# The anaerobic SBR process : basic principles for design and automation

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**Abstract** This study has determined the purification performance and the basic principles for the design of an anaerobic SBR (ASBR) to be used to treat wastewater generated in the food industries. Two ASBR's were set up and one fed with a slaughterhouse effluent at low concentration, the other with concentrated dairy wastewater. The maximum loading rate applied should not exceed 4.5 g of COD/L/day for the dilute effluent and 6 g of COD/L/day for the concentrated effluent. At higher loading rates, the reactors become difficult to operate, mainly because of sludge removal problems, and purification efficiency declines. A detailed study of the kinetics (TOC, VFA, rate of biogas production) throughout one treatment cycle led to the development of a simple control strategy based on the monitoring of the biogas production rate which was then applied to the reactor treating the dairy wastewater. After automation, the reactor worked free of problems at an average pollution load of 5.4 g of COD/L/day.

**Keywords** Anaerobic digestion, anaerobic sequencing batch reactor, automation, dairy wastewater, slaughterhouse effluent, wastewater treatment

## Introduction

The anaerobic sequencing batch reactor, or ASBR, is a methanisation process for wastewater treatment which works by cycles (Wirtz, 1996). Each cycle is made up of four stages : fill, react or agitation, settling and then drawing-off of the wastewater, with removal of sludge when necessary. The cycles should be as frequent as possible while allowing for completion of each of the 4 stages (Dague, 1992). Operating by batches enables the solids residence time (sludge age) to be independent of the hydraulic retention time (HRT) without recourse to a settling tank, since the reactor functions as a decanter whenever the stirring mechanism is turned off (Sung, 1995). Studies using the ASBR were carried out at laboratory and pilot scales with different types of effluent. Mainly soluble substrates, such as dairy wastewater, were investigated at the beginning of the 1990's. Dague (1992), among others, carried out the first studies on the efficiency of ASBRs and ascertained that the transformation of the organic matter into methane and carbon dioxide could take place at a hight rate. Applied loading rates were comprised between 0.5 g of COD/L/day and 5 g of COD/L/day at 35°C, with HRT of 2.17, 1.08 and 0.54 days. Ndon *et al.* (1994) studied the effect of temperature (between 15 and 35°C) on the behaviour of an ASBR treating a low concentration wastewater. Dugba *et al.* (1997), as well as Han *et al.* (1997), has developed a process called a temperature-phased anaerobic SBR which has two ASBRs in series : the first functions at a thermophilic temperature (55°C) and the second at a mesophilic level (35°C). With this system, treatment efficiency rises considerably, with COD elimination levels attaining 90% for a loading rate of 22 g of COD/L/day and a HRT of 18 hours (Welper, 1997). Studies of slaughterhouse wastewater treatment with an ASBR, carried out by Morris *et al.* (1997), compared two ASBR reactors seeded with different sorts of sludge : in one case granular sludge, in the second flocculated. These reactors functioned for 13 months. Purification yields were relatively modest, with 70% elimination of $BOD_5$ for a HRT of 30 hours.

The aim of the work presented here was to determine the basis for the design of an ASBR operating in mesophilic conditions (35°C) for the treatment of food industry wastewater; and to study the behaviour of the reactor during the reaction phase in order to design and confirm the performance of an automated control programme for the ASBR.

## Materials and methods

### Description of the reactors

This study was carried out using double walled reactors of 3.5 l effective volume maintained at 35°C by a thermostatically regulated water bath. Peristaltic pumps run by timers were used to fill the reactor and draw off the effluent after settling. Mixing in the reactors was done by a system of magnetic stirring. The wastewater awaiting treatment was stored at 4°C and kept under magnetic agitation. The volume of biogas produced was measured, in the case of the reactor treating the slaughterhouse wastewater, by a Schlumberger wet gas meter while for the reactor treating dairy wastewater, biogas measurement was done with an Aalborg mass flow meter 0-20 ml/mn fitted with a 4-20 mA output. The software "Modular SPC"(c), developed at the INRA-Narbonne laboratory, was used for acquiring and treating the data (gas output, pH). This programme also managed the automated operation of the reactor in the final part of the study.
The reactors were seeded with activated sludge taken from a stirred anaerobic reactor used to treat distillery vinasse and from an anaerobic pond treating winery wastewater.

### Characteristics of the wastewater

The slaughterhouse effluent was obtained at the wastewater collection sump at the slaughterhouse in Narbonne (southern France), after straining and degreasing. The composition of the wastewater varied between 3.5 and 4.3 g/L of total COD, 1.5 and 3 g/L of soluble COD and 0.5 to 3.5 g/L of suspended solids (SS). The wastewater contained an excess of nitrogen and phosphorus with an average $BOD_5$/N/P ratio of 100/19/2.8. The dairy wastewater was prepared by diluting skimmed milk to a concentration of 20 g/L of total COD, 16 g/L of soluble COD and 5 g/L of TOC. In both cases, the feed stock was stored at 4°C and renewed twice a week.

### Sampling and analysis

Samples were taken regularly at feed, in the reactor and at ASBR outflow. When necessary, samples were centrifuged at 6,000 g for 10 minutes before analysis to remove suspended solids. Total organic carbon (TOC) was determined by UV oxidation with a Dohrman DC 80 apparatus. Volatile fatty acids (VFA) were analysed using a gas chromatograph fitted with a flame ionization detector (Chrompac CP 9000) and coupled with an integrator (Shimadzu CR 3A). Other parameters were measured following Standard Methods (APHA (1992)).

## Results

Two food industry effluents were studied in order to assess the purification efficiency and the criteria for design of an anaerobic SBR (ASBR) functioning in very different contexts : one with a low concentrated slaughterhouse effluent containing 3.5 to 4.5 g/L of COD; the other with concentrated dairy wastewater with 20 g/L of COD. After seeding, the reactors were fed in both cases with a low organic loading rate. Then, the loading rate was increased regularly in each reactor, with bigger volumes of effluent feed at the start of each cycle.

Each operating cycle of an ASBR is made up of four stages : fill, react - agitation, settle and draw. At the start of the study, both reactors worked on fixed cycles of 12 hours made up of 11 hours of reaction and 1 hour at rest for settling and draw. In the case of the dilute wastewater (slaughterhouse), it was necessary at the end of the experiment to move from 2 cycles a day to 3 cycles of 8 hours, with 7 hours of reaction, on account of the large volumes of effluent that had to be introduced at each cycle in order to maintain the high organic loading rate. For the dairy wastewater, the cycles were of 12 hours during the first unautomated period of the study. In a second period, the reactor was run by an automated control programme which adjusted the length of the cycles in relation to the rate of production of the biogas.

**Slaughterhouse wastewater**

*Operating conditions.* In the month following seeding, a constant organic load of 0.6 g of COD/L/day and a HRT between 3.5 and 4.5 days were maintained. Thereafter, the volumetric loading rate was increased by about 20% each week (figure 1). The maximum loading rate tested was 6.1 g of COD/L/day after 3.2 months of operations, at which time HRT was 0.625 day.
The pH in the reactor varied from 7 to 7.6 and the alcalinity always remained above 1.5 g of $CaCO_3$/L, despite there being no measures taken to adjust pH.

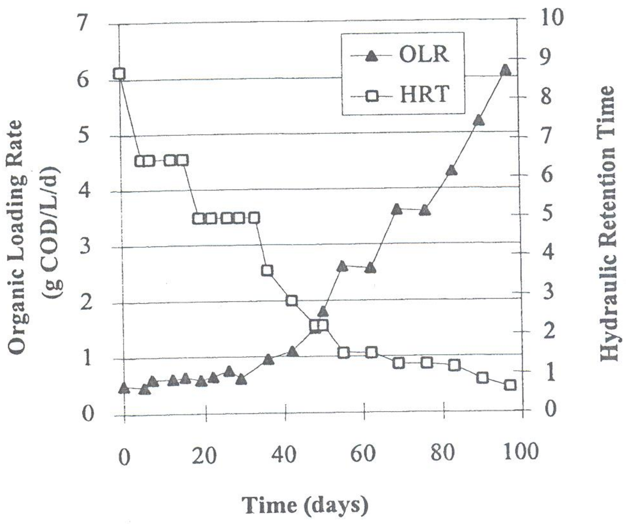


**Figure 1 :** Evolution of the organic loading rate and hydraulic retention time through time. Slaughterhouse wastewater.

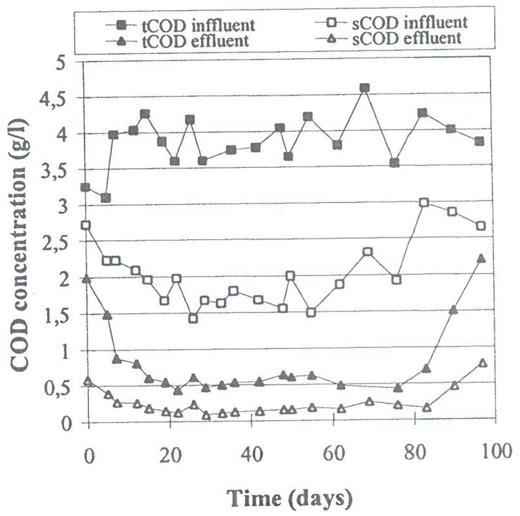


**Figure 2 :** Concentrations of total and soluble COD at intake and exit of the ASBR. Slaughterhouse wastewater.

*Elimination of organic matter.* After a start-up phase, the running of the reactor was stable up to an effective loading rate of 4.5 g of COD/L/day, with concentrations at exit of 0.5 g of total COD/L and 0.160 g of soluble COD/L (figure 2). Purification efficiency was 86% for total COD and 91% for soluble COD. The concentration of SS at exit was 0.67 g/L on average. At higher loading rates, purification efficiency began to drop, with a concommitant increase at exit of the concentration of total COD on account of increased concentrations of soluble COD and SS.
For an effective loading rate of 6.1 g of COD/L/day and a HRT of 0.625 of a day, the volume of wastewater fed in each day was considerable and the management of the reactor, especially the settling of the sludge, became very difficult.

*Concentration of SS in the reactor.* Sludge concentration in the reactor varied between 5.6 g/L at the beginning and 9.5 g/L at the end of the study. The sludge's aptitude for settling, as measured at the end of the settling period, declined with increases in the applied loading rate and in the concentration of sludge in the reactor : at the start of the study, amounts were 1 - 1.5 cm in height/g of sludge but 2 - 2.5 cm/g at the end.

In conclusion, when the wastewater was dilute, it was best to operate the ASBR at a maximum load of 4.5 g of COD/L/day which ensured an excellent purification performance without hindering the easy management of the reactor.

*Applied loading rate and hydraulic retention time.* After seeding, an organic loading rate of 1.5 g of COD/L/day was maintained for 15 days (figure 3). Thereafter, this loading rate was increased by about 20% each week, attaining a maximum of 6.25 g of COD/L/day after 2 months of operations. At the same time, the HRT of the wastewater in the reactor went from 12.8 days to 3.2 days at the end of the study.

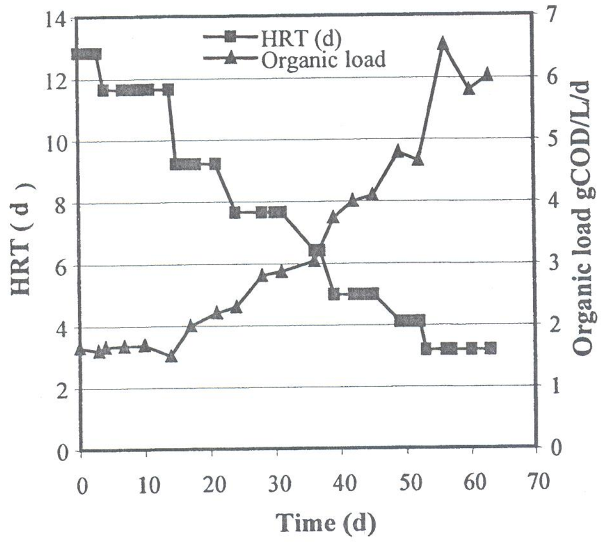


**Figure 3** : Evolution of organic loading rate and hydraulic retention time. Dairy wastewater

*Elimination of the organic matter.* Figure 4 shows that the concentrations of total and soluble COD at reactor outflow were relatively constant, with average values of 1.3 g/L for total COD and 0.4 g/L for soluble COD. Purification efficiency was between 90 and 97% for total COD and between 96 and 99% for soluble COD (figure 5). The concentration of SS in the treated wastewater was always less than 1 g/L.

*pH and alcalinity.* Without any regulation, the pH in the reactor always remained between 7 and 7.5, which indicates the efficiency of the anaerobic digestion process (Stronach, 1986). Alcalinity did not vary much during the study, with values always remaining above 3 g of $CaCO_3$/L.

*Concentration of SS in the reactor.* The concentration of SS in the reactor at the start of the study was 9.2 g of total SS/L. This concentration increased regularly throughout the study period and at the end attained 29.3 g of Total SS/L. Even with such high measurements, settling of sludge at the end of a cycle was sufficiently good that the drawing-off of the treated wastewater took place above the sludge level.

In conclusion, when wastewater had greater concentrations of organic matter, the maximum loading rate had to be kept down to around 6 g of COD/L/day. For higher loading rates, as observed with the slaughterhouse wastewater, reactor management became more problematic and sludge settling and purification efficiency declined.

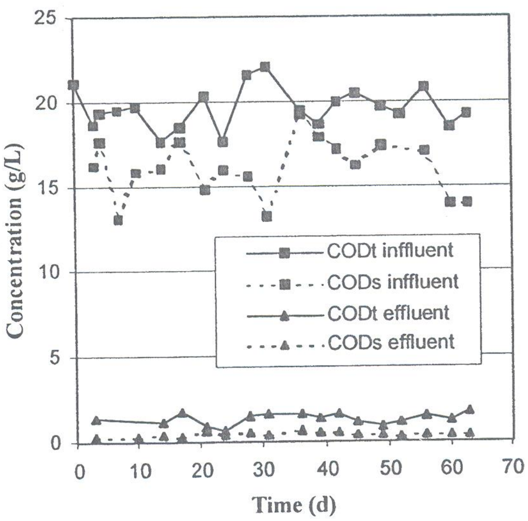


**Figure 4 :** Evolution of concentrations of COD before and after anaerobic treatment. Dairy wastewater

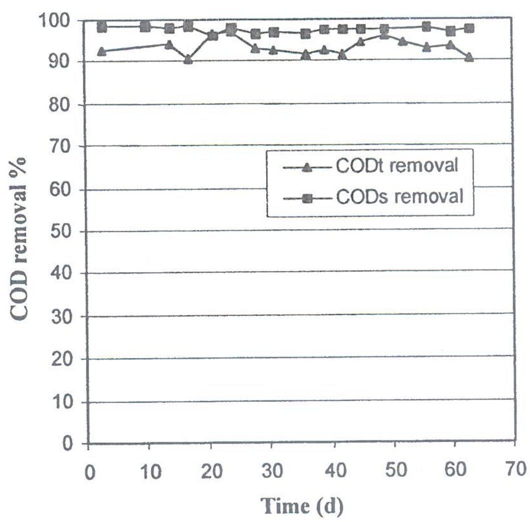


**Figure 5 :** Evolution of purification efficiency. Dairy wastewater.

*Biogas production.* Figure 6 shows three examples of the changes in the rate of production of biogas during a treatment cycle according to different organic loading rates.
The curves resemble each other : the rate of biogas production is greatest at the start of the cycle and then decreases with time, reaching very low and relatively stable levels at the end of the reaction stage. The uniform results obtained in the first minutes of a cycle correspond to the saturation of the flow meter during the period of raw wastewater input.
During the study, pollution loading rates and SS concentrations in the reactor were increased and, with the increase in the amount of organic matter fed in at the beginning of each cycle, the following results ensued : an increase in the amount of biogas produced per cycle, a lengthening of the time needed to complete a cycle and an increase in the instantaneous production rate of biogas.

*Evolution in the concentrations of VFA and TOC during a cycle.* During the overall monitoring work, concentrations of VFA and TOC were measured at intervals during a given cycle at different loading rates. Figure 7 shows the results obtained for a loading rate of 4.05 g of COD/L/day. At this level, the volume of raw wastewater added to each cycle was 710 ml, with a concentration of TOC of 5 g/L. At the end of the feed stage, concentration of TOC was only 168.4 mg/L instead of 1,014 mg/L, a result obtained by calculating the dilution in the reactor of the TOC added. This suggests that the micro-organisms accumulated organic matter within their cells during the feed stage. At the beginning of the reaction phase, the majority of the organic matter introduced was intracellular (around 83 % in the case studied here). In the course of the cycle, the concentration of TOC increased during a first period, reaching a maximum level for the cycle of 306 mg/L, then fell to a stable level between 60 and 70 mg/L six hours after the beginning of the reaction stage.
At the beginning of the cycle, the curve representing the evolution in concentration of VFA is similar to the TOC curve. It was verified that during the first two hours, the rise in concentrations of TOC was directly related to the release of VFA in the liquid phase.This passing accumulation of VFA results from the fact that, at the beginning, methanogenesis is not able to eliminate the total amount of VFA produced by the acid-producing bacteria. There was no VFA in the soluble phase five hours after the start-up of the cycle and, afterwards, TOC concentration hardly changed.

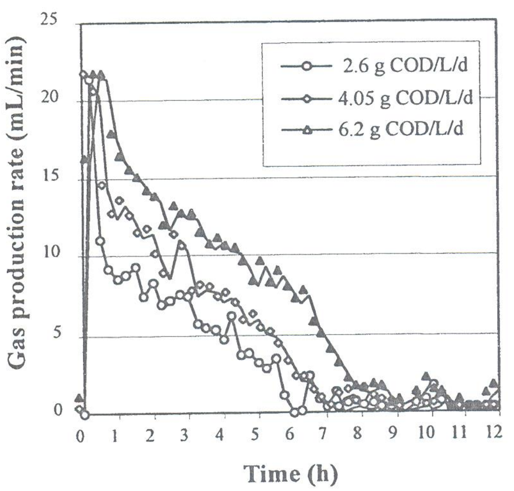


**Figure 6 :** Rate of biogas production during a cycle for various organic loading rates. Dairy effluent.

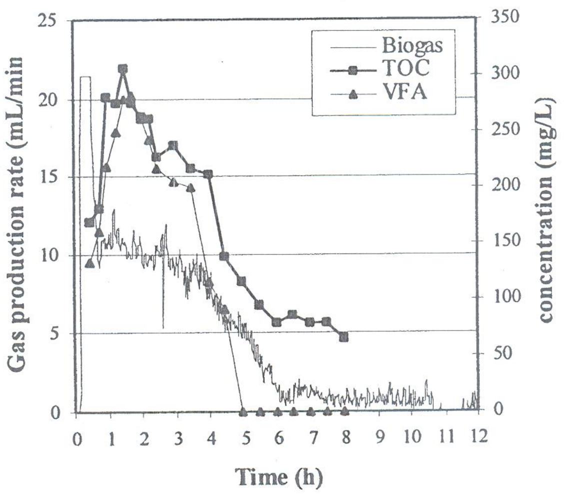


**Figure 7 :** Concentrations of VFA and TOC and rate of biogas production. Organic loading rate of 4.05 g COD/L/day. Dairy effluent.

*Automation of the ASBR.* The foregoing results show that it is possible to follow the state of progress of the reaction responsible for eliminating the organic matter in an ASBR by monitoring the rate of biogas production. Indeed, when a treatment cycle came to an end, the biogas production rate stablilised at levels around zero, indicating very weak metabolic activity. Furthermore, it was shown that at this stage, the concentration of VFA was nil and, for TOC, at its lowest.

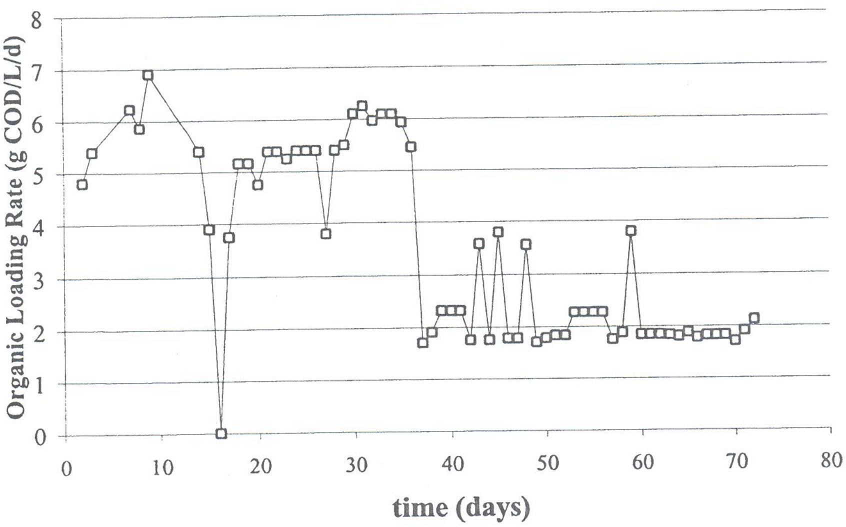


**Figure 8 :** Organic loading rates obtained with the controlled ASBR at 35 °C then 25 °C. Dairy effluent.

A software for data acquisition and automatic control ("Modular SPC" (c)), developed at the INRA Laboratory for Environmental Biotechnology in Narbonne, was used for automating the ASBR process. It allowed to avoid idle periods that might occur once the biological reaction was finished, as happened when fixed cycle periods were used.

The automated control was based on the measurement of the rate of biogas production during the reaction stage following additionnal feed. The halting of the reaction stage was set off when the biogas production rate dropped below a minimum limit, provided pH was at 7 or more and there had been a minimum reaction time per cycle. The reactor functioned 72 days in automatic mode and the volumetric loading rates obtained are shown in figure 8. On day 16, the wastewater storage tank was empty so that there was no feed intake and the loading rate was thus nil. Up to day 36, the reactor functioned at 35°C. During this period, the volumetric pollution load was an average 5.4 g of COD/L/day, with concentrations in the raw wastewater of 20 g of COD/L and a purification level of 99.2% for soluble COD.

In order to study the automatic control when confronted with disturbances, the concentration in the wastewater to be treated was modified at a given time for two cycles : from 20 g of COD/L to 30 g of COD/L on day 29 then from 20 g of COD/L to 10 g/L on day 31, during which time the volume of wastewater added at the beginning of each cycle was kept constant. Figure 8 shows that this step had little significant effect on the organic loading rate. The duration of the cycles was automatically adjusted according to the amount of organic matter introduced at the beginning of each cycle. Thus, the average length of a cycle was 7.2 hours when concentration in the wastewater was 20 g/L, 10 hours at 30 g/L and 5.23 hours at 10 g/L.

On day 36, reactor temperature was lowered to 25°C. The slowing down in the metabolic rate induced by this drop in temperature resulted in a major lengthening of the cycles (18.5 hours on average). Consequently, the pollution load went immediately from 5.4 g of COD/L/day to 2.11 g of COD/L/day when the temperature was 25°C, which represents a drop by a factor of 2.56.

## Conclusion

Two ASBR's were set up to function with fixed cycles, one fed with a low concentrated slaughterhouse effluent (3.5-4.5 g of COD/L), the other with concentrated dairy wastewater (20 g of COD/L). The organic load fed in at the start of each cycle was increased regularly in order to ascertain the maximum loading rate it was possible to apply.

The maximum volumetric loadings rates admissible in the operating conditions of the study were around 4.5 g of COD/L/day when the wastewater concentration was dilute, and around 6 g of COD/L/day when concentrations were high. It would appear preferable not to operate the ASBR at higher loads because : i) the reactors become difficult to operate, mainly because of poor sludge settling which can result in discharge of SS in the treated wastewater; and ii) purification efficiency declines.

Monitoring the evolution of concentrations of TOC and VFA during a cycle, along with the rate of production of the biogas, permits the development of a simple control system to manage the ASBR. Treatment cycles are then governed by the rate of biogas production. At the end of the react stage, biogas production drops relatively quickly which facilitates the identification of a minimum rate of biogas production below which the reaction stage is considered to have finished. This permits immediate refill of the reactor at the end of the draw period without any intervening idle time, irrespective of the pollution load at the start of a cycle.

After automation, the ASBR handling concentrated dairy wastewater functioned without a hitch at an average organic loading rate of 5.4 g of COD/L/day. Sporadic modifications of the concentration in the raw wastewater to be treated, or in the temperature, have shown that the automatic control system reacted well to such variations. Thus, it demonstrated its capacity to adapt the length of the reaction stage, and therefore the organic loading rate, to the treatment capability of the reactor.

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