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Effect of biomass configuration on the behavior of pilot-scale anaerobic batch reactors treating dairy wastewater

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ABSTRACT

Anaerobic sequencing batch reactors applied to the treatment of dairy wastewaters have received increasing attention in bench-scale studies, particularly because dairy plants intermittently operate. This study compared two mechanically stirred, pilot-scale reactors, the Anaerobic Sequencing Batch Reactor (ASBR) and the Anaerobic Sequencing Biofilm Batch Reactor (ASBBR), in the treatment of dairy-plant wastewater. The reactors were fed with wastewater from a dairy plant and were operated with two cycle times: 48 and 24 h. The organic matter concentration in the influent, measured as chemical oxygen demand (COD), was approximately 4500 mg l^{-1}. The ASBR exhibited highly efficient removal of organic matter (92.8 ± 5.9%), with production of bicarbonate alkalinity and low concentration of volatile fatty acids in the effluent for both cycle times. In contrast, the organic matter removal efficiency of the ASBBR decreased from 92.3 ± 16.5% to 60.5 ± 16.5% when the cycle time was changed from 48 h to 24 h. Moreover, the ASBBR also presented higher levels of instability during operation, showing lower bicarbonate alkalinity concentrations and higher concentrations of volatile fatty acids in the effluent when compared with the ASBR. The superior results exhibited by the ASBR may be related to larger changes in its microbial ecology and biomass configuration that occurred because of its better microbial selection and adaptation conditions. Granule diameters decreased greatly over time; however, this reduction did not affect settleability, assuring the performance of the ASBR.

1. Introduction

Because of their low operating costs and reduced sludge generation, anaerobic reactors are frequently used for the treatment of wastewater from agro-industries. These systems provide organic matter removal and methane generation, and this co-product can be harnessed for power generation, particularly in tropical and subtropical regions where the temperature favors the anaerobic digestion process. Studies on the anaerobic sequencing batch by Dague et al. (1992) for the treatment of swine wastewater intensified interest. The authors observed excellent degradation of organic matter, good sludge flocculating characteristics and efficient separation of solids, factors that enable high cellular retention times and confer robust stability to the process.

This reactor configuration has been receiving increased attention in recent years for applications in the treatment of dairy wastewater in bench-scale studies. Ratusznei et al. (2003) studied the feasibility of the anaerobic treatment of reconstituted milk powder in an anaerobic sequencing biofilm batch reactor (ASBBR) with biomass immobilized to an inert support. The study was performed using 8-h cycles with 200-rpm agitation at 30 °C. The organic loading rate was 0.81–5.7 g COD l^{-1} d^{-1}. The average efficiency of the system was 96% COD removal, with effluent concentrations below 160 mg l^{-1} Mockaitis et al. (2006) analyzed the effect of increasing organic matter and decreasing alkalinity supplementation with sodium bicarbonate in the influent (milk powder) in an anaerobic sequencing batch reactor (ASBR) containing granular biomass. The reactor was operated with an 8-h cycle and effluent concentrations equal to 0.500, 1.0, 2.0 and 4.0 g COD l^{-1}, corresponding to organic loading rates from 0.6 to 4.8 g COD l^{-1} d^{-1}. The observed removal efficiency remained above 90%. Zimmer et al. (2008) examined the influence of organic loading rate and filling time on the stability and efficiency of the

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ASBR (6 l) with granulated biomass in the treatment of diluted whey. The authors concluded that for an influent concentration of 4.0 g COD l^{-1}, the increased feeding time resulted in the decreased removal of soluble organic matter. For an 8.0 g COD l^{-1} influent, the increased feeding time resulted in lower total COD in the effluent. The study also showed that higher fill times led to reductions in the peak concentrations of organic matter, volatile acids and alkalinity requirements over the cycle. Bezerra Jr. et al. (2009) evaluated the influence of different feeding times and organic loading rates on the performance of an ASBBR (3.8 l) containing immobilized biomass on polyurethane foam with a liquid phase recirculation in the treatment of whey. The authors found that when the system was fed with an organic load equal to 3 g COD l^{-1} d^{-1}, the filling time did not influence the efficiency of organic matter removal, but when the system was fed with an organic load equal to 6 g COD l^{-1} d^{-1}, a decreased efficiency with higher fill times were observed.

Belançon et al. (2010) compared two configurations of anaerobic reactors in the treatment of dairy effluent: a hybrid UASB reactor and a ASBBR. The reactors were fed with effluents from the pasteurization of milk and cheese production without whey separation (~5.0 g COD $^{-1}$). The ASBBR showed a 93.5% average efficiency of organic matter (measured as COD) removal, whereas the hybrid UASB reactor showed an efficiency of 80.1%. In addition, there was a loss of approximately 18% in the reactor bed due to the flotation of granules, emphasizing the greater stability and effectiveness of ASBBR in removing organic matter. Fuzzato et al. (2009) observed organic matter removal rates higher than 90% and high alkalinity production with organic loading rates ranging from 1.1 ± 0.2 g COD l^{-1} d^{-1} to 12.1 ± 2.4 g COD l^{-1} d^{-1} when using a bench-scale ASBBR with a 24-h cycle time for dairy wastewater treatment.

These previous studies have shown the unquestionable feasibility of applying anaerobic sequencing batch reactors to the treatment of effluents from dairy products at the bench scale. Santana et al. (2014) verified high organic matter removal (87 ± 9%) in a pilot-scale ASBBR agitated through recirculation in treating dairy wastewater with a 48-h cycle time. The present study aimed to ascertain how the biomass configuration and the cycle time affect the removal efficiency of organic matter in pilot-scale anaerobic sequencing batch reactors treating dairy wastewaters.

2. Materials and methods

2.1. Reactor characteristics and operation

Two anaerobic pilot-scale reactors (1 m^3) were operated in sequencing batches, one using granular biomass (anaerobic sequencing batch reactor – ASBR) and another filled with biomass immobilized in polyurethane foams (anaerobic sequencing batch biofilm reactor – ASBBR), in the treatment of effluent from a small dairy plant operating at the University of Sao Paulo, Brazil (Fig. 1). The effluent was pumped through a tank for fat separation, followed by gravity separation in an equalization tank, to reduce variation in flow, pH and the composition of wastewater for biological treatment. Prior to being sent to the anaerobic sequencing batch reactors, lime and sodium bicarbonate were used for pH adjustment. The support used to immobilize the biomass in the ASBBR was polyurethane foam placed in a cylindrical polypropylene frame (BioBob®) 5 cm in diameter and 6 cm in length. This support was confined in a cylindrical basket (1.20 m high), which was made of stainless steel 304 sheets perforated with 1.5-cm holes, surrounding the impeller shaft. To increase turbulence and improve contact between the substrate and the microorganisms, the ASBR was equipped with four stainless steel baffle plates

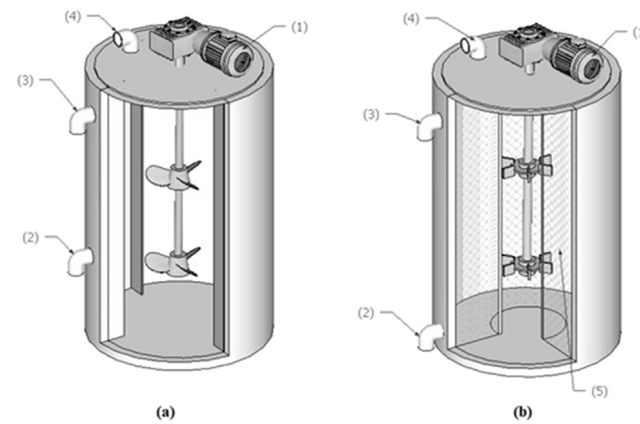

Fig. 1. Experimental reactor sketches: (a) ASBR and (b) ASBBR. Caption: (1) Mechanical stirring system with adjustable-speed motor and impeller, (2) discharge valve, (3) feed valve, (4) gas outlet, and (5) basket with immobilized biomass.
Adapted from Novaes et al. (2010).

10 cm wide at an angle of 90° from one another. To promote mixing, a reduction motor (3 HP) was installed with a capacity of 250 rpm, a vertical shaft and impellers, and a frequency inverter was used to control the required rotations at 40 rpm for both reactors. Capacitive level sensors were installed in the reactors to control the liquid level. Two sets of six-blade vertical flat turbines were used as impellers in the ASBR, and two sets of three-blade helix impellers were used as impellers in the ASBBR. All impellers were made of 2-mm-thick sheets of stainless steel 304. The choice of these impellers was based on results obtained by Novaes et al. (2010). The reactors were operated at ambient temperatures in 48-h and 24-h cycles. At the beginning of the cycle, during the filling phase (length: 30 min), 0.65 m^3 dairy wastewater were pumped into the both reactors. Next, agitation was started at a fixed rate (40 rpm). The duration of the reaction phase was different for each configuration because 30 min was necessary for biomass sedimentation in the ASBR, during which agitation was interrupted. Discharge phase was also performed in approximately 30 min for both reactors, after which a new cycle was started. The 1-m^3 volume in the ASBR consisted of 0.35 m^3 mixed liquor that remained in the reactor after settling and 0.65 m^3 fed/discharged (i.e., treated) wastewater per operational cycle. The 1-m^3 volume in the ASBBR consisted of 0.35 m^3 polyurethane foam and adhered biomass, which remained in the reactor, and 0.65 m^3 fed/discharged (i.e., treated) wastewater per operational cycle. Initially, cycle time of 48 h was employed for 100 days. Later, the cycle time was reduced to 24 h. The data at the beginning and the end of the reactor cycles were monitored for at least 60 days (30 cycle times) for both operational conditions.

2.2. Physicochemical analysis

The reactors were monitored through COD analysis (total organic matter = total COD; the filtered organic matter obtained from the filtration of a sample through membranes with a pore size of 1.1 µm = filtered COD) and the concentrations of total volatile acids (TVA), bicarbonate alkalinity (BA), total phosphorus (TP), soluble phosphorus (SP), total Kjeldahl nitrogen (TKN-N), ammonium nitrogen (NH_4^+-N), total solids (TS), total volatile solids (TVS), total suspended solids (TSS) and volatile suspended solids (VSS). The analyses were all performed according to the Standard Methods for the Examination of Water and Wastewater (APHA/AWWA/WEF, 1998). After the steady state was reached, data profiles were generated from the analyses of the samples collected for each cycle time. The collected samples were analyzed for COD and