

A preliminary test of the possibility for reclamation of phosphorus from aquaculture sludge

A CtrlAQUA pre-project

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Report

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<p><i>Summary/recommendation:</i></p> <p>The concentrations of dissolved phosphates (PO₄) and total phosphorus was analysed in sludge samples collected from Nofima's RAS facilities. The highest concentration of phosphorus was found in sludge from the swirl separators that are mounted at each tank, and most (approximately 90 %) of the phosphorus was bound to particles.</p> <p>Hias IKS has developed a biological method for reclamation of water dissolved phosphorus (PO₄) from waste water. This method may be applicable for reclaiming phosphorus from aquacultural sludge. A simple test showed that dissolved phosphorus (PO₄) from the water fraction was almost completely removed with Hias' method in sludge samples of 12 ‰ brackish water. However, since only approximately 10 % of the phosphorus in the sludge was dissolved in the water, pretreatment of the sludge to release dissolved PO₄, is necessary for Hias' method to remove phosphorus from aquacultural sludge effectively.</p>	
<p><i>Summary/recommendation in Norwegian:</i></p> <p>Konsentrasjonen av vannløselige fosfater (PO₄) og totalt fosfor ble analysert i prøver av slam fra Nofima sitt RAS-anlegg. Slam fra virvelseparator som er montert på hvert kar hadde høyest konsentrasjon av fosfor, og det meste (om lag 90 %) av fosforet var bundet til partikler.</p> <p>Hias IKS har utviklet en biologisk metode for å gjenvinne vannløselig fosfat (PO₄) fra avløpsvann som kan være aktuell for å gjenvinne fosfor fra slam fra akvakultur. I en enkel test ble det vannløselige fosfattet tilnærmet fullstendig fjernet fra slamprøver med 12 ‰ brakkvann med Hias' metode. Siden bare rundt 10 % av fosforet i slammet var løst i vann, er imidlertid forbehandling av slammet for å frigjøre vannløselig PO₄ nødvendig for at Hias' metode skal kunne gjenvinne fosfor fra slam fra akvakultur på en effektiv måte.</p>	

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1 Aim

The aim of this preproject was to investigate the potential for reclamation of phosphorus from sludge from closed or semi-closed aquaculture with a new, biological method developed by Hias, and briefly evaluate possibility for using the Cambi process for producing biogas from the sludge.

2 Phosphorus

Phosphorus (P), in the form of various phosphates, is an essential element for all living organisms, and is thus present in both agricultural fertilizers and all animal feeds. The P sources currently available, are expected to be drained within a few decades and P is thus a limited resource (Schröder et al., 2009). A large fraction of the P used in human activities originates from land, and is transferred to the sea by means of waste, waste water, sewage, percolating water from agriculture, and from aquaculture. The increasing amount of plant ingredients used in salmon feed has led to an increasing flow of P from land to the sea. Part of the P in the sea will end up in sediments and not being used for biologic production.

Salmon feeds contain approximately 1 % of P. The digestibility of P in salmon feed is moderate and variable, and thus 30-60 % of the P from feed passes through the fish and ends up in the sludge and water. Most of the dissolved P in the fish' intestine is probably absorbed by the fish. The undigested fraction of P in salmon feed is probably mainly bound to phytic acid from plant ingredients and hydroxyapatite from bones in fish meal.

3 Aquacultural sludge

The production in land-based and semi-closed systems in Norwegian aquaculture is increasing, resulting in an increased production of aquacultural sludge from such farming systems. For the fish farmer, the sludge is a waste product that needs to be taken care of in a cost effective way. In a larger perspective, the aquacultural sludge contains energy and nutrients that should be recycled and utilized with technology that requires minimal input of fuel or other resources.

At present, there is no technology to adequately treat the sludge from salmon production, and there are some main issues that needs to be solved:

- Effective filter technology that captures all particles
- Adequate dewatering technology to reduce sludge volume
- Technology for effective utilization of the energy in the sludge
- Technology for reclamation of nutrients, such as phosphorus

3.1 Composition of sludge

The composition of aquacultural sludge is variable and depends on several factors. Land based farms commonly have two filter systems, a primary and a secondary filter, to entrap particles. Measurements of the sludge that is formed show variable dry matter content, probably due to both real variation in the dry matter content, and to challenges in taking representative samples of the sludge. However, measured dry matter content of sludge is often below 10 % (Ytrestøyl et al., 2013). When stripping faeces from salmon (Austreng, 1978), a method commonly used in feeding trials, the dry matter content of the faeces is normally below 15 % and often 10-12 %. Assuming the dry matter content of the excreted faeces is the same, higher dry matter content of faeces from sludge than this can not be achieved with simple dewatering techniques such as passive filtering. Feed has a dry matter content around 95 % and normally high water stability, and thus, feed spill will contribute to increasing the dry matter content of the collected sludge. However, high feed spill is obviously not desirable.

The chemical composition of the dry matter fraction of sludge is also variable (Ytrestøyl et al., 2013), and will depend on factors such as feed composition and amount of feed spill. The apparent digestibility of dry matter of today's commercial salmon feeds is approximately 65-75 % (Hillestad et al., 1999; Oehme et al., 2014), meaning that 25-35 % of the feed is converted to faeces. However, feed and faeces have completely different composition. Salmon feed has a high content of fat and protein, but these are almost completely digested and absorbed by the fish, and the faeces contains larger amounts of undigested carbohydrates and minerals, including P. Thus, feed spill will alter the sludge composition compared to a feeding regime with minimal feed spill.

Faecal particles are fragile structures, which if captured carefully directly at the tank outlet have a pellet-like appearance. However, when exposed to mechanical forces these disintegrate easily and produce small particles, which are challenging to capture. Filters with 350 µm pore size are commonly used in land based salmon farming, meaning that when the filter is clean, dissolved components and particles smaller than 350 µm are not captured. When in use however, particles stick to the filter resulting in smaller (than 350 µm), but unknown pore size.

In flow-through systems, small particles will follow the outlet water, whereas in recirculating systems, these may affect water quality. Due to the pellet structure with high water quality normally found in commercial feeds, feed pellets are probably more efficiently captured on the filters than faeces.

The size distribution of particles in aquacultural sludge is poorly documented and will probably vary, depending on factors such as feed ingredients, feed composition, amount of feed spill and mechanical treatment of the faecal particles.

3.2 Amounts of sludge

Some land-based smolt producers have a rule of thumb that they produce 0.6 % sludge with 18 % dry matter per kg feed used (pers. comm.). In accordance with this, one specific land based smolt producer reports to produce 640 tons of sludge (dry matter content not given) per 1,000 tons of smolt produced (pers. comm.).

If assuming 75 % total apparent digestibility of the feed of close to 100 % dry matter (i.e. roughly 25 % undigested material), and a feed conversion ratio of 0.8 (meaning 0.8 kg feed is used per 1 kg fish produced), a production of 1,000 tons of fish would require 800 tons of feed and produce 200 tons of faeces as dry matter. Theoretically thus, assuming 10 % dry matter in the sludge, this fish production would produce 2,000 tons of sludge only from faeces. A certain amount of feed spill is also present in the sludge, and a modest assumption of 5 % overfeeding results in 40 tons of feed spill in the example above. Again assuming 10 % dry matter of the sludge, only this feed spill would produce additional 400 tons of sludge, in total 2,400 tons of sludge, compared to the 640 tons at a real farm. However, this assumes all faeces and feed spill to be present as particles, whereas there may be an unknown fraction that dissolves in the water, and the theoretical estimate may thus overestimate the amount of sludge formed. However, based on the theoretically expected amounts of sludge to be produced, it seems that today's technology for collecting particles from land based salmon farms have a limited efficiency.

3.3 Current treatment of sludge

Currently, sludge from land-based aquaculture is commonly transported to central plants where waste is used for biogas production (see description of the Cambi process below). The transport implies transport of large amounts of water, and effective dewatering is necessary to reduce cost and energy used for transport.

Some sludge is spread on agricultural fields nearby the fish farming site. Spreading on agricultural fields is an attractive idea since distances may be short and nutrients such as P can be utilized for new food production. However, there are very limited periods of time when fertilizers can be spread. Furthermore, the sludge must be within limits for mineral concentrations allowed in fertilizers, the nutrients may not be readily available for plants, and strong odor may be a problem.

In some cases, sludge is released to the sea. In some locations, this may not cause environmental problems. However, unless integrated multitrophic aquaculture (IMTA) is applied at the site, releasing the sludge into the sea causes loss of valuable nutrients, and increases the flow of e.g. phosphorus from land to sea.

Also, the sludge may go to the sewage system. Using the sewage system for aquacultural sludge increases the load on the sewage treatment, and valuable nutrients and energy are lost unless the local sewage systems utilizes these.

Aquaponics is an option for using waste nutrients from aquaculture. This may be most relevant for the fraction of nutrients that is dissolved in water. Aquaponics requires extra area, investments, knowledge and man-power, and the light and temperature conditions in Norway limits the effectivity of such production.

4 Cambi's technology for sludge treatment – biogas production

The energy content of sludge is variable (Ytrestøyl et al., 2013) and will depend on the content of dry matter and feed spill in the sludge. The energy from the sludge may be used for production of biogas, and several research projects are or have been investigating this option. Biogas production, like aquaponics, requires area, investments, knowledge and man-power, and besides, it does not reduce the volume of sludge significantly. Thus, biogas from aquacultural sludge may be most effectively produced at central plants. This require transport of sludge, which again calls for effective dewatering techniques.

Cambi (located in Asker, Norway) has technology that is used at several plants in Norway and other countries for sludge treatment from sewerage. Cambi's technology includes biogas production. In the Cambi process, the sludge is heated at high pressure, and releasing the pressure rapidly causes particles to expand and 'explode', becoming easier digestible for microorganisms that produce biogas. The remaining sludge is dewatered and transformed to biosolids, which can be used as agricultural fertilizer. The Cambi process is not economically sustainable for single fish farmers (Harald Kleiven, Cambi, pers. comm.), and central plants are required for this process.

5 Removal of dissolved phosphorus – Hias IKS

Hias IKS (Hamar, Norway) is responsible for refuse collection, water and sewerage in Hamar, Løten, Ringsaker and Stange municipalities in Hedemark in Norway. Hias has developed technology for a biological method for biological P removal from the water fraction of waste water. The method allows cellular bacterial incorporation of PO_4 , which is the dissolved fraction of P. Hias has applied for a patent for this process. Dissolved P is removed from water by means of bacteria which are capable of absorbing up to 30 % of their biomass as P. This technology is currently in use in Hias' experimental pilot plant at Ottestad for the second year.

5.1 Dissolved and particle bound phosphorus in sludge

The amount of dissolved and total P was analysed in samples collected at Nofima's RAS facilities. The following samples were collected: 1) sludge from one of the swirl separators that are fitted to each tank (primary filter), 2) sludge from the Salsnes filter (secondary filter) and 3) water which enter the biological filter, after Salsnes filter (Fig. 1). At the current time, only 12 ‰ brackish water was used in the system and consequently, the collected samples was from 12 ‰ brackish water.

The samples were frozen and stored at $-20\text{ }^\circ\text{C}$, and thawed over night before analysis.

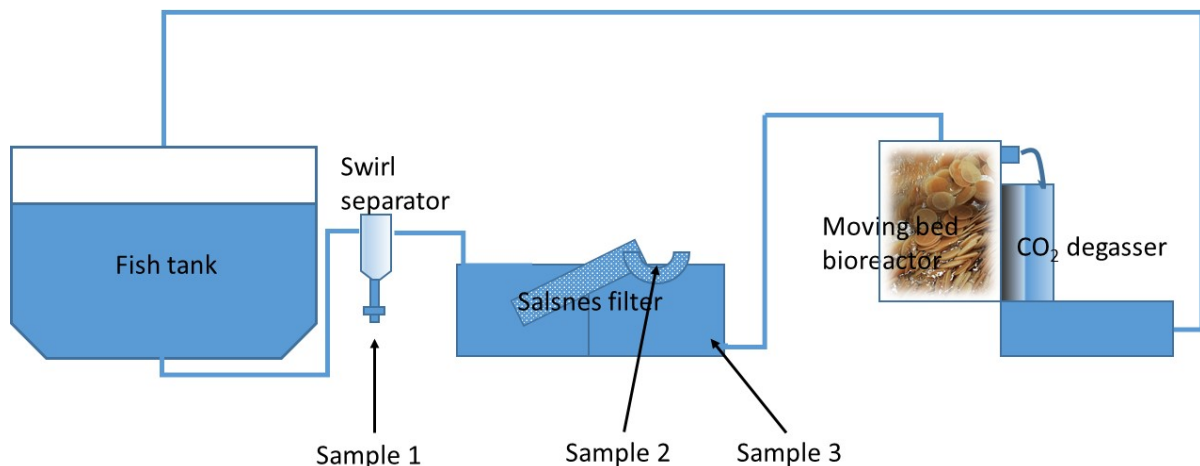


Figure 1 A simple overview of the RAS. Samples were collected at 1) the outlet of the swirl separator, 2) at the Salsnes filter, and 3) the water which enter the biological filter.

The amount of total and dissolved P was measured in the three samples (Table 1). Dissolved P was measured photometrically as PO_4 after filtering at $1.2\text{ }\mu\text{m}$ and reaction with sulphuric acid and a colouring agent. Taking representative samples of sludge is challenging, particularly at the Salsnes filter. Furthermore, prior to analysis, dilution of the sludge samples was required. Thus, the figures in Table 1 represent approximate, and not absolute, values.

The highest concentration of both dissolved and total P was found in sludge from the swirl separator. In the water that enters the biofilter, very little P was present. (Table 1). The concentration of PO_4 was 506, 105 and 0.53 mg/L PO_4 in samples from sampling point 1, 2, and 3, respectively (Table 1). Given as P instead of PO_4 , this corresponds to 165, 34 and 0.17 mg/L , respectively, in the three samples. Thus,

in the sludge from the swirl separator, where the highest P-concentration was found, the dissolved PO₄ constitutes approximately 10 % of the total P.

Table 1 Chemical analysis of sludge (analyzed at Hias' laboratory).

Sample	Dissolved PO ₄ (mg PO ₄ /L)	Total P (mg P/L)	NO ₂ (mg NO ₂ -N/L)	NO ₃ (mg NO ₃ -N/L)	NH ₄ (mgNH ₄ - N/L)	sCOD (degradable organic matter, mg/L)
1)Sludge from swirl separator	506	1700			380	
2)Sludge from Salsnes filter	105	1350			120	
3)Water before biofilter	0.53	0.52	0.02	3	0.5	55

5.2 Using Hias' method for reclamation of P from aquacultural sludge

A simple test was run to test if the method could function in the water fraction of aquacultural sludge of 12 ‰ brackish water. The biological method for reclamation of PO₄ was tested on a solution prepared from 5 % of water filtered from sludge from the Salsnes filter (sample 2) and 95 % of water before biofilter (sample 3). Within six hours, 98.5 of the PO₄ was reclaimed. Also, NH₄ was reduced by 75 %. Thus, Hias' method for reclamation of PO₄ seemed to function in the water fraction of aquacultural sludge with 12 ‰ brackish water.

The highest concentration of P was found in sludge from the swirl separator, where also presumably most of the sludge is collected. Consequently, any effort on reclaiming P in a RAS where such swirl separators are mounted, should be done on the sludge collected with these. However, 90 % of the P was bound to particles, and Hias' method only removes the 10 % of P that is dissolved. Thus, for this method to be an effective way of reclaiming P from the sludge, pretreatment such as anaerobic digestion, that releases dissolved PO₄, will be required.

6 Conclusion

The highest concentration of P was found in sludge from the swirl separators. Phosphorus in the sludge was predominantly bound to particles (90 %).

For uptake of dissolved phosphorus, Hias' method functioned well on a sample with 12 ‰ brackish water. However, approximately 90 % of the P was bound to particles and thus, actions that release water dissolved PO_4 from particles are necessary for this method to be efficient for reclamation of P from aquacultural sludge.

Using the Cambi process for biogas production from sludge will require central plants.

7 Acknowledgement

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