

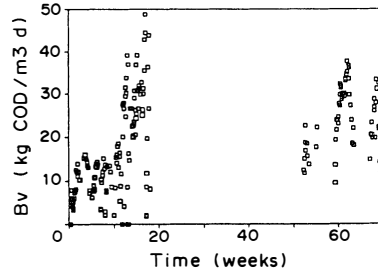


Figure 6. Organic Loading Rate. FB reactor.

The use of the organic loading rate (B_v) as a control parameter is directly connected with the COD analysis schedule. If wastewater is suspected to have big fluctuations of volume and composition, a good system of equalization / holding tanks must be provided, along with an adequate analysis schedule. For the UASB reactor (Figure 5), B_v is controlled by the wastewater concentrations since the

flow rate is almost constant, and goes from 5 to 11 kg COD/m³ d. The FBR reactor, however, shows fast changes in B_0 (Figure 6) due to both flowrate and influent COD changes. The values are bigger than the UASB reactor, with a maximum of 36-38 kgCOD/m³ d. Those values are relatively low for a FBR in comparison with laboratory scale studies previously published (Garcia Encina, 1986) but are in correspondence with the low organic load of the wastewater (average COD_t = 4000 mg/L).

Alkalinity. One of the most important control parameters is alkalinity and its associated alkalinity ratio parameter. This value is strongly related to the pH control strategy followed in the wash/transport circuit. The addition of lime was kept as low as possible, in order to reduce calcium concentration in the anaerobic influent (Figure 7) (Figure 8). The effluent alkalinity is bigger than in the influent, due to bicarbonate produced during the anaerobic digestion. During the operation of the FBR a fast and simple method to evaluate the operating status of the reactor was considered of principal importance. The delay between sampling, analysis and corrective procedure using other parameters, like COD or Volatile Fatty Acid (VFA) concentration, is not as important in the UASB reactor as in the FBR, where the hydraulic retention times shorter than 2 hours can be achieved.

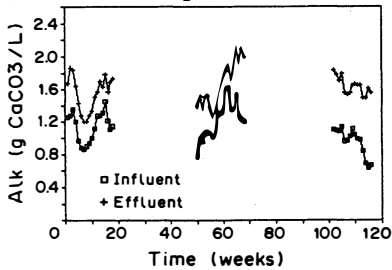


Figure 7. Alkalinity UASB

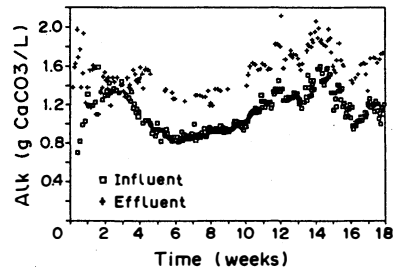


Figure 8. Alkalinity FBR (86-87)

Other possible parameters (TOC, gas composition, trace gases) require expensive apparatus for their determination and, most of the time, are not suitable for on-line control.

The method used for the alkalinity ratio measurement (Iza, 1987) is derived from previous papers (Jenkins, 1983) (Ripley, 1986). The values of alkalinity ratios found during the operation of the UASB are very stable and close to the theoretical value.

Calcium. Related to the amount of lime added to the wash/transport circuit, the concentration of calcium is important because of the physico-chemical reactions inside the reactor which conduces to the formation of calcium carbonate precipitates. This precipitate is not negative for the operation of the system unless the concentration (sludge mineralization) is big. In our case the amount of calcium in the influent and the effluent was almost the same, so the accumulation of calcium carbonate is not relevant. Considering an integral strategy of waste -and also process- management, it will be needed to evaluate the benefits for the global operation of process and waste treatment in terms of dependence of sugar losses and pH, lime costs, and calcium concentration and efficiency of waste treatment.

COD. The UASB reactor has shown a very stable behavior, with constant levels of effluent COD₅. The COD_t is more dependent on the amount of settleable material carried out of the reactor with the effluent.

The FBR showed during the first season a not very stable COD reduction pattern, mainly due to the operating limit conditions. It is important to emphasize that even after a total acidification of the reactor, the system is able to react and recover the normal level of efficiency.

REACTOR EVOLUTION

Biomass evolution. The modern anaerobic technology is based on the retention of methanogenic biomass and the increase of the biomass concentration in order to achieve better performance. In the UASB reactor, the biomass washout phenomenon, described in the literature (De Zeeuw, 1984), has been occurring during all seasons (Figure 9).

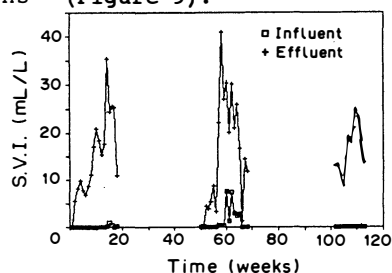


Figure 9. Settleable material UASB.

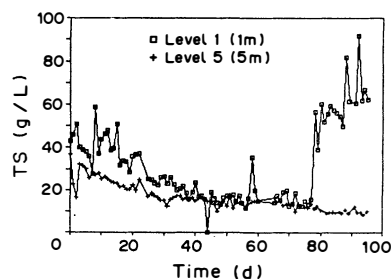


Figure 10. TS UASB. Level 1 and 5.

Figure 9 is a plot of settleable material in both influent and effluent of the UASB reactor. There is a close connection between solids captured in the effluent and solids washed out in the effluent. The 1988-1989 season was the final step of this process. Biomass was washed out continuously from the reactor, decreasing the biomass concentration, until the granulation phenomenon took place and the concentration in the bottom of the reactor drastically increased (Figure 10). The FBR showed a very different behavior during the two operating seasons.

The first one was a continuous run, trying to reach the capacity limits of the system using raw wastewater. The concentration of biomass increased continuously for the particles on top of the reactor. For the second run, the emphasis was put on the restart-up strategy. A severe reduction of biomass amount took place during the second set of experiments, producing an homogenization of the concentration of biomass in the bioparticles from bottom to top of the reactor.

Efficiency. The efficiency of the systems have been calculated by COD removal values. The characteristic of flocculent biomass and the phenomenon of wash-out make the evaluation of efficiency based on total COD values unreliable, and not related with the operation status of the system.

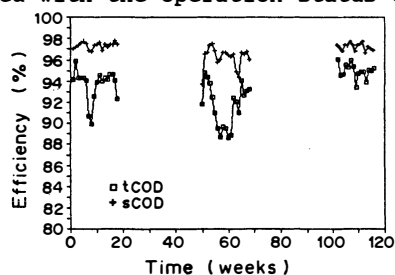


Figure 11. Efficiency UASB reactor.

From Figure 11 it can be seen that the efficiency of the UASB reactor is excellent, fairly constant and near 97%, being the remanent soluble COD approximately 100 mg/L. For the FBR, efficiency is always less than in the UASB reactor. COD_s values are over 150 mg/L, with efficiency values near 90%. The amount of biomass carried out with the effluent produces increases in the COD_t value of 200-800 mg/L. Foam formation has no effect on COD_s efficiency, but on COD_t values and on reactor operation.

Restart-up. Sugar production, as many other agroindustrial processes, is a seasonal one. It is very important to assess the restart-up methodology for a correct operation of the system. For a sugar beet factory, the anaerobic reactor is working at full capacity during the season. After the shut-down of the process, the system runs at low temperature for some 120 days, treating the excess wastewater stored in lagoons. The reactor is then shut-down during the summer months, at temperatures near 20 °C, before the system is restarted. It can be seen in Figure 4 that the initial flow rate is approx. 30% of the design

one, with daily increments of 5%. During this period of time, a recycle pump is used to homogenize the reactor contents and increase the microorganisms-substrate contact. The recycle line is also heated, to allow the reactor a faster warm-up. Following this strategy the reactor is fully started in less than two weeks.

CONCLUSIONS

-Both UASB and FB reactors are able to treat efficiently sugar beet wastewater. Although the COD₅ efficiency is greater than 90% in both cases, the UASB reactor is able to get efficiencies greater than 96%, with a better quality effluent (COD₅ less than 100 mg/L).

-Biomass washed out from both reactors is easily settleable and it can be eliminated with a simple lagoon. Foam formation, especially in the FBR, makes this separation more difficult.

-The FBR can operate at hydraulic retention times shorter than 2 h, whereas the UASB operates at 12 h. The FBR can achieve organic loading rates greater than 30 kg COD/m³d.

-All pretreatment, acidification, solids elimination and temperature control systems are similar for both technologies.

-The operation control systems are similar for both reactors. Due to the fact of the very short hydraulic retention time in the FBR, the analysis schedule should be tighter than in the UASB reactor, with a minimum of daily analyses.

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