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ScienceDirect
Bioresource Technology 99 (2008) 4086–4095
BIORESOURCE TECHNOLOGY

Enhancement of methane production from long chain fatty acid based effluents

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Received 1 May 2007; received in revised form 2 September 2007; accepted 4 September 2007
Available online 19 November 2007

Abstract

Two anaerobic sludges previously loaded with oleate and palmitate accumulated 4570 ± 257 and 5200 ± 9 mgCOD-LCFA $gVSS^{-1}$, respectively. These sludges were incubated in batch assays and methane production was recorded after addition of 100–900 mg L^{-1} of oleate and palmitate, respectively. The batch assays were conducted before and after allowing the depletion of the biomass-associated LCFA. The presence of biomass-associated LCFA decreased the capacity of both sludges to convert the added LCFA to methane. After the degradation of biomass-associated LCFA, the lag phases observed before the onset of methane production were significantly reduced, evidencing an increase in the tolerance of the acetotrophic methanogens to the presence of LCFA. In another experiment, three recurrent pulses were performed with a real dairy wastewater containing 3.6 gCOD L^{-1}, from which 53% was fat. Methane yields of 0.45 ± 0.01, 0.88 ± 0.02 and 1.29 ± 0.08 gCOD-CH_4 $gCOD_{fed}^{-1}$ were achieved in the first, second and third pulses, respectively, evidencing an increasing capacity of the sludge to convert substrate accumulated in previous additions.

Keywords: Oleic acid; Palmitic acid; Anaerobic biodegradation; Pulse feeding; Dairy wastewater

1. Introduction

Lipids are a group of organic pollutants whose conversion into biogas has been considered very difficult. Characterized either as fats or oils and greases, the lipids are one of the major components of organic matter in wastes and wastewaters such as those coming from food processing industries, slaughterhouses, dairy industries and fat refineries (Li et al., 2002). These compounds are glycerol bonded to LCFA, alcohols, and other groups by an ester or ether linkage. Triacylglycerides, also called neutral fats, are the most abundant family of lipids and are hydrolyzed by extracellular lipases to yield glycerol and LCFA. Glycerol is further degraded via acidogenesis while LCFA are degraded to acetate, H_2 and CO_2 through the β-oxidation process (syntrophic acetogenesis) (Stryer, 1995).

Theoretically 1.01 L of methane at standard temperature and pressure (STP) can be produced from for instance 1 g of oleate (unsaturated LCFA, C18:1), whereas only 0.37 L can be produced from 1 g of glucose. Therefore, wastes or wastewaters with a high lipid-content represent an attractive source for methane production (Kim et al., 2004). This potential is however limited due to operational problems. Diverse technologies applied to the anaerobic treatment of oily effluents are reported in the literature, but information available is not always complete (Table 1). For instance, the methane yield and effluent VSS are most of times omitted. It can be observed that these systems do not always accomplish a desirable performance in terms of COD conversion to methane, and reports of reactors' failure are quite frequent. In this way, the treatment of these types of wastewaters is still a challenge, continuously driven by emergent practical and fundamental knowledge (Sousa, 2007).

One of the most reported problems of high rate anaerobic reactor technology such as the upflow anaerobic sludge

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doi:10.1016/j.biortech.2007.09.005

Table 1
Treatment of wastewater containing lipids and LCFA in different anaerobic reactors (adapted from Sousa, 2007)

Type of wastewater	Type of reactor	HRT (d)	OLR ($gCOD\ L^{-1}\ d^{-1}$)	COD removal (%)	CH_4 yield ($LCH_4\ gCOD^{-1}$)	Reference
LCFA mixture	UASB	0.7–1.2	3.2–9.4	82–93	ND	Hwu et al. (1998)
LCFA mixture (+glucose)	CSTR + UASB	2.9	0.2–2.7	60–95	ND	Kim et al. (2004)
Oleate (+skim milk)	EGSB	1	4–8	69–97	0.03–0.28	Pereira et al. (2002a)
Oleate (+skim milk)	AF	3.3–0.64	0.7–12.5	80–95	0.09–0.36	
Saccharose + oleate or Saccharose + stearate	UASB or DAEB	1	4.2–6.4	76–93	ND	Miranda et al. (2006)
Dairy wastewater	IFB or ITB	63.6–3	0.5–10	75–98	ND	Arnaiz et al. (2003)
Dairy wastewater	BFBR	0.3–0.5	10 (up to)	85–90	Approx. 0.37	Haridas et al. (2005)
Ice-cream factory wastewater	AF	0.9	6.4	67	0.36	Hawkes et al. (1995)
	Contact process	5.5	1.1	82	0.39	
	FBR	1.5	4.2	56	0.37	
	UASB	1.6	2.2	49	0.19	
Food industry wastewater	UASB	5–1.25	1.3–8	84–98	0.18–0.48	Jeganathan et al. (2006)
Slaughterhouse wastewater	EGSB	0.2	15 (up to)	70	ND	Núnez and Martínez (1999)
Slaughterhouse wastewater	ASBR	2.9	31.3[a]	94	ND	Masse et al. (2002)
Slaughterhouse wastewater	UASB	0.3–0.1	13–30	60–93	0.20–0.28	Torkian et al. (2003)
Palm oil mill wastewater	MABR	3–10	1.6–5.3	87–95	0.32–0.42	Faisal and Unno (2001)
Sunflower oil factory wastewater	UASB	2–2.8	1.6–7.8	87	0.16–0.35	Saatci et al. (2003)

COD, chemical oxygen demand; HRT, hydraulic retention time; OLR, organic loading rate; UASB, upflow anaerobic sludge blanket; CSTR, continuous stirred tank reactor; EGSB, expanded granular sludge bed; AF, anaerobic filter; IFB, inverse fluidised bed; ITB, inverse turbulent reactor; DAEB, downflow anaerobic expanded bed; BFBR, buoyant filter bioreactor; FBR, fluidised bed reactor; ASBR, anaerobic sequencing batch reactor; MABR, modified anaerobic baffled reactor; ND, not determined.
[a] Calculated on the basis of 1 h feeding (subsequent reaction and settling phases lasted 69 h).

blanket (UASB) or the expanded granular sludge bed (EGSB) reactors, is the adsorption of LCFA that induces sludge disintegration, flotation and washout (Amaral et al., 2004). Also transport limitation phenomena, caused by LCFA accumulation onto the sludge, were found to have an important contribution to the observed lag phases preceding methane production, generally reported to be ascribed to mechanisms of cell wall damage or to long term acclimation (Pereira et al., 2005). It was found that the observed temporary decrease in the methanogenic activity after the contact with LCFA is a reversible phenomenon, being eliminated after the conversion to methane of the biomass-associated LCFA (Pereira et al., 2002a, 2004, 2005), suggesting that sequencing accumulation/degradation steps could promote a sustainable biogas production from LCFA.

Recently, Nielsen and Ahring (2006) also showed that the addition of oleate pulses to thermophilic reactors treating mixtures of cattle and pig manure had a stimulating effect on the overall process. Successful co-digestion of different types of waste with lipids, added in a discontinuous way, is a common practice in many full scale biogas plants. However, this addition is usually made empirically, causing, in some cases process failure. The dynamics of the LCFA accumulation, the maximum amount of lipids that can be added and the frequency of additions are some aspects that require further study.

In this work some further insights on the role of LCFA accumulation onto the sludge in the methane production course are presented. Two sets of experiments were designed. In experiment I, two sludges loaded with LCFA, obtained after prolonged contact with oleate or palmitate, were used to asses the effect of allowing the depletion of the biomass-associated LCFA prior to a new LCFA pulse, in terms of methane production and LCFA effect towards the acetotrophic methanogens. Palmitate (C16:0) and oleate (C18:1) where used as LCFA models, since they are respectively the most abundant saturated and unsaturated LCFA present in waste/wastewater (Viswanathan et al., 1962; Hanaki et al., 1981; Quéméneur and Marty, 1994).

In experiment II, anaerobic bioconversion to methane of a fat-rich dairy wastewater, using repeated pulse feeding, was assessed in batch assays.

2. Methods

Table 2 summarises the conditions used in the two experiments.

2.1. Experiment I: LCFA biodegradation capacity and effect of LCFA towards the aceticlastic methanogens

2.1.1. Sludge source

Suspended sludge containing biomass-associated LCFA, was obtained after continuous load with oleate (sludge 1) or palmitate (sludge 2) in two 1 L expanded granular sludge bed (EGSB) reactors seeded with the same inoculum, as described elsewhere (Pereira et al., 2005). When incubated in batch assays both sludges were able to produce methane exclusively from the biomass-associ-