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Bioresource Technology 97 (2006) 2389–2401
BIORESOURCE TECHNOLOGY

# Mesophilic anaerobic treatment of sludge from salmon smolt hatching

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Received 2 June 2005; accepted 6 October 2005
Available online 28 November 2005

**Abstract**

The mesophilic anaerobic treatment of concentrated sludge from an Atlantic salmon smolt hatchery (total solids (TS): 6.3–12.3 wt%) was investigated in a continuous stirred tank reactor (CSTR) at 35 °C and 55–60 days hydraulic retention time (HRT). COD-stabilization between 44% and 54% and methane yields between 0.140 and 0.154 l/g COD added (0.260–0.281 l/g VS added) were achieved. The process was strongly inhibited, with volatile fatty acid concentrations of up to 28 g/l. But the buffer capacity was sufficient to keep the pH-value at 7.4–7.55 during the whole operation. The fertilizing value of the treated sludge was estimated to be 3.4–6.8 kg N and 1.2–2.4 kg P per ton. However, the high VFA content would necessitate special means of application. The energy from the methane that was achieved in the present study would be sufficient to cover about 2–4% of the energy demands of a flow-through hatchery.


*Keywords:* Anaerobic treatment; Fish farming sludge; Inhibition; Ammonium; Long-chain-fatty-acids; Volatile fatty acids; Fertilizing; Biogas; Energy production; Stabilization

## 1. Introduction

In 2002, Norway produced 550,000 tons of salmonids, and was the world's greatest producer of Atlantic salmon with 42% of the global production volume. According to the life cycle of anadromous fish, salmon production starts with smolt hatching in freshwater, mainly in land-based plants, before salmonid grow out is carried out in seawater, mainly in open sea-cages. In 2002, 163 million smolts from 247 smolt hatcheries were set out in sea-cages (Directorate of Fisheries, 2002). Smolt hatcheries may be permitted to produce up to 2.5 million smolts per year, but, as indicated above, most of them produce 1 million or less. Most smolt hatcheries are flow-through plants with water and energy demands of up to 700,000 $m^3$ and 105–245 MW h per 100,000 smolts produced (Solbakken et al., 2005). The discharges of organic matter and nutrients, phosphorus and nitrogen, correspond to those of about 100 people per 100,000 smolts produced. Smolt plants are normally situated at locations with abundant freshwater supply, close to the sea, that is used as a receiving water for the discharges. Mostly, the self purification capacity of the sea is sufficient to cope with the pollution. However, when it is insufficient, especially when plants are situated close to each other, the plants are required by the authorities to purify their effluents by particle separation. Other smolt hatcheries are built as recirculation plants to save water and energy, and remove particles in the recirculation loop. Most often, the particle removal is carried out by microsieving (≈100 μm mesh size) of the effluents, which separates the particles from the effluent stream as a thin sludge-water with about 0.5 wt% total solids (TS). In some hatcheries, the particle separation is achieved hydraulically in the fish tanks using dual tank outlets for particles and for clear water, respectively, called particle traps. The particle stream is then usually concentrated in a kind of hydrocyclone, to a TS content of up to 10–12 wt% (Skybakmoen, 1993). The sludge is usually discharged through a long pipeline to the open sea, discharged to the local sewage

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doi:10.1016/j.biortech.2005.10.008

**Nomenclature**

| | |
|---|---|
| $CH_4$ | methane |
| COD | chemical oxygen demand (g/l) |
| CSTR | continuous stirred tank reactor |
| HRT | hydraulic retention time (days) |
| IC50 | concentration that causes 50% inhibition |
| LCFA | long chain fatty acids |
| MW h | mega Watt hour |
| $NH_3$-N | unionised ammonia nitrogen (mg/l) |
| NOK | Norwegian crowns |
| OLR | organic loading rate (g COD/l sludge day) |
| rpm | revolutions per minute |
| TAN | total ammonia nitrogen |
| Tot-N, N | Total nitrogen (g/l) |
| TS | total (dry) solids (% of weight) |
| VFA | volatile fatty acids |
| VS | volatile (organic) solids (% of weight) |
| vol.% | % of volume |
| wt% | % of weight |

system or local septic tank, or treated on land by infiltration in the ground. In a few cases the sludge is stored together with manure or stabilized by the addition of lime, in order finally to be reused as a fertilizer.

Thus to date the treatment of sludge produced by smolt hatcheries normally does not include recovery of the resources inherent in the sludge, i.e., the fertilizing value and the energy content. This study examines the anaerobic treatment of sludge from smolt hatcheries, with biogas production, in order to find out whether this treatment could be an economically feasible means of reducing the high-energy demands of smolt hatcheries. Additionally, the investigation considers whether the anaerobically treated sludge will be suitable as a fertilizer.

The anaerobic treatment of sludge from trout or salmon farming in freshwater has previously been investigated by Kugelman and Van Gorder (1991), Lanari and Franci (1998) and McDermott et al. (2001). The operating conditions and performance of these studies are provided in Table 2. Kugelman and Van Gorder (1991) investigated the treatment of concentrated sludge (4–6 wt% TS, 2.5–3.5 g/l Tot-N) and diluted sludge (2–3 wt% TS, 1.3–1.8 g/l Tot-N), respectively, in CSTRs at mesophilic temperature, 35 °C. Lanari and Franci (1998) investigated the treatment of less concentrated sludge (1.3–2.4 wt%, <250 Tot-$NH_4$-N) in an anaerobic filter at 24–25 °C. McDermott et al. (2001) treated a sludge with 0.4 wt% TS (<350 mg/l Tot-$NH_4$-N) in a semi-continuous stirred tank digester at 18–20 °C. Kugelman and Van Gorder (1991) found strong inhibition of the process with concentrated sludge with VFA-concentrations of up to 7.8 g/l in the reactor, and measured methane yields corresponding to only 35.7–46.9% of the theoretical maximum yields (cf. Table 2). The inhibition was attributed to the ammonium concentration in the sludge and could be overcome by 1:1 dilution with tap water. Lanari and Franci (1998) and McDermott et al. (2001) did not find any inhibition or high VFA-concentrations during the treatment of the less concentrated sludge, and both studies found high degrees of stabilization of organic matter (cf. Table 2). But they measured significantly different methane yields of 0.40–0.46 l/g VS added (Lanari and Franci, 1998) and 0.08–0.10 l/g VS added (McDermott et al., 2001), which may be explained by the different temperatures applied in the two studies and by different pathways for organic matter degradation in anaerobic filters and CSTRs.

In the present study, the anaerobic treatment of a concentrated type of sludge (10–12 wt% TS), collected by means of particle traps and completing hydro-cyclones from tanks of an experimental Atlantic salmon smolt hatchery, was investigated in semi-continuous stirred tank reactors at mesophilic temperature (35 °C). The concentrated sludge was chosen to minimise the energy demand for heating the sludge suspension to process temperature.

## 2. Methods

### 2.1. Inoculum

The inoculum was taken from an experimental anaerobic digester that had been operated using saline fish farming sludge for a period of four months (Gebauer, 2004). Thus the sodium content of the inoculum was about 9000 mg/l. Originally, the inoculum consisted of a mixture of digested sewage sludge and cow manure and was kindly provided by the Agricultural University of Norway at Ås. Anti-agent tests (Ahring and Nørgaard, 1994) showed that the methanogenic biomass was dominated by species that are normally found in low-salinity digesters with suspended cultures, such as *Methanosarcina barkeri* and *Methanococcus varnietii*.

### 2.2. Fish farming sludge (substrate)

The sludge (substrate) was collected once a day from particle traps that were mounted on tanks used for the production of Atlantic salmon smolts at the research and demonstration plant at Kyrksæterøra in South Trøndelag, Middle Norway (Skybakmoen, 1993). The composition of the sludge is shown in Table 1. The sludge was collected during a two-week period in 1992 when a high feed-coefficient of 1.38 was applied (feed coefficient = kg feed used/kg