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ANAEROBIC DIGESTION OF PROCESSED MUNICIPAL SOLID WASTE USING A NOVEL HIGH SOLIDS REACTOR: MAXIMUM SOLIDS LEVELS AND MIXING REQUIREMENTS

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SUMMARY

Novel, laboratory-scale, high solids reactors operated under mesophilic conditions were used to study the anaerobic fermentation of processed municipal solid waste (MSW) to methane. The anaerobic digestion consortium was introduced to high solids levels through gradual adaptation. The maximum sludge solids level for stable anaerobic fermentation performance was identified as approximately 36% wt/wt. Recovery of the anaerobic consortium, following dilution of inhibitory high solids levels, was swift. Reactor mixing requirements were also studied. No significant difference in fermentation performance was observed between agitator speeds of 1 and 25 rpm. Preliminary fermentation performance tests showed that solids loading rates as high as 9.5 g VS (volatile solids) feed/L sludge·d, at 32% solids within the reactor, were possible. Under these conditions, operation was stable with an average pH of 7.8-8.0, total volatile fatty acid pools of <20 mM, and a biogas composition of 55%-60% methane.

INTRODUCTION

Economic evaluations of anaerobic digestion for production of biogas from organic feedstocks such as municipal solid wastes (MSW) show that reactor capital costs are an important economic factor because of the large reactor volumes required in current anaerobic processes. If the reactor volume could be reduced significantly, and power use maintained or decreased, the economics of anaerobic digestion would improve. Elevated solids concentrations in the reactor are particularly beneficial in this respect, because a decrease in reactor volume is possible while maintaining the same solids loading rate and retention time. However, high solids slurries are viscous and tend to resemble solids more closely than typical fluids. Conventional mixers, therefore, do not ensure reactor homogeneity and may result in an inadequate dispersion of substrates and microorganisms.

Although numerous reactor designs have been employed to study high solids anaerobic digestion, including both non-mixed (generally with recirculation of effluent) (i.e., Molnar and Bartha, 1988; Ghosh, 1985; Hall et al., 1985; Goebel, 1983; Jewell et al., 1980; Lin, 1983; Snell Environmental Group, 1983; and Wujcik and Jewell, 1979) and mixed (i.e., Begouen et al., 1988; de Baere and Verstraete, 1984; Gaddy and Clausen, 1985; and Goldberg et al., 1981), the maximum sludge solids levels that permit an active mesophilic anaerobic consortia have not been identified. Additionally, mixing requirements for effective digestion rates (specific for each reactor configuration) have not been established.

The reactors employed in this study were based on a new design (U.S. patent filed) that is significantly different from those previously reported in the high solids anaerobic digestion literature. This device was used to determine the maximum sludge solids permissible within the mixed reactor system for active anaerobic microbial degradation and to determine preliminary mixing requirements and fermentation performance.

MATERIALS AND METHODS

Operation and Design of High Solids Reactors: The laboratory-scale high solids reactors used in this feasibility study were described previously (Rivard et al., 1989) and consist of a cylindrical glass vessel positioned with a horizontal axis and capped at each end. The agitator shaft runs horizontally along the axis of the cylinder and mixing is obtained with rod type agitators (tines) attached to the shaft in four longitudinal rows. Shaft rotation is provided by a low-speed, high-torque, hydraulic motor (Staffa, Inc., England). The glass vessel was modified with several ports including two 3/4-in. ports for liquid introduction and gas removal and one 2-in. port fitted with a ball valve (PVC; Harrington Plastics, Denver, CO) used for dry feed introduction and effluent removal. The latter operation is accomplished by the momentary rotation of the entire vessel about its centroidal axis, thus positioning the large port for the appropriate operation.

The four high solids reactors used in this study were maintained at 37°C in a temperature-controlled room (Figure 1). The reactors were batch-fed by the separate addition of dry-milled MSW feed and a liquid nutrient solution on a daily basis. The MSW feedstock used in this study was processed and densified MSW (also referred to as refuse derived fuel, RDF) obtained from Future Fuels Inc. (Thief River Falls, MN) and was milled with a pilot-scale knife mill (All-Steel, product of Entoleter Corp., Newhaven, CT) equipped with a 1/8-in. round hole rejection screen. The milled MSW was found to be 5.3% moisture and the total solids was composed of 90.8% volatile solids and 9.2% ash (w/w). The nutrient solution used was that previously described by Rivard et al. (1989).

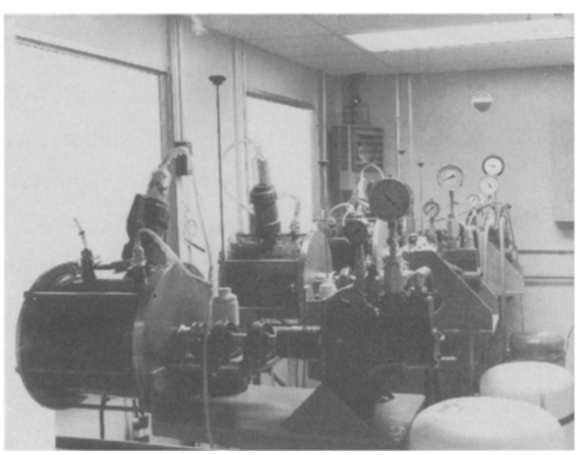

Figure 1. Four bench-scale high solids reactors fed processed MSW. The 20-L cylindrical glass vessels are mixed by agitators driven by individual hydraulic motor assemblies.

Digester Sludge Analysis (performed bi-weekly): Levels of volatile and non-volatile organic acids were determined by gas-liquid chromatography (GLC) and high pressure liquid chromatography, respectively, as previously described (Rivard et al., 1989).

The extent and rates of reactor digestion was assessed by determining the acid/detergent fiber (ADF) content of sludge samples following the method of Goering and Van Soest (1970). This analysis results in values for acid detergent solubles (microbes, fats, and protein), cellulose, lignin, and ash. The ultimate biological yield of methane from sludge samples after 90-day incubation was performed by the biological methane potential assay (BMP_{90}) suggested by Owen et al. (1979).

The solids concentration in digester effluents was analyzed on a wt/wt basis by drying 30-g sludge samples for 48 hours at 45°-50°C. The percent volatile solids and ash was determined by combustion of the dried samples at 550°C for 3 hours in a laboratory furnace.

Gas Analysis: Total biogas production was monitored using pre-calibrated water displacement reservoirs. The biogas produced was analyzed for composition by gas chromatography as previously described by Rivard et al. (1989).

RESULTS AND DISCUSSION

The development of novel, laboratory-scale reactors (Figure 1) permitted high solids fermentation to be conducted at low agitation rates with accurate and convenient gas collection, rapid sludge removal, separate liquid and dry feed introduction, and reliable performance over an extensive period of continuous operation (i.e., >18 months). The protocols established previously (Rivard et al. 1989) were used to develop an active high solids anaerobic consortium on a processed MSW feedstock with nutrient amendment. To achieve a stable high solids fermentation, the sludge solids level was allowed to gradually increase from low solids levels (5.0%) to high solids levels (30%-35%) through addition of dry feedstock and minimal liquid nutrient addition, which permitted a slow adaptation by the microbial consortium (Figure 2).

The minimum rate of mixing was determined when the reactors were at 14% solids. The results shown in Table 1 indicate that there was no significant difference between the fermentation performance with mixing speeds of 1, 5, 10, and 25 rpm. Therefore, the operating rpm chosen for continued solids buildup and further fermentation analysis was the slowest examined, 1 rpm.

Table 1. Fermentation performance for high solids digestion at various agitation rates with four reactors conducted at identical organic loadings.

Reactor	A	B	C	D
Agitation rate (rpm)	1	5	10	25
Total biogas prod. (mL/reactor/day)	15720±830	15060±1150	14980±1180	14470±1230
Gas composition (% CH_4)	55.8	54.4	55.9	56.4
Sludge pH	8.1	8.0	8.0	7.9
Sludge solids (% w/w)	14.2	14.1	14.1	14.1

The fermentation performance for day 1 through 250, measured as an average for four high solids reactors operated in parallel, is shown in Figure 2. During this period, the total sludge solids increased from approximately 5% wt/wt to the highest value of 36%. Sludge pH and total volatile fatty acid pools remained stable at >7.5 and ≤ 20 mM, respectively, during most of the solids buildup. An inhibitory condition was experienced when the sludge solids level approached 35%-36% (day 170-200). At this high solids level, the pH dropped slightly and the total volatile fatty acid pools increased to over 100 mM. Upon dilution of the sludge to 32% wt/wt, fermentation performance stabilized.

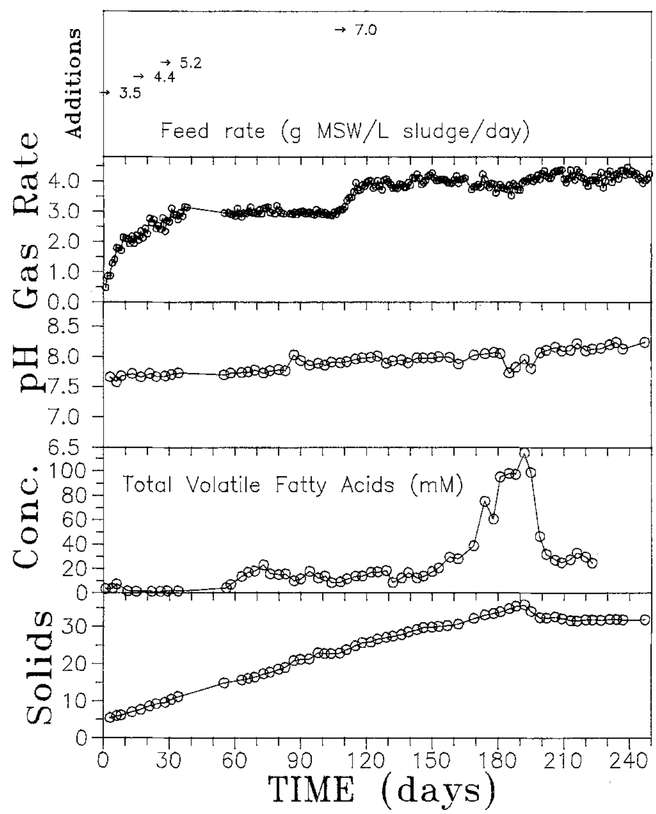

Figure 2. Fermentation performance for high solids anaerobic digestion of MSW through gradual solids buildup. Data represents the average of four high solids reactors operated in parallel. Gas production shown is in volumes of biogas per volume of sludge per day. Volatile fatty acid pools reflect the total for C2-C5 iso- and normal acids. Sludge solids concentration were determined on a dry weight basis (wt/wt).

Figure 3 demonstrates the apparent upper limit of sludge solids concentration versus the fermentation performance as measured by gas production for one of the high solids reactors.

In non-mixed, batch systems, the maximum feed solids levels were established as ranging between 30% and 34% solids by Wujcik and Jewell (1979) for an active anaerobic microbial consortia. However, the actual sludge solids levels in these reactor systems were considerably lower because of rapid volatile solids destruction.

In the only agitated system reported to date, Meenen et al. (1988) demonstrated maximum sludge solids of 30%-35% for a thermophilic fermentation. In comparison, the present study reports that a sludge solids level of 36% is maximal in a thoroughly mixed, mesophilic, anaerobic digester consortia. This value is in good agreement with the previous thermophilic studies.

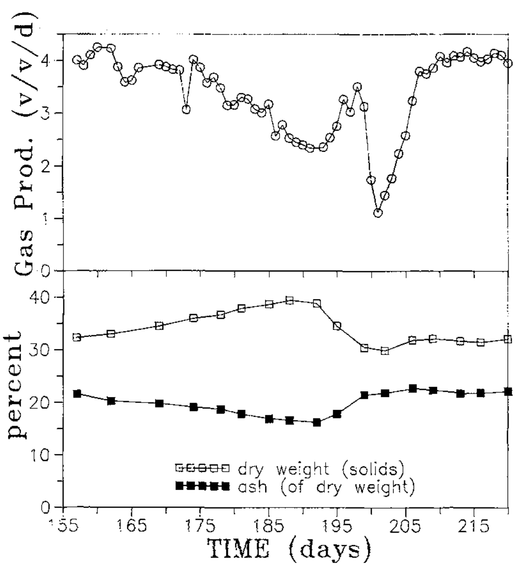

Figure 3. Fermentation performance of one high solids reactor approaching the apparent sludge solids maximum for stable performance of the microbial consortium.

Table 2 summarizes the gas productivity of the anaerobic digestion process utilizing high solids feed as a function of various organic loading rates. Biogas yields from these studies average 0.60 L biogas per g volatile solids added per day, with an average methane content of 57%. The experimental high solids methane production yields for processed MSW (i.e., 0.34 L CH_4/g VS added) agreed with the independent assessment of ultimate methane yields for the feedstock as determined by the BMP_{90} assay (i.e., 0.37 L CH_4/g VS added).

Table 2. Preliminary assessment of fermentation performance as a function of the feedstock loading rate.

Feedstock loading (g MSW/L sludge/d)	(g VS/L sludge/d)	Biogas yield (L biogas/gVS added)	Methane content (%)
3.50	3.18	0.584	55.6
4.40	3.99	0.632	55.9
5.20	4.72	0.601	56.6
6.96	6.32	0.610	59.7
8.70	7.90	0.606	60.1
10.43	9.47	0.584	61.6

The future focus of high solids fermentation research will include the maximization of the organic loading rate to the process and the minimization of the agitation rate to fractional rpm. The matter of scale-up of the process from the current 20-L glass vessels is also a challenging prospect and should be addressed soon. A primary concern for a 10- or 20-fold increase in vessel capacity is the question of scalability in mixing efficiency. Considering the paucity of modeling information for biological high solids processes, only actual implementation of such a system will provide useful data.

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