DIGESTION EFFECTS ON DEWATERABILITY OF THERMOPHILIC AND MESOPHILIC AEROBICALLY DIGESTED BIOSOLIDS

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ABSTRACT

Experience from full-scale operations revealed that autothermal thermophilic aerobic digestion (ATAD) results in deterioration of biosolids dewatering properties, and increased costs of biosolids conditioning. This paper presents findings of a laboratory study on effects of feed sludge characteristics, sludge retention time of digestion, and digesting temperature on dewaterability of thermophilic and mesophilic aerobically digested municipal biosolids. Parallel bench-scale reactors were operated at 60°C and 22°C, respectively, to digest primary, secondary, and mixtures of primary and secondary sludge for up to 30 days. This study found that thermophilic aerobic digestion significantly deteriorated dewaterability of the secondary sludge, but had less effect on the primary and the mixed sludge. Mesophilic aerobic digestion had gradual and continued effects that deteriorated dewaterability of all types of sludge. Sludge retention time was not a predominant factor for effects of thermophilic digestion on dewaterability, but was important in the effects of mesophilic digestion. Thermophilic digestion resulted in rapid deterioration in dewaterability of the secondary sludge, which was accompanied by rapid increase in amounts of soluble proteins, polysaccharides, and phosphate. For mesophilic digested biosolids, deterioration in dewaterability appeared to have a strong correlation with the amounts of soluble proteins and polysaccharides. Thermophilic digestion also resulted in smaller and finer biosolids flocs than mesophilic digestion, which might contribute to the deteriorated dewaterability and increased demands of conditioning polymers.

KEYWORDS

Dewaterability, thermophilic, mesophilic, aerobic digestion, biosolids, protein, polysaccharide.

INTRODUCTION

Autothermal thermophilic aerobic digestion (ATAD) is a high temperature sludge digestion process that produces Class A biosolids. Full-scale experience has shown that thermophilic digestion results in deterioration of biosolids dewaterability. Polymer dosages to adequately condition ATAD biosolids are reported as 3-10 times more than what are needed to condition mesophilic aerobically digested biosolids, and can be as high as 44 to 50 kg/dry-ton total solids (Burnett *et al.*, 1997, Kelly *et al.*, 2000, Murthy *et al.*, 2000b). For this reason, ATAD operation could increase costs of biosolids dewatering.

The current knowledge and understandings of dewatering ATAD biosolids are limited and incomplete. Full-scale application of ATAD process has had a relatively short history in North America (about 10 years since early 90'). Users of European ATAD facilities mostly land-apply biosolids directly without dewatering. Reported work relevant to ATAD biosolids dewatering includes the use of inorganic chemicals, such as pickle liquor (an industrial waste of ferrous chloride) and ferric chloride as a substitute for organic polymers to reduce overall cost of conditioning ATAD biosolids (Kelly *et al*, 2000, Murthy *et al.* 2000b). Storage of ATAD biosolids for 25 days in mesophilic aerated tanks was found to improve dewatering properties (Murthy *et al.* 2000a). These solutions were effective in reducing polymer dosages, and also reduced soluble phosphate from the supernatant of digested biosolids. However, the mass quantities of inorganic substitutes added into ATAD biosolids were greater (up to 5 times) than that of organic polymers. Consequently, the weights of biosolids for final disposal were increased. Also, the inorganic chemicals can be corrosive and need special handling and storage facilities. Extended storage and mesophilic aeration would need additional tankage and increased power cost, which would compromise the overall cost-effectiveness of ATAD process for producing Class A biosolids. The reported work, although advancing the knowledge of ATAD dewatering, did not provide information on effects of individual parameters (such as temperature and sludge retention time) on dewatering properties of the digested biosolids. The lack of information was partially because of the difficulties of experimental control associated with the operation of full-scale ATAD facilities, where these work were carried out. Therefore, a more in-depth study under controlled experimental conditions to explore causes and mechanisms of deterioration of ATAD biosolids dewaterability was needed.

This study was designed to investigate how feed sludge characteristics, sludge retention time (SRT) of digestion, and digesting temperature affect dewaterability of thermophilic and mesophilic aerobically digested biosolids, the production of extra-cellular biopolymers (*i.e.* proteins and polysaccharides), and the particle (biosolids flocs) size distribution.

MATERIALS and METHODS

Experiment digesters and operation: Four bench-scale aerobic sludge digesters (5 L each) were used. Two digesters were placed in a waterbath and operated at 60^oC; the other two were operated around 22^oC at ambient room temperature. Air diffusers provided fine bubble aeration and mixing. Contents in each digester were further thoroughly mixed (manually) prior to each sampling. Airflow rates, regulated by airflow meters, were set to be the same for all digesters during each run (tested at 7 v/v-hr and 11 v/v-hr). Digestions were also monitored for oxidation-reduction potentials (ORP). Evaporated water (mainly from thermophilic digesters) was replaced with tap water prior to each sampling.

Feed sludge: Sludge was taken from Greater Vancouver Regional District's Lulu Island Wastewater Treatment Plant (WWTP), which has a trickling filter/solids contact biological treatment process. Wastewater influent to Lulu Island WWTP was predominantly municipal sewage. Both of the primary and secondary sludge were thickened at the WWTP (primary sludge by gravity thickeners, secondary sludge by dissolved air flotation units). Collected sludge had approximately 4.5% total solids (TS), and was diluted with tap water to prepare for the feed. Three types of sludge compositions were studied, including 100% secondary sludge (*Secondary Sludge*), mixture of 40% (by weight) secondary and 60% (by weight) primary sludge (*Mixed Sludge*), and 100% primary sludge (*Primary Sludge*). Each feed sludge had approximately 2.5% TS.

Experiment analysis: Dewaterability was measured using a capillary suction timer according to *Standard Methods* 2710G, and was reported as specific CST (S-CST is CST normalized by TS, high S-CST indicated poor dewaterability, a S-CST of 5 to 10 sec-L/g was considered readily dewaterable). TS and TVS measurements followed *Standard Methods* 2540B and 2540E. Particle sizes (samples were diluted 200 times to suit instrument requirement) were measured using a Malvern Mastersizer (light-scattering method and Mie theory, *Standard Methods* 2560D). To measure soluble biopolymers, samples were centrifuged at 10,000g for 20 minutes, then were filtered through Fisher G-6 fiberglass filter papers of 1.5 µm pore size. Proteins were measured using Lowry method (Lowery *et al.* 1951) with bovine serum albumin as the standard. Polysaccharides were measured using Dubois method (Dubois *et al.* 1956) with glucose as the standard. After appropriate pretreatment and preservation according to *Standard Methods*, ammonium (NH_4^+), nitrate and nitrite (NO_x^-), total Kjeldahl nitrogen (TKN), orthophosphate (PO_4^{3-}), and total phosphorus (TP) were measured using a Lachat QuickChem Automated Ion Analyser.

RESULTS and DISCUSSIONS

Feed sludge composition effects on dewaterability

The compositions of feed sludge significantly affected dewatering properties. The S-CST of the undigested feed sludge were approximately 1 sec-L/g for *Primary Sludge*, 3 sec-L/g for *Mixed Sludge*, and 19 sec-L/g for *Secondary Sludge*. Sludge (untreated and digested) had better dewatering properties (lower S-CST) when primary sludge was present in the feed.

Thermophilic aerobic digestion (TAD) had the greatest effect on the dewaterability of the *Secondary Sludge*, but lesser effect on *Mixed* and *Primary Sludge* (Figure 1). S-CST of the *Secondary Sludge* increased from 19 to 49 sec-L/g after 1-day of digestion at 60^oC, and subsequently had relatively smaller changes for the next 29-day of thermophilic digestion (varied between 30 to 50 sec-L/g). There were some increases in S-CST of *Mixed Sludge* (to approximately 10 sec-L/g), and of *Primary Sludge* (to approximately 7 sec-L/g). However, thermophilically digested *Mixed* and *Primary Sludge* were considered readily dewaterable, due to their low S-CST.

Mesophilic aerobic digestion (MAD) resulted in gradual deterioration of dewaterability in all three types of feed sludge (Figure 2). Unlike the TAD *Secondary Sludge*, MAD at 22^oC did not result in immediate increase of S-CST after 1-day of digestion. After 30-day of MAD, S-CST of the *Secondary*, *Mixed* and *Primary Sludge* increased to approximately 50, 34, and 15 sec-L/g, respectively. Nevertheless, the digested biosolids that had primary sludge components were still more readily dewaterable than digested *Secondary Sludge*.

The untreated primary sludge appeared to be a heterogeneous suspension, containing discrete solids that readily settled out. The untreated secondary sludge was more homogeneous, and showed no distinct tendency for separation between solids and liquid. Poxon (1996) suggested that mesophilic anaerobically digested mixture of primary and secondary sludge exhibited an extensive, gel-like biocolloidal structure that restricted water movement. It was suggested that these biocolloids might exist in true solution as extensively hydrated, multi-molecular aggregates that do not have a distinct particle surface, and consequently form a homogeneous sludge. In our research work, the *Secondary Sludge*, but not the *Primary Sludge*, appeared to possess a gel-like structure and exhibited poorer dewatering properties.

Sludge retention time effects on dewaterability

For TAD biosolids from *Secondary Sludge*, significant deterioration of dewaterability occurred within 1-day (the first sampling point in the test) of digestion. Thereafter, sludge retention time (SRT) did not have substantial effects on dewaterability (Figure 1). For TAD biosolids from *Mixed* and *Primary Sludge*, longer SRT resulted in slightly increased S-CST, but the increase was not significant when compared to that of a *Secondary Sludge* feed. Further studies indicated that deterioration in dewaterability of *Secondary Sludge* by the thermophilic effect occurred within 3 hours of treatment at 60^{o}C (the first sampling point of the test shown in Figure 3). It appeared that SRT was not a dominant factor in the effect of thermophilic treatment on dewaterability.

For MAD biosolids, increased SRT resulted in progressive and gradual deterioration of dewaterability in *Secondary*, *Mixed*, and *Primary Sludge* (Figure 2). Therefore, SRT appeared to be an important factor in deterioration of dewaterability in MAD biosolids.

Typical reactor retention time is 5-6 days for TAD and 15-20 days for MAD. It appeared that the opportunity to optimise dewaterability by adjusting SRT of TAD was limited, since the effect of TAD occurred in short time of digestion. In contrast, shortening SRT of MAD (within the acceptable SRT range) could potentially result in improved dewatering properties of MAD biosolids.

Temperature effects on dewaterability

Results from parallel operation of thermophilic and mesophilic digestion (Figures 1 and 2) indicated that temperature was the dominant factor affecting dewatering properties of TAD biosolids from *Secondary Sludge*. This effect was less significant when the primary sludge was present in the feed, as if the composition of the sludge appeared to play a profound role in affecting dewaterability. The rapid deterioration (Figure 3) of dewatering properties of TAD biosolids from *Secondary Sludge*, which also occurred within 1 hour of treatment in 60^{o}C waterbath (results not shown here), suggested that the deterioration was due to “heat shock”, rather than due to growth of new microbial communities. The effect was not due to reduction of total volatile solids (TVS), since the TVS remained constant within the first 12 hours of thermophilic digestion when changes of dewaterability occurred (Figure 4). However, the “heat shock” did result in rapid and significant increase in amounts of soluble proteins, soluble polysaccharides, and phosphate (PO_4^{3-}), which suggested that microbial cells either lysed and released intracellular materials or produced new materials due to heat-induced stress.

Production of biopolymers (proteins and polysaccharides)

For TAD biosolids from *Secondary Sludge*, the rapid deterioration of dewaterability was associated with a rapid production of soluble proteins (increased from 190 mg/L to 2400 mg/L within 3 hours, Figure 5), and polysaccharides (increased from 310 mg/L to 1300 mg/L within 3 hours, Figure 6), and soluble phosphate (increased from 20 mg/L to 110 mg/l, not shown here). There were little changes of soluble proteins, polysaccharides, and phosphate in MAD biosolids from *Secondary Sludge* during the same 3 hours period (Figures 5 and 6).

In comparison to the *Secondary Sludge*, 1-day of thermophilic digestion of *Primary Sludge* resulted in a much smaller increase of soluble proteins, from 180 mg/L to 550 mg/L, and of polysaccharides, from less than 20 mg/L to 150 mg/L. Soluble proteins and polysaccharides from thermophilic digested *Mixed Sludge* were less than that of *Secondary Sludge*, but higher than that of *Primary Sludge* (data not shown here).

Dewaterability of MAD biosolids from *Secondary*, and *Mixed Sludge* had strong linear correlations to soluble proteins (Figure 7) and to soluble polysaccharides (Figure 8). Dewaterability of the TAD biosolids from *Mixed Sludge* appeared to have some correlation to soluble polysaccharides (Figure 8), but was weakly correlated to soluble proteins (Figure 7). The high S-CST for the TAD biosolids from *Secondary Sludge* appeared to be associated with high soluble proteins and polysaccharides (Figures 7 and 8), however, no linear correlation was observed. Instead, a threshold phenomenon seemed to exist. When biopl0ymer concentrations in TAD biosolids from *Secondary Sludge* exceeded the threshold, dewatering properties declined significantly. The proteins and polysaccharides have negatively charged functional groups (*e.g.* OH^{-1} and $-COO^{-1}$), which could affect sludge dewatering properties through sequence specific interactions, hydrophobic interaction, and hydrogen bonding (Higgins *et al.*, 1997, Sutherland, 1972, Novak *et al.* 1999, Novak and Bivins 2000). Increasing these soluble biopolymers likely contributed to increased polymer demands for conditioning.

Digestion effects on floc size distribution

It was reported by Zhou *et al.* (2001) that thermophilic digestion resulted in smaller and finer flocs than that from mesophilic digestion, but longer SRT during thermophilic digestion did not result in substantial additional changes in floc size distribution. Typical size distributions of biosolids floc from TAD and MAD biosolids were compared in Figure 9. After 5-days of digestion, a higher proportion of total surface areas in TAD biosolids from *Secondary Sludge* consisted of particles of smaller sizes than that in MAD biosolids from *Secondary Sludge*. Particle (biosolids floc) size affects the total particle surface area and the porosity of cakes formed from these particles. It has been shown that particle sizes affect dewatering properties and dosage of conditioning chemicals (Karr *et al.* 1978). Higher numbers of smaller flocs require higher dosage of polymers for surface interactions and bridging, tend to block water passageways through biosolids cakes, therefore, worsen dewaterability, and further increase polymer demands.

CONCLUSIONS

1. The composition of feed sludge affects dewatering properties. Thermophilic aerobic digestion resulted in a significant reduction in dewaterability of *Secondary Sludge*, but had less effect on dewaterability of *Primary* and *Mixed Sludge*. Mesophilic aerobic digestion had gradual and progressive reduction in dewaterability of all three types of tested feed sludge.

2. Sludge retention time was not a major factor in the thermophilic digestion effect on dewaterability, but was an important factor in deterioration of dewaterability of mesophilic digested biosolids.

3. The effect of temperature on thermophilic digested biosolids from *Secondary Sludge* was rapid, as if the effect was due to “heat shock” rather than the growth or adaptation of microbial communities.

4. Rapid deterioration of thermophilic digested biosolids from *Secondary Sludge* was accompanied with rapid increase in amounts of soluble proteins, polysaccharides, and phosphate. The deterioration of dewaterability of mesophilic digested biosolids appeared to have strong correlation with the amounts of soluble proteins and polysaccharides.

5. Thermophilic digestion resulted in smaller and finer particles (biosolids flocs) than mesophilic digestion. These smaller particles could also be a cause for worsened dewaterability and increased demands of conditioning polymers.

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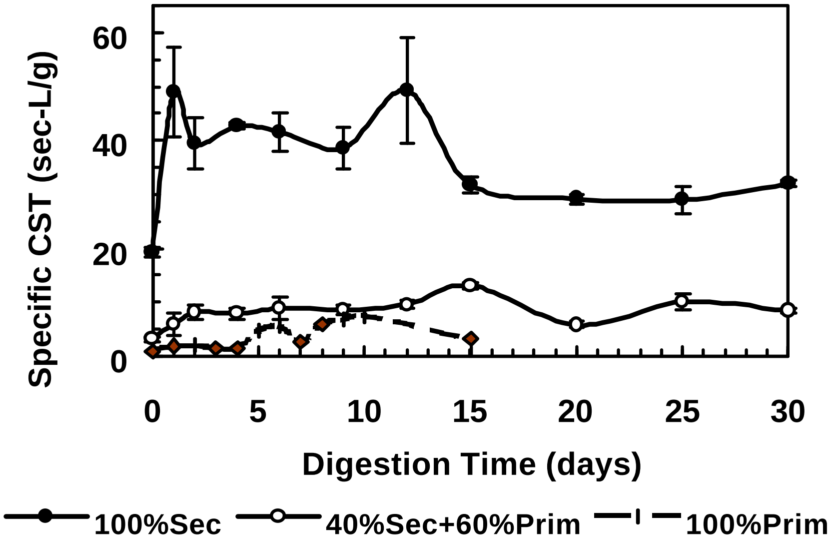

Figure 1. Effects of thermophilic aerobic digestion on dewaterability of primary, mixed, and secondary sludge. Error bars in all figures represent one time of standard deviation on either side.

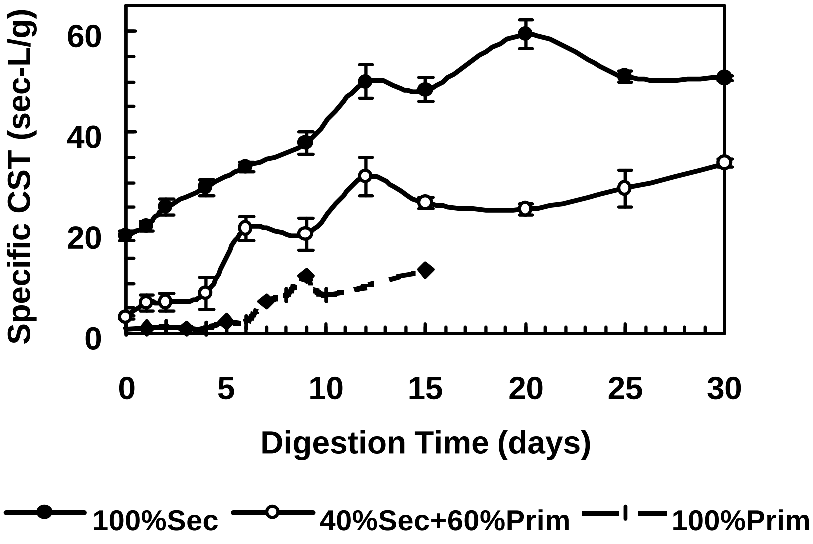

Figure 2. Effects of mesophilic aerobic digestion on dewaterability of primary, mixed, and secondary sludge.

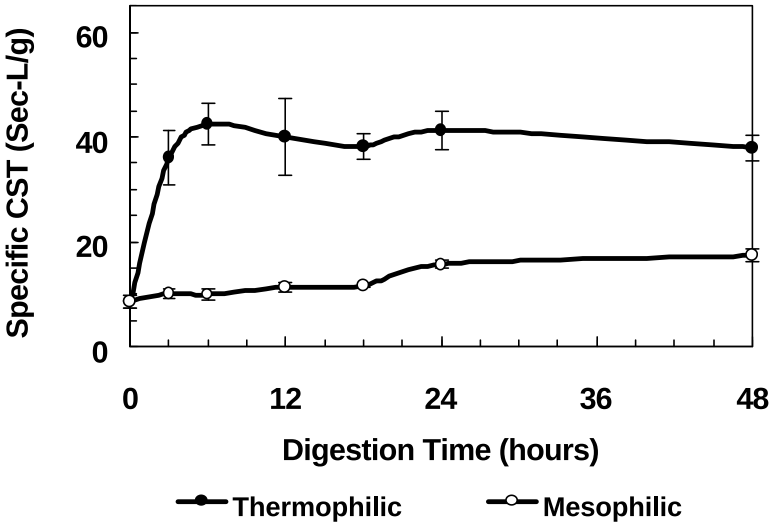

Figure 3. Effects of aerobic digestion on dewaterability of secondary sludge during the first 48 hours.

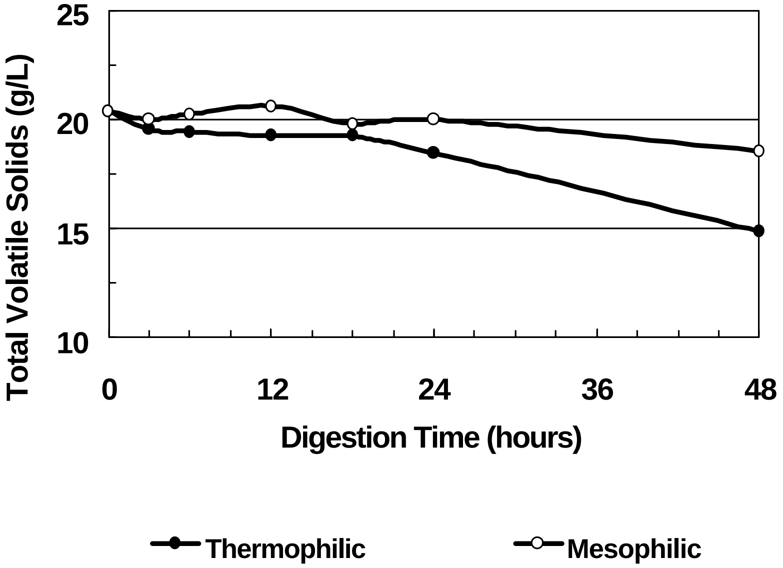

Figure 4. Effects of thermophilic aerobic digestion on reductions of total volatile solids in secondary sludge during the first 48 hours.

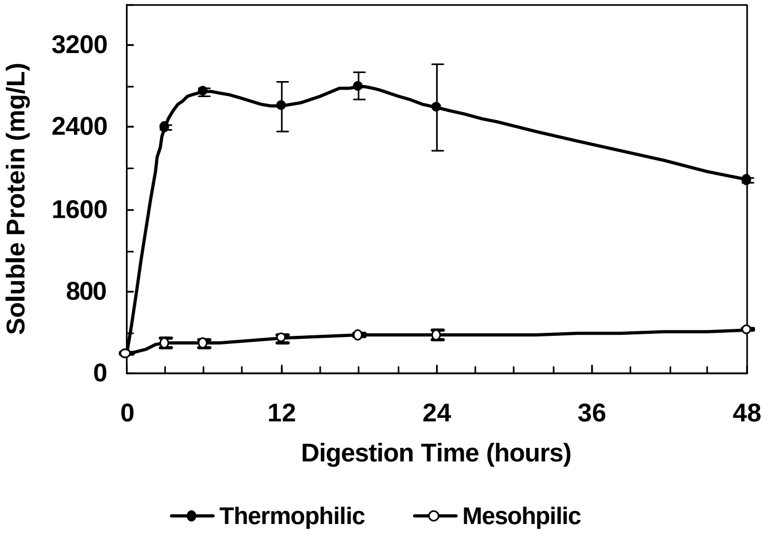

Figure 5. Effects of aerobic digestion on production
of soluble proteins in secondary sludge during the first 48 hours.

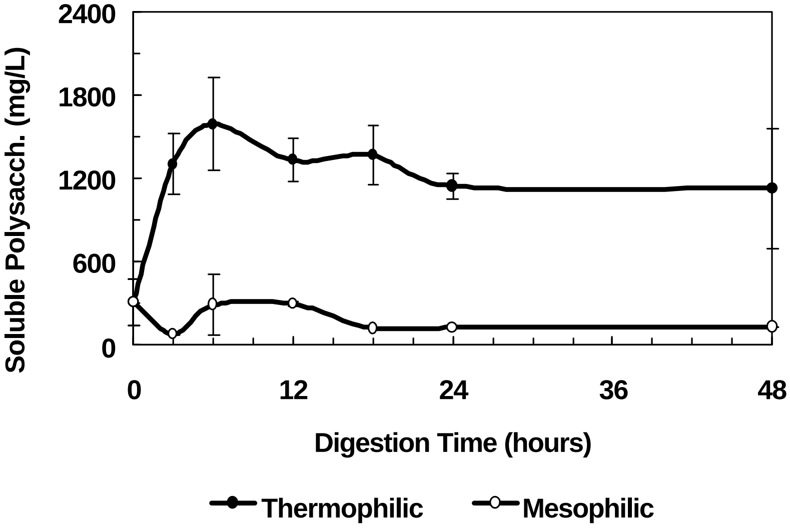

Figure 6. Effects of aerobic digestion on production
of soluble polysaccharides in secondary sludge during the first 48 hours..

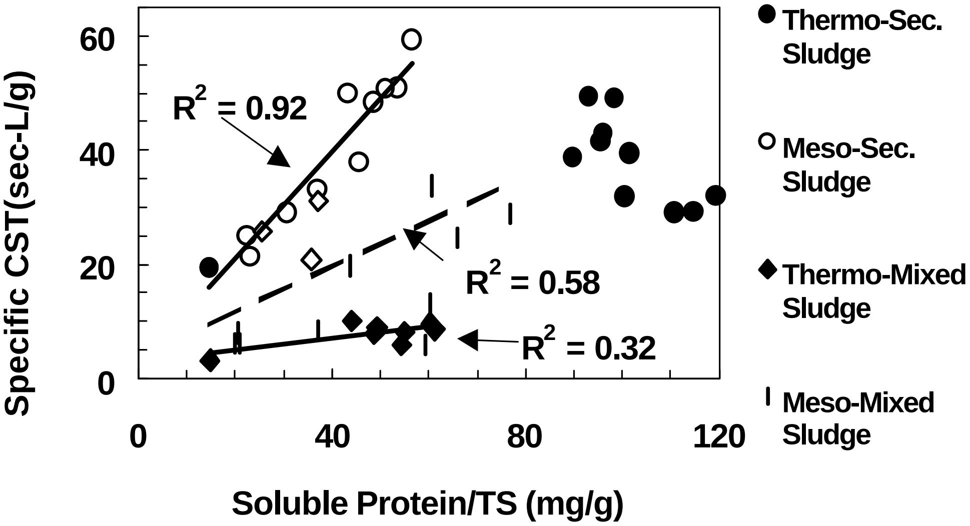

Figure 7. Correlation of dewaterability with soluble proteins in aerobically digested secondary and mixed sludge.

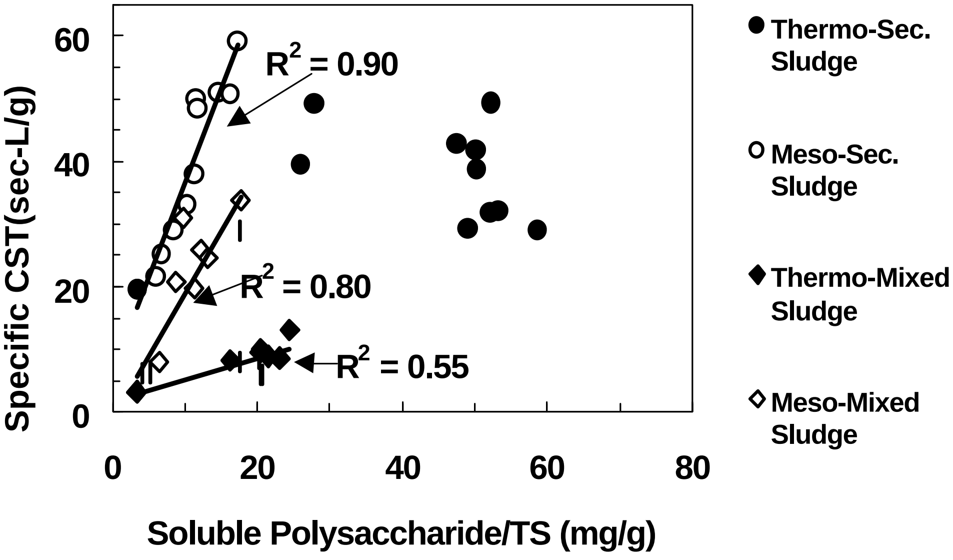

Figure 8. Correlation of dewaterability with soluble polysaccharides in aerobically digested secondary and mixed sludge.

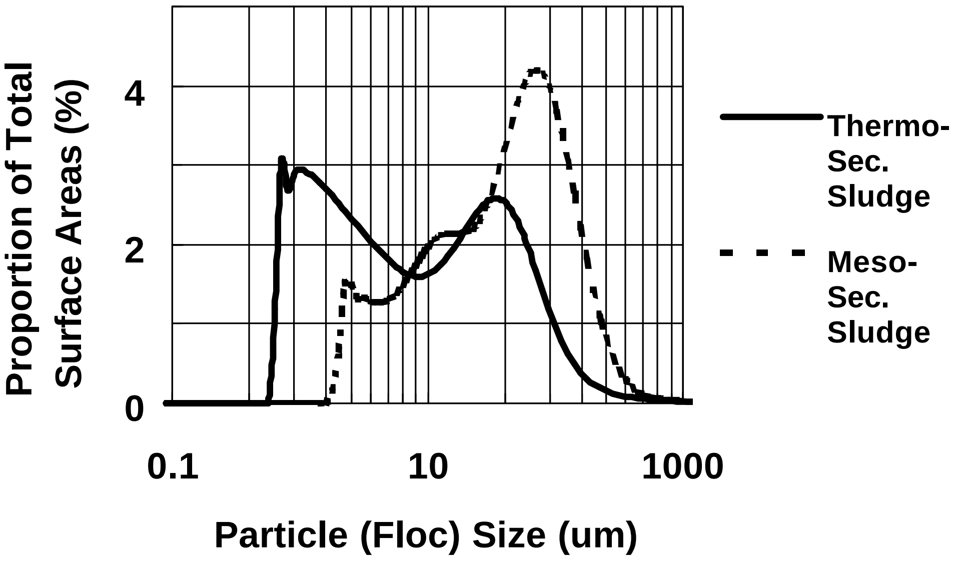

Figure 9. Floc size distribution in the secondary sludge after 5 days of thermophilic and mesophilic aerobic digestion