FLOC SIZE PROFILING TO CHARACTERIZE DEWATERING PROPERTIES OF THERMOPHILIC AND MESOPHILIC AEROBICALLY DIGESTED BIOSOLIDS

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ABSTRACT: This paper presents findings of a laboratory study on mechanisms of digestion effects on dewatering properties of thermophilic (TAD) and mesophilic (MAD) aerobically digested biosolids. The municipal secondary sludge was digested for 15-days in two parallel bioreactors: one at 60^{o}C, the other at 22^{o}C. This study found that TAD resulted in immediate deterioration in dewaterability, and produced many small particles following 1-day of digestion. Further thermophilic digestion did not result in significant changes in either dewaterability or floc size distribution. MAD resulted in gradual deterioration of dewaterability, and produced less small particles. Both TAD and MAD biosolids could be effectively conditioned, but the former consumed more polymers than the latter. This study suggested that floc size profiling could be used to describe and explain digestion effects on dewaterability; temperature, rather than digestion time, is a more important factor in affecting dewatering properties of TAD biosolids.

1. INTRODUCTION

The conditioning to improve dewatering properties of digested sludges (biosolids) is a significant cost factor in the operation of sludge handling systems of wastewater treatment facilities. The conditioning, mostly using chemicals such as polyelectrolytes (polymers), aims to ensure adequate capture of solids and to increase dewatering rates many-fold. The dewatering is to reduce water contents in sludge from about 90-95% to 65-80%, therefore to reduce final volumes to be transported and stored. Recent experience of full-scale operation revealed that biosolids from thermophilic aerobic digestion (TAD) consumed 3-10 times more polymers (up to 44 kg/dry-ton of total solids, Kelly *et al*, 2000) for conditioning than biosolids from mesophilic aerobic digestion (MAD). TAD is a high temperature sludge treatment process that produces high quality Class A biosolids, which can be beneficially reused as agricultural and forest fertilizers, but TAD results in an increase of conditioning and dewatering costs. Current knowledge and understandings of dewatering TAD biosolids are limited and incomplete, since TAD has a relatively short history in North America, European TAD facilities land-apply biosolids directly without dewatering. This paper reports findings of a lab-scale study on mechanisms of digestion effects on dewatering properties of TAD and MAD biosolids.

The importance of floc (sludge particle) size distribution rests on the role of flocs in the particle bridging model, which suggests that conditioning chemicals such as polymers form long molecular threads that attach multiple colloids, bridge gaps among flocs, capture and bind floc particles. Such formed floc structure is favorable for subsequent efficient dewatering. Sizes of floc particles also affect the total particle surface area and the porosity formed from these particles, therefore, the required coagulant doses and dewaterability. Karr and Keinath (1978) studied dewaterability of primary, activated, and anaerobically digested sludges having solids concentration of 0.7-1.3%, and found that effects of pH, biological degradation, mixing, and conditioning on dewaterability might all be explained from effects of these factors on particle size distribution. Supercolloidal solids (1-100 µm) have the most significant effect due to blinding of sludge cake and filter medium by these sizes of particles. Lawler *et al.* (1986) found that anaerobic digestion of mixed primary and activated sludge affected particle size distribution. Dewaterability was more sensitive to how digestion was operated rather the digestion itself. The dewaterability of digested sludges might be improved when digester worked well resulting in small particles being preferentially removed, or be worsened when digester did not work well resulting in large particle being destroyed and small particle being created. Burnett *et al*. (1997) found that the peaks of particle size of TAD sludge were similar to that of anaerobically digested sludge from two other sources of MAD facilities, all in the range of 5-7.5 µm, but TAD sludge had relatively fewer particles above 10 µm. Burnett's work was based on samples taken from the College Station TAD facility at Texas of USA.

The objectives of this study were to investigate how digestion affects floc size distribution of the digested biosolids, and whether or not the difference in TAD and MAD dewaterability could be attributed to the difference of their floc size distribution.

2. MATERIALS AND METHODS

The secondary sludge for our bench-scale work (carried out in mid August of 2000) was taken from Greater Vancouver Regional District's LuLu Island Wastewater Treatment Plant, which has a trickling filter/solids contact biological treatment process. The DAF (dissolved air flotation) thickened secondary sludge had 4.7% total solids (TS) and 3.9% total volatile solids (TVS), which was diluted to 2.3% TS as the feed. Sludge was digested for 15 days in two parallel bioreactors of 5 liters working volume each: one was placed in a waterbath and operated at 60^{o}C; the other was operated at room temperature of about 22^{o}C. Air diffusers provided fine bubble aeration and mixing. Dewaterability was measured as Specific Capillary Suction Time (S-CST is CST divided by TS).

Particle sizes were measured using a Malvern Mastersizer 2000 particle analyzer. This method is based on the principles of Fraunhofer diffraction and Mie scattering. The instrument projects laser lights through samples and detects the light scattering pattern resulted from the presence of particles in the sample. Particle sizes are determined from the amount of light that has scattered at angels built into the instrument by a calibration sphere of different diameters. Particle sizes are measurable in the range of 0.02-2000 µm, and are reported as a percent v/v (volume of particles having a specific diameter out of the total volume of particles). Results can also be reported as s/s (surface areas of particles having a specific diameter out of the total surface area of particles) and n/n (number of particles having a specific diameter out of the total surface area of particles); in either case, particles were assumed to have spherical shapes.

The sludge-conditioning polymer used Percol 757, a cationic polymer (60% charge density and 10-15 million molecular weight) by Ciba Inc.. The polymer was prepared as 0.25% (w/v) stock solution, allowed to age for 24 hours, then was further diluted to be 0.1% (w/v) working solution, prior to use.

3. RESULTS AND DISCUSSION

3.1 Digestion Effects on Dewaterability

Thermophilic and mesophilic aerobic digestion both affected dewaterability of the secondary sludge (Figure 1). TAD biosolids exhibited higher specific CST, suggesting more difficult to dewater, than MAD biosolids during the first 7-days of digestion, but subsequent differences in dewaterability were quite small. Thermophilic digestion resulted in immediate deterioration in dewaterability of the sludge, increased S-CST from about 16 sec.-L/g to 61 sec.-L/g following 1-day of digestion. Further TAD treatment did not result in significant changes in S-CST of TAD biosolids. The dewaterability of MAD biosolids deteriorated gradually during the 15-days digestion. It appears that, for TAD biosolids, the temperature, not the digestion time, was a dominant factor in affecting the dewaterability; for MAD biosolids, the worsening of dewaterability was associated with the progress of the digestion process.

3.2 Digestion Effects on Floc Size Distribution

Floc size distributions of TAD and MAD biosolids are illustrated in Figures 2 and 3. Results were presented as number base distribution (n/n). TAD produced many smaller particles following 1-day of digestion (Figure 2). Sizes of the most particles (number weighted) in TAD biosolids shifted from 2-3 µm to 0.6-0.8 µm. Further digestion at thermophilic temperature did not result in substantial additional changes in the distribution of particle sizes. Although MAD resulted in an increase in particles of smaller sizes, the impact was much less severe than that by TAD (Figure 3). Sizes of the most particles (number weighted) in MAD shifted slightly from 2-3 µm to around 2 µm. When all particles in the measured samples were taken into consideration, particles in TAD biosolids had distinctly smaller mean diameter (surface area weighted) than that in MAD biosolids (Figure 4).

Apparently, digestion effects on floc size distribution and on dewaterability corresponded well. The immediate deterioration of dewaterability in TAD biosolids following 1-day of digestion appears to be associated with the production smaller and finer particles. MAD produced less small particles, therefore, resulted in less deterioration of dewaterability in MAD bioslids. The production of smaller particles would increase total particle surface areas resulting in increased surface drag forces among particles, which would increase the difficulties of water-solids separation. Smaller particles also have stronger tendency to block pores of sludge cakes formed from these particles, therefore, worsen dewatering properties and decrease the rate of dewatering, which will increase the demand for conditioning chemicals as illustrated in the following Section.

3.3 Polymer Conditioning of TAD and MAD Biosolids

Both of TAD and MAD biosolids could be effectively conditioned by cationic polymer (Percol 757) for improvements of their dewaterability (Figure 5). The rate of S-CST reduction for MAD biosolids was more rapid that that for TAD biosolids. To reduce S-CST to 5 sec.-L/g (which was considered as readily dewaterable), polymer demands were 214 mg/L for TAD biosolids and 118 mg/L for MAD biosolids. The former was 80% more than the latter. It appears that polymer addition had immediate effect on MAD biosolids. This was evident in Figure 5, where S-CST reduction vs. polymer doses, from 0 mg/L to 100 mg/L, followed nearly a straight line. However, for TAD biosolids, rapid S-CST reduction occurred only after 50 mg/L polymer was already added.

The difference in pattern of S-CST reduction in TAD and MAD biosolids following polymer conditioning could be due to the difference in their floc size distribution. Smaller and finer particles having larger available surface area will result in more polymers absorbed onto their surfaces, and demand higher doses of polymers for bridging the high number of small particle for effective coagulation. This work agreed with findings from Knocke and Zentkovich (1986) that indicated the dosage of polymers for optimum dewatering were a direct function of particle sizes in the sample, and the optimum polymer dosage was directly correlated to available surface area in a suspension. This work suggested that the mechanism of TAD biosolids dewatering is likely through particle bridging and floc binding.

3.4 Implications for Full-scale Operations

The work presented in this paper suggested that dewaterability deterioration of TAD biosolids is associated more with the thermophilic temperature rather than the digestion time. The opportunity to optimize TAD process for improvements of dewaterability of TAD biosolids rests on the factors such as operation temperature rather than sludge retention time. The production of small and fine particles due to TAD suggested that long chain cationic polymer would be more effective in conditioning TAD biosolids. Through the selection of more effective conditioning polymers, chemical dosages could be minimized, consequently, the costs of sludge handling operation could be reduced.

4. CONCLUSION

Both thermophilic and mesophilic aerobic digestion resulted in significant deterioration of dewaterability in digested secondary sludge. Thermophilic digestion had more severe and rapid impact on dewaterability than mesophilic digestion. The worsening of dewaterability in TAD digested biosolids was associated with the production of smaller and finer particles, which corresponded to higher demand of polymers in conditioning TAD biosolids. Floc size profiling could be used to characterize the dewatering properties of digested biosolids.

5. ACKNOWLEDGEMENTS

This study was financially supported by Natural Sciences and Engineering Research Council of Canada (NSERC), Science Council of British Columbia, Dayton & Knight Ltd. of West Vancouver, Canadian Council of Professional Engineers, and Manulife Financial Insurance Company. Experiment work was carried out in the Environmental Engineering laboratory, Department of Civil Engineering at the University of British Columbia. Particle size analysis was performed in the laboratory of Dr. Peter Englezos, Department of Chemical and

Biological Engineering, the University of British Columbia.

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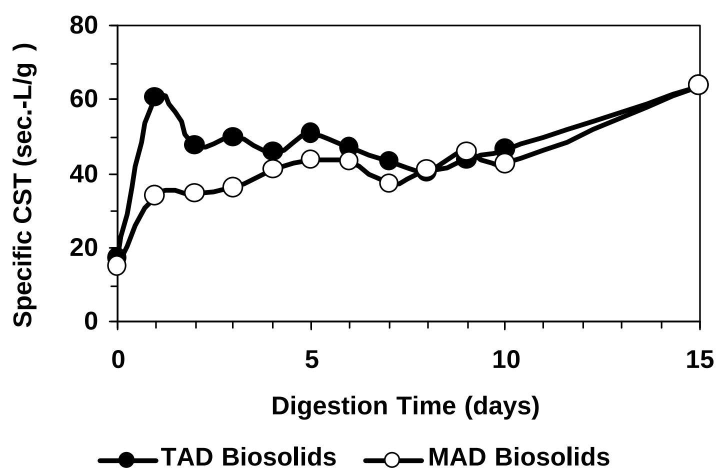

Figure 1. Effects of thermophilic and mesophilic aerobic digestion on dewaterability of the secondary sludge. Dewaterability was measured as specific capillary suction time.

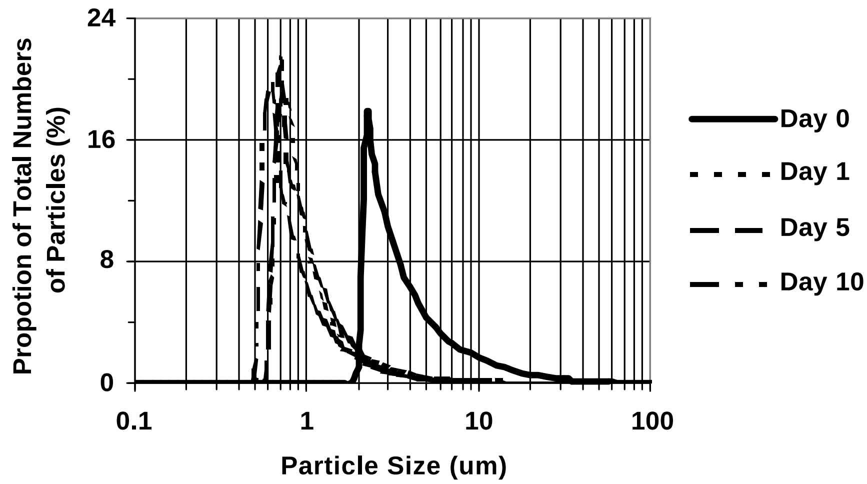

Figure 2. Effects of thermophilic digestion on floc (sludge particle) size distribution in the secondary sludge following 0, 1, 5, and 10 days of aerobic digestion.

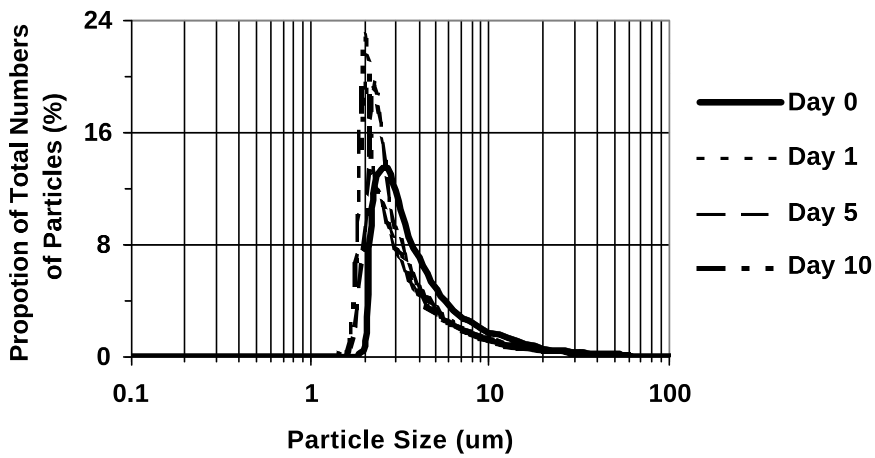

Figure 3. Effects of mesophilic digestion on floc (sludge particle) size distribution in the secondary sludge following 0, 1, 5, and 10 days of aerobic digestion.

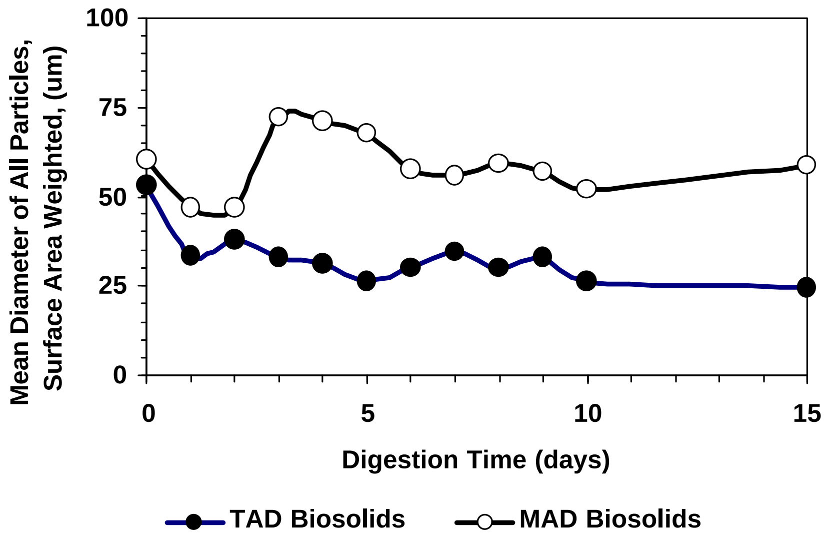

Figure 4. Mean diameters (surface area weighted) of all particles in thermophilic and mesophilic aerobically digested biosolids.

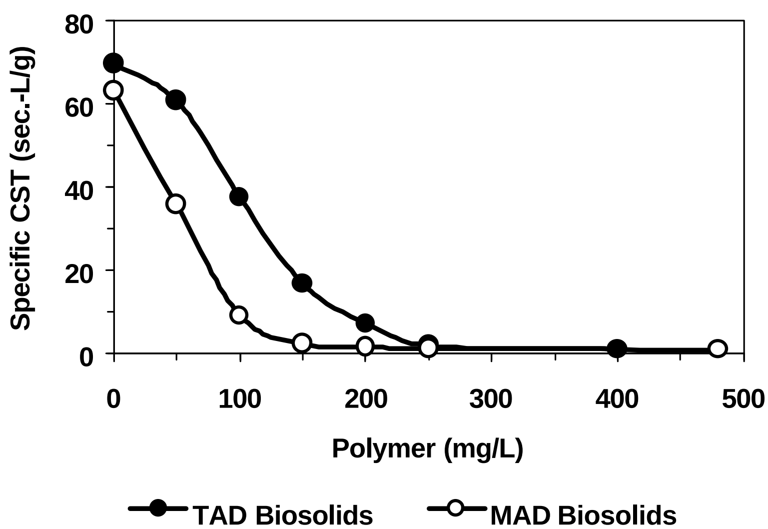

Figure 5. Polymer conditioning effects on dewatering properties of thermophilic and mesophilic aerobically digested biosolids. The cationic polymer was 0.1% (w/v) Percol 757 Samples were taken following eleven and half days of digestions. Dewaterability was measured as specific capillary suction time.