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Co-digestion of waste from the salmon aquaculture sector with regional sewage sludge: effects on methane yield and digestate nutrient content

Abstract
In Western Norway, the availability of aquaculture waste resources is relevant for both biogas production and nutrients recovery. In this study, fish sludge from the farming of salmon was tested as co-digestion substrate in the anaerobic digestion of municipal sewage sludge from different regional treatment plants. Additions of 5, 10, 25 and 30% of fish sludge in volume were evaluated. Fish sludge did not improve the methane yield of Grødaland sewage sludge. In contrast, Bergen plant's sewage sludge yield increased up to 40% with additions of 25% fish sludge. Co-digestion mixtures are being further tested in semi-continuous reactors for its long-term process stability, methane yield, and the effects that fish sludge may have on the final digestate's nutrient content.

Keywords: fish sludge, co-digestion, sewage sludge, methane, nutrients.

1. Introduction

Optimizing the exploitation of available waste resources for nutrients, energy and biomaterials recovery will be vital in the future circular economy society. In Norway, around 27,000 tons of nitrogen (N) and 9,000 tons of phosphorus (P) are lost to the sea as fish sludge each year; a sludge which is mainly composed of fish manure and surplus feed (Hamilton et al., 2016). It is estimated that the amount of nutrients lost in connection to fish sludge is of the same order of magnitude as with animal manure. Thus, the eco-intensification of aquaculture and its production growth can only be sustainable if fish sludge is recognized as a valuable resource of nutrients and collected to be utilized, e.g. by acting as a mineral fertilizer substitute (Egle et al., 2016).

In Western Norway, the availability of waste resources coming from the fisheries, aquaculture and fish processing sectors, is relevant to consider for promoting biogas production and nutrients recovery (Hamilton et al., 2016; Solli et al., 2014; Gebauer, 2004). New on-land based plants are planned in the region, and due to stricter regulations, the trend is towards new closed-systems plants (RAS: Recirculation Aquaculture Systems), which will provide higher amounts of sludge inland as well as will require proper and sustainable treatment and management. Implementing biogas plants within the aquaculture farms is not an economically feasible option for the sector but an interesting alternative is to treat the sludge and waste at already existing biogas plants that have such capacity to co-digest them with other substrate fractions, as sewage sludge (Vangdal, 2014). This will contribute to higher biogas potentials and higher degree of nutrients recirculation.

In that respect, two new biogas plants have been recently inaugurated at Western Norway, in the regions of Rogaland and Hordaland (Fig. 1). These plants are centralized as they aim to treat the municipal sewage sludge produced at the regional wastewater treatment plants (wwtp), and they possess important available capacity to treat other regionally available organic waste fractions as co-substrates.

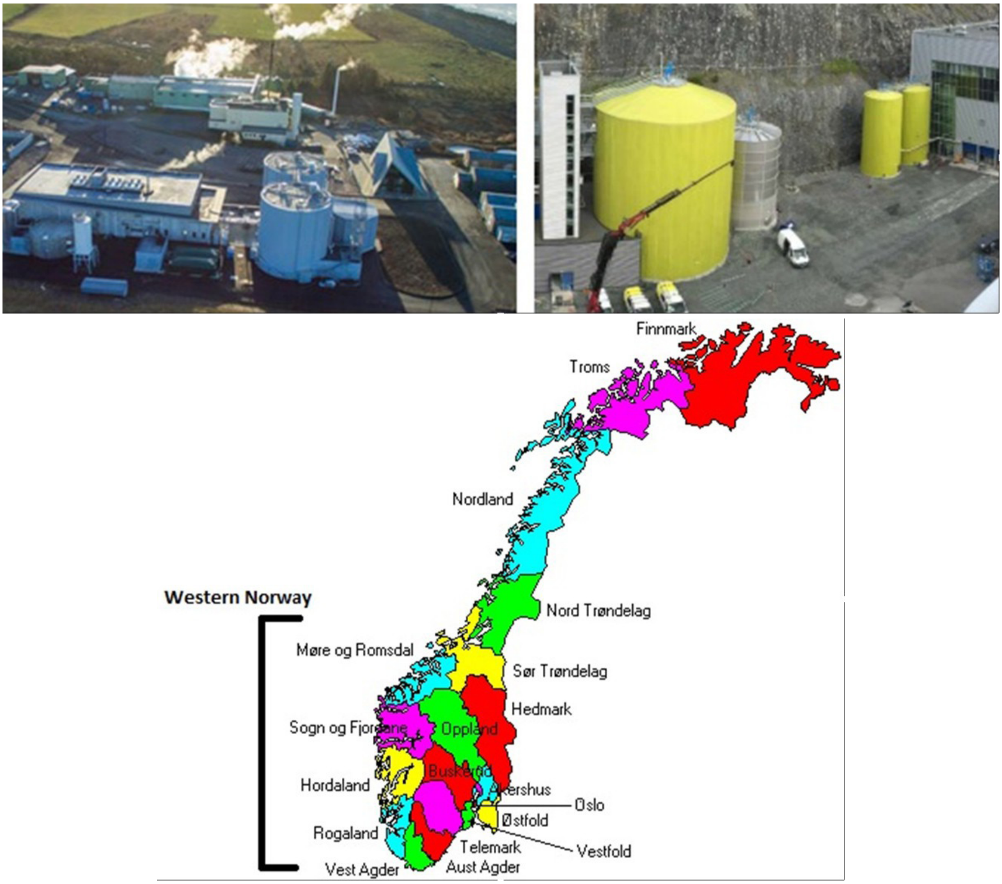

Fig. 1. Grødaland biogas plant in Rogaland and Bergen-Rådalen biogas plant in Hordaland, Western Norway

The newest biogas plant built by Bergen Municipality's Sewage and Water agency at Rådal, Hordaland, is designed to treat approx. 10,000 tones TS/year of sewage sludge and 1,000 tones/year of source-sorted organic fraction of household municipal solid waste (OFHMSW).

The Regional wwtp of Nord Jæren (SNJ) north of Stavanger, Rogaland, is the biggest waste treatment plant in the Jæren region, and is operated by the inter-municipal water, wastewater and waste company IVAR IKS. The plant receives and treats wastewater from the densely populated Stavanger region and produces biogas mainly from the sludge and minor amounts of food waste and liquid fat from commercial kitchens. In addition to SNJ, Grødaland is the newest and largest biogas plant built by IVAR in Hå municipality in the southern part the region. This is one of Norway's biggest biogas plants to date and is dimensioned to treat 22,600 tones TS/year of both regional sewage sludge and OFHMSW (30 and 70%, respectively).

2. Methods and Materials

Fish sludge coming from Western Norway's aquaculture production of salmon in open and closed systems, were tested as co-digestion substrates in the anaerobic digester of municipal sewage sludge.

Fish sludge sample A came from an extended smolt farm (pilot plant-seawater); sludge sample B came from a recirculation aquaculture system (brackish water); sample C came from freshwater closed aquaculture system (freshwater); sample D from a hatchery facility (freshwater) and sample E came from a smolt plant (seawater). All sludge samples originates from sedimentation tanks after being drum filtered. In addition, fish sludge A was rinsed on-site with fresh water to decrease salt concentration.

Sewage sludge samples from the main biogas plants at Western Norway: Bergen-Rådalen (Bergen Municipality, Hordaland), Grødaland (IVAR, Hå, Rogaland) and SNJ (IVAR, Nord Jæren, Rogaland) were applied as main substrates. The Bergen plant sludge is composed from chemically and biologically treated sewage sludge and some septic sludge that undergoes a hygienisation process at the plant (pasteurization at 70°C for one hour). The Grødaland sludge is composed of mainly primary (filtered) sludge and some biologically treated sludge, as well as very low amounts of chemically treated sludge. The SNJ sludge is composed of primary and biological sludge.

Table 1 shows the results of the initial characterization of the substrates. After being received and analyzed, all the substrates were either diluted or concentrated in order to achieve the volatile solids (VS) content level of 2–3% required according to procedure of the biochemical methane potential (BMP) trials.

Table 1. Characteristics of sewage and fish sludge substrate samples

Substrates as received	pH	Conductivity (mS/cm)	TS (g/Kg)	VS (g/Kg)
Bergen sewage sludge	7.1	8.5	60.3	45.7
Grødaland sewage sludge	5.3	4.5	24.5	21.0
SNJ sewage sludge	5.8	3.0	80.6	66.0
Fish sludge A	5.6	9.5	132.6	121.6
Fish sludge B	4.7	4.4	103.9	91.8
Fish sludge C	5.1	2.0	235.2	209.1
Fish sludge D	5.7	1.2	86.5	71.8
Fish sludge E	6.1	12.2	82.0	55.0

The trials were performed by employing AMPTS© II system (Bioprocess Control, Sweden), on sewage sludge alone as substrate and on mixtures combining both sewage sludge and fish sludge in proportion of 5, 10, 25 and 30% in volume. To maintain characteristics of the real scale process at the plants, trials were performed at thermophilic temperature (54°C) when including the Bergen sludge, and at mesophilic temperature (37°C) when using the Grødaland and SNJ's sludge. Inoculum samples were taken from local biogas plants running at the same process temperatures.

Co-digestion in a semi-continuous pilot reactor system of 20 l working volume was performed for a mixture containing 75% SNJ sewage sludge, and 25% fish sludge E (% in volume). An additional reactor run as control with SNJ sewage sludge alone. The process is semi-continuous as it is batch fed, once per day, 5 days a week. The process run at mesophilic temperature, with a continuous agitation of 80 rpm for a total period of 4 months. The hydraulic retention time (HRT) was 19 days and the organic loading rate (OLR) 2 g VS/l d.

Total and volatile solids (TS and VS) content, COD, Total-P, Total-N, PO_4-P and NH_4-N were measured according to Standard Methods (APHA, 1995) and employing Hach Lange© cell kits, respectively. For the semi-continuous reactor processes, agitation speed, pH, and temperature were constantly monitored by the systems' own software. TS and VS were measured weekly and COD, Total-P, Total-N, PO_4-P and NH_4-N were measured every second week according the previously stated methods.

3. Results and Discussion

Results of co-digestion differ when comparing various sewage sludge samples. For the Rogaland region, sewage sludge from Grødaland showed good yields (514–560 Nml CH_4/g VS added) that were not improved at additions of 5, 10, or 30% of any fish sludge (% vol.). Only a slight improvement for fish sludge B was detected (Fig. 2). Sewage sludge from SNJ had a similar slight improvement when 10% of fish sludge D was added. As mentioned, the Rogaland sewage sludge are mainly composed from primary and biological sludge and the process run under mesophilic conditions.

On the other hand, the sewage sludge mix from the wastewater plants at Hordaland region, containing biological, septic and also chemical sludge types, got a beneficial effect by adding fish sludge. The co-digestion of this Bergen sludge with different types of fish sludge gave a considerable increase in the yields, both at 10 and 25% co-digestion mixing ratios for fish sludge A and C and at 10% ratio for fish sludge B. The methane yield from Bergen's plant sewage sludge (332–393 Nml CH_4/g VS added) got an increase of up to a 40% (495 Nml CH_4/g VS added) with a 25% addition of fish sludge A. These processes run at thermophilic temperature.

Regarding nutrients content, analysis of the digestates showed for thermophilic trials higher total-N and ammonium-N contents (5.3% TS) than for others (2.7–3.3% TS), which may be a cause of early inhibition in a continuous long-term process.

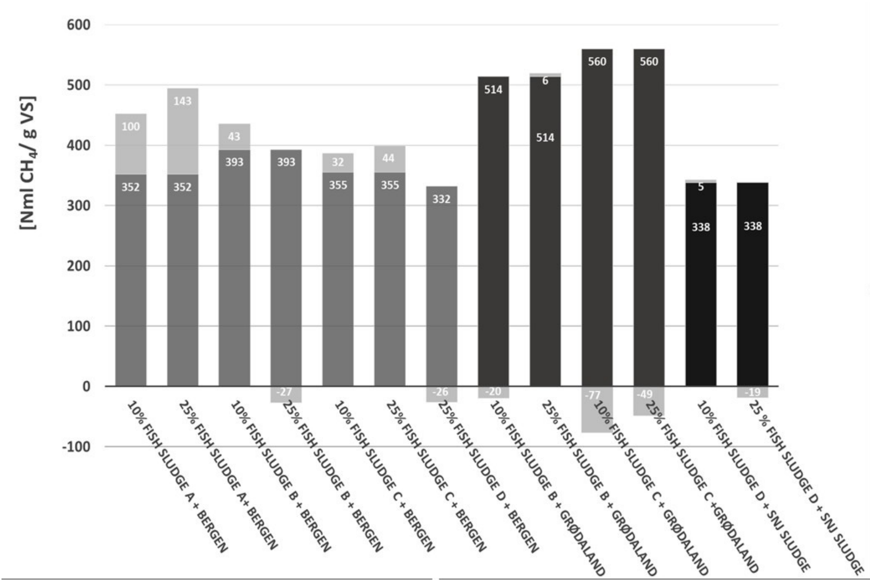

Fig. 2. Specific methane yield (Nml CH_4/g VS added) for the co-digestion mixtures of different sewage sludge and fish sludge samples. Light grey bar on top and under the main bars show the increment or decrement on the sewage sludge's methane yield by addition of fish sludge (grey bars: the Bergen sewage sludge; darker grey bars: the Grødaland sewage sludge; black bars: the SNJ sewage sludge)

Co-digestion in semi-continuous pilot reactor system with the SNJ sludge alone (reactor 1) and in combination with fish sludge E (reactor 2) gave a stable digestion process for the entire experimental period of 4 months (6 HRTs). The co-digestion reactor (2) gave a methane yield up to 35% higher than the control reactor (1) (Table 2). Higher levels of both ammonium-N and total phosphorous were detected for this reactor by the end of the period, and an increase in the solids and COD content. It is interesting to note that the total phosphorous increase was followed by an increase of the dissolved ortho-phosphate (PO_4-P) fraction, giving values two times higher for reactor 2 fed with 25% vol. of fish sludge. Degradation grade in terms of VS was very similar for both reactors and ranged between 40–58% on the whole period.

Table 2. Overview of main results of the semi-continuous pilot reactor system

Reactor	Substrate mix (% vol.)	Specific methane yield (ml CH_4/g VS)	NH_4-N (mg/l)*	Total-P (mg/l)*	COD (mg/l)*	TS (%)*
1	SNJ sludge	265–350	890	441	18.028	1.90
2	SNJ sludge (75) + fish sludge E (25)	370–450	1100	842	20.910	2.35

* values after 6 HRTs (end of experimental period)

Analysis of the co-digestion of Bergen sewage sludge and fish sludge in a semi--continuous long-term thermophilic process is currently being performed.

4. Conclusion

This research study reveals that fish sludge obtained from different aquaculture systems provides different effects on the methane yield of a co-digestion process. In addition, differences within the treatment process to which the municipal sewage sludge is exposed to, are crucial for a co-digestion process to succeed. Both these factors will determine to which extent the inclusion of a new substrate to a biogas plant can be beneficial.

The importance of performing pre-trials in order to evaluate the co-digestion effect is emphasized here.

Semi-continuous mesophilic co-digestion of sewage sludge with fish sludge from a salmon smolt farm provided higher methane yield, and higher levels of nitrogen and phosphorous in the final digestate. The process run stable the whole experimental period of 4 months, showing no signs of inhibition due to salt or ammonium-N content. The dissolved phosphorous levels doubled for this reactor when compared to the reactor only digesting sewage sludge, which will translate into an enhanced digestate resource for the production of valuable fertilizer.

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