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Jacobs Journal of Environmental Sciences

Research Article

Application of Geotextile Bag Filters in Flow-Through Aquaculture Systems: Solid Waste Management and Water Quality Implication

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Received: 01-31-2015

Accepted: 02-07-2015

Published: 03-24-2015

Abstract

Solids management plays an important role in the optimal aquacultural production and water quality improvement. The geotextile bag filters (GBFs) were used to dewater biosolids from flow-through aquacultural raceways in this study. Jar tests and geotextile cone tests were conducted to determine the polymer flocculant and its optimum dose for GBF application. In the meanwhile, the effect of GBFs on soluble nutrients (N&P) and BOD_5 was also evaluated. The solids content in the raw sludge generated from the flow-through aquacultural raceways in this study was highly variable ranging from 234 to 4290 mg/L (or 0.02 to 0.43% solids). GBFs was very effective in capturing the solids in the aquacultural sludge from flow-through raceways and the addition of Hyperfloc 626 polymer improved the solids removal by GBFs from 87.1±6.9% to 97.3±1.9%. Geotextile bags also effectively removed BOD_5 from the aquacultural sludge and enhanced removal (83.9±2.2%) was observed with polymer addition. On the other hand, the concentrations of soluble nutrient species (N and P) in the geotextile bag filtrate were higher than those in the raw sludge as a result of the decomposition of the particulate organic matter in the geotextile bags.

Keywords: Geotextile bag filter; aquacultural sludge; solids removal; flow-through raceway; dewatering

Introduction

Removal of solids from aquacultural systems is important in maintaining optimum production, preventing disease outbreaks, improving water quality, and minimizing the environmental impact of aquaculture industry [1]. Biosolids from fish farming operations consist of uneaten feed, fish feces, and biological flocs, and the amount of biosoilds can account for up to 30% of the feed [2,3]. For economic reasons, most aquacultural operations choose relatively low-tech options to remove solids from the effluents, including microscreen drum filters and sedimentation in small quiescent zones, large settling ponds, or constructed wetlands [4-9]. In general, the sludges generated from solids removal are very dilute (low solids content) and consist mostly of small particles which are difficult to dewater [10-13]. Placement of dilute sludge in storage lagoons or ponds is problematic because leaching of contaminants (such as TP, TKN, and BOD) is a great concern and the supernatant needs further treatment prior to discharge to avoid significant water quality impact [14-16]. Meanwhile, disposal of high volumes of dilute liquid waste is expensive due to high hauling costs required either for land application or other off-site disposal [17]. Consequently, effective sludge dewatering to reduce final volume is desired to mitigate water quality impact and minimize the waste handling and final disposal costs.

A variety of sludge treatment technologies have been applied to dewater aquacultural sludge with the aim for sludge volume reduction, and each has its own specific advantages and disadvantages, as well summarized by Sharrer et al [10,18]. Among these options, gravity thickening settlers, inclined belt filters, and geotextile filters are very promising and receive significant attention [10,13,19,20]. A geotextile is a woven permeable fabric of high strength polymer compounds and has been used to remove solids from highway runoff [21] and construction site erosion control [22]. Woven tubes of geotextile fashioned into bags, called geotextile bag filters (GBFs), can be used to effectively dewater various waste sludges, such as municipal sewage sludge [23]. lagoon sludge of animal manure [24, 25] and tailing and minewater sludges [26]. In particular, GBFs can be an effective method for the dewatering of aquacultural sludges [10,18,27]. Sharrer et al. [10] evaluated the use of GBFs to dewater the microscreen backwash from intensive recirculating systems and the effect of chemical coagulation and flocculation aids on sludge dewatering. They found GBFs with chemical aids were effective in capturing suspended solids (>95%) and achieving filter cakes with high solids contents (~20%), However, GBFs were not effective in containing the release of COD, $cBOD_5$, TN, and TP. Sharrer et al. [18] further compared the performance of GBFs with that of gravity thickening settlers and inclined belt filters and found that GBFs were most effective in sludge volume reduction while they were expensive to operate due to the high cost of filter bag replacement. One disadvantage of GBFs is the need for final disposal of the geotextile after the volumetric capacity of the filters are exhausted and the bags are destroyed [27]. To address the GBF bag disposal and high cost of bag replacement [27], evaluated dewatering of the sludge from a commercial biofloc system of tilapia rearing using burlap bag filters. Burlap is a renewable and biodegradable textile which can be woven into GBF type bags for the dewatering of sludges. It was found that there was no difference in solids removal efficiency (~81%) between burlap bags and GBFs, and sludge dewatering with burlap bags resulted in significant cost savings [27]. However, the quick degradation of multiple fillings and weak mechanical strength were the disadvantages of burlap bags [27].

It is worth noting that all GBFs in the aforementioned studies were used to dewater sludges from recirculating aquacultural systems. Little research was found in the literature on the use of GBFs in flow-through raceway aquacultural systems. Due to the inherently different design from the recirculating systems, the characteristics of biosolids are different in the flow-through raceways, where the solids are less frequently removed and are often more dilute[11,28]. Given the promising dewatering performance of GBFs in treating recirculating aquacultural sludges, the objective of this study was to determine the efficacy of GBFs in removing solids generated from a flow-through fish rearing operation. In addition, previous studies indicated coagulants and flocculants aided in the dewatering of aquacultural sludges [10,27,29]. Therefore, the effectiveness of chemical aids was also studied, and the nutrient removal and reduction in BOD_5 from solid wastes were evaluated.

Materials and Methods

Site description

This study was conducted in the aquacultural research facility of Reymann Memorial Farm, Wardensville, WV, where fish waste was generated and used for the GBF dewatering experiments (Fig. 1). The type and size of fish reared in the facility varied from year to year due to the nature of the research and demonstration projects. During the period of this study, the facility reared rainbow (Oncorhynchus mykiss) and brook (Salvelinus fontinalis) trout with a capacity of 3629 kg (8000 lb). The water source for the raceways is from an artesian spring with a flow of approximately 1514 L/min (400 gal/min). There are 8 raceways, positioned such that there were 2 series of 4 raceways on one side. On each side, water flows serially from one raceway into the next. Spring water flows by gravity into a headbox and is aerated with two fine bubble diffusers at the head of each raceway to increase the concentration of dissolved oxygen because the ten-inch waterfall created by the elevation difference between raceways is not sufficient in replenishing dissolved oxygen concentrations (Fig.1). Splashboards are also used between each raceway to aid in aeration.

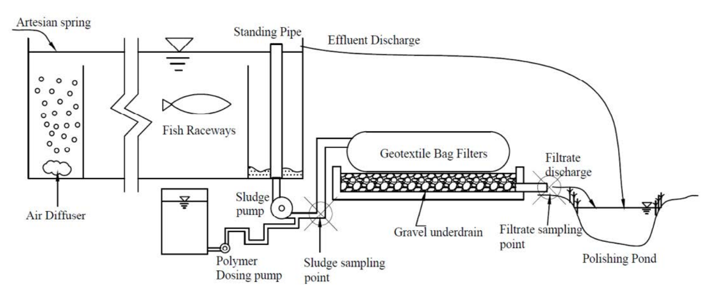

Figure 1. Schematic of fish raceways and geotextile bag filter testing apparatus at Reymann Memorial Farm, Wardensville, WV.

Flocculant selection

A total of eleven commercial polymers with different molecular weights and different polymer types were acquired from two suppliers for initial screening. All of them were cationic because a previous polymer flocculation study indicated cationic polymers had better overall performance in treating sludge from recirculating aquacultural systems than their anionic counterparts [29].From initial screening results from jar tests (data not reported), four polymers were identified for further study because they had superior performance in treating the flow-through raceway sludge. Listed in Table 1 is the summary information of the four polymers including their trade name, molecular weight, polymer type, charge status, viscosity and pH, provided by their suppliers.

Table 1. Summary of polymers and their properties

Trade Name	Molecular Weight	Type	Charge	Viscosity (cps)	pH
Hyperfloc 625	medium	polyDADMAC	Cationic	200 - 600	5.0 - 7.0
Hyperfloc 626	high	polyDADMAC	Cationic	700 - 1000	5.0 - 7.0
Praestol 187	250,000	polyDADMAC	Cationic	8000 - 13000	5.0 - 8.0
Praestol 189	250,000	Polyamine	Cationic	5000 - 9000	4.0 - 7.0

Jar test

Standard jar tests were conducted to evaluate the performance of polymer flocculants prior to their application in geotextile bag filtration. Prior to a jar test, each polymer was diluted with deionized (DI) water to a 0.5% solution, mixed with a mechanical mixer for ten seconds, and further diluted with DI water to a 0.1% solution mixing with a stir bar, following manufacture's recommended procedures. All solutions were allowed to age for at least one hour before applied and no solution over 24 hours old was used. In a typical jar test, flocculant was added to a 500 ml sample and flash-mixed at 200 rpm for 30 s to thoroughly distribute the flocculants. The sample was then stirred at 40 rpm for 2 min to promote floc formation followed by a 10 min settling period. All mixing was done using a Phipps & Bird six paddle stirrer with illuminated base. Flocculant performance was quantified by measuring the turbidity of the supernatant, where low turbidity indicated better performance. Turbidity was measured with a 2100P turbidimeter (Hach Company, Loveland, CO).

Geotextile cone test

Although jar testing is an effective tool to screen a wide range of coagulants and flocculants, a geotextile cone test can provide a direct indication of how the polymers perform in GBF dewatering. Therefore, geotextile cone tests were performed with the four polymers identified from jar testing. In the cone test, a 15" circle of geotextile material was folded into a cone and clamped to a 5 gallon bucket. The geotextile material was wetted prior to the cone test to eliminate surface tension. Flocculant addition to the sample and mixing were the same as for the jar tests. Instead of allowing the sample to settle, the flocculant/sample mixture was then poured through the geotextile cone. The filtrate was collected and analyzed for total suspended solids and turbidity. Filtration rate (L/hr/cm^2) was calculated from measurements of filtration time of 0.5 L sludge over a surface area of 285 cm^2.

Geotextile evalutation

In the study site, each raceway consisted of a rearing zone followed by a quiescent zone where solids accumulate (Fig. 1). In the center of each quiescent zone was a standpipe drain that transports accumulated wastes from the quiescent zone to a collection sump, where the sludge was pumped to GBFs during the study. Quiescent zones were cleaned once per day, six days per week. Two GBFs, manufactured from GT-500 polyproprolyene fabric (TenCate Geotube, Commerce, GA) with an apparent opening size of 425 μm, were used in this study (Fig. 1). The geotextile bags were 7.6 m (25') long, with a 9.1 m (30') circumference. To facilitate data collection, the geotextile bag was placed on a gravel pad underlain with an EPDM liner that formed an impermeable barrier. The filtrate from the GBFs was collected via a tile drain, which was constructed of gravel and PVC pipe placed over the EPDM liner. The tile drain directed the filtrate to a collection sump and the overflow drained into a polishing pond. To study the effect of polymer addition on GBF dewatering, one geotextile bag was operated with flocculant treatment with the other one as the control. The polymers were dosed into the pumping pipe by a dosing pump. To promote the contact between sludge particles and polymers and subsequent floc formation, series of 90 degree elbows were chosen as the mixing manifold before the sludge entered the GBFs.

Sludge samples were taken from the inlet pipe before the sludge entered the geotextile bag while filtrate samples were taken at the collection sump at the end of the tile drain (Fig.1). Samples were analyzed for total suspended solids (TSS), biological oxygen demand (BOD_5), particle size, and soluble nutrients (ammonia-N (NH_3-N), nitrite-N (NO_2-N), nitrate-N (NO_3-N), phosphate-P (PO_4-P)) in accordance with Standards Methods for the Examination of Water and Wastewater [30]. Samples were held at 4°C until they were analyzed which occurred within 24 hours for all analytes except NO_3-N which was kept frozen until analyzed.

Results and Discussion

Waste characterization

The raw fish waste from the flow-through raceways in this study was highly variable within and between sampling events. Total solids averaged 1627 ± 1168 mg/L with a range of 234 to 4290 mg/L (0.02 to 0.43%). Suspended solids made up the bulk of the total solids averaging 1549 mg/L (0.15%). BOD_5 ranged between 136 and 1974 mg/L with an average of 589 mg/L. Mean particle size was 259 µm with a range of 57 to 522 µm. Ammonia concentrations ranged from 0.10 to 6.50 mg/L with an average of 1.85 mg/L, nitrite concentrations ranged from 4 to 45 µg/L with an average of 14 µg/L, nitrate concentrations ranged from below detection to 0.56 mg/L with an average of 0.19 mg/L and phosphate concentrations ranged from 0.14 to 12.77 mg/L with an average of 3.90 mg/L.

There was a high degree of variability in waste characteristics due in part to the cleaning process. As the standpipe is removed from the quiescent zone, solids were transported to the pump creating denser sludge. Sludge density decreased as the quiescent zone was cleaned and was lowest during the intervals between quiescent zones. Creating additional variability in waste characteristics was inconsistency in the number of days between cleaning of the quiescent zones. A third factor creating variability in waste characteristics was harvesting activities which reduced biomass and therefore the amount of feed applied and subsequent waste generation.

Jar tests

Presented in Fig. 2 are the results of four polymer flocculants in removing turbidity from jar tests. It is evident that addition of polymer flocculants improved the sludge settling as indicated from the turbidity removal data after 10 min settling (Fig. 2). All four polymers were effective to remove > 80% turbidity at dosages of 10 mg/L or higher. Turbidity removal of >86% was achieved at polymer dosage of 20 mg/L. However, no significant increase in turbidity removal was observed when polymer dosage was above 20 mg/L. Therefore, polymer dosage above 20 mg/L should be avoided to save chemical cost and prevent overdosing.

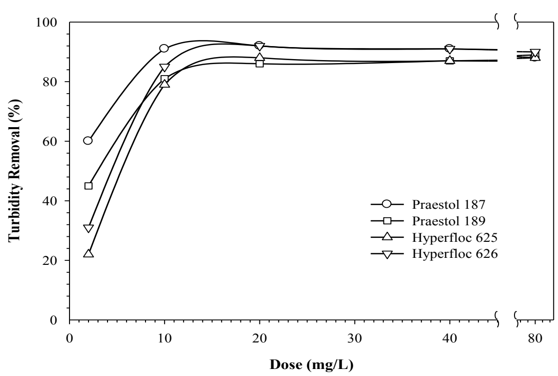

Figure 2. Percent removal of turbidity for polymer flocculants with different dosages in jar tests

Overall, the polymers Praestol 187 and Hyperfloc 626, both of which are high molecular-weight, cationic polyDADMAC compounds, had better performance than the other two polymers. Polymers act through charge neutralization thus reducing the van der Waals forces which promotes colloidal aggregation, and through interparticle bridging where the polymer becomes attached to adsorption sites on the particles [31]. Bridging occurs when particles become attached along the length of the polymer chain creating larger particles that can be removed via sedimentation [31].

Geotextile cone tests

The results of geotextile cone tests for the four polymers identified from jar tests are presented in Table 2. It is to note that only the performance of each polymer at its best dosage is presented. The content of total suspended solids in the raw sludge is 3,495 mg/L and the cone test without addition of any polymer was used as a control. It is evident that geotextile was effective in removing suspended solids (>94% removal) even without any polymer treatment of the aquacultural sludge (Table 2). Sludge treatment with all four polymers increased the solids removal to ~99%. In the meanwhile, the polymer treatment significantly reduced the filtrate turbidity from 261 NTU to less than 44NTU, compared with the control, indicating effective agglomeration of small particles by polymers. It is worth mentioning the conditions for geotextile cone tests are quite different from geotextile bag filtration operations, where the pore size or size distribution of the packed (compressed) sludge dictates the sizes of the particles in the filtrate. In the geotextile cone tests, initial sludge layers were thin and were not packed or compressed. On the other hand, sludge treatment with polymers significantly improved the filtration rate (Table 2), indicating polymer treatment improved the permeability of sludge layers by flocculation [32]. Improved filterability could be very beneficial in full-scale GBF operations.

Table 2. Filtrate characteristics for four polymers in geotextile cone tests*.

Polymer (Dose in mg/L)	Total Suspended Solids (mg/L)	(%removal)	Turbidity (NTU)	Filtration Rate ($L/hr/cm^2$)
Praestol 187 (20)	11	99.7	13	0.67
Praestol 189 (80)	33	99.1	31	0.50
Hyperfloc 625 (40)	44	98.7	41	0.58
Hyperfloc 626 (20)	39	98.9	30	0.67
Control	188	94.6	261	0.38

**the total suspended solids in the raw sludge is 3,495 mg/L*

Overall, Praestol 187 and Hyperfloc 626 were most effective in removing solids and turbidity and improving the filterability from the geotextile cone tests, which is consistent with the results of aforementioned jar tests. In the meanwhile, both polymers were effective at relatively low concentrations (20 mg/L), as opposed to 40-80 mg/L for Praestol 189 and Hyperfloc 625. However, there were substantial differences in cost between the Hyperfloc 626 (~$0.65 per pound (454 g) and Praestol 187 (~$1.20 per pound (454 g)), based on initial cost estimates provided by polymer suppliers. Consequently, Hyperfloc 626 at a dosge of 20 mg/L was chosen for the geotextile bag filtration experiments, based on cost and effectiveness of the polymers from the jar and cone tests.

Geotextile evaluation

Presented in Table 3 are the total suspended solids, BOD_5, and mean particle size in the raw fish sludge and the GBF filtrate during the study period. Clearly, GBFs were very effective in capturing the solids in the aquacultural sludge from flow-through raceways with and without Hyperfloc 626 treatment (Table 3). The solids capture rate of GBF operation with polymer treatment (97.3±1.9%) is significantly higher than that without polymer treatment (87.1±6.9%) (t-test, P=0.029), and the GBF performance with polymer treatment was more consistent as indicated from the smaller standard deviations. Therefore, addition of Hyperfloc 626 improved the solids removal by GBFs. The solids capture rate of GBFs with polymer treatment was consistent with that of a previous GBF study to dewater sludge from recirculating aquacultural systems [10]. where a flocculant (Hychem CE 1950 polymer) combined with coagulants (alum, ferric chloride, or lime) was used and a solids removal of ~95% was achieved. Prior to the GBF experiment, it was anticipated that suspended solids retention by the bags would be initially lower as pore spaces between fibers would be greater, and the solids capture rate would improve as the pores were clogged and initial sludge layer were formed. However, the improvement in solids capture with time apparently did not occur based on the data of samples collected in different months during the duration of this study (Table 3). Suspended solids retention was relatively consistent during the study period.

Table 3. Performance of GBF operation in treating flow-through raceway sludge with and without flocculant: suspended solids, BOD_5, and mean particle size.

Months[1]	GBF with flocculant Raw sludge	Filtrate	% Capture	Months[1]	GBF without flocculant Raw sludge	Filtrate	% Capture
Total suspended solids (mg/L)							
1	1077 ± 562	15 ± 6	98.6	2	2182 ± 1952	275 ± 7	87.4
3	1115 ± 420	17 ± 4	98.5	4	1675 ± 1209	381 ± 66	77.3
6	699 ± 478	38 ± 5	94.6	8	479 ± 227	47 ± 12	90.2
9	3888 ± 1571	103 ± 20	97.4	11	785 ± 506	53 ± 7	93.3
BOD_5 (mg/L)							
1	547 ± 219	70 ± 15	87.0	2	683 ± 600	214 ± 4	68.7
3	341 ± 65	55 ± 9	83.9	4	833 ± 539	664 ± 98	20.3
6	355 ± 52	64 ± 1	82.0	8	256 ± 144	392 ± 22	-53.2
9	880 ± 409	151 ± 38	82.8	11	1108 ± 756	150 ± 11	86.42
Mean particle size (µm)							
1	373 ± 2	73 ± 20		2	152 ± 57	41 ± 2	
3[2]				4[3]	82	15	
6[2]				8	288 ± 73	44 ± 6	
9	354 ± 56	95 ± 21		11	274 ± 15	100 ± 25	

[1]Months from the start of GBF operation; [2]no data due to instrument malfunction; [3]only one sample run due to instrument malfunction.

Geotextile bags also effectively removed BOD_5 from the aquacultural waste streatm (Table 5). The BOD_5 removal efficiency was improved significantly to 83.9±2.2% for the GBF with polymer addition (Table 3), largely due to the improved solids capture as most of the BOD_5 in the raw sludge was from the suspended solids. The BOD_5 removal with polymer treatment of this study was much higher than the previous study using GBF to dewater sludge from recirculating systems [10] For the GBF without polymer treatment, the BOD_5 in the filtrate was higher (from 150 to 664 mg/L) and BOD levels higher than the raw sludge were also observed (Table 3), which was likely due to the anaerobic conditions in the geotextile bags which promoted the production of readily biodegradable organic carbon as measured by BOD_5 test [10]. As indicated from the mean particle sizes in the raw sludge and in the filtrate, geotextile bags were effective in intercepting large particles and the particles in the filtrate were much smaller than in the raw sludge (Table 3).

Presented in Table 4 are soluble nutrients (i.e. NH_3-N, NO_2-N, NO_3-N, and PO_4-P) in the raw fish sludge and the GBF filtrate during the study period. NH_3-N concentration ranged from 0.37 to 4.74 mg/L in the raw sludge while its concentration in the GBF filtrate varied from 4.65 to 58.50 mg/L. NO_2-N concentration in the raw sludge ranged from 4.43 to 21.76 µg/L while its concentration in the GBF filtrate varied from 10.87 to 330.61 µg/L. NO_3-N concentration in the raw sludge ranged from 0.05 to 0.20 mg/L while its concentration in the GBF filtrate ranged from below detection to 5.98 mg/L. Compared with the study on the recirculating aquacultural systems [10]. the concentrations of NO_2-N and NO_3-N in the raw sludge and in the GBF filtrate in the flow-through raceways were significantly lower. The PO_4-P concentration in the raw sludge ranged from 0.46 to 9.14 mg/L with GBF filtrate concentration in the range of 2.12 to 18.76 mg/L.

Table 4. Performance of GBF operation in treating flow-through raceway sludge with and without flocculant: soluble nutrients (NH_3-N, NO_2-N, NO_3-N, and PO_4-P).

Months[1]	GBF with flocculant Raw sludge	Filtrate	ΔC	Months[1]	GBF without flocculant Raw sludge	Filtrate	ΔC
Ammonia-N (mg/L)							
3	4.29 ± 1.46	4.65 ± 0.68	0.36	2	2.11 ± 2.04	5.58 ± 0.53	3.47
6	0.50 ± 0.28	5.73 ± 0.48	5.23	4	2.58 ± 2.68	58.50 ± 14.42	55.92
9	4.74 ± 1.86	11.71± 1.63	6.97	8	0.57 ± 0.46	26.38 ± 0.91	25.81
12	0.37 ± 0.20	17.69 ± 1.98	17.32	11	1.36 ± 0.82	14.62 ± 1.37	13.26
Nitrite-N(µg/L)							
3	4.43 ± 0.00	10.87 ± 0.06	6.44	2	20.93 ± 10.73	54.24 ± 4.82	33.31
6	5.77 ± 0.62	60.23 ± 3.20	54.46	4	14.62 ± 7.24	83.35 ± 27.54	68.73
9	21.76 ± 20.05	330.61 ± 222.11	308.85	8	12.17 ± 0.86	1.48 ± 0.17	-10.69
12	11.03 ± 5.34	153.41 ± 24.94	142.38	11	11.90 ± 1.01	55.45 ± 12.21	44.55
Nitrate-N (mg/L)							
3	0.19 ± 0.09	0.00 ± 0.06	-0.19	2	0.11 ± 0.04	0.13 ± 0.01	0.02
6	0.20 ± 0.16	5.98 ± 2.28	5.78	4	0.19 ± 0.01	0.16 ± 0.04	-0.03
9	0.05 ± 0.09	0.33 ± 0.26	0.28	8	0.14 ± 0.04	0.01 ± 0.01	-0.13
12	0.16 ± 0.07	0.23 ± 0.08	0.07	11	0.14 ± 0.07	0.88 ± 0.48	-0.74
Phosphate-P (mg/L)							
3	9.14 ± 3.67	12.32 ± 2.08	3.18	2	6.38 ± 4.49	5.39 ± 0.23	-0.99
6	1.05 ± 0.49	2.12 ± 1.60	1.07	4	5.05 ± 4.24	9.15 ± 0.74	4.10
9	8.78 ± 4.20	18.76 ± 0.79	9.98	8	0.82 ± 0.41	8.30 ± 0.37	7.48
12	0.46 ± 0.24	18.09 ± 1.91	17.63	11	0.47 ± 0.30	11.99 ± 1.42	11.52

[1]Months from the start of GBF operation

In general, the concentrations of all soluble N and P species in the geotextile bag filtrate were higher than those in the raw sludge, as indicated from the mostly positive concentration changes (Δ C) (Table 4), demonstrating decomposition of the particulate organic matter in the geotextile bag was occurring. Several factors would be expected to affect decomposition rates within the bag. As the bag received more solids over time, more particulate matter would be available to decompose releasing more soluble nutrients. In that case, soluble nutrient concentrations in the effluent should increase with time. On the other hand, seasonal temperature and rainfall fluctuations might also affect decomposition rates within the bag with higher rates expected during warmer weather and lower rates in cold weather. However, it was observed in this study soluble nutrient concentrations in the filtrate were highly variable across the sampling period with no apparent increasing or decreasing pattern. This might be caused by the high variability of raw fish sludge, as discussed in Section 3.1 and the TSS and BOD_5 data in Table 3, which inundated any anticipated trend of nutrient leaching with time and weather conditions.

Moreover, due to the high variability of nutrient data in Table 4, there was no statistically significant difference in GBF's performance in controlling nutrients with or without addition of the polymer flocculant (Hyperfloc 626), although polymer was proved effective in enhancing the capture of solids and BOD_5 by the geotextile bags. Based on the jar and cone tests, the geotextile alone was very effective at retaining particles. Polymer use will increase costs of the geotextile bag operation including the purchase of the polymer and the need for a dosing pump to deliver the polymer. In addition, the polymer must be kept unfrozen in cold regions, which required a protected space and heating to prevent freezing. Due to the added expense as well as the added complexity associated with polymer usage, application of GBFs in aquacultural sludge dewatering from flow-through raceway needs to consider the tradeoff between cost and effectiveness.

Nonetheless, the elevated soluble nutrient concentrations in the filtrate effluents can be a deterrent to the adoption of GBFs to dewater aquacultural sludges from flow-through raceways and meet stringent effluent guidelines [33]. The impacts of N and P pollution are diverse and far-reaching. Not only does excessive N&P discharge affect human health and the environment, but its cascading effect can cost millions of dollars per year, such as the need for advanced treatment for drinking water. In the testing facility of this study, the filtrate from the geotextile bag was discharged into a polishing pond where dilution and biological activity reduce the soluble nutrient concentrations to acceptable limits. An alternative would be the addition of coagulants (such as alum or ferric chloride) which demonstrated excellent removal of orthophosphate from recirculating system effluents in jar tests [34]. However, Sharrar et al. [10] later found these coagulants had only moderate efficacy in removing total N and total P when used in conjunction with a polymer in geotextile filtration to treat recirculating aquacultural sludge. Another option would be the use of the nutrient rich effluent as source water to grow plants in aquaponic systems [35].

Conclusion

The solids content in the raw sludge generated from the flow-through aquacultural raceways in this study was highly variable ranging from 234 to 4290 mg/L (0.02 to 0.43%). Based on the results of jar tests, all four cationic polymers were effective to remove > 80% turbidity at dosages of greater than 20 mg/L and the polymers Praestol 187 and Hyperfloc 626, high molecular-weight cationic polyDADMAC compounds, had overall better performance. Geotextile cone tests demonstrated that geotextile was effective in removing suspended solids from the aquacultural sludge (>94% removal). Sludge treatment with all four polymers increased the solids removal to ~99% and significantly improved the filtration rate, indicating polymer treatment improved the permeability of sludge layers by flocculation. Based on the results of geotexitle bag filtration experiments, GBFs was very effective in capturing the solids in the aquacultural sludge from flow-through raceways and the addition of Hyperfloc 626 improved the solids removal by GBFs from 87.1±6.9% to 97.3±1.9%. Geotextile bags also effectively removed BOD_5 from the aquacultural sludge and enhanced removal (83.9±2.2%) was observed with polymer addition. In general, the concentrations of all nutrient species (soluble N and P species) in the geotextile bag filtrate were higher than those in the raw sludge as a result of the decomposition of the particulate organic matter in the geotextile bags.

Acknowledgements

This work was made possible with the financial support from the United States Department of Agriculture, National Institute of Food and Agriculture. We would like to thank Mr. Tom Vowls for his assistance in this project.

References

1. Martins CIM, Eding EH, Verdegem MCJ, Heinsbroek LTN, Schneider O. New developments in recirculating aquaculture systems in Europe: A perspective on environmental sustainability. Aquacult Eng 2010, 43(3): 83-93.

2. Chen Y-S, Beveridge MCM, Telfer TC. Settling rate characteristics and nutrient content of the faeces of Atlantic salmon, Salmo salar L., and the implications for modelling of solid waste dispersion. Aquac Res 1999, 30(5): 395-398.

3. IDEQ, Idaho Waste Management Guidelines for Aquaculture Operations. Twin Falls, Idaho: Idaho Division of Environmental Quality; 1998.

4. Summerfelt RC, Penne C.R. Solids removal in a recirculating aquaculture system where the majority of flow bypasses the microscreen filter. Aquacult Eng 2005, 33(3): 214-224.

5. Lin YF, Jing SR, Lee DY, Wang TW. Removal of solids and oxygen demand from aquaculture wastewater with a constructed wetland system in the start-up phase, Water Environ Res 2002, 74(2): 136-141.

6. MacMillan R. Economic implications of water quality management for a commercial trout farm. In: Proceedings of the National Workshop for National Livestock, Poultry, and Aquaculture Waste Management. Kansas City, Missouri, 1998, 185-190.

7. Axler RP, Tikkanen C, Henneck J, Schuldt J, McDonald M.E. Characteristics of effluent and sludge from two commercial rainbow trout farms in Minnesota. Prog Fish-Cult 1997, 59(2): 161-172.

8. Henderson JP, Bromage NR. Optimising the removal of suspended solids from aquacultural effluents in settlement lakes. Aquacult Eng 1988, 7(3): 167-181.

9. Mudrak VA. Guidelines for economical commercial fish hatchery wastewater treatment systems. In: LJ. Allen and E.C. Kinney (eds), Proceedings of the Bio-Engineering Symposium for Fish Culture. American Fisheries Society, Fish Culture Section, Bethesda; 1981, 174-182.

10. Sharrer MJ, Rishel K, Summerfelt S. Evaluation of geotextile filtration applying coagulant and flocculant amendments for aquaculture biosolids dewatering and phosphorus removal. Aquacult Eng 2009, 40(1): 1–10.

11. Maillard VM, Boardman GD, Nyland JE, Kuhn, DD. Water quality and sludge characterization at raceway-system trout farms. Aquacult Eng 2005, 33(4) 271-284.

12. True B, Johnson W, Chen S. Reducing phosphorus discharge from flow-through aquaculture I: facility and effluent characterization. Aquacult Eng 2004, 32(1): 129–144.

13. Cripps SJ, Bergheim A. Solids management and removal for intensive land-based aquaculture production systems. Aquacult Eng 2000, 22(1-2): 33–56.

14. Piedecausa MA, Aguado-Giminez F, Garcia-Garcia B, Ballester G, Telfer T. Settling velocity and total ammonia nitrogen leaching from commercial feed and fecal pellets of gilthead seabream (Sparus aurata L. 1758) and seabass (Dicentrarchus labrax L. 1758). Aquacult Res 2009, 40(15): 1703–1714.

15. Brazil BL, Summerfelt ST. Aerobic treatment of gravity thickening tank supernatant. Aquacult Eng 2006, 34: 92–102.

16. Stewart NT, Boardman GD, Helfrich LA. Treatment of rainbow trout (Oncorhynchus mykiss) raceway effluent using baffled sedimentation and artificial substrates. Aquacult Eng 2006, 35(2): 166–178.

17. Summerfelt ST, Vinci BJ. Better management practices for recirculating systems. In: Tucker, CS, Hargreaves, JA. (Eds.), Environmental Best Management Practices for United States Aquaculture. Blackwell Publishing, Ames, Iowa; 2008.

18. Sharrer M, Rishel K, Taylor A, Vinci BJ, Summerfelt ST. The cost and effectiveness of solids thickening technologies for treating backwash and recovering nutrients from intensive aquaculture systems. Bioresource Technol 2010, 101(17): 6630–6641.

19. Sindilariu PD, Brinker A, Reiter R. Waste and particle management in a commercial, partially recirculating trout farm. Aquacult Eng 2009, 41(2): 127–135.

20. Ebeling JM, Welsh CF, Rishel KL. Performance evaluation of the hydrotech belt filter using coagulation/flocculation aids (alum/polymers) for the removal of suspended solids and phosphorus from intensive recirculating aquaculture microscreen backwash effluent. Aquacult Eng 2006, 35(1): 61–77.

21. Barrett ME, Malina JF, Charbeneau RJ. An evaluation of geotextiles for temporary sediment control. Water Environ Res 1998, 70(3): 283-290.

22. Rickson RJ. Controlling sediment at source: an evaluation of erosion control geotextiles. Earth Surf Proc Land 2006, 31(5): 550–560.

23. Fowler J, Bagby R, Trainer E. Dewatering sewage sludge with geotextile tubes. In: Proceedings of the 49th Canadian Geotechnical Conference, St John's, Newfoundland, Canada; 1996.

24. Cantrell KB, Chastain JP, Moore KP. Geotextile filtration performance for lagoon sludges and liquid animal manures dewatering. T ASABE 2008, 51(3): 1067-1076.

25. Muktar S, Lazenby LA, Rahman S. Evaluation of a synthetic tube dewatering system for animal waste pollution control. Appl Eng Agric 2007, 23(5): 669-675.

26. Newman P, Hodgson M, Rosselot E. The disposal of tailings and minewater sludge using geotextile dewatering techniques. Miner Eng 2004, 17(2): 115–121.

27. Danaher JJ, Shultz RC, Rakocy JE. Evaluation of two textiles with or without polymer addition for dewatering effluent from an intensive biofloc production system. J. World Aquacul Soc 2011, 42(1): 66-72.

28. Yeo SE, Binkowski FP, Morris JE. Aquaculture effluents and waste by-products: Characteristics, potential recovery, and beneficial reuse. North Central Regional Aquaculture Center, Ames, Iowa, 2004.

29. Ebeling JM, Rishel KL.Sibrell PL. Screening and evaluation of polymers as flocculation aids for the treatment of aquacultural effluents. Aquacult Eng 2005, 33(4): 235–249.

30. APHA: Standard Methods for the Examination of Water and Wastewater. 20th ed. Washington, DC: American Public Health Association; 1998.

31. Metcalf and Eddy Inc. Wastewater Engineering: Treatment and Reuse, fourth edition. McGraw Hill, New York, NY; 2002.

32. Vanotti MB, Rice JM, Ellison AQ, Hunt PG, Humenik FJ, Baird CL. Solid-liquid separation of swine manure with polymer treatment and sand filtration. T ASAE 2005, 48(4): 1567–1574.

33. EPA, Effluent limitations guidelines and new source performance standards for the concentrated aquatic animal production point source category, Final Rule. 40 CFR Part 451. Washington, DC: U.S. Environmental Protection Agency; 2004.

34. Ebeling JM, Sibrell PL, Ogden SR, Summerfelt ST. Evaluation of chemical coagulation/flocculation aids for the removal of suspended solids and phosphorus from intensive recirculating aquaculture effluent discharge. Aquacult Eng ; 2003, 29(1-2): 23-42.

35. Rakocy JE, Losordo TM, Masser MP. Recirculating aquaculture tank production systems: Aquaponics - integrating fish and plant culture. Southern Region Aquaculture Center Publication No. 454. Texas, USA: Texas A & M University; 2006.