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Anaerobic Digestion of Ice-Cream Wastewater: A Comparison of Single and Two-Phase Reactor Systems

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The anaerobic digestion of ice-cream wastewater, a complex substrate which includes milk proteins, carbohydrates and lipids, has received little attention. Work using an anaerobic contact system (Ripley and Totzke 1988) showed that at a 7.5-d hydraulic retention time (HRT), with an organic loading rate of 1.7 g COD/Ld and influent TSS (total suspended solids) of 5870 mg/L, the effluent COD was 628 mg/L, BOD was 91 mg/L and TSS was 674. Anaerobic filters have also been used (Marques *et al.* 1989) at organic loadings of 6 kg COD/m^3d applied at a HRT of 0.42 day, with COD removals of 80%. Goodwing *et al.* (1990) showed that this waste was capable of being treated by the UASB process with granulation commencing after 60-70 days, and gas production ranging between 0.73 and 0.93 L CH_4/g COD removed with loading rates between 0.7 and 3.0 g TOC/Ld.

Two-phase anaerobic digestion is an innovative fermentation mode that has recently received increased attention. The kinetically dissimilar fermentation phases, hydrolysis-acidification and acetogenesis-methanation are operated in two separate reactors (Ghosh and Klass 1978); the first of which is maintained at a very short HRT. The effluent from the first, acid-forming, phase is then used as the substrate for the methane-phase reactor which has a longer HRT or cell immobilization. The aim of this work was to compare the methane production capability and performance of a single-phase upflow fixed bed reactor with a two-phase digestion system. The two-phase digestion system consists of a completely mixed reactor for the acidogenic reaction and an upflow fixed bed reactor for the methanogenic reaction.

Because of the high lipid content and COD of ice cream wastewater off site disposal has proved to be both expensive and poses problems to the receiving effluent treatment plant. For this reason the potential for a rapid anaerobic stabilization of the waste, with energy recovery in the form of methane gas, has been investigated in an attempt to minimize plant size and maximize gas production.

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MATERIALS AND METHODS

In the single-phase anaerobic digestion, a 2-L fixed bed reactor was used. In the two-phase digestion system, the first unit (acid phase) was a 3-L completely mixed reactor for the acidification reaction and the second unit (methanogenic phase) was a 2-L fixed bed reactor.

The fixed bed reactors were constructed of an 8 cm internal diameter acrylic plastic tube. The fixed bed reactors were random packed with 500 g of foamed clay of 5-10 mm diameter. The chemical composition and features of the support were described in detail elsewhere (Fiestas *et al.* 1990). Internal mixing was achieved by recirculating biogas using a time-controlled peristaltic pump operating for 15 min every hour. The digesters were maintained at a constant temperature in a thermostatic chamber at 35 °C. Feed was added through the botton and effluent withdrawn from the top. The biogas produced was continuously collected and measured indirectly by saline water displacement in Boyle-Mariotte's flasks.

The digesters were inoculated with biomass from an industrial anaerobic reactor processing dairy wastewater. The composition of the biomass was: TSS, 47.5 g/L; VSS (volatile suspended solids), 36.5 g/L.

The composition and features of the ice-cream wastewater used were: pH, 5.1; COD, 5.2 g/L; total solids (TS), 3.9 g/L; volatile solids (VS), 2.6 g/L; TSS, 3.1 g/L; VSS, 2.1 g/L; total volatile fatty acids (VFA), 185 mg/L; acetic acid, 130 mg/L; propionic acid, 50 mg/L; butyric acid, 22 mg/L; alkalinity, 0.22 g CO_3Ca/L; nitrogen (NH_4^+), 15 mg/L; phosphorus (PO_4^{3-}), 14 mg/L; proteins (%), 0.033; carbohydrates (%), 0.21; polyols (%), 0.001; starch (%), 0.001; saturate fat (%), 0.046; mono-unsaturate fat (%), 0.015 and polyunsaturate fat (%), 0.002.

The completely mixed and fixed bed reactors were seeded with 1.0 and 0.65 L of inoculum, respectively. There was an initial acclimatization period, in which the acid-phase reactor (completely mixed) was operated at loading rates equivalent to HRTs between 0.5 and 0.2 d to achieve a pH in the range 4.9-5.4. The effluent from the acid-phase was used as the substrate for the methanogenic phase and during the acclimatization phase HRT's between 1.5 and 5 d were maintained in the second-phase reactor.

Analytical procedures were performed using Standard Methods (APHA 1985). VFA concentrations were measured daily by gas chromatography (Borja *et al.* 1992). Biogas composition was determined using gas chromatography with a stainless steel column (200 x 0.3 cm) packed with active carbon (30 to 60 mesh) using thermal conductivity detection.

All values reported represent the average values for results from experimental runs under steady-state condition, which was indicated by constant (±5%) methane production, pH, VFA concentration and COD of the effluents measured at each case.

RESULTS AND DISCUSSION

During the experimental run the acid-phase reactor was operated at a loading rate equivalent to an HRT of 0.3 d and its effluent used as the substrate for the methanogenic phase so as to maintain an HRT of 1 d. Both reactors were batch fed once a day and prior to feeding, each reactor was thoroughly mixed and the support medium then allowed to settle. A fixed volume of effluent was then withdrawn and an equal amount of feed material added.

Steady-state performance data from the two-phase system is presented in Table 1. A methane yield of 0.345 L CH_4/g COD added and a methane production rate of 1.02 L CH_4/Ld could be obtained at a system HRT of 1.3 d. As expected, acidogenic fermentation was predominant in the first-phase reactor, whereas methanogenesis predominanted in the second-phase reactor, as indicated by culture pH, methane production, and effluent VFA concentration.

Table 1. Performance of a two-phase digestion system at an HRT of 1.3 d (0.3 d for acid phase and 1 d for methane phase).

Operating conditions	Acid phase	Methane phase	Total system
Loading rate, g COD/Ld	17.3	5.0	4.0
Methane production rate L CH_4/Ld	0.69	1.53	1.02
Methane yield, L CH_4/g COD added	0.04	0.305	0.345
Methane content (%)	34	64	
Effluent characteristics:			
pH	5.1	7.0	7.0
COD (g/L)	5.0	0.55	0.55
VFA (total as acetic)	1820	140	140
Acetic acid (mg/L)	1150	85	85
Propionic acid (mg/L)	550	45	45
Butyric acid (mg/L)	275	25	25

The effluent total VFA concentration from the first-phase reactor increased to 1820 mg/L (as acetic acid), 10 times higher than that of the influent. Acetic, propionic and butyric acid concentrations increased 10, 9 and 12 times respectively, over those of the influent. Thauer *et al.* (1977) reported that the formation of products such as propionate or butyrate provided the energetically more efficient routes.

As expected, the effluent total VFA concentration of the second-phase reactor decreased to 140 mg/L (as acetic acid). Acetic acid was also the predominant VFA in the effluent.

The average methane content of the biogas generated in the first-phase reactor was 34%, whilst that in the second-phase fixed bed reactor was 64%. The acidogenic reaction in the first-phase reaction only reduced the overall COD by 4% as might have been expected by the low methane yield.

The results obtained from the two-phase digestion were compared with those of the single-phase anaerobic digestion (fixed bed) using similar feed materials. The fixed bed reactor was operated at HRTs of 1 and 1.3 d at 35 °C again using a batch feed system similar to that used for the two-phase system.

Table 2. Performance of a one-phase digestion system using fixed bed reactors at HRTs of 1 and 1.3 d.

Operating conditions and results	1 d	1.3 d
Loading rate, g COD/Ld	5.2	4.0
Methane production rate L CH_4/Ld	1.06	1.40
Methane yield, L CH_4/g COD added	0.205	0.350
Methane content (%)	60	61
Effluent characteristics:		
pH	6.9	7.1
COD (g/L)	0.65	0.45
VFA (total as acetic)	205	130
Acetic acid (mg/L)	105	70
Propionic acid (mg/L)	85	45
Butyric acid (mg/L)	45	20

Steady-state performance data from the single-phase fixed bed reactor is presented in Table 2. The methane yields of 0.20 and 0.35 L CH_4/g COD added were obtained at HRTs of 1 and 1.3 d, respectively, and corresponded to methane production rates of 1.06 and 1.40 L CH_4/Ld.

From the results obtained with single and two-phase digestions at a HRT of 1.3 d, both the methane production rate and the methane yield for the single phase system was higher than that of the two-phase digestion system. It appeared that by comparing the whole system performance at 1.3 d HRT the two-phase digestion of ice-cream wastewater had no advantages over the one-phase digestion in terms of the methane production rate and yield.

The effect of phase separation was evident in the runs performed at 1 d HRT for the fixed bed reactors used in both single and two-phase systems. A maximum methane production rate of 1.53 L CH_4/Ld and methane yield of 0.305 L CH_4/g COD added were obtained with the fixed bed reactor at an HRT of 1 d during the methanogenic phase of the two-phase system, whereas only 1.06 L CH_4/Ld and 0.205 L CH_4/g COD added were obtained under the same conditions during the single-phase high rate digestion. At a 1 d HRT, the acidogenesis pretreatment prior to the methanogenic phase resulted in up to a 7% increase in biogas methane content, a 44% increase in volumetric methane production rate, and a 49% increase in methane yield, over the single-phase digestion. Separate acidogenesis performs a metabolic buffer function (Cohen 1982), thereby producing an effluent of constant quality; this results in an increased stability and a higher biogas production rate in the subsequent methanogenic phase.

The results presented indicate that an anaerobic pre-treatment of high lipid containing wastewater is both possible and practicable. Separation of the phases of the degradation into two stages improves process performance, increases biogas yield and has shown better stability than a traditional single phase anaerobic digester.

The implications of these findings is likely to increase the confidence of manufacturers of dairy related products in the process of anaerobic digestion both as a cost saving wastewater pre-treatment option and for energy recovery.

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