

High COD wastewater treatment in an aerobic SBR: treatment of effluent from a small farm goat's cheese dairy

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Abstract In France, small goat's cheese dairies using traditional craft methods often have no profitable solution for dealing with the whey byproduct of their cheesemaking activity: it is usually mixed with the cleaning wastewater which, in the absence of other possibilities, is then discharged directly into the environment. The volume of such wastewater is small but it has a high COD of around 12–15 g/L. An aerobic SBR was proposed as a method for treating the mixture of wastewater and whey and the first installation was set up on a farm with 170 goats. Its operations were monitored for 7.5 months, particularly in order to measure any excess volume of sludge and to check that such excess remained within acceptable limits, given the high COD of the effluent requiring treatment. The results obtained show that the treated wastewater was of excellent quality, well within the most rigorous discharge norms. With this type of wastewater, excess sludge was produced in only very low amounts with 0.2 g of SS/g of COD. Moreover, the sludge proved to be quick settling which made it possible to: i) maintain a high level of SS in the reactor (up to 15 g/L); ii) withdraw sludge with concentrations reaching 30 g/L after 2 hours of settling. This resulted in a low volume of excess sludge (less than 5% of treated volume), making such aerobic biological treatment in an SBR competitive when compared to the straightforward spreading of all the wastewater.

Keywords Dairy effluent; high COD wastewater; sequencing batch reactor; wastewater treatment; whey

Introduction

In France, the production of goat's cheese using traditional craft methods is carried out by some 5,000 farmers, usually on very small holdings with an average herd size of 50 goats.

The dairies generate two sorts of pollution: (i) wastewater from cleaning down the milking equipment, the milk storage facility and the cheesemaking plant: known as “white water”, it has low concentrations (COD < 5 g/L); (ii) the whey, a byproduct of the cheesemaking process, whose COD is of the order of 70 g/L. More often than not, the whey is thrown away with the cleaning water. Average wastewater production per farm is some 400–800 L/day, including 100–200 L of whey. Because many of the goat's cheese producers have no other economically or technically acceptable means for disposing of their wastewater, they often discharge it directly into the environment.

Two solutions presently exist for treating such pollution: (i) the pure whey can be recycled and given back to the goats to drink but this practice has been very much limited by the risk of self-contamination by caprine arthritis encephalitis virus (CAEV); (ii) the mixture of cleaning water and whey can be spread directly over the land but this requires storage facilities and spreading equipment. Furthermore, stocking can lead to unacceptable smells which may consequently require the installation of stirring and aerating devices. Thus, those involved in traditional goat's cheese production are looking for ways that will be efficient, robust and cost-effective for dealing with the mixture of wastewater and whey on the farm.

An initial process based on the use of bacterial cultures developed in gravel beds is currently under study (Boutin *et al.*, 2002; Menoret *et al.*, 2002). It involves two aerobic filters made up of pouzzolane, fed alternately by wastewater which trickles through them.

The SBR process has already been recognised for treatment of just the “white water” only in cheesemaking plants that keep the whey separately for further use (Torrijos and Moletta, 1997b; Torrijos *et al.*, 2001). Using the SBR process to treat a mixture of cleaning water and whey raises the same general issues involved in all such processes based on activated sludges used for purifying effluent which contain high levels of COD. In the case of farm-based traditional goat’s cheese production, the average COD of the untreated wastewater is of the order of 12–15 g/L. With such a level of COD at the outset, two parameters need to be studied with particular attention with a view to obtaining acceptance of an SBR process for the treatment of a mixture of cleaning water and whey: (i) the production of excess sludge: the volume of excess sludge, that is to say the quantity of solid waste that must finally be spread, must remain small in comparison to total treated volume in order for the SBR process to be a preferable solution when compared to spreading of the total volume of untreated effluent; (ii) costs, especially operating costs, must be competitive when compared to those involved in spreading the total amount of untreated wastewater.

In 2002, the agricultural lycée (high school) at Mâcon-Davayé (Saône et Loire, France) set up the first installation in France based on an SBR process for treating “white water” and whey coming from dairy and cheesemaking operations. This paper presents the results obtained from 7.5 months of monitoring at this first treatment plant. The monitoring was designed to measure actual technical performance (taking special note of the behaviour of the sludge), assess maintenance requirements and determine operating costs.

Material and methods

The SBR plant of the lycée at Mâcon-Davayé. A pumping station of 100 L working volume was set up at the inlet of the treatment plant to transfer the effluent produced to the SBR. The aerobic reactor tank had a total volume of 40 m³. This tank was half-buried and equipped with fine-bubble diffusers and a blower. A single submersible pump served to run off the treated wastewater and occasionally, when necessary, to remove any excess sludge at the end of the settling phase through a separate draw-off circuit. The automated equipment that governs the successive stages in the SBR cycle was very simple: the feed pump in the pumping station was controlled by a level feeler gauge, the air blower was controlled by a timer and the run-off pump of the reactor controlled by a timer and a level feeler gauge. The SBR worked at one cycle of 24 h per day. A cycle began at 6 a.m., with the start of aeration. Settling took place 21 hours after the start of the cycle and lasted for 2 hours. During the 24th hour of the cycle, the volume initially introduced was run off, allowing a new cycle to be started. The volumetric exchange ratio was between 2% and 7.5%. During the peak milk production period, aeration was continuous. When milk production was low, aeration time was decreased and the blower stopped several times during the cycle for one hour each time.

Sampling. The volume of effluent produced was measured from the working time of the pump located in the pumping station at inlet which had a flow rate of 3.57 m³/h. Average samples of the raw effluent were collected thanks to a peristaltic pump, slaved to the relay pump, connected to the pipe between the pumping station and the reactor. Average samples of the treated effluent were collected thanks to a peristaltic pump slaved to the pump running off the supernatant at the end of the settling phase and connected to the pipe at the outlet of the reactor. Each week, samples were taken in the reactor to monitor the evolution of the SS concentration in the reactor and to make a settling test in a 1 L cylinder.

Analysis. When necessary, samples were centrifuged at 6,000 g for 10 min before analysis to remove suspended solids. COD was measured according to the Dichromate reactor

digestion method test (Hach 0–1,500 mg/l vials). Other parameters were measured following Standard Methods (APHA (1992)).

Results

The herd and the cheesemaking plant of the lycée at Davayé

The herd of the agricultural lycée at Davayé consists of 170 goats which live permanently on site. Their enclosure is made up of a concrete outside area of 500 m² and of a grazing plot of 3,000 m² with free access. The surface of the stable is 400 m². The feeding system is grass and hay. Reproduction is aseasonal with two birthing periods: October/November then March/April. The milking shed has 18 milking machines and milking is done twice per day, at 7:30 a.m. and 5:30 p.m. Figure 1 presents the volume of milk produced per day (white squares) during this experiment (July 1st to February 15th). The curve shows that milk production is lowest in August and September. The production peaks in October–November. From mid-November, milk production starts to decrease from its maximum until the end of the experiment. The milk is made into cheese on site, in a cheesemaking plant of 110 m² located close to the stable. Total milk production for the year 2002 was 119,300 L.

Characterisation of the wastewater

Whey was not recovered separately and the effluent to be treated was made up of: (i) the water used for cleaning the milk-carrying piping and the cheesemaking plant; (ii) the whey produced during cheesemaking.

Volume of effluent

Figure 1 presents the volume of effluent discarded during this experiment (black squares). This curve shows that the volume of wastewater is directly related to the management of the herd: there was less than 1,000 L of effluent during the low milk-production period (August–September) but volumes of between 1,500 and 3,000 L of effluent per day during the peak period of milk production following the autumn birthing period. During the second fortnight of November (November 16th to 29th), that is to say about one month after the beginning of maximum milk production, a peak of effluent production was recorded, lasting less than 15 days, with average values around 3,000 L/d. Thereafter, the volume of effluent remained between 1,500 and 2,000 L/d.

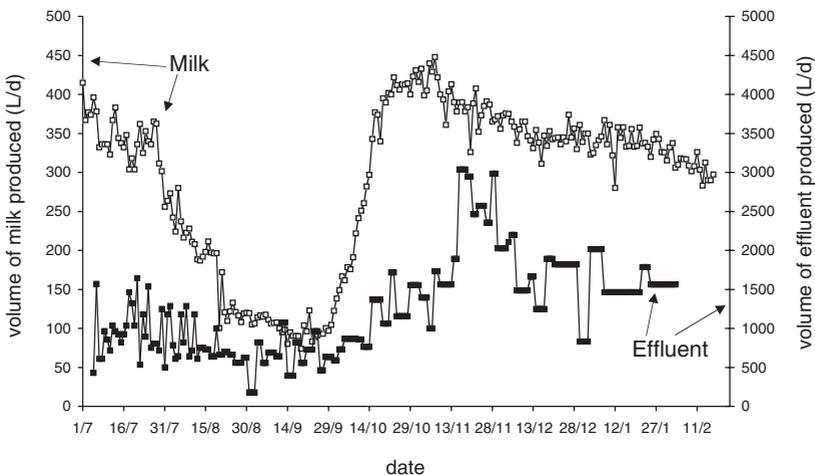


Figure 1 Evolution through time of the volume of effluent and of the amount of milk produced between July 1st 2002 and February 15th 2003. Goat farm of the lycée at Davayé

From Figure 2, the average relationship can be established between the volume of effluent discharged and the volume of milk produced. The relationship between these two parameters gives a rate of 4 L of effluent discharged per litre of milk produced.

This value is only an average value and variability could be high, especially when milk production was also high. Thus, for milk production higher than 330 L/d, the average rate was 4.32 ± 1.51 L of effluent/L of milk.

Remark. The data corresponding to the peak of effluent production in the second fortnight of November (black squares on the graph) were not taken into account for the graph linear regression.

Composition of the raw effluent

The evolution of total and soluble COD and SS at the inlet of the SBR is presented in Figure 3.

Remark. Between October 11 and November 15, the samples taken at the inlet of the SBR were not representative on account of disturbance of the sampling pump which led to an excessive uptake of whey. Data corresponding to these results are not shown in Figure 3.

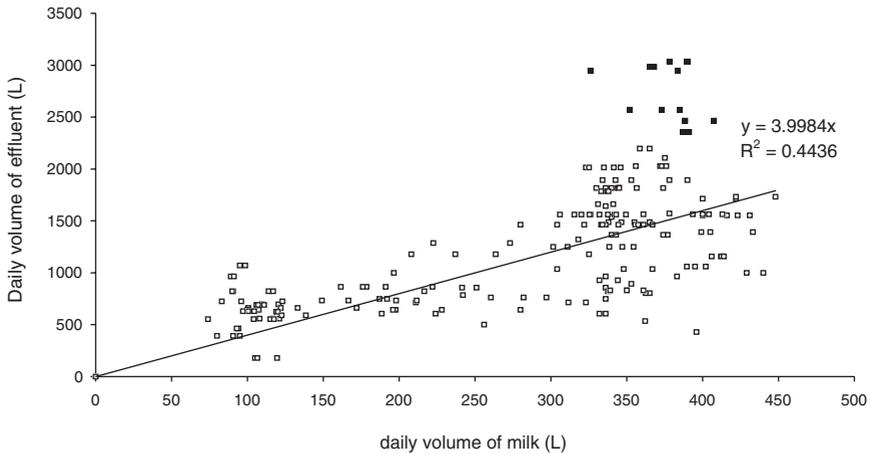


Figure 2 Volume of effluent versus volume of milk produced between July 1st 2002 and February 15th 2003. Goat farm of the lycée at Davayé

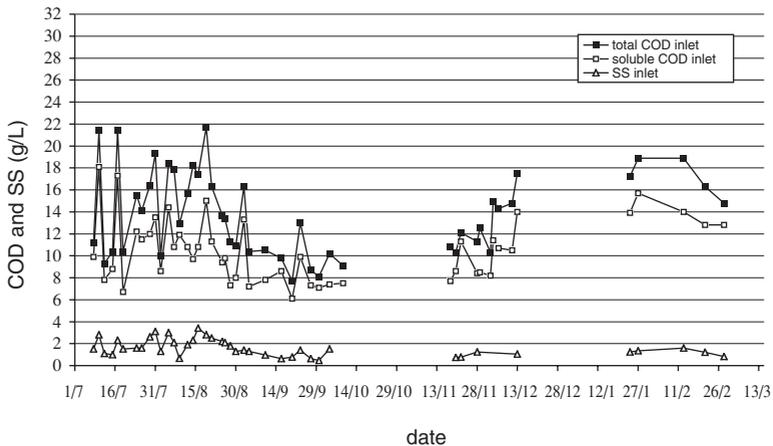


Figure 3 Composition of the raw effluent at inlet of the SBR. Goat farm of the lycée at Davayé

With 14.4 g of total COD/L and 11.2 g of soluble COD/L, the raw effluent was characteristic of a milk effluent when whey is not recovered separately but mixed with the water used for cleaning. The organic matter was mainly soluble and the soluble COD represented 78% of total COD. SS were always low, with an average value of 1.6 g/L. The ratio COD/nitrogen/phosphorus was 200/4.8/2.8, indicating sufficient nitrogen content but a slight excess of phosphorus.

Monitoring of the functioning of the SBR

The SBR plant was monitored over 7.5 months (July 4th 2002 to February 15th 2003).

Seeding. The reactor was seeded with 4 m³ of activated sludge from a domestic wastewater plant.

Working conditions. During summer and up to the first autumn reproduction period (mid-October), the SBR worked at an average volumetric loading rate (VLR) of less than 0.4 kg of COD/m³.d and a mass loading rate (MLR) of less than 0.20 kg of COD/kg of VSS.d (Figure 4). During the peak period of milk production, the volumetric loading rate increased greatly to reach values around 0.9 kg of COD/m³.d. Conversely, because of the increase in volatile suspended solids (VSS) in the reactor during the start-up period, the mass loading rate always remained low, at 0.107 kg of COD/kg of VSS.d on average.

Composition of the effluent after biological treatment. Figure 5, representing the evolution over time of the total and soluble COD at the outlet of the SBR, shows that the sludge used for the seeding of the reactor acclimatized very rapidly to the goat effluent and from the 4th day, COD at the outlet was below 100 mg/L. Throughout this monitoring, the concentration of the treated effluent discharged into the environment was on average: 65 mg/L for total COD, and 49 mg/L for soluble COD.

Given the high COD at inlet (14.4 g/L on average for total COD) and the very low COD at outlet, purification efficiency was always very high, with an average removal of 99.5% for soluble and total COD. Measuring was done at the outlet of nitrogen and phosphorus concentrations. The results obtained show that nitrification was good, with removal of 95% of N-NTK; 87% of total phosphorus was also removed.

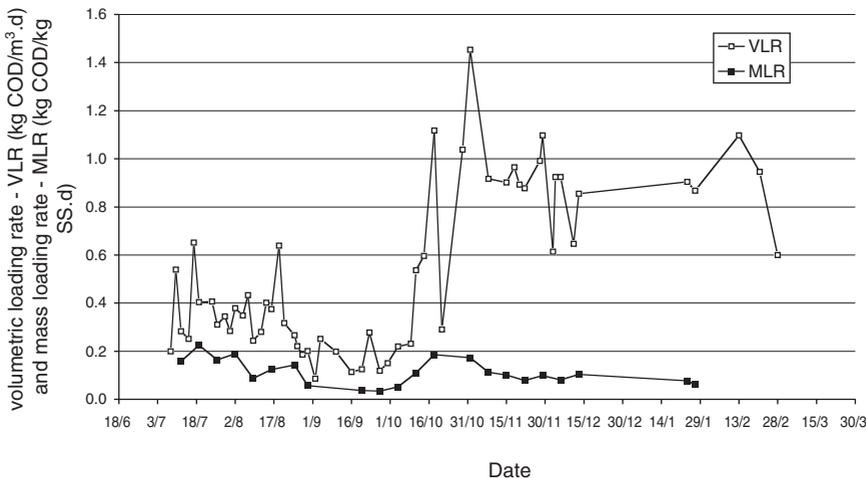


Figure 4 Evolution over time of the volumetric and mass loading rates. Goat farm of the lycée at Davayé

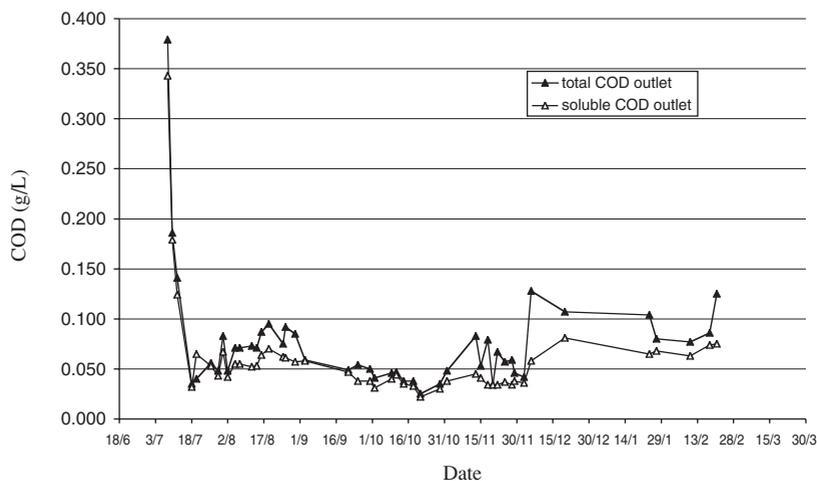


Figure 5 Evolution over time of soluble and total COD after biological treatment. Goat farm of the lycée at Davayé

Behaviour of the sludge

Special attention was paid to the behaviour of the sludge in the SBR as this is a critical factor when treating concentrated wastewater with an activated sludge. Consequently, the sludge concentration in the reactor, along with the volume occupied by the sludge at the end of the settling phase, was measured once a week (Figures 6 and 7).

In order to represent the settling conditions prevailing in the SBR, the volume of the sludge was measured after 2 hours of settling in a 1L cylinder, with no dilution of the sludge.

At start-up, sludge concentration in the reactor was around 2 g/L (Figure 6). It increased regularly as time went on, subsequent to the daily addition of organic matter, reaching 15 g/L after 155 days of operation. On day 159 (December 10th), 6 m³ of sludge, at a concentration of 23 g/L, were withdrawn from the reactor. At the end of the monitoring of the reactor, after 250 days of operation (March 10th), another 8 m³ of sludge were again withdrawn from the reactor at a concentration of 30 g of SS/L and 22.5 g of VSS/L. Sludge was pumped from the bottom of the SBR at the end of the settling phase and introduced directly into a 4 m³ tank for immediate spreading. Sludge production was low and was estimated at 0.2 kg of SS/kg of COD applied. The values measured were very close to those of winery

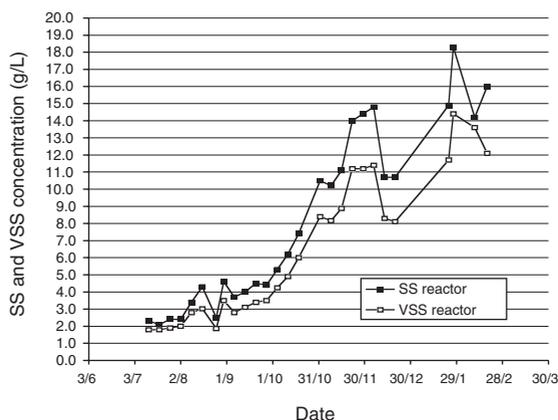


Figure 6 Evolution over time of sludge concentration in the SBR. Goat farm of the lycée at Davayé

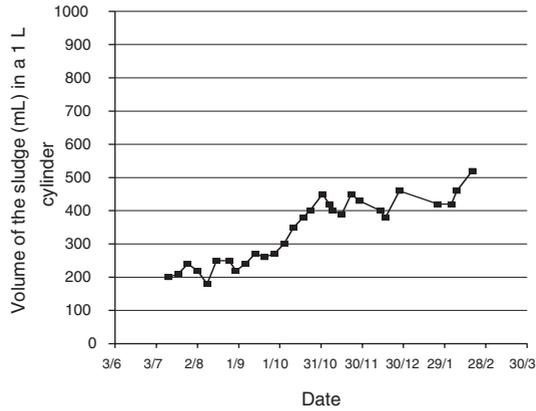


Figure 7 Evolution over time volume of the sludge after 2 hours of decantation in a cylinder of 1 L

wastewater and wastewater from cheese plants where whey is recovered separately (Torrijos and Moletta, 1997a; Torrijos *et al.*, 2001). The settlability of the sludge was calculated as the ratio between the volume occupied by the sludge at the end of the settling phase (Figure 7) and the SS concentration in the reactor (Figure 6). This parameter represents the volume occupied by 1 g of SS after 2 hours of settling.

The results obtained are presented in Figure 8. At the beginning of the experiment, the settlability of the sludge was around 100 mL/g, which is typical of sludge used for treating domestic wastewater. The settling index diminished rapidly when the reactor was fed with the goat effluent, a result showing that the sludge's aptitude for settling improved markedly. Very low values were measured at the end of the experiment, indicating the sludge's excellent aptitude for settling in the course of treating goat's cheese wastewater. This enabled a high SS concentration to be maintained in the reactor (more than 15 g/L) and then to work with a high volumetric loading rate while maintaining a low mass loading rate throughout. The volume of the sludge after 2 hours of settling in a 1 L cylinder is the only parameter measured routinely by the operator of the plant. When the sludge reaches a pre-determined level in the cylinder, the operator should remove any excess sludge to avoid the

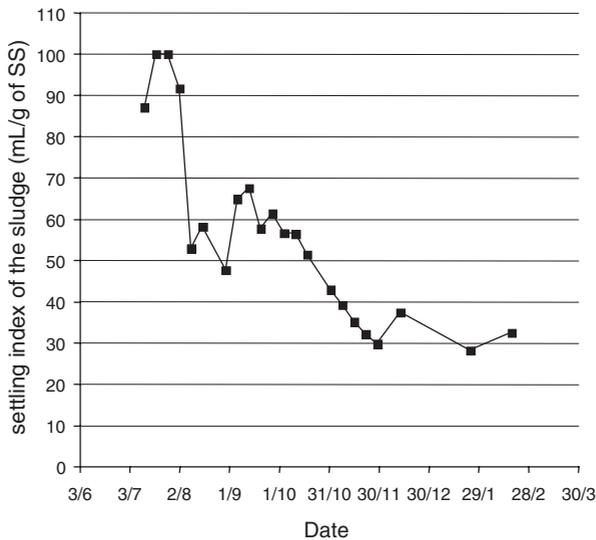


Figure 8 Evolution over time of the settling index of the sludge. Goat farm of the lycée at Davayé

discharge of sludge along with the treated effluent. When working with an effluent with a high COD, the volume of excess sludge produced compared to the volume of treated effluent is an extremely important parameter, as one of the aims of aerobic biological treatment is to reduce the volume that has to be handled. An assessment of volume reduction at the SBR plant was carried out on March 10th, after 250 days of operation. The volume treated was 323 m³ and the volume of excess sludge 14 m³ (6 m³ + 8 m³). The quantity of sludge withdrawn from the reactor represented 378 kg of SS. The volume of excess sludge represented less than 5% of the volume of treated effluent, which is very low considering the high COD at the inlet. This result was possible thanks to low biomass production and, above all, to the very good settleability of the sludge. Consequently, the excess sludge could be withdrawn from the reactor at a high concentration, thus making it possible to remove large amounts of biomass in a small volume.

Running costs

The running costs linked to the operation of the SBR plant remain within the financial capacity of the dairy. They are mainly made up of: (i) the consumption of electricity; (ii) manpower; (iii) spreading of excess sludge. Electricity was mainly used for the aeration of the reactor by a blower injecting air in a fine-bubble diffuser network located at the bottom of the reactor. The consumption of the feed and withdrawal pumps was negligible. From July 4th to February 3rd, the consumption of electricity was 3,338 kWh which represented an average of 15.6 kWh/day or 5,700 kWh/year. A person need be involved only 1 to 2 hours a week in treatment unit operations: daily check of LCDs on the control panel and measurement, every 7 to 10 days, of the level of the sludge in a 1 L cylinder. Sludge production is a function of the activity of the goat's cheese plant and sludge withdrawal is carried out as required, according to the level of the sludge in the reactor at the end of the settling period as estimated by the settling test in a 1 L cylinder. According to the results obtained in this study, the volume of excess sludge will be around 8 m³ four times a year, which represents 2 days of work for spreading and a maximum of half a day for each sludge extraction operation.

Conclusions

The aerobic SBR was used to treat an effluent with a high organic content (COD around 14.4 g/L) made up of a mixture of the cleaning wastewater and the whey from a goat's cheesemaking facility located on the goat farm. The follow-up of the first treatment plant, lasting 7.5 months, focused on the purification efficiency but, more generally, on the behaviour of the sludge and on the excess sludge volume produced, both of which are critical parameters when treating a concentrated effluent using activated sludge. The results obtained show that purification efficiency was very high (more than 99%) and the levels of COD and SS in treated water were well within the limits for discharge. Sludge production yield was low, with 0.2 g of SS/g of COD. The settling of the sludge was very good and, after two hours of settling, the sludge level in the reactor was at about half of the height of the liquid, even with mixed liquor concentrations up to 15 g/L. Sludge concentration at the bottom of the reactor at the end of the settling phase was very high so the excess sludge withdrawn had a high concentration (up to 30 g/L). Thanks to low sludge production and to the excellent settleability of the sludge, the volume of the residue after aerobic treatment was low and represented less than 5% of the volume of treated effluent.

The low volume of excess sludge and the low running cost mean that an SBR process offers a financially attractive alternative to the direct spreading of totally untreated effluent.

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