0273-2289/90/2425—0765$02.00

Aerobic and Anaerobic Digestion of Processed Municipal Solid Waste

Effects of Retention Time on Cellulose Degradation

Scientific Note

TODD B. VINZANT, WILLIAM S. ADNEY, KAREL GROHMANN, AND CHRISTOPHER J. RIVARD*

Applied Biological Science Section, Biotechnology Research Branch, Solar Fuels Research Division, Solar Energy Research Institute, 1617 Cole Blvd., Golden, CO 80401

ABSTRACT

Effective disposal of municipal solid wastes (MSW) through biological processes must focus on the maximal reduction in bulk. Since cellulose is a major component in processed municipal solid waste, biological treatment processes must result in near complete degradation of the polymer. Specific cellulose degradation rates were determined for aerobic and anaerobic digestion systems fed a high cellulose, processed MSW feed, while maintaining optimum nutrient levels, mesophilic temperature (37°C), and a pH of 7.0–7.4. Reducing the retention time resulted in reduced cellulose conversion for both aerobic and anaerobic systems with similar trends. Anaerobic retention times of less than 12 d resulted in unstable digestion, with increased volatile fatty acid pools and decreases in pH. Reducing aerobic retention times below 8 d dramatically reduced cellulose conversion without unstable digestion conditions or volatile fatty acid accumulation.

Index Entries: Anaerobic digestion; aerobic digestion; processed MSW; cellulose degradation; retention time.

INTRODUCTION

An estimated 250 million tons of municipal solid wastes are discarded each year in the US, representing about 1.5–2.0 Quads of energy (*1*). The

*Author to whom all correspondence and reprint requests should be addressed.

bulk of this material is either landfilled or burned. Owing to public concern over hazardous emissions from combustion processes and decreasing number of landfill sites, interest in alternative waste disposal processes has increased. Although the composition of MSW varies with respect to location, season, and time of day, the major components are biodegradable and in the form of cellulose (paper), lignocellulosics (sawdust, wood, grass clippings, and cardboard), and food wastes (*2–4*). Mechanical processing of the MSW to remove recyclable materials, such as glass and metals, decreases the heterogeneity and increases the cellulose content (*5*).

Anaerobic digestion is a biological process that converts the biodegradable fraction of the MSW to an energy product (methane) and a nitrogen/mineral rich soil enhancer. However, to be considered as an effective disposal process and maximize energy yields, the degradation process must bring about a major reduction in bulk of the MSW, and therefore, degradation of cellulose is very important.

Of the various simple and complex components in biomass and waste feedstocks, the cellulose polymer and its hydrolysis has been identified as one of the most important limiting steps in the anaerobic digestion of MSW to methane (*6,7*). The importance of cellulose hydrolysis is compounded by the high proportion (40–60%) in most MSW feedstocks. Few characterizations of cellulose contents in MSW wastes and analysis of degradation yields for anaerobic digestion processes exist in the literature (*8,9*). However, when the degradation rates of volatile solids are examined for aerobic, as well as anaerobic processes, the rates of hydrolysis are low. Generally, long retention times are required for substantial degradation of the more complex polymeric components by both aerobic (21–28 d) (*10,11*) and anaerobic (20–30 d) (*7,11,12*) processes.

Improved volatile solids degradation rates, and particularly increased rates of cellulose hydrolysis, have been demonstrated by use of specialized consortia from the rumen (*13*), or through use of fungal-derived enzyme systems (*14*) for MSW feedstocks. However, baseline data for cellulose hydrolysis of actual processed MSW feedstocks under controlled aerobic and anaerobic conditions, as it relates to hydraulic retention time, has not been demonstrated in the literature.

This study examines the effects of variation in retention time on cellulose degradation in aerobic and anaerobic digestion systems maintained under similar conditions of temperature and pH and with adequate nutrient levels.

MATERIALS AND METHODS

Anaerobic and Aerobic Digesters

Four anaerobic digesters with 3.5 L working vol were constructed and operated as previously described (*15,16*), with the addition of heat tape (1 inch × 6 ft, Briskheat) and a temperature controller (model 601, Omega)

used to maintain the 37°C constant temperature. The three aerobic reactors were 2 L Applikon fermenters (1.2 L working vol) with motor speed controller, pH control (model 704, Horizon Ecology), and temperature control at 37°C via temperature-controlled, circulating water bath (Model 8000, Fisher Scientific). Aerobic operation was monitored using a dissolved oxygen meter and probe (New Brunswick Scientific, Edison, NJ, model 40). Both aerobic and anaerobic reactors were batch fed daily a 5% w/v feed of MSW meal in nutrient solution. The feedstock was knife milled (1 mm round hole rejection screen, Wiley Mill), processed, and densified (pelletized) municipal solid waste obtained from Future Fuels Inc., Thief River Falls, MN. The processed MSW was 52% cellulose, 20% lignin/plastics, 2% ash, and 26% acid detergent solubles by the acid detergent fiber analysis (ADF) (*17*). The nutrient solutions were as previously described (*11*) and for anaerobic digesters were: 8 g/L yeast extract (Difco), 50 m*M* K_2HPO_4, and 1X trace mineral addition (*18*); for aerobic digesters, the solution also contained 100 m*M* NH_4Cl and 5X trace mineral addition. All other chemical components were reagent grade reagents obtained from national laboratory supply houses. Effluent was removed on a daily basis and stored at 4°C until analyses were performed.

Enzymatic Hydrolysis

A 40 g sample of MSW meal was subjected to saturating loadings of fungal cellulase enzyme supplemented with β-glucosidase for determination of maximum hydrolytic rates for the feedstock, as previously described (*19*). The MSW was added to a solution of 22.2 mL Celluclast 1.5 L (85 International FPU/mL cellulase activity, Novo Industri A/S, Denmark), 2.01 mL Novozym 188 (132 IU/mL β-glucosidase activity, Novo), and 50 m*M* Citrate buffer (pH 4.8) in a final vol of 1 L. Tetracycline and chloramphenicol were added to a final concn. of 40 and 30 μg/mL, respectively, to inhibit microbial growth during the incubation period. The enzymatic hydrolysis was conducted in a shaking incubator at 50°C and 120 rpm. Triplicate 50 mL samples were removed daily and frozen until acid detergent fiber analysis.

Sludge Analysis

The aerobic and anaerobic fermentation systems were assessed at various retention times. After shifts in retention time operation, the digestion systems were allowed a time period equal to three retention times to reach steady-state before data collection and effluent assessment. The fermentation performance, including cellulose degradation, was determined over an additional three-retention time period for aerobic and anaerobic digestion systems. For the 10 d retention time anaerobic digestion system, analysis was conducted after the three-retention time period even though the digestion performance was unstable, requiring daily pH adjustment to maintain a pH of 7.0.

Analysis of volatile and nonvolatile fatty acids, phosphate, nitrate, and sulfate were performed as previously described (*11,20*) by high performance liquid chromatography (HPLC). Free ammonia was determined by an Orion gas sensing electrode (*16*). Minerals were determined by inductively-coupled plasma-arc spectrophotometry (*21,22*).

Analysis of digester effluent solids was conducted with 20–30 mL samples of sludge in duplicate. The sludge samples were dried for 48 h at 45–50°C, cooled to room temperature in desicators, and weight differentials determined using a top loading balance (Sartorius model 1264MP).

Analysis of digestion rates and extent was assessed by determining acid detergent fiber (*17*). This analysis results in values for acid detergent solubles (microbes, fats, protein, and hemicellulose), cellulose, lignin/plastics, and ash. The analysis protocol was as previously described (*16*).

Gas Analysis

Production of biogas from anaerobic reactors was monitored on a daily basis using calibrated water displacement reservoirs. Biogas produced by the various digesters was analyzed for methane and nitrogen composition by gas chromatography, as previously described (*20*).

RESULTS

The determination of the ultimate cellulose biodegradability was obtained using the commercial fungal cellulase enzyme preparations at levels known to be saturating and indicated that 78% of the cellulose in the processed MSW feedstock is digestible (Fig. 1). Using saturating levels of cellulase enzyme and optimum enzyme hydrolysis conditions of temperature and pH, the majority of cellulose was degraded within 24 h.

To investigate and compare the biological cellulose degradation, four anaerobic and three aerobic CSTR digestion systems were operated for a total period of 21 mo at various retention times on a processed MSW meal and nutrient solution. Both aerobic and anaerobic systems were operated at 37°C and a pH of 7.0 ± 0.1. Nutrient requirements for both aerobic and anaerobic digestion systems were monitored and maintained by adjustments in the nutrient solution, as previously described (*11*), to maintain adequate levels of nitrogen, phosphate, and minerals. Nutrient requirements were previously determined and were higher for the aerobic systems (*11*). In the batch fed reactors, the solids retention time (SRT) was equal to the hydraulic retention time (HRT). Cellulose, the major component of processed MSW and many biomass feedstocks, was monitored in the digestion systems effluent. The degradation of cellulose was determined by comparison of the cellulose content of the feed vs the effluent at various retention times operation, as shown in Fig. 2. Analysis of the aerobic and anaerobic digestion systems on the MSW feedstock indicates that trends are similar for the two systems, with cellulose digestion de-

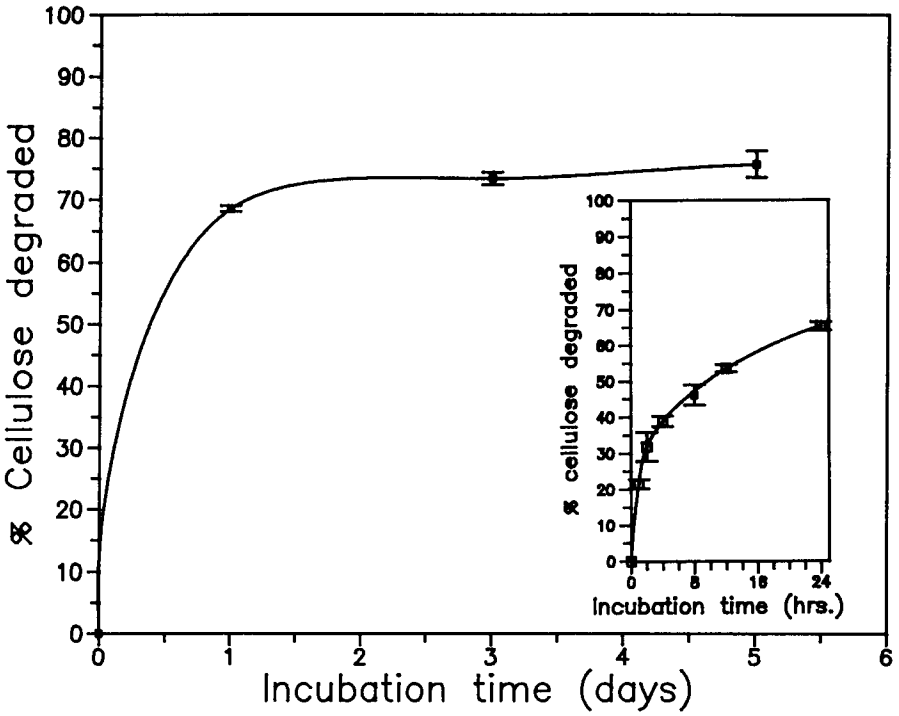

Fig. 1. Kinetics of enzymatic hydrolysis of the cellulose component of the processed MSW feedstock, determined by dry weight loss at saturating cellulose enzyme loading levels. Inset graph demonstrates cellulose hydrolysis during the first 24 h of incubation. Error bars indicate standard deviation of triplicate determinations. Ultimate cellulase hydrolysis after 5 d was equal to 78% of cellulose added.

creasing with retention times. Substantial cellulose degradation occurred for aerobic and anaerobic digestion systems at retention times of 12 and 20 d, respectively.

DISCUSSION

This study reports baseline data for cellulose degradation using processed MSW as feedstock for aerobic and anerobic digestion systems maintained at pH 7.0, 37°C, and with adequate nutrient levels. Aerobic systems degraded substantially more cellulose at retention times equal to anaerobic systems. Additionally, aerobic systems did not become unstable at lower retention times in comparison to anaerobic digestion systems. The extent of cellulose degradation in this study was significantly higher than demonstrated for activated sludge (*10*) on filter paper or cotton wool. This may be owing to nutrient limitations in the activated sludge study or as a result of the acclimation of the aerobic microbial consortium to the high cellulose MSW feedstock. Cellulose degradation rates in this study

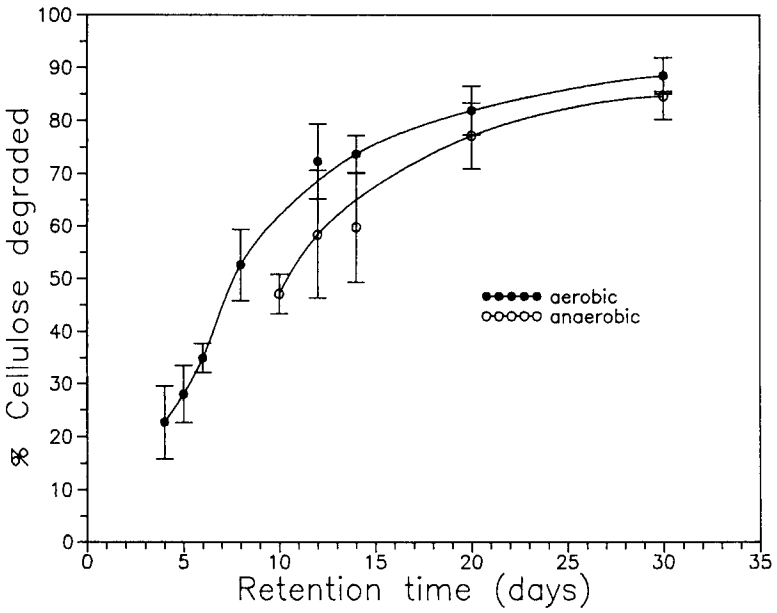

Fig. 2. Composition of results for cellulose degradation in aerobic and anaerobic digestion systems maintained under identical conditions of temperature and pH under steady-state operation at various retention times. Error bars equal the standard deviation of multiple analyses performed during a three-retention time period after attaining steady-state operation.

are comparable to total volatile solids degradation rates reported by other authors for 10 d HRT and SRT under anaerobic conditions (*12,23*).

In summary, biological processes treating feedstocks, such as processed MSW, in which the major component is cellulose, requires near complete degradation (of the biodegradable portion) to be considered effective, both as a waste disposal and energy production process. Without augmentation with specific hydrolytic enzymes, specific microorganisms producing these biocatalysts, or separate control of the HRT and SRT, these biological digestion systems are limited to retention times on the order of 12 and 20 d for aerobic and anaerobic systems, respectively, to allow substantial cellulose digestion even when maintained under optimal batch operation.

ACKNOWLEDGMENTS

The authors thank Marzena Krawiec for technical support in ADF analysis. This work was funded by the Biochemical Conversion Program of the DOE Biofuels and Municipal Waste Technology Division.

REFERENCES

1. Goodman, B. J. (1987), *SERI/CP-232-0300,* Solar Energy Research Institute, Golden, CO.
2. Hasselriis, F. (1984), *Refuse Derived Fuel Processing,* Ann Arbor Science, Boston, MA.
3. Schwartz, S. C. and Brunnner, C. R. (1983), *Energy and Resource Recovery from Waste,* Noyes Data Corp., NJ.
4. US Environmental Protection Agency (1974), *Third Report to Congress,* Pub. No. SW-161, Washington, DC.
5. Ohlosson, O. O., Pearson, C. V., and Lazar, J. (1988), *Presentation at the American Power Conference,* Chicago, IL, April 18–20.
6. Boone, D. R. (1982), *Appl. Environ. Microbiol.* **43,** 57.
7. Noike, T., Endo, G., Chang, J.-E., Yaguchi, J.-I., and Matsumoto, J.-I. (1985), *Biotechnol. Bioeng.* **27,** 1482.
8. Biljetina, R., Srivastava, V. J., Fannin, K. F., Janulis, J. A., and Henry, M. P. (1987), *Annual Report for Walt Disney Imagineering,* Contract No. 9MP-86-1.
9. Stenstrom, M. K., Ng, A. S., Bhunia, P. K., and Abramson, S. D. (1983), *J. Environ. Eng.* **109,** 1148.
10. Verachtert, H., Ramasamy, K., Meyers, M., and Bevers, J. (1982), *J. Appl. Bacteriol.* **52,** 185.
11. Rivard, C. J., Vinzant, T. B., Adney, W. S., and Grohmann, K. (1989), *J. Environ. Health,* **52,** 96.
12. Gujer, W. and Zehnder, A. J. B. (1983), *Wat. Sci. Tech.* **15,** 127.
13. Gijzen, H. J., Zwart, K. B., Teunissen, M. J., and Vogels, G. D. (1988), *Biotech. Bioeng.* **32,** 749.
14. Clanet, M. and Durand, H. (1968), *Biotech. Bioeng.* **32,** 930.
15. Henson, M. J., Bordeaux, F. M., Rivard, C. J., and Smith, P. H. (1986), *Appl. Environ. Microbiol.* **51,** 288.
16. Rivard, C. J., Bordeaux, F. M., Henson, J. M., and Smith, P. H. (1987), *Appl. Biochem. Biotechnol.* **17,** 245.
17. Goering, H. K. and Van Soest, P. J. (1970), *US Dept. of Agriculture Handbook #379,* Washington, DC.
18. Balch, W. E., Fox, G. E., Magrum, L. J., Woese, C. R., and Wolfe, R. S. (1979), *Microbiol. Rev.* **43,** 260.
19. Grohmann, K., Mitchell, D. J., Himmel, M. E., Dale, B. E., and Schroeder, H. A. (1989), *Appl. Biochem. Biotech.* **20,** 45.
20. Rivard, C. J., Himmel, M. E., and Grohmann, K. (1985), *Biotech. Bioeng. Symp.* **15,** 39.
21. Nygaard, D. D., Chase, D. S., and Leighty, D. A. (1985), *Analysis of Wastewaters by ICP Spectrometry,* Application Note #177.
22. US Environment Protection Agency (1982), *Method* **200,** 7.
23. Pfeffer, J. T. (1968), *J. WPCF* **40,** 120.