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Pretreatment Technology for the Beneficial Biological Reuse of Municipal Sewage Sludges

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ABSTRACT

Modern municipal sewage waste treatment plants use conventional mechanical and biological processes to reclaim waste waters. This process has the overall effect of converting a water pollution problem into a solid waste disposal problem (sludges). The costs for conventional disposal of sewage sludges have risen dramatically because of increased environmental mandates, which restrict their disposal, as well as a dwindling number of landfills. Previously, we determined that secondary bioprocessing (specifically anaerobic digestion) was not effective in reducing the organic content and bulk of the sludge waste *(1)*. Therefore, we have examined the potential of a variety of pretreatment technologies designed to disrupt the macrostructure of the sludge and thereby enhance its subsequent biodegradation. Two thermal/mechanical pretreatments tested were found to have a dramatic effect on the subsequent bioconversion of the microbial sludges. Both technologies evaluated, sonication and shear, were found to be affected by sludge solids levels, duration of treatment, and treatment temperature. Optimum sonication pretreatment occurred with sludge solids of 1% and treatment times of 4–8 min. The most effectivee treatment temperature tested was 55°C. The optimum enhancement in bioconversion potential for the sonication pretreatment was 80–83% of the materials carbon oxygen demand (COD) content. The optimum shear pretreatment occurred with sludge solids of 1–2% and treatment times of 6–10 min. The most effective treatment temperature tested was 87°C. The optimum enhancement in bioconversion potential for the shear pretreatment was 88–90% of the material's COD content. These data were the basis for US patent no. 5,380,445, granted January 10, 1995.

Index Entries: Sewage sludge; pretreatment, shear; sonication; thermal treatment; anaerobic digestion.

INTRODUCTION

Current Practice

Modern municipal sewage waste treatment plants convert the majority of the solids in the incoming water into microbial mass, carbon dioxide, water, and methane. The plant's overall effect is to convert a water pollution problem into a solid

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waste disposal problem. The origin and nature of sludge and the problems of its disposal are best understood in light of the simplified process flow diagram of a large, modern treatment plant (Fig. 1). The primary purposes of digestion are to reduce the organic content, volume, and odor potential of the sludge, and to reduce the concentration of pathogenic microorganisms *(2–5)*. The dewatered sludge from anaerobic digestion represents the largest solid output from sewage treatment plants and the major disposal problem. Sludge processing and disposal are perhaps the most challenging problems in the field of waste-water treatment. This is because:

1. Sludge contains most of the substances responsible for the offensive nature of the waste water;
2. Much of the sludge consists of volatile solids (VS), which may undergo further decomposition; and
3. Only a small fraction of the sludge is solid matter *(6)*.

Recently, the volumes of sludge produced have increased dramatically as a result of increases in the organic loading of waste waters and environmental regulations that require a higher degree of waste-water treatment *(7–9)*.

Generally, the ultimate disposal of sludge is by land application, landfilling, or combustion *(3,10)*. Disposal by landfilling is becoming increasingly expensive, especially in the eastern US. The maturation and subsequent closure of existing landfills, reduced siting of new landfills, public concern about groundwater contamination, and safety problems associated with the methane produced by biological activity in landfills further compound the problem. Public concern about possible hazardous emissions produced by combustion processes and possible heavy metal contamination from the resulting ash has reduced acceptance of combustion as a disposal option for municipal sewage sludges *(11)*. The land application of sewage sludge is also problematic because biological activity produces methane and residual volatile solids result in contamination of groundwaters by organics.

The cost of disposing of sludge is often high and is increasing. Also, increased loads on existing treatment plants lead to sharply higher disposal costs. Increasing environmental requirements on the quality of waste-water treatment have resulted in a more complex process *(12)*, which produces greater microbial biomass for disposal. The greater organic loading of waste-water streams has created a higher stress on the treatment processes that often reduces the organic removal efficiency *(13)*. Higher levels of volatile organics in the sludge reduces its dewaterability substantially *(14)*, increasing the water content and volume of the final waste. Increasing dewatering efficiency at higher volatile solids content requires the use of organic polymers to enhance flocculation *(15–17)*. Polymer usage increases both the disposal costs and the organic loading of the final waste. The net result is that the amount and cost of sludge disposal can increase disproportionally when an existing plant must deal with increased loadings and clean-up requirements.

Most recent research has focused on reducing the volume of the final waste by improving dewatering technology *(18–23)*. However, the pollution potential of the sludge is unchanged because the dewatering does not reduce the VS fraction.

The VS content of treated sludges ranges from 40–75% *(3,6,7)*, and the content of undigested sludge is even higher. Clearly, the potential for further reductions in sludge volume still exists. However, because sewage sludge is primarily water and the standard vessels employed in digestion are stirred-tank reactors that are large and expensive, further (secondary) anaerobic digestion is not currently cost-effective.

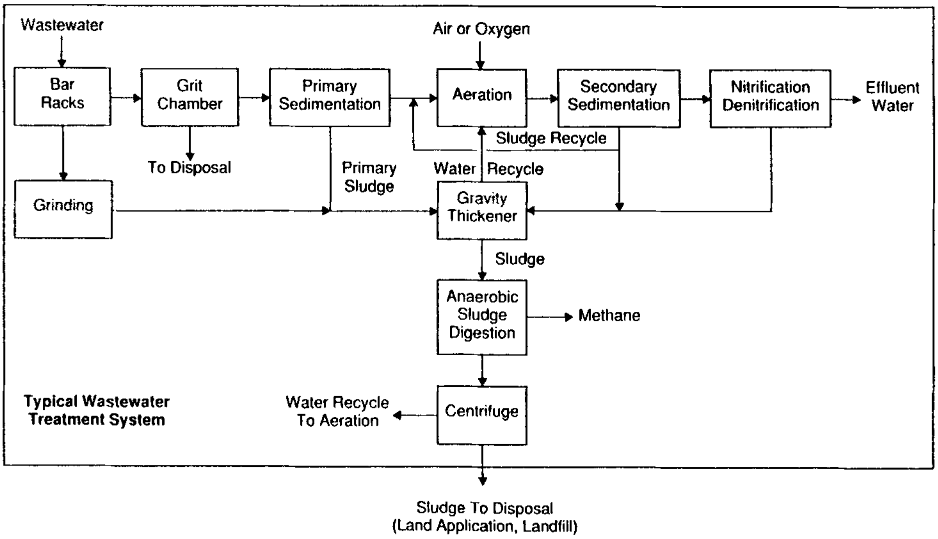

Fig. 1. Simplified process flow diagram for a conventional municipal sewage treatment plant.

The current study builds on our understanding of the factors affecting the secondary anaerobic digestion of municipal sewage sludges. Although previous studies identified that sludge pretreatment may improve subsequent biological digestion of sludges, pretreatments employing thermal, enzymatic, or chemical additions appeared to have only marginal effects *(1,24)*. This study evaluates combining thermal and mechanical forces to pretreat microbial sludges effectively, thereby releasing soluble and insoluble organic carbon oxygen demand (COD). In this way, a ready substrate for the application of secondary anaerobic digestion is created.

MATERIALS AND METHODS

Dewatered Municipal Sewage Sludge

Dewatered sewage sludge was obtained from the North Metropolitan Wastewater Reclamation Plant, Denver, CO. This plant employs conventional treatment processes as outlined in Fig. 1, with low-solids anaerobic digestion as the final biological treatment prior to residue dewatering and disposal. The sludge residue was collected immediately following centrifugation in 30-gal plastic drums and stored at 4°C to suppress nonexperimental deterioration.

Sludge Analysis

Total solids analysis of sewage sludge was performed using 1.0-g aluminum weigh tins. A 20- to 30-g sludge sample was loaded into preweighed tins and dried at 65°C for 48 h. The dried sample was then cooled to room temperature in a laboratory desiccator and weighed using a Sartorius balance (Model 1684MB). The percent total solids was calculated on a weight/weight (wt/wt) basis. Volatile solids and ash were determined by combustion of the dried samples at 550°C for 3 h in a laboratory-scale furnace.

Analysis of COD was as previously described *(25)*. The COD assay employed the microdetermination method, using commercially available "twist tube" assay vials (Hach, Loveland, CO).

Polymer composition of the sewage sludge was determined by acid/detergent-soluble fiber analysis *(26)*. This analysis results in values for acid detergent solubles (e.g., microbes, fats, and protein), cellulose, lignin, and ash *(26,27)*.

Sewage Sludge Pretreatments

The effects of sonication as a pretreatment for enhancing the release of soluble COD from sewage sludge was performed using a Braunsonic model 1510 sonicator (B. Braun, Germany). The sonicator was operated at 80% of sonication intensity. Sewage sludge was pretreated at total solids levels ranging from 1 to 3% (wt/wt). During sonication, sludge solution temperature was measured using a mercury thermometer. Sonication treatment times were varied from 0 to 10 min.

The effects of shear forces as a pretreatment for enhancing the release of soluble COD from sewage sludge was performed using an Ultra-Turrax (Tekmar model SD-45 [Ika-Werg Germany]). The Ultra-Turrax applies shear to the sample through the operation of opposing knife edges. The Ultra-Turrax was operated at 80% of the maximum motor rotational speed. Similar to sonication pretreatments, the sewage sludge total solids level and treatment time were varied from 1 to 3% and 0 to 10 min, respectively. The sludge solution temperature was measured using a mercury thermometer. For one experiment, the temperature of the sample was maintained at 40°C using a jacketed sample holder and by recirculating chiller water at 20°C.

Two methods were used to obtain power measurements. Amperage was measured using a Fluke model 88 multimeter, with watts calculated by multiplying amperage times voltage. The second method used a TIF model 2000 wattprobe to measure watts directly. Watts per hour were calculated by dividing the number of watts by the time (in min) for performing the pretreatment, and then normalizing for 1 h.

Analysis of Pretreatment Effectiveness

In an earlier study, we established a direct correlation between the soluble COD level of sewage sludge samples and the samples' anaerobic digestability *(24)*. Therefore, the effectiveness of sewage sludge pretreatment was measured as increases in the samples' soluble COD level. Briefly, a 1-g aliquot of the pretreated sample was diluted 10-fold in distilled water and subjected to low-speed centrifugation (10 min at 2000 rpm [1200*g*]) using a Sorvall GLC-4 equipped with an H-1000 rotor. Sample supernatants were collected and immediately analyzed for increases in soluble COD.

RESULTS

Digested, dewatered municipal sewage sludge was obtained from the Denver Metropolitan Wastewater Reclamation Plant. Sludge analysis, described in Table 1, indicates that most or the volatile solids content of the sludge comprises protein/hemicellulose (presumably microbial cells). Two pretreatment technologies were evaluated for their ability to release soluble COD from sewage sludge. In both cases, laboratory-scale equipment was utilized. The effects of sonication pretreatment on the release of soluble COD from municipal sewage sludge are shown in Fig. 2. A large reduction in treatment efficiency was determined as the sludge solids level

Table 1
Analysis of Denver Municipal Sewage Sludge
(as Received)

Parameter	Denver sewage sludge
Total solids (TS)	17.3 + 0.1
Volatile solids (VS of TS)	67.0 ± 0.2
Ash (of TS)	33.0 ± 0.2
pH	8.01
Protein/hemicellulose[a]	91.8 ± 2.9
Cellulose[a]	5.3 + 0.3
Lignin/plastics[a]	2.9 ± 0.7
Total COD[b]	187.5 ± 16.3
Soluble COD[b]	9.2 ± 0.8

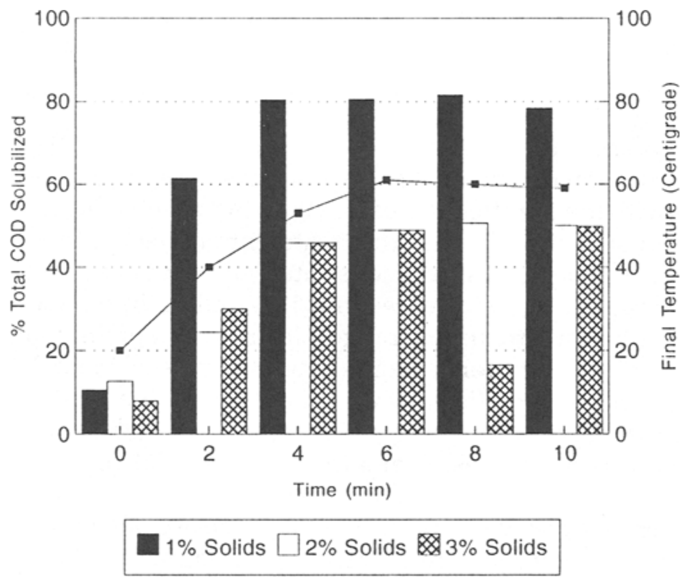

Fig. 2. Effects of sonication pretreatment of municipal sewage sludge on the release of soluble COD.

was increased above 1%. The data also indicate that the optimum treatment duration is approx 4 min (although longer treatment times do not diminish the effectiveness of pretreatment). Sonication of sewage sludge resulted in elevated temperatures. Increasing the duration of sonication resulted in an increase in temperature through the first 6 min. Treatment times of 6–10 min resulted a maximum sample temperature of 55°C. The maximum enhancement of anaerobic bioconversion potential for sewage sludge sonication pretreatment was 80–83% as measured by release of soluble COD.

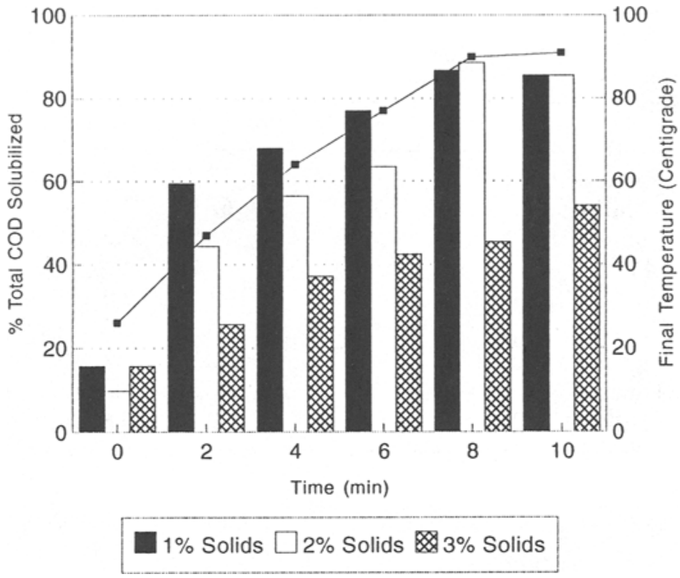

Fig. 3. Effects of shear pretreatment of municipal sewage sludge on the release of soluble COD.

The effects of shear pretreatment on the release of soluble COD from municipal sewage sludge are shown in Fig. 3. The data indicate that the efficiency of pretreatment increased with the duration of treatment up to 8 min. Treatment times exceeding 8 min did not significantly alter the treatment efficiency. Increasing the total solids level of the sewage sludge demonstrated a pronounced effect on the treatment efficacy. Sludge total solids exceeding 1% resulted in reduced pretreatment efficiency over the 2–6 min treatment range. Shear treatment times of 8 min or more resulted in similar treatment for sewage sludge samples of 1 and 2% solids. However, reduced pretreatment efficiency was noted for sludge total solids exceeding 2%. Increasing the duration of shear pretreatment resulted in increasing sludge temperature to a maximum of 90°C at a treatment time of 10 min. The maximum enhancement of anaerobic bioconversion potential for sewage sludge employing shear pretreatment was 88–90%, as measured by release of soluble COD.

To establish the synergistic effect of shear pretreatment with thermal input, an experiment was conducted in which the sludge sample temperature was controlled utilizing a water jacketed container. A chilled water bath was used to maintain the sludge temperature at 40°C. The data are shown in Fig. 4 and demonstrate that when the shear pretreatment is performed under a reduced temperature (40°C), pretreatment efficiency is reduced.

Analysis of power requirements for sewage sludge pretreatment is described in Table 2. The power requirements for optimum pretreatment of sewage sludge for both sonication and shear pretreatment are similar for the 1% solids case. Increasing the sludge total solids content reduced the power input per gram of sludge solids, but also resulted in reduced effectiveness for sonication. Shear pretreatment also demonstrated reduced power input with increasing solids level. However, in contrast to sonication, shear pretreatment at 2% solids results in optimum treatment effectiveness with reduced power requirements.

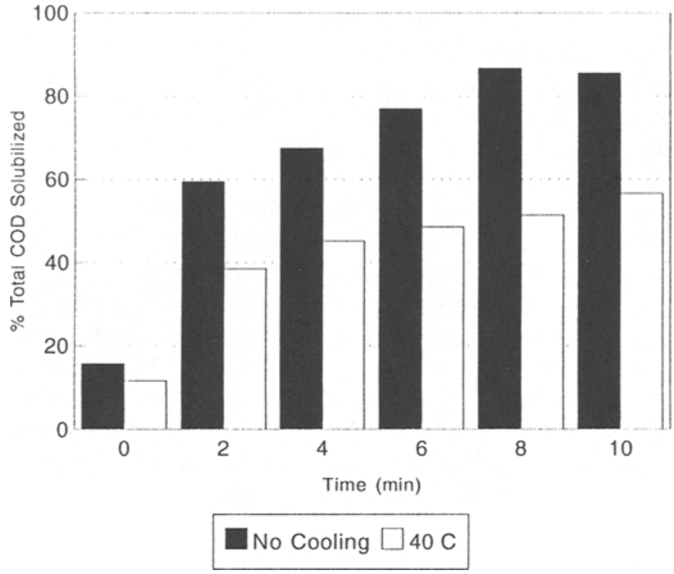

Fig. 4. Effects of thermal input on shear pretreatment of municipal sewage sludge on the release of soluble COD.

Table 2
Effects of Pretreatment Method, Sludge Solids, and Power Input on COD Release from Denver Municipal Sewage Sludge

Method	% Solids	Power, w/h	W/h/per g dry wt	% COD release
Shear	1	23.8	23.8	86.7
	2	25.8	12.9	88.6
	3	33.9	11.3	54.1
Sonication	1	23.2	23.2	80.4
	2	34.0	17.0	48.6
	3	34.3	11.4	46.7

DISCUSSION

Disposal of solid wastes from conventional municipal sewage treatment works is receiving increased attention as the primary disposal route, landfilling, becomes more restrictive. The most recent standards proposed by the US Environmental Protection Agency (EPA, Part 503, 28) identify the requirement for pathogen and vector attraction reduction (Subpart D) for beneficial reuse of digested sewage sludge as a soil amendment.

The use of shear and sonication was evaluated for their capability to disrupt the macrostructure of the sewage sludge, specifically, to break open microbial cells and thus render them "available" for biological conversion. We determined previously that measurement of soluble COD is the best method for predicting increases in a substrate's anaerobic biodegradation potential *(24)*. Both sonication and shear appear to be useful in disrupting the structure of the sludge and thereby increasing the level of soluble COD. From this work we may predict that 80–90% of the sludge COD may be further biodegradable under the optimum treatment parameters. The data also demonstrate the synergistic effect of thermal treatment with shear (and presumably sonication). However, the application of shear or sonication pretreatment appears to be limited in application to dilute sludges. Increasing the solids loading beyond 1–2% may require additional energy input to accomplish a similar level of treatment effectiveness. High energy costs for treatment of sludges in excess of 2% may thereby limit the applied value of the process.

In general, this study identifies two technologies that may be used to meet guidelines for pathogen and vector attraction reduction. Both technologies act by destroying microbial cells, thus sanitizing the sludge. This allows for further biological digestion, thus reducing the VS content. In addition, reductions in sludge VS content allow for a greater level of dewatering efficiency, which benefits final transportation costs. Although the fate of heavy metals that may be present in sewage sludges was not evaluated in the present study, ongoing research focuses on their ultimate fate during secondary anaerobic digestion as well as the development of similar pretreatment technologies for high-solids sludges (i.e., >10% total solids).

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