Pilot scale anaerobic sequencing batch reactor for distillery wastewater treatment

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Abstract: Anaerobic digestion is an established technology for distillery effluent treatment. In Italy the most common anaerobic digester for distillery factory is the Completely Stirred Tank Reactor whose average volumetric organic loading rate is lower than 3 kg COD m^{-3} d^{-1}. In this paper the performance assessment of a pilot-scale high rate Anaerobic Sequencing Batch Reactor, treating 4 different distillery effluents, is presented as an alternative to continuous systems.
The average applied loading rate was 4 kg COD m^{-3} d^{-1} and after a shock load condition (15 g COD_T l^{-1} d^{-1} maintained for one day) the reactor showed stable response.
The results obtained show the feasibility of this anaerobic discontinuous process for distillery effluent treatment, representing a valid option to up-grade the existing WWTP.
Keywords Anaerobic digestion, distillery wastewater, anaerobic sequencing batch reactor

Introduction

In the wastewater treatment field, systems based on anaerobic biological processes have traditionally been adopted to stabilize both primary and secondary waste sludge (Parkin and Owen, 1986), as this application is well suited to the main requirements of anaerobic systems. These include:

- good removal ability of the biodegradable substrates;
- efficiency levels that are not excessively high;
- high production of biogas;
- and low running costs, mainly due to the lack of a forced aeration system.

However, over the last few years, the search for “sustainable” treatment systems capable of minimizing energy consumption (Jetten et al., 1997) has encouraged the use of anaerobic biological systems even for intensive wastewater treatment, where the main goal is to eliminate the biodegradable dissolved fraction in carbonaceous substrates (Lettinga et al., 1979, Pfeiffer et al., 1986).

These applications were used mainly for high-strength organic wastewaters such as those produced by the distilleries (that represents an important sector of Italian economy, due the huge availability of by-products to be changed in alcohol), as the effects of the intrinsically slow anaerobic processes are less serious (Malina and Pohland, 1992). Wastewater is the most important waste stream in the distillation industry; quantity and quality of the effluents streams are subject to considerable change, due to the wide diversity of the raw materials; in particular high concentration of organic substances (from 20 to 150 g/l COD) are typical for this kind of wastewaters.

New and efficient anaerobic plant configuration were developed in the last twenty years, all of these plants are characterized by a high substrate removal rate per unit reactor volume (kg COD m^{-3} d^{-1}), obtained by retaining the biomass in the reactor independently of the incoming wastewater (solids retention time, SRT, is higher than hydraulic residence time, HRT). High-rate anaerobic biological systems may be classified into three broad groups, depending on the mechanism used to achieve biomass detention. These are fixed film, suspended growth, and hybrid systems (Barber and Stuckey, 1999).

Among these new high rate anaerobic plant configurations, Dague and co-workers (1992) proposed the ASBR (acronym of Anaerobic Sequencing Batch Reactor) as alternative to continuous systems. The batch operation allows good effluent quality control since the reactor draw can be made just when the compliance with legal standard has been attained. Operation of the Anaerobic Sequencing Batch Reactors consists of four steps: feeding, reaction, settling and treated effluent withdrawal. The main factors affecting the overall performance of the ASBR are: agitation, Substrate/Biomass ratio, geometric configuration of the reactor and the feeding strategy. The feasibility of the process was proved at lab-scale by Sung and Dague (1995) treating non-fat dry milk synthetic substrate; Ruiz et al. (2002) obtained encouraging results working with winery effluents.

The object of the work presented in this paper is the performance assessment of a pilot-scale ASBR (total volume 180 l), at 35°C, treating 4 different distillery wastewaters.

Material and methods

Reactor

The treatment of four different distillery wastewaters was carried out using a pilot scale reactor (Figure 1) of 180 l working volume, the reactor has a length to diameter ratio, L/D, of 6 m/0.194 m, maintained at 35°C by a thermostatically regulated heating cable. In the upper part of the reactor was placed an inert (polyurethane) support (total height of 0.20 m) for cell immobilization to improve the solid retention. The reactor was equipped with six sampling ports (at 0.75m intervals from the bottom to the top of the reactor), two pH probes and two temperature probes.

A volumetric pump (Hydra EM24) was used to fill the reactor; agitation was provided by recycling the mixed liquor from an intake below the inert support and injecting it upwards from the bottom of the reactor. The produced biogas was measured by an Elkro gas (BK-P) meter.

The reactor was seeded with excess sludge from a full-scale completely stirred anaerobic reactor treating distillery wastewaters. The distillery wastewaters were stored at 4°C and kept under agitation.

Sampling and analyses

The functioning of the reactor was monitored over four months, regularly samples were taken at feed, and treated effluent, periodically were performed track studies to monitor the in-reactor trends of filtered COD, VFA, TOC and alkalinity within a cycle treatment.

Total Solids (TS), Volatile Solids (VS), Total Suspended Solids (TSS), Volatile Suspended Solids (VSS), N-NH_4^+ were regularly performed for the untreated and treated effluents according to the Standard Methods (APHA, 1996). Monovalent anions were analysed using a HPIC (Dionex 5000i). Total alkalinity (TA) was measured by titration at pH 3.8. VFA were determined, on filtered 0.45 µm samples, by gas chromatography, using a DANI 8510 GC equipped with a FID detector. Total and filtered (0.45 μm) COD was analysed by Dr Lange kit. TOC, on filtered (0.45 μm) samples, was determined by TOC meter (Shimadsu TOC 5000 VPN).

The sludge of the reactor was observed by a phase -contrast light microscopy (Jenalumar A/D contrast light microscope, 1000 X magnification) in bright field phase contrast, Nomarski interferential contrast and brield field.

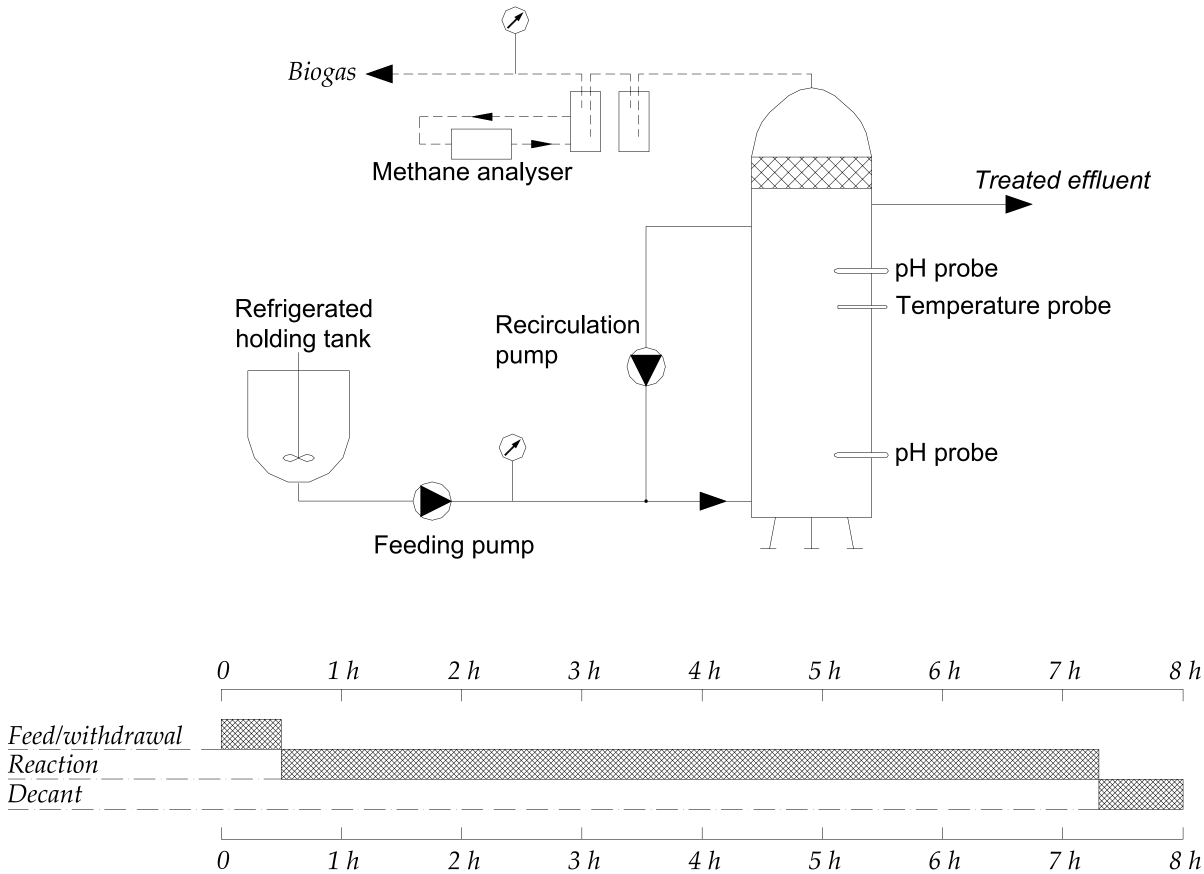

Figure 1 Experimental set-up of the pilot ASBR treatment process

The methane content in the biogas was measured using a Siemens Ultramat. Biogas production, methane content and pH were monitored continuously.

Operating conditions

The ASBR treatment cycle was characterized by three process phases each lasting for a defined period: fill and withdrawal, react and decant. The reactor was sequenced three times per day, providing a sequence length of 8 hours, the fill length were adjusted to guarantee a volumetric organic loading rate (OLR_V) of 3-4 g COD_T l^{-1} d^{-1}.

Results and discussion

Distillery influent characteristics. The distillery wastewaters were obtained from a factory located in

Ravenna (Italy). The distillery wastewaters characteristics are reported in table 1.

Table 1 Distillery wastewaters characteristics

Parameters	Unit	Wastewater No. 1 Borland	Wastewater No.2 Mixed ww	Wastewater No.3 Mixed ww	Wastewater No. 4 Winassis
COD_T	[g l^{-1}]	42	16	15	125
COD_S	[g l^{-1}]	35	14	13	102
TOC	[g l^{-1}]	11.6	4.7	4.8	58
TC	[g l^{-1}]	11.6	5.2	4.9	58
IC	[g l^{-1}]	0	0.5	0.1	0
pH		3.5	6.9	11.8	4.7
Acetic acid	[g l^{-1}]	1.1	1	0.9	3.7
Propionic acid	[g l^{-1}]	0	0	0.3	0
N - Butyric acid	[g l^{-1}]	0	0	0	0
I- Butyric acid	[g l^{-1}]	0.3	0	0	0
VFA Total	[g l^{-1}]	1.4	1	1.2	3.7
Total Alkalinity	[g $CaCO_3$ l^{-1}]	ND	3.5	5.7	6.8
TS	[g Kg^{-1}]	35	27	25	115
VS	[g Kg^{-1}]	27	11	12	82
TSS	[g Kg^{-1}]	4.9	5.5	3	13
VSS	[g Kg^{-1}]	4.3	2.7	1.9	10

The volumetric organic loading rate (OLR_V) trend is reported in figure 2; in particular the fill length was adjusted to guarantee a constant volumetric organic loading rate (OLR_V) of 3-4 g COD_T l^{-1} d^{-1}, the OLR_V was rapidly increased to 15 g COD_T l^{-1} d^{-1} during day 133 to evaluate the reactor response (process flexibility) under shock loading conditions; the efficiency COD removal is reported in figure 3.

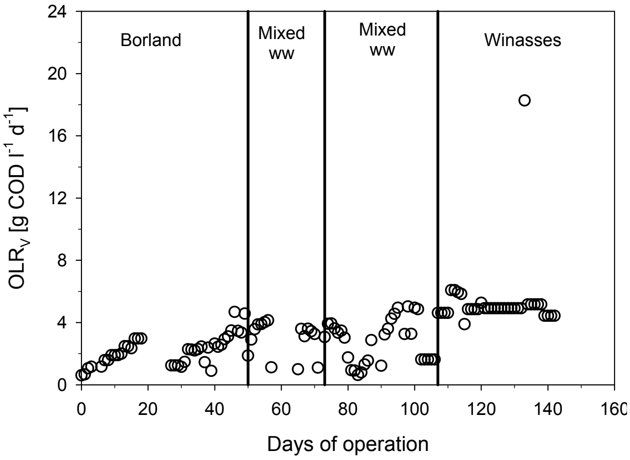

Figure 2 OLR_V trend during the experimental campaign

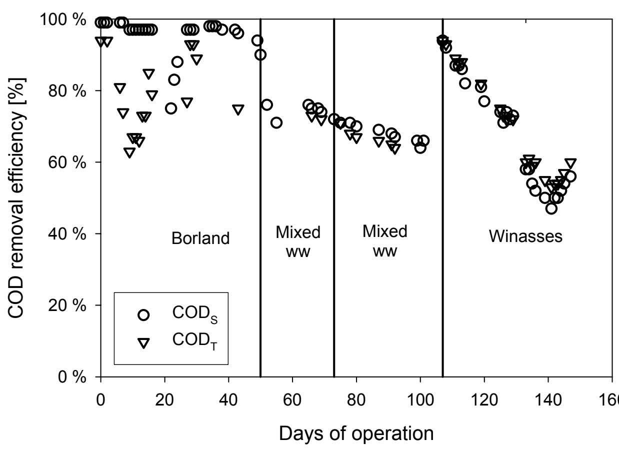

Figure 3 COD removal efficiency during the experimental campaign

During the experimental period, COD removal efficiency was variable depending on the organic loading rate (at higher OLR_V a decrease of COD reduction can be observed) and on wastewater to be treated (up to 93% for COD_T with the Borland wastewater). The biogas production ranged between 1 to

3 Nl $l^{-1}_{reactor}$ day^{-1}, and the methane content was 50-80% depending on the wastewaters.

pH values ranged between 7.2 and 7.8, with VFA (Figure 5) concentration ranging from 2000 to 6000 mg l-1, always presenting acetic acid as the prevalent, except after shock loading when propionic acid was the main intermediate product and the VFA measured total VFA concentration was 25 g l^{-1}.

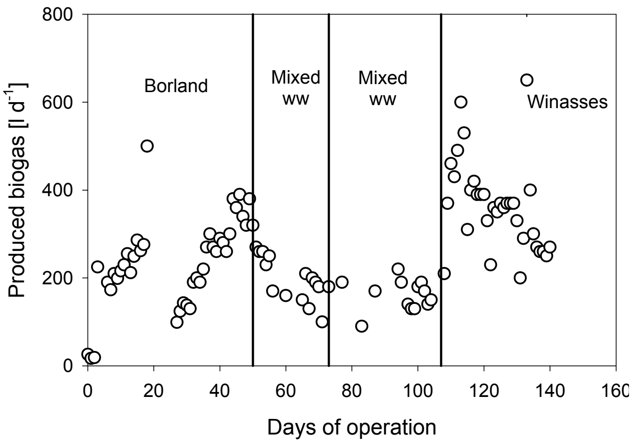

Figure 4 Biogas production measured during the experimental campaign

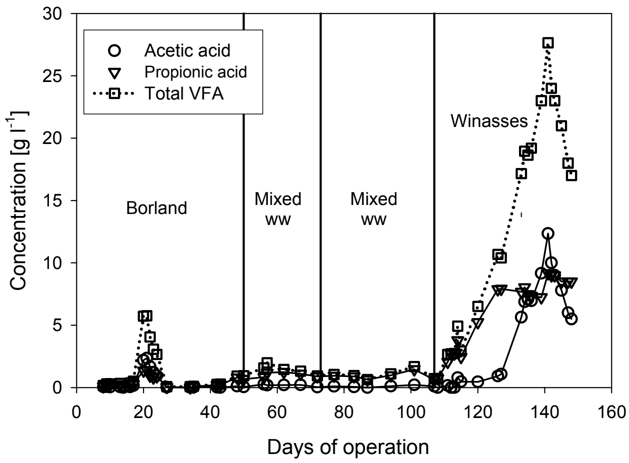

Figure 5 Volatile fatty acid concentration measured in the effluent during the experimental campaign

The shock load applied during day 133 determined a pH reduction, but the system showed high flexibility: when the organic loading rate has been reduced to previous values VFA concentration rapidly decreased. Any way no inhibition was observed on the anaerobic biomass activity as confirmed by the amount of methane produced per unit of COD converted, equal to 350 l CH_4 per kg COD converted.

The dynamic COD and produced biogas profiles referred to the mixed wastewater for a loading rate of 4.5 g COD_T l^{-1} d^{-1}, during one treatment cycle are reported in figure 5 and figure 6 respectively.

The soluble COD concentration is high at the start of the cycle but drops off rapidly and is essentially back to its original concentration in 4 hours. The biogas production rate is high at the start of the cycle and is low at the end of the cycle. These aspects are essential for a development of a good settling sludge: at the end of the react period, COD removal and biogas production rate are lower to ensure conditions for solids settleability.

The anaerobic biomass observed by microscope have shown a flock structure after about two months, but no granule formation was observed during the experimental investigation.

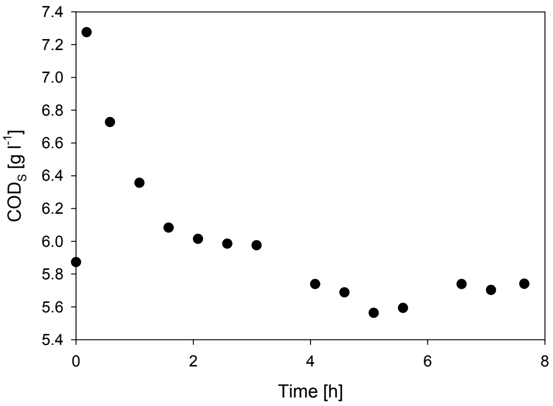

Figure 5 Dynamic COD_S profile throughout day 99

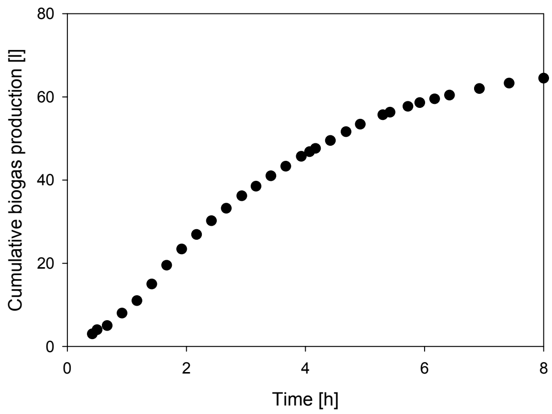

Figure 6 Dynamic cumulative biogas production profile throughout day 99

Conclusion

The ASBR pilot plant treating different distillery factory effluents showed high process stability.
The treated wastewaters had a large variability in the content of organic matter expressed as COD, ranging from 20 to 120 g COD l^{-1}, never less the removal efficiency ranged from 70 to 80 % in terms of soluble COD, with a methane conversion efficiency ranging from 300 up to 350 $l_{methane}$ $kgCOD^{-1}{}_{removed}$, close to the theoretical values. The average applied loading rate was 4 kg COD m^{-3} d^{-1} and after a shock load condition (15 g COD_T l^{-1} d^{-1} maintained for one day) the reactor showed stable response.
This anaerobic discontinuous process could represent an alternative to the existing CSTR WWTP especially when this reactors should be follow an increasing of the wastewater to be treated discharged from the productive process.

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