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Research paper

Evaluation of blue mussels (*Mytilus edulis*) as substrate for biogas production in Kalmar County (Sweden)

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ABSTRACT

The Baltic Sea is an over-fertilized inland sea; the blue mussels have potential to absorb nutrients as well as being a source of renewable energy in the form of biogas. The aim of this study was to evaluate technology to utilize blue mussels for biogas production in a pilot scale. Blue mussels (*Mytilus edulis*) were anaerobically digested in a two-stage digestion process (430 L), consisting of a percolation bed and an up-flow anaerobic sludge blanket reactor. Frozen mussels with shells were placed in the percolation bed and digestion was performed at 36 °C during 37 days. The methane potential achieved with this technique was 310 L kg^{-1} volatile solid substances (273.15 K, 101.3 kPa). This result suggests that blue mussels can be efficiently digested in a larger scale and have the potential of contributing to a sustainable energy mix in the Baltic region and at the same time decrease the eutrophication of the Baltic Sea. No addition of nutrients and no pretreatment of the mussels (peeling) were needed.

1. Introduction

The Baltic Sea is today over-fertilized with frequent burst of algae blooms during summer time which influence the important tourist industry. Thus, removing nutrients from the sea is of particular interest since it could help decrease the eutrophication. Therefore, an interesting approach would be to harvest sea based substrates such as blue mussels since they have potential for renewable energy extraction and they also absorb nitrogen and phosphorous by filtering planktonic algae and animals from the sea. The current study was performed as a part of the project "Biogas-New substrates from the sea". The aim of the project was to evaluate the harvesting of common reed, blue mussels and macro algae to decrease eutrophication and extract energy in the form of biogas. The study presented here was focused on blue mussels as a source for substrate.

Cultivation of blue mussels in the Baltic Sea has shown that up to 1200–1800 kg of nitrogen and 80–120 kg $ha^{-1}y^{-1}$ of phosphorous can be removed [1]. The county administrative board of Östergötland (the county north of Kalmar) has furthermore shown that 55 $km^2$of mussel cultivation on the Baltic Sea coast lead to Sweden fulfilling its commitment of limiting emissions of nitrogen and phosphorous [2]. Due to the low salinity of the Baltic Sea water, the blue mussels grown there are very small, approximately 30% of the size of the mussels on the West Coast of Sweden facing the North Sea, making commercial cultivation for food production unrealistic [3,4]. Additionally, the shells of the Baltic Sea mussels are soft; hence making crushing or peeling unnecessary for biogas production if suitable technology is used. Consequently, cultivation and harvesting of blue mussels in the Baltic Sea have a potential to counteract eutrophication and increase access to biomass for renewable energy uses.

Conventional continuously stirred tank reactor (CSTR) technology have the drawback that shells most likely need to be crushed or removed to obtain a pumpable slurry [5]. Another more suitable technology is the two-stage anaerobic digestion process used in the present study; where the mussels are hydrolyzed in a percolation bed and the hydrolysate containing the soluble organic material is pumped into the methane reactor, an up-flow anaerobic sludge blanket reactor (UASB). Moreover, the use of granular sludge in the reactor is beneficial in processes with nitrogen rich substrates [6]. Additionally, reactors with granular sludge generally contain higher microbial densities than suspended sludge and the microorganisms in the center of the granules are better protected against toxic compounds [6]. E. g. Singh et al. [7] compared three different process designs for digestion of grass; a dry continuous process, a wet continuous process and a two-stage process consisting of a batch leach bed combined with an UASB reactor. The two-stage process was found to produce most biogas. Furthermore, mussels and common reed has earlier been successfully anaerobically digested in a two-stage leach bed UASB laboratory scale (1 L) process [5]. However, there is a lack of data evaluating upscaling of digestion of blue mussels. The aim of the present study was to evaluate the use of

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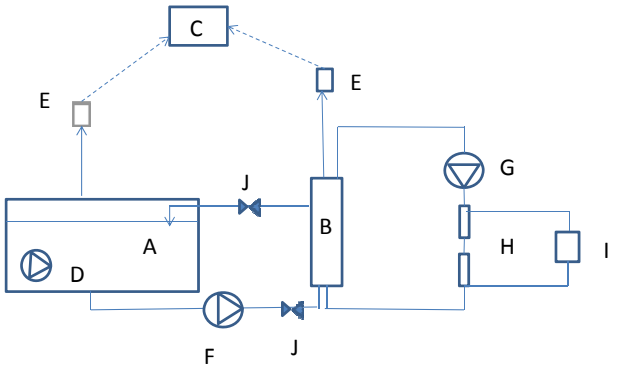

Fig. 1. The two stage dry digestion process used for digestion of the mussels. A percolation bed B UASB reactor C computer D recirculation pump percolation bed E gas flowmeters F feeding pump G recirculation pump H heat exchangers I water heater J valves for sampling.

blue mussels for biogas production and creation of sustainable nutrient cycles using an adapted process in larger scale.

2. Material and methods

2.1. Two stage digestion experiment with blue mussels

Thirty-five kilograms of blue mussels were digested in a two-stage batch digestion process consisting of a percolation bed, A Fig. 1, and an up-flow anaerobic sludge blanket reactor (UASB), B Fig. 1. The percolation bed had a volume of 390 L while the UASB reactor had a volume of 40 L. The temperature in the percolation bed was kept at 305.15 K by an immersion heater. The UASB reactor was kept at 309.15 K using a water heater, I Fig. 1, and two heat exchangers, H Fig. 1, which were placed in the recirculation of the reactor content.

The UASB reactor was filled with 5 L of granules. All mussels were added initially together with 350 L of tap water into the percolation bed which was working in batch mode. The mussels were thoroughly covered with water, to avoid arid zones, channel formation and poor soaking of the bed [8]. The solution was continuously circulated in the percolation bed (approximately 75 L min^{-1}) by a submersible pump (AL-KO drain 6001, BrØnderslev, Denmark), D Fig. 1. The feeding from the percolation bed to the UASB reactor was performed once a day starting day two. The feeding was done by a pump (Watson Marlow 621FX, Boston USA) operating at 25 Hz (1.5 L min^{-1}), F Fig. 1. The pump was started manually and the amount of feeding was adjusted depending on the COD concentration of the leachate in the percolation bed to maintain the organic loading rate of the UASB reactor at 1.5 g COD L^{-1} d^{-1}. The UASB reactor content was continuously recirculated by a Motive G71 BC pump (Nova Rotors, Vicenzia, Italy) running at 30 Hz (approximately 2 L min^{-1}), G Fig. 1. The temperature was measured in the percolation bed and in the inlet and outlet of the UASB reactor. The experiment was performed three times with similar results. The first two runs had some technical complications. The results reported here are from the third batch that was most stable and continued for 37 days. The third run gave the best results; yet, the findings from run one and two also support these conclusions.

2.2. The blue mussels

Five hundred kilograms of blue mussels with mixed age were harvested at 56.674064 °N, 16.420919° E in October 2011 and immediately transported to a freeze room (255.15 K) in which they were stored until the transport to the laboratory. The mussels were kept frozen during transport and storage.

2.3. Inoculum

The granules (microorganisms growing naturally in aggregates) used in the experiment were collected from a mesophilic wastewater treatment plant treating wastewater from Carlsberg brewery (Frankenberg, Sweden). The pH of the granules was 7.0, the total solids (TS) 5% (mass), the volatile solids (VS) 86% (of TS) and the soluble chemical oxygen demand (SCOD) 40 mg L^{-1}.

2.4. Analyses

The methane volume fraction was measured by a gas analyzer GFM series 410 from Gasdata Ltd (Coventry UK). The flow rate of biogas was measured by gas flow meters (Alicat scientific, Tucson, AZ, USA). The analyses were performed according to the following methods: total solids (TS) and volatile solids (VS) [9], soluble chemical oxygen demand (SCOD) HACH LANGE LCK 014 or LCK 114 [10], organic acids HACH LANGE LCK365 [10], ammonium-N HACH LANGE LCK 303 [10] and alkalinity HACH LANGE LCK 362 [10]. The samples were filtered through 0.45 μm syringe filters (Satorius, Stockholm Sweden) prior to analyses. VS is given as a % of TS. The C:N ratio was analyzed according to the ASTM D5373 and SS-EN 13342 methods. Temperatures were measured by PT 100 elements. Crude fat was analyzed according to [11] and crude fiber according to [12]. Total Kjeldahl nitrogen was analyzed according to standard method SS 028101:1–92. Phosphorous was analyzed according to NMKL N0 161 1998 mod./ICP-MS. Sampling was performed once a day.

3. Results

3.1. Two stage anaerobic digestion experiment with blue mussels

The 35 ± 0.5 kg mussels that were put in the percolation bed were hydrolyzed leading to an increase of the soluble COD concentration to 5 g L^{-1} in the bed solution day 8, Fig. 2. The VFA concentration was 2.5 g L^{-1} the same day. The feeding to the UASB reactor lead to COD concentrations in the reactor solution of 0.8–2.3 g L^{-1}, Fig. 3, and VFA concentrations of approximately 0.2 g L^{-1}. Biogas was produced both in the percolation bed and in the UASB reactor due to the transfer of liquid between the two reactors. The methane production in the percolation bed was low during the first 10 days and reached a maximum at day 22, meanwhile the UASB reactor produced the maximum amount of methane day 8 and it continued to produce gas until day 16 when it was taken off line, Fig. 3. The experiment continued for 37 days, during which the percolation bed produced 486 L (all gas volumes are reported at standard conditions of 273.15 K and 101.325 kPa), Fig. 4, and the UASB reactor produced 208 L, resulting in a total volume of 694 L of methane gas. The average methane volume fraction of the biogas from the UASB reactor was 69% while the methane volume fraction of the gas from the percolation bed was stabilized at around 70%. A calculation shows that 75% (mass %) of the ingoing organic carbon is found in the biogas. The calculation is based on the assumption that 31% of the mass fraction of VS of the mussels consists of carbon [13], see Appendix 1 for the whole carbon balance. The shells were visually clean when the process was closed down.

Approximately 30% of the methane was produced in the UASB reactor while 70% was produced in the percolation bed. The chemical composition of the blue mussels is shown in Table 1.

The total methane potential of the mussels was 310 L kg^{-1} of VS. Furthermore, the pH in the percolation bed increased from 6.6 to 8.1 during the experiment while the pH in the UASB reactor increased from 7.1 to 7.9 (Fig. 5) meanwhile the alkalinity of the UASB reactor solution was approximately 3 g L^{-1} as HCO_3^-.

The ammonium-nitrogen concentration in both the UASB reactor and the percolation bed was between 400 and 500 mg L^{-1}during the experiment except for the first days before the hydrolysis was