Anaerobic digestion of brewery wastewater using a fixed-film reactor

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Lo, K. V. and Liao, P. H. 1989. **Anaerobic digestion of brewery wastewater using a fixed-film reactor.** Can. Agric. Eng. **31**: 61–63. A laboratory-scale anaerobic fixed-film reactor receiving brewery wastewater was studied over a range of hydraulic retention times at 35°C. Ale yeast wastewater could be successfully digested in a fixed-film reactor, with methane production of 1.18–1.43 litre methane per litre of reactor volume per day and 70-82% reduction in chemical oxygen demand. The fixed-film reactor performed well at hydraulic retention times of 8 and 10 days without pH control.

INTRODUCTION

Ale yeast waste is a by-product of malt beverage production. This wastewater has high concentrations of organic and inorganic materials which often causes disposal problems for the brewing industry. The anaerobic digestion process offers a treatment approach from both energy conservation and pollution control considerations. Anaerobic digestion could reduce the pollution strength of the wastewater with the production of energy in the form of methane.

Anaerobic treatment of brewery effluents has been investigated to some degree using conventional completely-mixed reactors (Keenan and Kormi 1977, 1981). Generally, the conventional systems require long hydraulic retention times (HRTs) and low substrate loading rates. Keenan and Kormi (1977, 1981) also reported that the most favorable conditions for methane production were a 10-d HRT and an organic loading rate of 5.5 g of substrate per litre of reactor volume per day ($g\ L^{-1}d^{-1}$). Reactor failures were reported at organic loading rates above 6 $g\ L^{-1}\ d^{-1}$.

By contrast, when used to treat dairy and other food processing wastes, fixed-film reactors were proven to be capable of being operated at high organic loading rates and short HRTs (Lo and Liao 1985a,b). The fixed-film reactor design utilizes the prospensity of bacteria to attach to solid materials and form a film. The bacterial biomass is retained in the reactor and is independent of the flow rate of the wastewater. This high concentration of active biomass allows efficient digestion of soluble wastes at high loading rates and short HRTs. It was thought that by using a fixed-film reactor, improved efficiency of anaerobic treatment of brewery wastes could be achieved. This study was initiated to explore the use of anaerobic fixed-film reactor to treat ale yeast waste. The objectives were: (1) to study the effect of loading rate and hydraulic retention time on the rate of methane production and, (2) to evaluate the treatment efficiency of this process.

EXPERIMENTAL METHODS

Feed substrate

Ale yeast waste was obtained from Molson Brewery Ltd., Vancouver, British Columbia and stored in a coldroom at 4°C. The waste was diluted with tap water to 2.3% volatile solids (VS) before digestion. The composition of the waste is presented in Table I. The pH value of the ale yeast waste was about 4.1. In this study, neither buffer solution nor a nutrient supplement was added to the waste.

Fixed-film reactor

A cylindrical reactor was constructed of acrylic tubing (15.2 cm i.d.). A fixed-film supporting structure was made from nylon cloth with thread reinforcements and was set up in a spiral configuration with 1.27 cm spacing and 27.9 cm deep (Fig. 1). The structure was positioned about 6 cm above the reactor bottom and 3 cm below the operating fluid level. The surface area-to-volume ratio of the reactor was 110 $m^2\ m^{-3}$, and the working volume was 3.6 L. The configuration of the fixed-film reactor, the start-up procedure and reactor operation were reported in previous papers (Lo and Liao 1985a,b). In this study, the reactor was operated at 35°C and HRTs of 10, 8 and 6 d.

Chemical analyses

Effluent and gas samples were collected for 3 consecutive days during steady-state conditions for each HRT. The steady-state condition was defined as the period of time at which gas production rates remained constant (±5%) for a minimum of two HRT cycles. Laboratory analyses conducted on the influents and effluents were: total solids (TS), volatile solids (VS), chemical oxygen demand (COD), volatile fatty acids (VFA) contents and pH, according to procedures recommended by the American Public Health Association (1985). Total Kjeldahl nitrogen (TKN) and ammonia nitrogen (NH_3-N) were determined using a block digester and a Technicon Auto Analyzer II as described by Schumann et al (1976).

Gas samples were collected in gas-tight glass sampling tubes. Both gas samples and VFA contents were assayed on a Hewlett Packard 5890 gas chromatograph. A stainless steel column (183 cm × 0.32 cm i.d.) filled with Porapack Q-80 mesh at 80°C was used to determine the methane composition. The VFA analyses used a glass column (183 cm × 0.64 cm i.d.) packed with Carobpack C/0.3% Carobwax 20M/0.1% phosphoric acid. Column temperature was set at 125°C and the carrier gas was helium. Methane production results are expressed in terms of litre CH_4 per litre of reactor per day ($L\ CH_4\ L^{-1}\ d^{-1}$), litre CH_4 per gram VS added ($L\ CH_4\ g^{-1}$ VS) and litre CH_4 per gram COD destroyed ($L\ CH_4\ g^{-1}$ COD destroyed).

RESULTS AND DISCUSSION

The fixed-film reactor had been used previously for the digestion of screened dairy manure (Lo and Liao 1985a,b). Biomass

Table I. Methane production and chemical characteristics of brewery waste

Parameter	HRT 10 d	HRT 8 d	HRT 6 d
Loading rate ($g\ VS\ L^{-1}\ d^{-1}$)	2.15	2.69	4.67
Methane production rate ($L\ CH_4\ L^{-1}\ d^{-1}$)	1.18±0.18	1.43±0.04	—
Methane yield			
($L\ CH_4\ g^{-1}$ VS added)	0.549±0.008	0.530±0.001	—
($L\ CH_4\ g^{-1}$ COD destroyed)	0.379±0.079	0.319±0.041	
Biogas methane content (%)	54.7±0.5	55.3±2.2	—
Influent characteristics			
COD ($g\ L^{-1}$)	44.4±1.2	44.4±1.2	
TS (%)	2.3±0.1	2.3±0.1	
VS (%)	2.2±0.1	2.2±0.1	
TKN-N ($g\ L^{-1}$)	1.9±0.1	1.9±0.1	
NH_3-N ($g\ L^{-1}$)	0.04±0.01	0.04±0.01	
pH	4.1±0.1	4.6±0.1	
Effluent characteristics			
COD ($g\ L^{-1}$)	13.2±0.4 (70%)‡	8.2±0.6 (82%)‡	
TS (%)	1.1±0.1 (52%)‡	0.8±0.0 (65%)‡	
VS (%)	0.9±0.1 (59%)‡	0.6±0.0 (73%)‡	
TKN-N ($g\ L^{-1}$)	1.9±0.1	2.1±0.1	
NH_3-N ($g\ L^{-1}$)	0.86±0.02	0.80±0.03	
pH	7.3±0.1	7.2±0.1	
VFA ($mg\ L^{-1}$)			
acetic acid	105±29	119±46	
propionic acid	65±28	89±60	

†Steady-state condition could not be maintained.
‡Percent reduction.

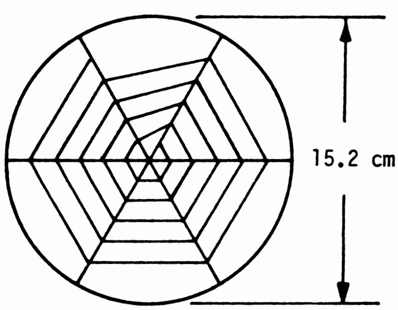

Fig. 1. Cross-sectional view of the fixed-film structure.

was present on the fixed-film structure when this study was commenced. The digestion of brewery wastewater was started by introducing 360 mL of the preheated substrate (pH 4.1) into the reactor. Daily feeding began at this rate (equivalent to a HRT of 10 d). In the first 10 d, methane was produced at the rate of 2.3 $L\ CH_4\ L^{-1}\ d^{-1}$. The pH levels in the reactor remained in a range of 7.4–7.8. Within two volume turnovers, however, gas production declined to a low level of 0.21 $L\ CH_4\ L^{-1}\ d^{-1}$ and the pH had decreased to 6.3. VFA concentrations increased from 1430 $mg\ L^{-1}$ of acetate and reached levels exceeding 5500 $mg\ L^{-1}$ as acetate. Acetate concentration was found as a major component of VFA concentration; however, the ratio of propionic to acidic acid remained at 0.24. This indicated some inhibition for methanogenesis. VFA concentration and the propionic to acetic acid ratio have been used as performance indicators of the anaerobic digestion. High acetic acid concentration and/or high propionic to acetic acid ratio (over 1.4) tend to indicate impending reactor failure (Hill and Holmberg 1988). VFA concentrations returned gradually to previous levels after 7 d without feeding, then the feeding was resumed. No buffer solution was used throughout the experiment. Whenever the pH of the reactor decreased sharply, the feeding was stopped. Steady-state condition was achieved only after three months of operation.

Methane production data are presented in Table I. A methane production rate of 1.18 $L\ CH_4\ L^{-1}\ d^{-1}$ was obtained at a HRT of 10 d. A higher methane production rate of 1.43 $L\ CH_4\ L^{-1}\ d^{-1}$ was obtained when the reactor was operated at a HRT of 8 d. However, methane production rate in terms of $L\ CH_4\ g^{-1}$ COD destroyed decreased to 0.319 from 0.379. Methane yield in terms of $L\ CH_4\ g^{-1}$ VS added also decreased from 0.549 to 0.530. Chemical characteristics of the feed materials and effluents are also presented in Table I. Treatment efficiency is characterized by COD, TS and VS reduction. In this study, 59–73% of the VS was degraded. The COD reductions were between 70 and 82%.

An attempt was made to lower the HRT to 6 d. However, after 2 d of operation, acetate concentration increased to 3080 from 101 $mg\ L^{-1}$ and propionate increased to 708 from 121 $mg\ L^{-1}$. As a result of the increase of VFA concentrations, the effluent pH dropped to 6.1 from 7.3. Gas production also declined. It was concluded that methanogenesis was inhibited. The 6-d HRT run was then terminated. This was a clear indication that the fixed-film reactor could not cope with such an organic loading for treatment of the poorly buffered ale yeast wastewater. It took 10 d to re-establish steady-state condition at 8 d HRT and an organic loading rate of 3.50 $g\ VS\ L^{-1}\ d^{-1}$.

Table II. Comparison of anaerobic treatment processes for brewery wastewater

Reactor	Temp. (°C)	Raw waste COD ($g\ L^{-1}$)	Hydraulic retention time (d)	Loading rate ($g\ L^{-1}\ d^{-1}$)	COD percent removal (%)	Methane yield ($L\ CH_4\ g^{-1}$ VS added)	Methane production ($L\ CH_4\ L^{-1}\ d^{-1}$)	Reference
Fixed-film (3.6 L)†	35	44.4	10	2.15	71	0.55	1.18	This study
	35	44.4	8	2.69	82	0.53	1.43	
Completely-mixed (14 L)†	37	43.7	10	3.68	40	0.32	1.02	Keenan and Kormi (1977)
	37	64.8	10	5.52	38	0.31	1.58	
	37	22.6	8	2.30	35	0.35	0.70	
	37	22.6	15	1.23	55	0.44	0.46	

†The reactor volume.

This result indicated that without pH adjustment and nutrients addition, the fixed-film reactor receiving ale yeast waste could not be operated at a HRT as low as 6 d.

A comparison of treatment efficiency and gas productivity of brewery waste using fixed-film and completely-mixed reactors is presented in Table II. The fixed-film process had higher treatment efficiency and gas productivity than that of completely-mixed reactors. The methane yields of 0.53–0.55 $L\ CH_4\ g^{-1}$ VS added were achieved for a fixed-film reactor, whereas only 0.31–0.44 $L\ CH_4\ g^{-1}$ VS added were obtained for completely mixed reactors. Besides, fixed-film reactors were less susceptible to total failure than were the conventional, completely-mixed reactors (Lo et al 1984). The fixed-film reactor was able to recover quickly after a severe organic overloading as mentioned earlier in this study. From both treatment efficiency and reactor stability point of view, the fixed-film reactor had an advantage over the conventional reactors. Anaerobic digestion of brewery wastewater using a fixed-film reactor could provide efficient waste treatment and bio-energy production. Studies are being planned to further investigate the effects of pH control and the addition of micronutrients on the process stability and methane production rate. Assessment of the economic benefit of such a reactor design for brewery wastewater treatment remains to be investigated.

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