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Co-digestion of cultivated microalgae and sewage sludge from municipal waste water treatment

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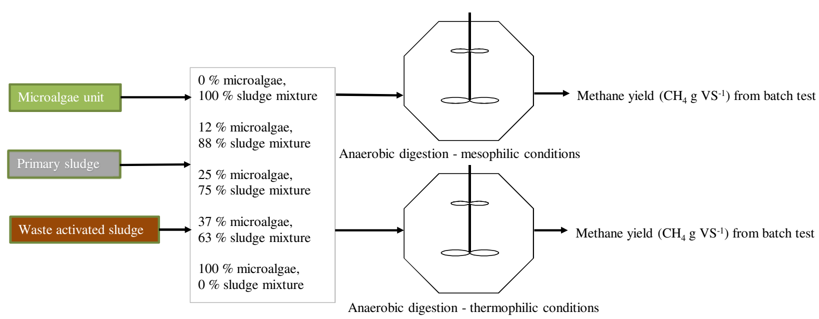
HIGHLIGHTS

- Microalgae were co-digested with a sewage sludge mixture in batch studies.
- Highest CH_4-yield, of 408 ± 16 Ncm^3 g VS^{-1} was reached in 37 °C with 37% microalgae.
- In 55 °C the same increase in methane yield with microalgae added could not be seen.
- The microalgae seems to be easily degraded with a short lag phase in the batches.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study two wet microalgae cultures and one dried microalgae culture were co-digested in different proportions with sewage sludge in mesophilic and thermophilic conditions. The aim was to evaluate if the co-digestion could lead to an increased efficiency of methane production compared to digestion of sewage sludge alone. The results showed that co-digestion with both wet and dried microalgae, in certain proportions, increased the biochemical methane potential (BMP) compared with digestion of sewage sludge alone in mesophilic conditions. The BMP was significantly higher than the calculated BMP in many of the mixtures. This synergetic effect was statistically significant in a mixture containing 63% (w/w VS based) undigested sewage sludge and 37% (w/w VS based) wet algae slurry, which produced 23% more methane than observed with undigested sewage sludge alone. The trend was that thermophilic co-digestion of microalgae and undigested sewage sludge did not give the same synergy.

1. Introduction

Anaerobic digestion of sewage sludge from municipal wastewater treatment is a common stabilization method for biosolids. The combustible biogas produced in the process is considered to be a renewable energy source thereby making the expansion of biogas production systems an important contributor to the global conversion from fossil fuels to renewable energy systems (Tchobanoglous and Burton, 2002). The demand for biogas continues to grow and it is therefore important for municipal wastewater treatment plants (WWTP) to maximize biogas production. One way to do this is by using microalgae cultivated with wastewater as a co-substrate in the digestion process. Microalgae can be cultivated in a treatment

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step in photo bioreactors or microalgae ponds in the final polishing wastewater treatment in the WWTP (Larsdotter, 2006) or as a treatment for nutrient rich side streams like reject water from sludge dewatering (Ficara et al., 2014; Rusten and Sahu, 2011). Simultaneous nutrient recovery, water treatment and biomass production are thus possible. Successful cultivation of microalgae in wastewater has been demonstrated in recent studies (Odlare et al., 2011; Su et al., 2011).

Rusten and Sahu (2011), Ficara et al. (2014) and Ma et al. (2014) have evaluated the process of cultivation of microalgae from reject water, and have found that microalgae remove nitrogen and phosphorous from the reject water, consequently reducing the impact of returning side streams to the main stream of the treatment plant. Microalgae have also been used to successfully reduce nutrients in nutrient rich digested piggery wastewater (Wang et al., 2013a).

According to Wang et al. (2013b), waste activated sludge (WAS) can be a suitable co-substrate with microalgae. Co-digesting a microalgae mix containing *Chlorella* sp. with varying amounts of waste activated sludge (WAS), 59–96% in mass of VS-content, the biogas yield is improved which is 73–79% larger than the gas yield from pure algae digestion sets. Krustok et al. (2013) have shown in an anaerobic batch experiment with municipal food waste and harvested microalgae cultivated in lake water that the biogas production is improved after addition of microalgae. The experiment has been carried out with fermentation bottles where 0%, 12%, 25% and 37% of the food waste is replaced with harvested microalgae. During the first 25 days of fermentation the replacement of 12% food waste with microalgae has given the highest biogas production rate. A possible explanation for the synergetic effect of co-digesting microalgae with other substrates is an optimization of the C/N-ratio. Since anaerobic digestion is inhibited when using microalgae alone as a substrate due to the high protein content in the algae biomass (Brune et al., 2009; Wiley et al., 2011) other carbon rich substrates can enhance the C/N-ratio. The use of co-digestion of substrates to stabilize the digestion process by improving the C/N-ratio has been suggested by several authors (Brune et al., 2009; Khalid et al., 2011; Mata-Alvarez et al., 2011). Yen and Brune (2007) have reported increased gas yields from co-digestion of microalgae with waste paper from recycling bins by adjusting the low C/N-ratio in microalgae. The results have shown that an optimum C/N-ratio for co-digestion of algal sludge and wastepaper is in the range of 20/1–25/1. The anaerobic co-digestion between corn silage and the marine microalga *Nannochloropsis salina* have also shown a better process stability and enhanced biogas yields by microalgae addition (Schwede et al., 2013). This positive influence in co-digestion according to Schwede et al. (2013) can be explained by an optimized C/N-ratio but also enhanced alkalinity and addition of important trace elements for the digestion. The enhanced alkalinity that microalgae bring to the co-digestion has also been mentioned by Formagini et al. (2014). In this study vinasse from ethanol production was co-digested with microalgae. The alkalinity of the algae suspension is higher but not enough to keep the pH –level stabilized to a neutral level together with the vinasse (Formagini et al., 2014).

Although there have been recent development in the field of co-digestion of microalgae with other substrates, there is still a lack of knowledge regarding co-digestion of microalgae with a representative mix of sewage sludge for a municipal WWTP in both thermophilic- and mesophilic conditions. This would be important knowledge for further studies and development of systems for using microalgae as a co-substrate together with traditional wastewater treatment and anaerobic digestion in full scale applications. Earlier studies in the area of co-digestion between sewage sludge and microalgae have only focused on co-digesting the microalgae and the biological waste activated sludge (WAS). However, the experiments have only been made in mesophilic conditions (Ficara et al., 2014; Wang et al., 2013b).

This study was designed to investigate cultivation of indigenous microalgae from a nearby lake and in municipal wastewater and using it as a co-substrate in anaerobic digestion with undigested sewage sludge in various proportions. The methane potentials of the different mixtures were evaluated in anaerobic batch tests in mesophilic and thermophilic conditions. The aim of the study was to investigate whether co-digestion of microalgae and sewage sludge were more efficient for biogas production than digestion of the sewage sludge alone.

2. Methods

2.1. Substrates and inocula

To get a broad approach in the study three different microalgae cultures were used as a co-substrate to the undigested sewage sludge. The inoculums used in the BMP-experiments were all taken from digesters at waste water treatment plants so that the micro culture were already adapted to the undigested sewage sludge.

2.1.1. Microalgae A – wet

Microalgae A were cultivated in a water sample from Lake Mälaren taken in mid-June 2012. Cultivation began on the day of the water sampling, without any prior preservation or storage step. Batch cultivation was set up in two 120 dm^3 glass aquariums each containing 10.5 dm^3 lake water and 21.5 dm^3 tap water. A modified version of the nutrient mix Jaworski's medium (3.5 dm^3) as described by Odlare et al. (2011) was added to each aquarium in order to ensure sufficient growth of microalgae. The aquariums were placed in a room with constant light. Light intensity at the beginning of the cultivation period was measured at 7000 lux (100 μmol photons $m^{-2} s^{-1}$). The microalgae culture were all stored at 2 °C until the start of the anaerobic batch tests.

2.1.2. Microalgae B – wet

Microalgae B were cultivated in a water sample taken in mid-December 2012 at the same place in Lake Mälaren. The batch cultivation setup was the same as for microalgae A.

2.1.3. Microalgae C – dry

A third microalgae culture was cultivated in municipal wastewater in a photo bioreactor placed on the roof of the power plant in Umeå, northern Sweden (63°52). This culture was a mixture of natural green freshwater algal species and was grown in a 650 dm^3 open natural light photo bioreactor for 5 days in August 2012. The photo bioreactor was constructed following the open ponds principle, and water flow was generated by a mechanical device (paddles). A metal supporting structure held the photo bioreactor above the roof surface. The reactor was made from thin fiberglass in order to allow light penetration on all surfaces. The municipal wastewater influent was collected at the local wastewater treatment plant (Umeva, Umeå) and transported once a week to the power plant station. A 1 m^3 tank was used for transportation and for partial settling of the influent (Axelsson and Gentili, 2014).

Treated flue gases from the local combined heat and power plant (Umeå Energi, Umeå), which burns municipal and partly industrial solid wastes were pumped from the smokestack and bubbled into the algae culture through a ceramic tubular gas diffuser (Cole-Parmer, USA) at approximately 3 dm^3/min. The bubbling was stopped at night. The length of the night varied from 4 h 45 min in the beginning of August to 8 h 40 min at the end of the same month (Axelsson and Gentili, 2014).