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Anaerobic treatment of low-strength wastewater with a high fraction of particulate matter in an unconventional two-phase ASBRs system

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ABSTRACT

The results of a two-phase anaerobic system using anaerobic sequencing batch reactors (ASBRs), treating low-strength wastewater (COD ~ 500 mg/L) with a high fraction of particulate organic matter (70%, COD basis), are presented. Two reactors in series were used; the first one was hydrolytic–acidogenic, while the second one was methanogenic. This configuration was proposed to promote high efficiency solids removal. During the experiment, 69% and 50% efficiencies of total COD removal were obtained for OLRs of 0.63 and 1.22 kgCOD/(m^3 d), respectively. Values of the solubilized organic fraction (SOF) achieved in the hydrolytic–acidogenic reactor were within the range of 0.3–0.6 $gCOD_{solubilized}/gpCOD_{removed}$, and the average acidified organic fraction (AOF) was 0.6 $gCOD_{VFA\text{-}produced}/gsCOD_{fed}$. The methanogenic reactor had a VFA removal fraction (VFARF) between 0.4 and 0.6 $gCOD_{VFA\text{-}removed}/gCOD_{VFA\text{-}fed}$ for the OLR of 0.63 and 1.22. The two-phase ASBR system is suitable, and can be implemented, for the anaerobic treatment of this kind of wastewater.

1. Introduction

The anaerobic treatment of low-strength wastewater, such as domestic wastewater, has not been extensively implemented because the process has a lower performance under these conditions. This is because the concentration of organic matter (substrate) is in the same range or near the value of the saturation constant of the anaerobic biomass (*Ks*). Hence, biomass is not growing at the maximum specific growth rate and, at the same time, is consuming the substrate at a low-degradation rate (with respect to the Monod kinetics). Moreover, if a high fraction of particulate or suspended organic matter is present (≥0.45 μm), the overall reaction slows down even further since hydrolysis of the complex composite particulates must first occur [1], which can become the limiting step of the whole process.

The application of a two-phase anaerobic system to treat this type of effluent may present significant advantages over a one-phase system. The separation of the main reactions of anaerobic digestion, acidogenesis and methanogenesis, allows the selection and enhancement of microbial populations in each reactor in terms of temperature and pH as well as control of the intermediate products [2]. Pohland and Ghosh [3] proposed the separation of acid-producers and acid-consumers in two reactors in order to optimize the activity of each population, improving their particular environmental and operational conditions.

The implementation of these systems has focused on the treatment of high-strength waste and wastewater using continuous anaerobic reactors. Different configurations have been evaluated: CSTR + UASB [4,5], CSTR + CSTR [6–10], and CSTR + UAF [11].

The anaerobic sequencing batch reactors (ASBRs), developed by Sung and Dague [12], is an anaerobic digestion system that works through consecutive cycles of operation, each of which has the following stages: feeding, reaction, settling, discharge and idle time. At the beginning of the reaction stage, the concentration of organic matter is at its maximum level, which in turn maximizes the degradation rate since the substrate is greater than the *Ks*. This situation presents an important kinetic advantage over continuous systems, where the concentration of substrate in the reactor is equal to the effluent, which is lower than the *Ks* [13]. Thus, the application of a two-phase ASBR system, besides enriching the development of both populations, can increase their growth rate and hence their degradation ability, improving the acidogenesis and hydrolysis rates in the first reactor and methanogenesis rate in the second one, and the overall performance of the system.

Few studies have evaluated or tested a two-phase system with ASBRs. Dugba and Zhang [14] worked with two ASBR in series, but in this case the objective was to study the effect of temperature (thermofilic/mesofilic, thermofilic/thermofilc) using an industrial effluent. Bouallagui et al. [15] reported a study with two-phase ASBR system (acidogenic and methanogenic), in which fruit and

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Nomenclature

ASBBR	anaerobic sequencing batch biofilm reactor
ASBR	anaerobic sequencing batch reactor
$COD_{VFA}i$	COD of VFA of the ASBR1 influent
$COD_{VFA}1$	COD of VFA of the ASBR1 effluent
$COD_{VFA}2$	COD of VFA of the ASBR2 effluent
k_H	hydrolysis catalytic constant
Ks_1	saturation constant of acidogenic biomass
Ks_2	saturation constant of methanogenic biomass
OLR	organic load rate
pCOD	particulate COD
pCODi	particulate COD of the ASBR1 influent
pCOD1	particulate COD of the ASBR1 effluent
sCOD	soluble COD
sCODi	soluble COD of the influent
sCOD1	soluble COD of the ASBR1 effluent
tCOD	total COD
VFA	volatile fatty acids

Greek letters

μ_{M1}	maximum specific growth rate of acidogenic biomass
μ_{M2}	maximum specific growth rate of methanogenic biomass

vegetable wastes were treated. The focus was to optimize each of the reactions, which resulted in over 80% hydrolysis in the first reactor and high percentages of biogas production (320 L/kg$COD_{affluent}$) in the second reactor. Both studies were carried out with high-strength substrates.

The objective of this study was to implement and evaluate the performance of a two-phase ASBR system in the treatment of low-strength wastewater with a high fraction of particulate organic matter, simulating domestic wastewater.

2. Materials and methods

2.1. Experimental setup

Two laboratory scale reactors of acrylic, both with a total volume of 6 L and effective volume of 5 L were used (ASBR1, hydrolytic–acidogenic and ASBR2, methanogenic). Both reactors were jacketed and the temperature kept at approximately 35 °C. The reactor was mixed by liquid recirculation during the reaction step. Peristaltic pumps were used for feedings, effluent discharge and mixing. The automated operation of the system (pumps, valves and mixer) was programmed using timers and counters in Microwin STEP7 using a PLC Siemmens S7200. Fig. 1 shows a diagram of the system used in this study. The time distribution for the stages in each reactor was as follows: feeding 15 min, settling 30 min, discharge 20 min, and idle time 5 min. The reaction times were 410 and 180 min for OLR1 and OLR2, respectively.

The ASBR1 was fed with synthetic wastewater that simulated domestic wastewater with the following composition: Potato solution 2.0 g/L, ovoalbumin 0.12 g/L, vegetable oil 0.025 g/L, urea 0.033 g/L. In addition to the macronutrients NH_4Cl 0.074 g/L and KH_2PO_4 0.01 g/L, the following micronutrients were added: $FeCl_3{\cdot}4H_2O$ 4.0 mg/L, $ZnCl_2$ 0.1 mg/L, $MnCl_2{\cdot}4H_2O$ 1.0 mg/L, $CoCl_2{\cdot}6H_2O$ 4.0 mg/L, $CuCl_2{\cdot}2H_2O$ 0.06 mg/L, $NiCl_2{\cdot}6H_2O$ 0.1 mg/L, H_3BO_3 0.1 mg/L, $Na_2SeO_3{\cdot}2H_2O$ 0.2 mg/L and $(NH_4)6MoO_2{\cdot}4H_2O$ 0.18 mg/L. To maintain the alkalinity of the system, 0.5 g/L $NaHCO_3$ was added. The ASBR1 was seeded with acidogenic sludge, with negligible methanogenic activity. The ASBR2 was fed with the effluent of the ASBR1 and it was seeded with an anaerobic granular sludge, with a methanogenic activity of 0.62 gCOD_{CH_4}/(gVSS d). Each of the reactors was inoculated in order to obtain an initial biomass concentration of 5 gVSS/L.

2.2. Start-up and operation of the two-phase system

The start-up was carried out with the operation of ASBR1 at an OLR of 1.21 ± 0.12 kgCOD/(m^3 d) (3 cycles/day) and a pCODi/tCODi ratio of 0.66 ± 0.04. Once start-up of the ASBR1 was complete, the ASBR2 was connected to the system and fed with the discharge of ASBR1. A system OLR of 0.63 ± 0.064 kgCOD/(m^3 d) with a pCODi/tCODi ratio of 0.67 ± 0.04 was applied, as well as a second system OLR of 1.22 ± 0.16 kgCOD/(m^3 d) (6 cycles/day) with a pCODi/tCODi ratio of 0.70 ± 0.04. The dynamic behavior of the reactor was analyzed by follow-up procedures, which were done by taking consecutive samples during the reaction stage in both reactors. The first samples were taken from the ASBR1. Samples were then taken from ASBR2 when the effluent was fed from the ASBR1.

2.3. Analytical methods

During the operation of the system, the influent to the system, the ASBR1 and the ASBR2 effluents were sampled for the following analysis: total COD (tCOD) and soluble COD (sCOD) were measured by the Closed Reflux-Titrimetric Method [16]; samples for sCOD

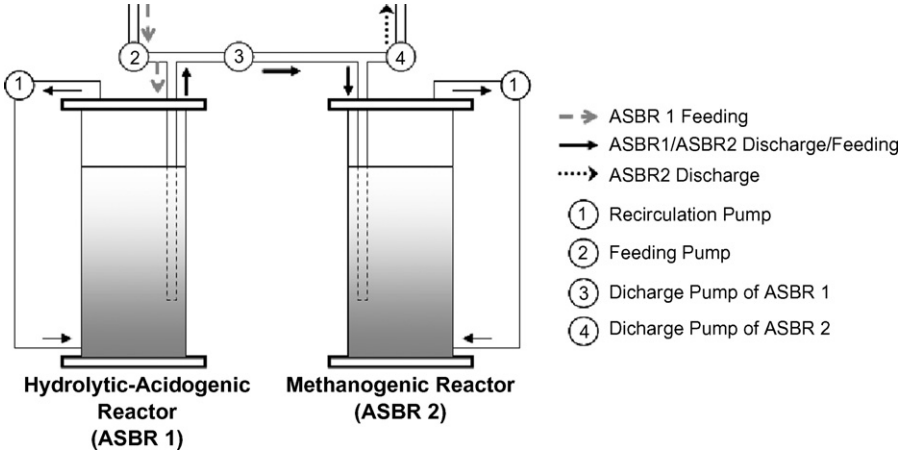

Fig. 1. Schematic diagram of the two-phase system implemented for the anaerobic treatment of low-strength wastewater with a high fraction of particulate organic matter.