WILL DRIED SLUDGE FROM FISH FARMING BECOME A CONTRIBUTOR OR COMPETITOR TO THE UTILIZATION OF MUNICIPAL SLUDGE?

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Abstract

Production of Nordic Salmon has become an industry with continuous growth and the aim to exceed oil and gas in terms of Norwegian export value in 2030.

This rapid growth in a traditional farm based production has required need for regulations and technical solutions in order to handle both waste water treatment and sludge handling.

Scanship has successfully transferred technical solutions from waste handling at cruise ships to the land based fish farming. The solution is dewatering and drying of sludge to a stable bi-product. This will reduce transport cost and make it possible to store the product over longer periods in the remote fjord areas of the Norwegian west coast.

As part of the solution Scanship has established collaboration with end users for the reuse of sludge as a bi-product. The different areas where the bi-product has become a value are within fertilizer, biogas and incineration.

The nutritious rich product with high energy content makes it a high-quality biproduct.

Keywords

Aquaculture, circular economy, drying technology, fish farming, nutrient recovery, phosphorus recovery, sludge, waste handling.

Introduction

Fish production in Norway has changed from being family owned production facilities to be larger and more industrialized facilities. The industrialization has resulted in fish production controlled by larger companies like Marine Harvest, Lerøy and Salmar etc. in addition to the individual producers. The first part of the fish production starts in land based hatcheries where fish traditionally has been grown from eggs to smolt at a size of 90-120 gram (Blytt et al 2011), before it goes to open sea cages. The challenge with sea lice and expensive license for growing fish along the Norwegian coast has been some of the drivers for larger size of fish that are produced in the fish hatcheries to 250 gram and even larger with some plants aiming for fish at 1 kg (Hægh 2017) and (Ilaks. 2017[a]). The size of plants has changed from production facilities of 1000-2000 ton biomass per year to 5000-10.000 ton biomass per year for new plants which can be seen on the license for new facilities that has been granted the last 2 - 3 years. It has been predicted that the Norwegian aquaculture production will increase 5 times from the level of 2010 to 2050 (DKNVS and NTVA. 2012), giving the challenge of growth for this industry.

The type of technology has changed from type of “Flow Through” plants where water simply runs through the fish tanks, to plants including recycling of water with internal water treatment in order to reduce the water consumption, commonly known as RAS-technology (Recirculation Aquaculture Systems). The RAS plants typically consist of separation step for particles, biological treatment of soluble organic components, followed by nitrification step. After biological treatment the water is aerated for removal of CO_2 and N_2, before the water is oxygenized and returned to fish tanks This treatment produces obviously a large amount of sludge that need to be handled outside of the plant.

The sludge treatment at fish farms has traditionally been considered as separation technology in order to transport sludge to common facilities. But with increasing size of fish plants the need for logistic and reuse of sludge has become more and more important. Drying of fish sludge is therefore considered as a perfect solution for this type of sludge handling

The increase in fish production the larger capacity of plants and the larger size of fishes produced on land all contribute to the challenge of reducing the pollution from this growing industry. This has changed the legislation and discharge permits for the industry and caught the attention from the consumers with the question what happens with the valuable components in the by product from fish production.

The fish industry has become a sludge producer and handling sludge from fish industry has become an interesting marked both in terms of technology and recycling of this sludge.

Sludge amount and nutrient value

The amount of produced sludge from fish industry is not as well defined as we know from municipal waste water treatment plants, but it has been estimated that total sludge production can be calculated as 0,15-0,2 kgDM/kg Feed pellets (Blytt et al 2011). Total feed to the fish industry (salmon and trout) was 1.642.377 tonnes of feed in 2016 (Fiskeridirektoratet[a]) and the amount of sludge can then be predicted to about 250.000 tonnes of DM /year. For the same year the amount of feed used in hatcheries was only a few procentages of this total amount. But the planning of larger plants and larger fish produced on land will consequentially increase the amount of fish sludge from land based fish production.

A new research has indicated that 27.000 tonnes nitrogen (N) per year and 9.000 tonnes phosphorus (P) per year are lost to the sea as feed loss and faeces (fish sludge) during fish farming each year (Hamilton et al. 2015) and 7.000 tonnes of the P is estimated to be particular P (Reitan, K. I., 2017). Same paper (Hamilton et al. 2015) state that Norway imports 30.000 tonnes of phosphorus in total and 9.000 tonnes are used for fish feed, meaning that the secondary P source from aquaculture are comparable to the imported amount of P for fish feed. With 5 times increase in fish production in 2050 (3 times increase in 2030) the export of secondary P source will be essential for the overall world P balance. Another research suggest that dried fish sludge will be able to replace 50-80% of nitrogen in mineral fertiliser, with the potential of Norway to be exporter of recycled fertiliser (Brod et al 2017)

This is further supported by estimated potential reuse of P from agriculture in Norway representing a yearly value of 8,7 – 11,4 tonnes of P with an estimated demand of 5,8 tonnes of plant available P/year (Hamilton et al 2017) showing the need for exporting recovered P from aquaculture.

Scanship and the Technology

Scanship AS is a company which supplies waste water treatment and waste handling to cruise ships, being the supplier of this technology to more than every second cruise ship leaving the ship yards.

- Cruise market leading solution for purifying black and grey water (AWP, *Advanced Water Purification*) including galley water, reject from food waste and reject water from bio-residue treatment

- Efficient recovery of treated water with more than 98,5% recovered as clean effluent and less than 1,5% separated out as bio residue for dewatering and drying

- Scanship's footprint with 85 Scanship AWP systems for black & grey water whereas:

    - 57 are in operation, 26 has been installed as turn-key retrofits, 31 installed in the newbuild market in the past, 28 are being delivered to future newbuilds (in backlog)

- Vacuum foodwaste conveying system to eliminate overboard discharge and risk of contamination

- Bio-residue treatment of wastewater solids with dewatering and drying

- Food waste digester options in galleys to eliminate solid handling and logistics, with easy interface to Scanship AWP

- Incinerator system from 600kW up to 4,000kW exceeds IMO Marpol Annex V standard – new refractory lining to reduce maintenance and unique ash cooling system

- External steam dryers for 24/7 operations, zero discharge of bio residues using incinerators, and bagging options for landing

Scanship technology for fish farms

The waste water treatment at fish farms separate particles and sludge on a drum filter and flush the filter continuously in order to keep the filter cloth clean at all times. This result in a sludge flow with approximately 0,1% DM pumped to the sludge handling facility delivered by Scanship

The sludge treatment then consists of a two step dewatering followed by Scanship dryer. First dewatering step is a belt filter with high hydraulic capacity for dewatering to 8-10% DM and low concentration in the effluent. Next dewatering step is a decanter centrifuge with the ability to dewater the sludge to a concentration of 25 % DM or even higher

The process flow and type of equipment can be seen in figure 1 below, where it also can be seen that total recovery of sludge can be more than 90% if required in discharge permit.

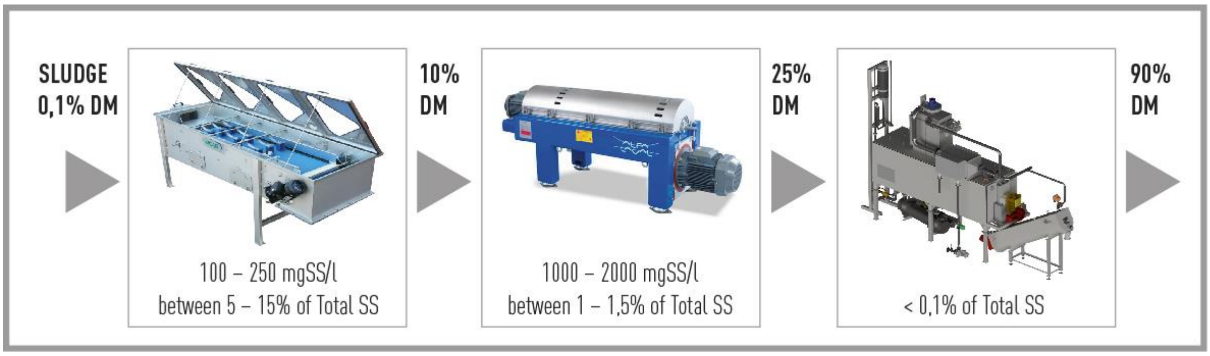

Figure 1: Process flow and equipment for fish sludge handling.

The Scanship drying technology

The dewatered bio sludge enters by gravity into a dewatered bio mass tank. The tank has a stirrer to ensure the bio-solid is kept homogenous and liquid.

The biomass is pumped into the dryer based on time and volume.

The biomass dryer is a batch fed HET-oil heated contact dryer. The thermic-oil is an external heater with circulating system to distribute the hot oil inside the dryer

A paddle, inside the dryer, ensures proper movement of the bio sludge in order to have good contact between the bio-sludge and the heated areas. The dewatered sludge concentration is increased from approx. 25% to desired solid concentration, normally more than 90% DM. The dryer is controlled by time and temperature and can be adjusted by the operator to tune the dry sludge concentration as optimal as possible.

When discharging, a hatch opens and the paddle move the dried biomass by gravity into a cooling conveyer. The cooling conveyer can handle one drying batch in order to control temperature before releasing the dry solid into a big-bag. The conveyer is sealed avoiding air and oxygen to enter into the silo to avoid self-ignition. The biomass will stay in the cooling conveyor until next drying batch is ready. Then a conveyor inside the cooling silo discharges the cooled biomass into a big bag. The volume in the big bag is controlled by a weight cell. The system will give an alarm when the bag is full and when it is time to change to a new bag.

The system is also equipped with water fire extinguishing system in case fire is detected in the drier or cooling conveyer.

The dryer is based on a closed loop principle to recover energy from the system and keep control of the odor. This system consists of an automatic cleaned dust filter with a fan for circulation of air. Humid air flows from the fan through a condenser, cooled by seawater (or fresh water). The dry and cooled air is returned to the dryer chamber. A small fraction of the air is bleeded off in order to have a slight under pressure in the system. The pressure and flow of the seawater is controlled by a pump suitable for seawater.

The heat recovery system is based on pumping seawater from the “cold” seawater loop upstream the heat pump system of the fish farm heat system. The “warm water” from the condenser is brought back to the seawater loop downstream the suction side. This enables significant energy recovery of about 80% which can reduce the corresponding energy consumption on the heat pump system at the hatchery.

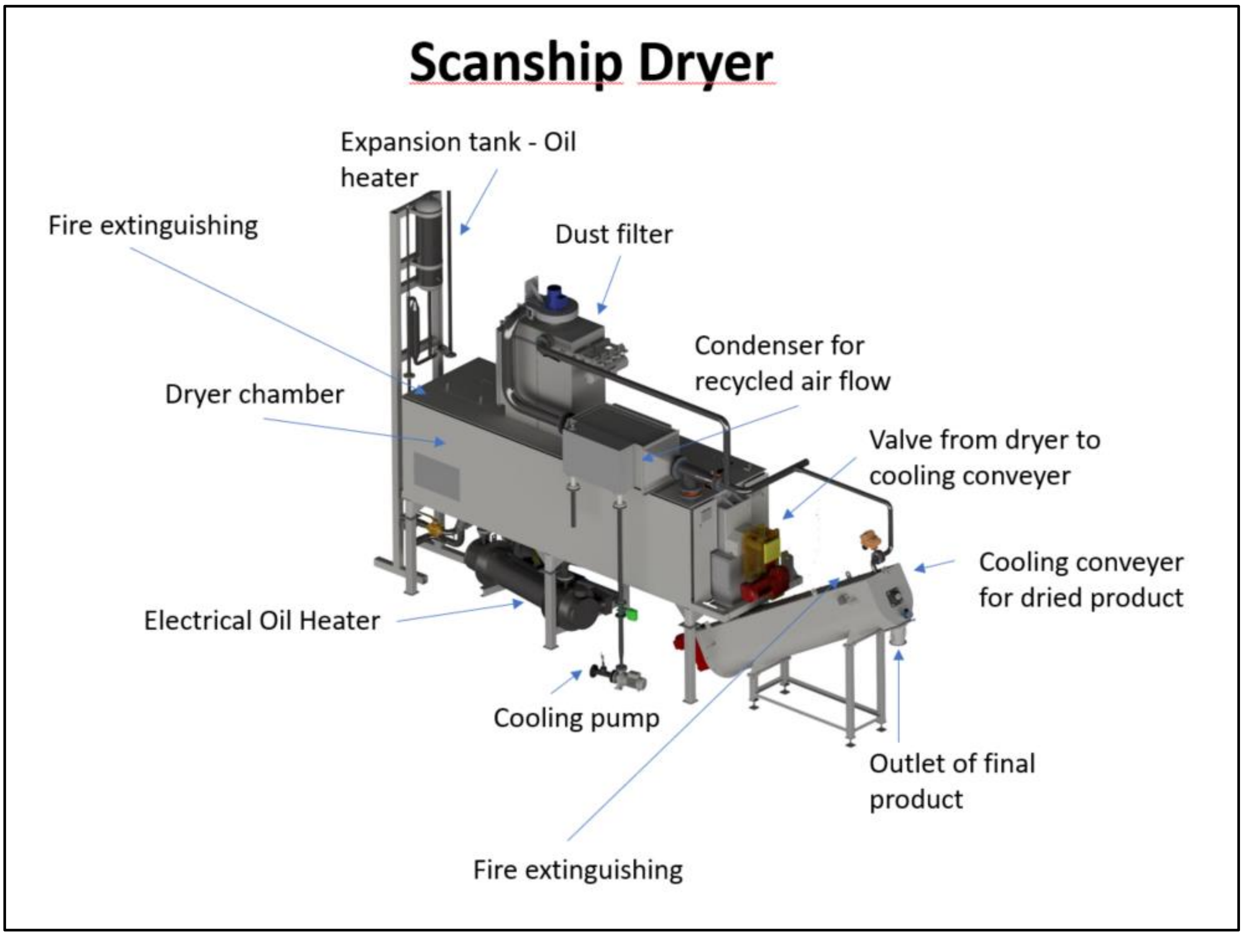

Figure 2: Scanship dryer as a complete unit with integrated heating system.

A separate extraction fan is ensuring the closed loop system and dryer is continuously running with under-pressure. Any air removed from the system passes through a separate odor-reduction unit.

Integrated energy recovery in Fish farm

The use of electrical oil heated dryer technology is selected for fish farm since steam is not part of fish farm operation. Electricity is the only energy source at the plant, where heat pumps are used for temperature control of the water in the fish tanks. This means that condensation technology in the drying process makes it possible to reuse cooling water in the heat pump for heating intake water, even though the energy consumption for drying is only in the range of 5% compared to the total energy consumption of the total fish farm. (Based on feasibility investigation, Fiskeridirektoratet[b])

Results from Steinsvik Settefisk Plant (Scanship reference Plant) shows energy consumption of less than 1 kWh/kg sludge treated (25% DM) including dewatering technology. At the same plant it has been verified that 70-80 % of the total energy consumption can be reused as thermal energy for heating the intake water. The overall energy consumption for drying sludge can then be reduced to 0,3 kWh/kg sludge (25% DM) with 70-80% of the electrical heat recovered. This represent an efficiency of 0,2 KWh/l water evaporated.

Fish Sludge composition after drying compared with municipal sludge after digestion

Dried sludge from fish farms represent a value both in terms of energy and nutrients, where the energy generates from the organic material and the nutrient value is based on N and P together with micro nutrients.

The dry matter in sludge from fish farms consist of 80-90% organic material and 10-20% inorganic material, inclusive N and P(Blytt et al 2011), (Brod et al 2017), depending on the amount of feed loss. The calorific value of the sludge varies between 15 -20 MJ/kg (Aas et al 2016) with 15 MJ/kg if the plant is operated with low feed loss. The concentration of P is around 1,5 -2% and the nitrogen content is in the range of 6-7%.

The concentration of heavy metals generates from the fish feed and especially Zn and Cr can be critical, if the dried sludge is applied directly as fertiliser.

The composition of dried sludge from fish farms can vary in terms of feed residuals but the general composition can be determined as shown below in table 1. Since most WWTP have anaerobic digestion it will be relevant to compare dried fish sludge with digested and dried municipal sludge.

Table 1: Analysis of Fish Sludge and Municipal Sludge

		Fish Sludge1)	Fish Sludge Dried1)	Fish Sludge Dried2) (Scanship)	Municipal sludge3) (Bergen)	Dried Digested Municipal sludge4)	Fish Sludge Dried5) (Steinsvik)
DM	g/100 g DM	13	95	94	4,7	89,6	87,5
OM	g/100 g DM	79	88	80	73	53,6	78
pH		5,8	5,5	5,6	-	8,2	-
N-total	g/kg DM	82	71	58	46	34	-
P-Total	g/kg DM	24	14	20	14	22	30
K	g/kg DM	8,2	0,27	0,94	2,2	0,7	1
Ca	g/kg DM	42	28	43	7,8	14	65
Cd	mg/kg DM	0,77	0,26	-	0,45	0,68	<1,5
Pb	mg/kg DM	0,59	0,17	-	35	13,3	1,8
Hg	mg/kg DM	0,038	0,038	-	0,2	0,5	-
Ni	mg/kg DM	1,2	0,6	-	<20	11,1	<15
Zn	mg/kg DM	410	430	260	370	361	624
Cu	mg/kg DM	22	17	9,2	170	234	15
Cr	mg/kg DM	4,8	4,2	-	14	17	31

1) Analysis from (Brod et al. 2017)
2) Scanship analysis from Steinsvik Settefisk Plant (carried out by HØST)
3) Analysis from Bergen (not realised phD study)
4) Analysis from Norwegian WWTP with Anaerobic digestion and drying (Supplied by HØST)
5) Steinsvik Settefisk analysis of dried fish sludge from Scanship dryer

In table 1 it can be seen that dried fish sludge contains more N-total than dried digested municipal sludge which is natural since organic bound N will be mineralized to the liquid phase as NH_4 and separated from the solid fraction before drying. This is the same for K where the dry fish sludge contains less K per kg DM compared with sample with higher water content.

P is in the same range for dried digested municipal sludge and the average of analysed dried fish sludge. In Norway plant available P is measured as P-AL (dissolved with ammonium lactate and acetic acid) (Egnér et al.1960) and type of P removal at the WWTP (chemical or biological) will have a high influence on the plant available P in municipal sludge (Blytt et al 2011).

Heavy metals seem to be higher in municipal sludge, except for Zn and Cr.

In addition to values in table 1 for Scanship analysis of dried fish sludge, micro nutrient as Bor (B) and Mangan (Mn) was measured to 8,4 and 88 mg/kgDM.

Chloride (Cl) has been measured in the sample from Steinsvik settefisk Plant to 0,2 g/100g DM and not considered as a problem for land based fish production. If sludge is collected from sea based fish production, this need to be evaluated in terms of fertiliser value. Same analysis shows a calorific value of 15 MJ/kg.

Value of Dried fish sludge and potential use

The dried fish sludge as a product may not represent a high economical value for the fish farms compared to other operation cost and the value of the fish. Recycling of valuable nutrients might then be a much higher value for the industry in terms of reputation and imaginary values represented by environmental responsibility and taking care of resources for the worlds food production.

After evaluating the potential of recycling dried fish sludge we have identified three different markets for this product

- Biogas
- Combustion as renewable biofuel
- Fertiliser

Biogas

By evaluation the potential use for energy production in biogas plants it is important to understand the traditional business model for Norwegian biogas plants. The economy is manly based on gate fee for handling the organic waste and the nutrient content are not reducing the gate fee, since the allowed amount of recycled nutrients already are covered by other waste streams (e.g. municipal sludge or manure from agriculture). This is the basis for the conclusion that drying fish sludge is almost the same economy as transporting dewatered sludge to Norwegian biogas plants (Brod et al 2017).

In order to evaluate the biogas potential of dried fish sludge from the Scanship drier a lab test was carried out for determine the digestibility of this biomass. The results can be seen in figure 3 and shows that approximately 65% of organics material are converted to biogas representing a biogas potential of 450 -500 m3 biogas /tonnes DM of sludge.

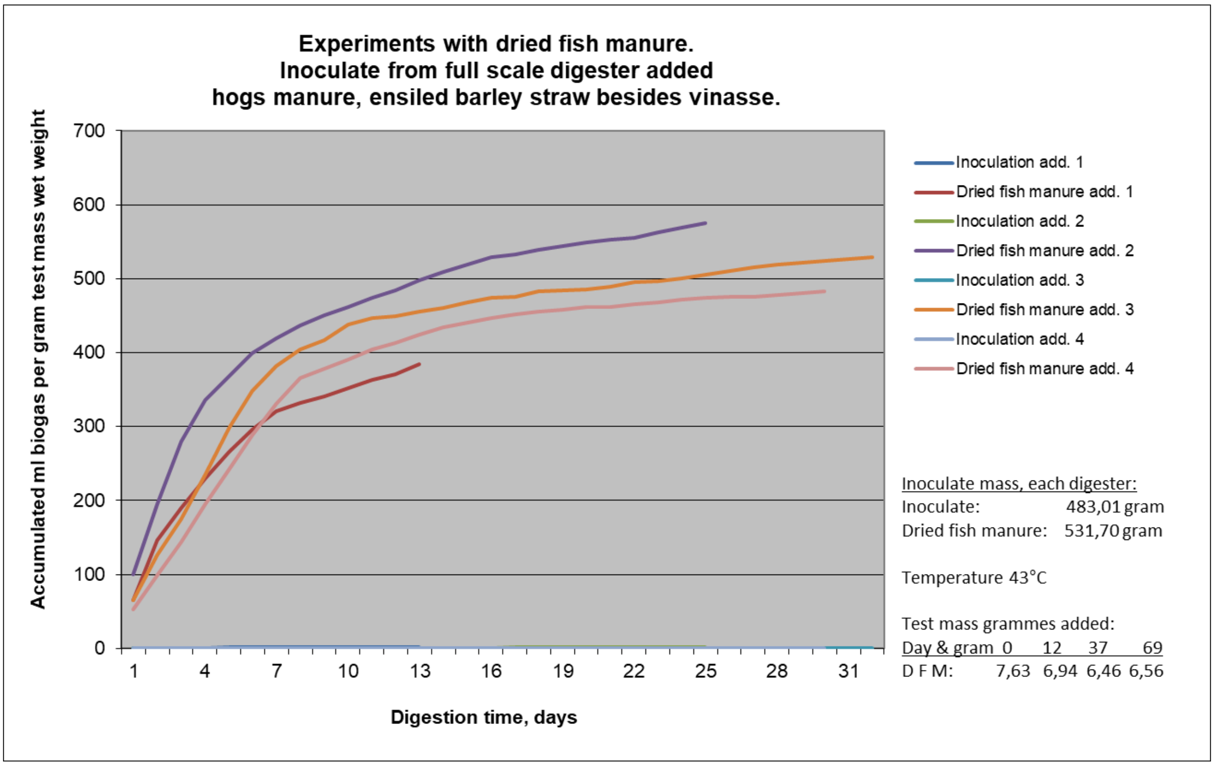

Figure 3: **Biogas Potential in dried fish sludge from Scanship dryer. (Internal report)**

The biogas potential was used for evaluating dried fish sludge as feed stock to Danish biogas plants where biogas is upgrated (by CO_2 removal) and used in the Danish Natural Gas grit as substitute for Natural gas. The value was estimated to be 80 €/ton with handling fee of 13 €/tonnes. Transport cost of 30 tonnes dried sludge to a biogas plat in Denmark was estimated to 2.282,- € resulting in transport cost of 76 €/tonnes. This concludes that the total value of the dried fish sludge is close to zero.

Since biogas plants already handle manure from agriculture and other organic waste with nutrients which are spread on local farm land, the need for recycling N and P from fish industry in biogas plants are limited and thus being a problem more than a contribution.

The evaluation of using this biomass for biogas production concludes that countries with intensive animal production will not be able to pay for the value of fertiliser, if manure is the main substrate for the biogas production.

If the liquid fraction is separated from the solid fraction after anaerobic digestion, the soluble Nitrogen as NH_4 will be lost as fertiliser value, or add to the treatment cost, if this liquid is recycled in a WWTP.

Combustion as renewable biofuel

The Company Norcem has successfully tested the value of using dried fish in the cement production as an alternative to fusil fuel (http://www.norcem.no/no/fiskeslam_som_brensel), (Ilaks[b]. 2017). The prices for handling dried fish sludge in cement production are not public, but handling fee and transport cost has been suggested to be a cost for the fish farm. The combustion of fish sludge will off cause eliminate the potential of direct recycling nutrients and by that represents a less attractive solution for the fish industry.

Fertiliser

If dried fish sludge should be used as fertiliser in Norway, it will need to compete with manure and municipal sludge where farmers need to spread manure according to the Norwegian legislation (Forskrift om husdyrgjødsel. 2002) and farmers will often receive a fee for “handling” municipal sludge. As previous described the amount of P fertiliser in manure are in the same order of magnitude as consumed mineral P for agriculture (Hamilton et al. 2015).

Compared with municipal sludge the dried fish sludge will have some advantages based on N and P content. The sludge will have a well known origin, probably less micro pollutants and less micro plastics. Higher content of micro nutrients In the future this can be some parameters that favour use of dried fish sludge instead of municipal sludge.

The fertiliser value of dried fish sludge has been evaluated in terms of nitrogen (Brod et al 2017), but the same kind of study has not been carried out for phosphorus. It is suggested, that P from fish sludge will have a higher availability for plants than municipal sludge based on the P-AL value, but as an overall potential of secondary P, the incentives for recycling P in Norway is limited and export is more likely as recycling potential.

Further investigation is needed to conclude if the organic content in this product is beneficial for the fertiliser value. The question is, if the organic material is enhancing the microbial fauna in the soil and thereby the overall fertility of the soil, by using this product as fertiliser.

From a global perspective it is obvious that P need to be exported since 75% of P in fish feed is imported (Hamilton et al 2015). But the export of this product as fertiliser will have the same challenges with transport cost as described in example with using this biomass in Danish biogas plats.

Solution for export of sludge as fertiliser

The overall economy for handling dried fish sludge is very dependent on the transport cost and where the values in the sludge are reused.

In order to overcome this transport cost and export of dried fish sludge, a group of 4 companies has joint a common project with the goal of reusing nutrients in the dried fish sludge (ilaks.no 2017[c]).

The supplier of dried fish sludge is Marine Harvest, Steinsvik Settefisk Plant.

The companies are:

- *Scanship.no* as technology provider and responsible for the quality of the dried material
- *Skretting.com* as fish food supplier with own logistic for distributing fish feed from production facility to fish plant
- *Høst (verdieniavfall.no)* as fertiliser company responsible for quality of fertiliser product and export of final fertiliser
- *IVAR.no* as fertiliser producer with blend of organic material and mineral fertiliser to a final commercial fertiliser product, where the organic material derives from digested organic waste like food waste and municipal sludge. The product already exists on the market as Minorga® .

The role of the partners:

Scanchip is handling the sludge from the fish farm in the Scanship dryer, and produce dry, stable and pathogen free product that can be stored and transported out of the fish farm.

Skretting is delivering the feed to the fish farm by truck or boat and take the dried sludge in return with the same transport delivering the feed. The dried product is transported to the feed factory in Stavanger at a closed area for pick up by fertiliser company.

IVAR collects the dry sludge and brings it to the fertiliser production, which is also based in Stavanger. As a back up for the fertiliser production, IVAR can use the dry sludge as a subtrate for biogasproduction together with food waste and municipal sludge.

Høst are responsible for design of the final fertiliser product and the quality of this product. The aim is to use the dried fish sludge together with municipal sludge in the Minorga® fertiliser. HØST have already established collaboration with companies in Vietnam and the goal of this project is to export Minorga® with fish sludge to Vietnam.

Minorga® will contain 10-20% dried municipal sludge. By using dried sludge from fish farms this will compete with municipal sludge.

Conclusion

Sludge from fish production will represent a value as dried product and drying of the fish sludge makes it possible to transport the dried fish sludge over longer distance.

Dried fish sludge will have some advantages compared to municipal sludge in terms of plant available N and P and a higher content of micro nutrients. The single source of origin and the expected nonexistence of micro pollutants and micro plastic also contributes to a better acceptance of this product as a fertiliser. If more of the N and P are collected from the sea based fish production the salt content and especially the chloride concentration need to be further investigated if the dried fish sludge is used directly as a fertiliser.

In countries like Norway with animal production and thereby available manure as a free and regulated secondary fertiliser, it is less likely that the dried fish sludge will represent a positive value. In direct competition with municipal sludge the price can be zero or even be negative, since farmers are getting paid for receiving the municipal sludge.

The biogas potential in the dried fish sludge has been confirmed to represent a value outside of Norway, if the sludge is delivered directly at the plant. Transport cost will be in the same order of magnitude as the price for the dried fish sludge.

In Norway it has been evaluated that investment in drying the fish sludge and delivering to biogas plans will be the same cost for sludge handling as dewatering the sludge and transporting the wet sludge to biogas plant.

The opportunity to use the dried sludge as a bioenergy is an available option and the dried fish sludge will be able to compete with municipal sludge both in terms of energy potential and quality. This utilisation of the dried fish sludge will unfortunately not contribute to recycling of the excess N and P generated from the fish production.

If the fish food supplier transport the dried fish sludge directly to a production facility for fertiliser as part of return transport after delivery of the fish food, it is possible to create a positive economy for the dried fish sludge.

The collaboration between Scanship, Skretting, HØST and IVAR makes it possible that excess N and P generated from fish production in Norway can be exported to countries where nutrients can be made available for production of new feed for human and fish.

With the use of dried fish sludge in the fertiliser product Minorga, the dried fish sludge will be a direct competitor to municipal sludge, even on an international scale.

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