DEWATERING IMPROVEMENTS OF THERMOPHILICALLY DIGESTED BIOSOLIDS THROUGH ADDITION OF METAL SALTS AT THE SALMON ARM WATER POLLUTION CONTROL CENTRE

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ABSTRACT: This paper presents the findings of an in-plant investigation into the improvement of centrifuge dewatering of thermophilic aerobic digested biosolids at the District of Salmon Arm WPPC in Salmon Arm B.C., Canada. The Salmon Arm treatment facility produces primary solids and waste biological nutrient removal (BNR) solids with high phosphorus content. The combined solids are treated in autothermal thermophilic aerobic digesters (ATAD) prior to dewatering in a centrifuge. Two constraints are to be met in the dewatering operation. The first is the production of an acceptable cake at a low cost. The second is the recovery of phosphorus from the centrate to prevent return to the BNR process. For the first, several polymer combinations were used and although cake solids percentages exceeded 30 % dry solids, polyelectrolyte use was considered unacceptable. For the second, a centrate treatment step was added to the treatment train to precipitate the phosphorus by chemical means. Following literature research and in-house laboratory and full scale testing with ferrous iron as pickle liquor, the use of pickle liquor allowed for the reduction of polyelectrolyte by one-half previous use. The added pickle liquor also assisted with the down stream precipitation of the phosphorus from the centrate.

KEY WORDS

ATAD biosolids, BNR biosolids, dewaterability improvements, ferrous iron, polyelectrolyte reductions

1. INTRODUCTION

In 1986, the District of Salmon Arm in British Columbia, Canada upgraded their treatment plant by incorporating an untried biological nutrient removal (BNR) concept that included trickling filters in the main process train. They also included one of the first autothermal thermophilic aerobic digester (ATAD) facilities in North America. The design of the plant was described previously by Kelly, (1987) and Kelly *et al*., (1995).

The BNR design at Salmon Arm was named the fixed grow reactor, suspended growth reactor (FGR-SGR) process. The design for this process was developed from known principals for biological phosphorus removal in activated sludge systems, and from those developed for BOD removal and nitrification in trickling filter systems. The FGR-SGR process includes suspended growth tanks both upstream and down stream of a two stage trickling filter. Primary settling tanks precede the biological process. Operational success and control criteria were described by Gibb *et al*., (1998).

The digestion of the combined waste biological and primary solids has been undertaken through the ATAD since 1990. Treated biosolids were stored in lagoons. In 1997, the Salmon Arm WPCC underwent a further expansion that included the decommissioning of the lagoons and the addition of a centrifuge dewatering device that allowed for a polyelectrolyte dewatering aid and a chemical centrate treatment system. Following commissioning of the expansion in 1998, the centrifuge dewatering system was able to consistently achieve a cake of over 30% dry solids, and on occasion over 40% dry solids. Polyelectrolyte use was however, excessive, resulting in high dewatering costs.

The waste biological solids from the Salmon Arm BNR process are rich in phosphorus. Phosphorus is released from solution during ATAD digestion, resulting in orthophosphate concentrations as high as 500 mg-P/L in the centrate. Since the centrate is returned to the liquid process, treatment to reduce the phosphorus return loading is required. This is currently undertaken by chemical treatment of the centrate stream with waste pickle liquor, (ferrous iron).

Improvements to the polyelectrolyte additions were needed and the District of Salmon Arm undertook to evaluate other options. These included different feed arrangements for the polyelectrolyte but most recently the evaluation of pickle liquor addition to the biosolids feed.

2. BACKGROUND

To reduce polymer cost, Chitikela and Dental (1998) studied the use of inorganic salts (ferric chloride) and cationic surfactant as a partial substitute for expensive cationic polymer. Various concentration combinations were studied with polymer on anaerobically digested sludges from two US cities, but although the inorganic conditioners reduced polymer requirements, the salt addition was not cost effective.

From another perspective for improving dewaterability, Novak (1998) demonstrated that an optimum ratio between monovalent cations and divalent cations could show improvements to dewatering for industrial watewater treatment mixed liquor in terms of a reduction in specific capillary suction time of 2 to 3 times. Their research found that when monovalent to divalent cations increased as a ratio beyond 2:1, dewatering properties became poor. The conclusions were pointed at the concentration of the monovalent cation sodium but others such as ammonium would be of concern as well. The researchers suggested that the improvements were not entirely physical-chemical but that a change in the physiology of the biomass may occur as well. The physiology change was proposed as a change in the biopolymer concentration of the mixed liquor. Biopolymer concentration reduced with increasing ratio of divalent to monovalent cations.

In a discussion of the Novak paper by Cousin and Ganczarczyk (1999), it was noted that the addition of sodium decreased dewaterability and reduced floc strength. It was also noted that other monovalent cations, specifically potassium, affected the floc strength differently, agreeing with Novak's hypotheses that the ions affect the biomass physiology. When the divalent cation magnesium was added, dewaterability improved; the magnesium was seen to displace the monovalent cations in the floc. It was postulated that dewaterability improved because floc size decreased to allow a shorter path for the water to travel, or floc porosity increased to allow water to travel more freely from the floc.

In their response, the authors of the Novak paper hypothesized that divalent cations "bridge negatively charged functional groups on biopolymers" to give strength to the floc. The addition of the divalent cations is, however, to be undertaken during floc formation so that the cations are incorporated into the floc by the biomass and not by subsequent additions in a batch operation. The authors noted that addition of divalent cations after floc formation did not result in the incorporation of the cations in the floc. Monovalent cations were said to reduce floc size, increase density and reduce dewaterability.

Murthy and Novak (1999) provided a relevant discussion on the dewaterability of aerobically digested biosolids that showed improved cake solid concentrations of between 1.6 and 6% dry solids in laboratory test results. Polyelectroyte addition was postulated to be less if divalent cations are added to the biological process prior to digestion. If the divalent cations are low in concentration relative to the monovalent cations, floc binding is poor and polysaccharides are released from the floc to solution.

Novak (2000) studied both anaerobic and aerobic digested biosolids, and reported a significant difference in ratios of protein to polysaccaride.

Anaerobic digestion showed three times the protein concentrations to polysaccaride while aerobic digestion showed less than one half. Chemical requirements were shown to be correlated with protein concentration which appears to be correlated with ammonium ion concentration. Since the ATAD reactor is similar to the anaerobic digestion in this sense, a similar response is expected. Novak (2000) hypothesized that the accumulation of proteins was due to a lack of iron to bind the proteins to the flocs. The anaerobic environment solubilizes iron, decreasing its availability for floc and protein binding. The authors also speculated that the ammonium ion likely acts similar to the sodium ion, causing biopolymer release. They noted that aerobic digestion degrades proteins and oxidizes ammonia, but not polysaccarides. A comparison of polysaccaride degradation between aerobic and anaerobic digestion was not made, but it is commonly known that polysaccaride degradation is less than fats or proteins for either process (Kelly, 1990).

Monovalent cations in the form of the ammonium ion are a dominant species of cation in the ATAD reactor. Ammonia is the product of protein degradation. The production of ammonia increases the alkalinity of the biosolids by several multiples, often from less than 500 mg/L $CaCO_3$ to 2000 mg/L $CaCO_3$ with coincident pH increases from 5.5 to 8 as recorded by Kelly (1990).

The variability in the ammonia and ammonium ion production in the ATAD reactor is not well understood but the implication of the presence of the ammonium ion and its effect on dewaterability appears to be important given the hypotheses presented above. The ionized ammonia fraction is above 95% at pH 8 and 55^0C, but as the biosolids are cooled and pH drops the ionized fraction is increased to more than 99.9% at pH 6 and 35^0C. Lowering the pH is therefore partly counterproductive although the increase in monovalent ammonia ion concentration is only about 5%. Currently the Salmon Arm ATAD pH is about 7.

The ATAD microbiology differs from a conventional aerobic environment in several ways. The physiology of the biomass and subsequently the floc are the result of a conversion from a larger and more diverse biology to one that is selective to thermophilic bacteria alone. The higher forms have died and are replaced by the growth of the rod shaped single cell thermophiles. To improve floc dewaterability, as proposed by Novak (1998) through the addition of divalent cations to the FGR-SGR biological treatment system, would be of no advantage in this case, since the biomass that is wasted to the ATAD treatment is presumed to be lysed in the ATAD reactors. This would reduce the argument that the cation strengthens the floc when added to the liquid treatment.

Anecdotal information from Rietz (1999) suggests that addition of the trivalent cation aluminum to the last ATAD reactor vessel has improved the dewaterability at the Wastewater Treatment Plant at Avon, Colorado, USA. The plant also receives water treatment plant alum sludge that is combined with the unstabilized wastewater treatment plant biosolids. The total aluminum addition represents less that 1 percent by dry weight of biosolids. The addition of aluminum in the final reactor vessel represents less than 0.01 % by dry weight of biosolids. Another example of improved dewaterability of conventional aerobically digested biosolids through the addition of alum sludge from a water treatment plant is at Canton, Illinois, USA. Cook (1999) records 40% dry solids off their belt filter press**.** Polymer use is about 2.67kg/dry tonne. Polymer use for several ATAD operating facilities is given in Table 1.

TABLE 1. Polyelectrolyte Use for ATAD Biosolids Dewatering

Location	Biosolids source and treatment	Cake Solids %	Polymer Kg/dt
French Creek, Parksville, B.C.	ATAD biosolids from primary and trickling filter, solids contact, cooling and cationic polymer addition for belt filter press	28	8-12
Whistler WWTP Whistler, B.C.	ATAD biosolids from primary and chemically enhanced phosphorus removal with trickling filter, solids contact, cooling and cationic polymers (2) additions for belt filter press	28-31	12.5-15
Avon WWTP Avon, Colorado	ATAD biosolids from primary, activated and water treatment alum sludge with addition of 7.5 L Alum to last reactor daily, cooling and cationic polymer for centrifuges	>30	15

The impact of iron and its valence state, the use of trivalent cations, protein and biopolymer concentrations, monovalent cation concentrations among others appears to impact dewaterability in a variety of ways.

3. EXPERIMENTAL METHOD

Bench-scale batch tests were conducted at the Salmon Arm WPCC, to evaluate the effects on polymer use of adding divalent and trivalent cations to the digested biosolids. The bench-scale tests were conducted on samples of the digested biosolids taken from the ATAD reactor. The biosolid samples contained 4.7% solids by dry weight. The polymer was Percol 778 FS25 (0.5% solution representing about 0.25% neat polymer).

Control Sample: Polymer was added in 20mL aliquots to a 200mL sample of digested biosolids. After the addition of each aliquot, the solution was gently mixed by inverting the sample bottle, and then allowed to stand briefly. This procedure was repeated until a visual separation of the solids from solution was observed.

Alum Additions: Three 200mL samples of digested biosolids were mixed with various amounts of alum solution (1.5mL, 3mL, and 4.5mL). The alum solution contained 9% aluminum. Polymer additions were then applied as described for the control sample, and the total polymer dose required to achieve solids separation for each sample was recorded. This test was repeated a second time with the addition of alum solution being 4mL, 5mL and 6mL.

Ferrous Iron Additions: The procedure described for alum was repeated using waste pickle liquor containing 12.6% ferrous iron (free acid content 0.14%, specific gravity 1.33). In the first test, 7.5mL of pickle liquor were added to a 200mL sample of biosolids. The test was then repeated on two additional biosolids samples with pickle liquor additions of 4mL and 5mL.

Two full-scale centrifuge tests were subsequently undertaken using the pickle liquor. Polymer use without pickle liquor addition was compared to polymer use in combination with various pickle liquor additions. The pickle liquor was added to the digested biosolids in the feed line to the centrifuge. The orthophosphate concentration of the centrate stream was also recorded.

The percent solids of the dewatered cake at Salmon Arm are not routinely recorded. Polymer use is dictated by visual observations of the dewatered cake. Occasional grab samples show that the cake is typically about 35% dry solids by weight. ATAD biosolids concentration was 4.7% dry solids into the centrifuge.

4.0 RESULTS AND DISCUSSION

Table 1 illustrates a desirable benchmark for thermophilic digestion, polymer addition at about 10 to 15 kg/dry tonne, although even the values in Table 1 may in time be improved.

The results of the bench-scale tests are summarized in Table 2. As shown, an increase in the amount of alum solution added resulted in a corresponding decrease in the polymer required to achieve separation. The polymer requirement for the control sample was 100 mL, compared to a polymer requirement of only 20 mL where the alum addition was in the range 4-5 mL. Similarly, pickle liquor additions in the range 4-5 mL reduced the polymer requirement to 25 mL.

The results of the full-scale centrifuge tests are summarized in Table 3. As shown, a pickle liquor dose of 900 mL/min reduced the polymer requirement from 12-17 L/hr to 7.5-8.8 L/hr, a reduction of 25%-55%. Increasing the pickle liquor dose to 1200 reduced the polymer requirement by an additional 25% in Test No. 1. In Test No. 2, increasing the pickle liquor dose to 1400 mL/min resulted in an additional decrease in polymer use of only about 4%.

The results of the full-scale test show that the concentration of orthophosphate (PO_4^{3-}) in the centrate was reduced from 460 mg P/L to less than 100 mg P/L by the addition of pickle liquor. These results are similar to previous operation, when the pickle liquor for phosphorus removal in the return centrate stream was added downstream of the centrifuge.

TABLE 2 Polymer Additions to Effect Clear Separation of Solids

Test No 1		
Polymer, mL	Alum, mL	Pickle Liquor, mL
100	0	0
70	1.5	0
50	3	0
30	4.5	0
20	5	0
15	0	7.5
Test No 2		
Polymer, mL	Alum, mL	Pickle Liquor, mL
130	0	0
20	4	0
20	5	0
20	6	0
25	0	4
25	0	5

TABLE 3 Full Scale Centrifuge Tests

Biosolids Feed (L/s)	Polymer Feed (L/hr)	Pickle Liquor Feed, (mL/ min)	Centrate pH	Centrate PO_4^{3-} (mg P/L)
Test 1				
1	11.9	0	5.6	460
1	6.1	1200	4.6	97
1	8.8	900	4.8	89.5
Test 2				
1	17	0	5.4	460
1	6.8	1400	4.6	N/A
1.2	7.5	900	5.2	100

Chemical costs and use for the Salmon Arm facility are given in Table 4. The addition of the pickle liquor has provided a significant improvement to the overall chemical costs by significantly reducing the polymer use. The importance of the ferrous divalent cation in either chemical or physiological changes in the biomass is not known. Nor is the affect of the monovalent cations such as ammonia. This study has not proceeded sufficiently far to determine why the improvements have occurred.

TABLE 4 Chemical Cost and Use

Bio-solids	Polymer		
t/d	kg/d	kg/dt	$/dt
4.0	132.6	33.4	$439.61
4.0	89.76	22.6	$297.58
4.0	89.76	22.6	$297.58
4.0	173.4	43.6	$574.88
4.0	69.36	17.5	$229.95
4.8	76.5	16.0	$211.35

Bio-solids	Ferrous Iron			TOTAL
t/d	kg/d	kg/dt	$/dt	$/dt
4.0	0.0	0.0	$0.00	$439.61
4.0	289.8	72.9	$21.74	$319.32
4.0	217.3	54.7	$16.30	$313.89
4.0	0.0	0.0	$0.00	$574.88
4.0	338.1	85.1	$25.36	$255.31
4.8	217.3	45.6	$13.59	$224.94

5. CONCLUSION

By observation, the Salmon Arm WPCC achieves a high solids cake percentage. Limited test data have shown dry cake concentrations by weight of 30% to 40%, but the cost of chemical additions as polymer has made the dewatering problematic.

The addition of pickle liquor to the ATAD biosolids prior to centrifuge dewatering has significantly reduced polymer use. The polymer was reduced by one-half and the overall chemical costs where reduced by up to one-half.

It is not known if the divalent cations assist chemically or physiologically in the dewatering improvement. This requires further study. The low cost of the pickle liquor provides a cost effective improvement in dewatering.

The addition of pickle liquor prior to centrifuge dewatering reduced ortho-phosphate concentrations in the centrate return stream by about 75%.

More study is needed to determine solutions to improving dewaterabilty. The science may be currently lacking sufficient understanding to make improvements based on theory. Further empirical experimentation is planned at the Salmon Arm facility.

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