Energy efficient combination of sewage sludge treatment and hygenization after mesophilic digestion – Pilot study

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Abstract

Biogas production is probably the most feasible way of utilizing sewage sludge as energy source, simultaneously with nutrient recovery by recycling the biogas digestate (i.e. the residue) to arable land. However, the sludge commonly contains high amounts of human pathogenic bacteria excreted in faeces and urine. To use sludge as fertilizer on food producing land is therefore a controversial issue, partly because of the risk of spreading disease-causing pathogens. The Swedish environment protection agency (SEPA) pre-approved two hygenization methods for the treatment of the sludge due to their positive effects on the sludge quality. One of them, conventional pasteurization (70 °C, 1 h), was investigated for its feasibility in Uppsala, Sweden, and it was found that the heat consumption was very high. The other method has the advantage of potentially increase the produced biogas. This hygenization method has been investigated in the present study through a pilot experiment where thickened mesophilic digested sludge is digested once more at thermophilic conditions (55 °C). The aim of the study was to investigate the possibility to develop this self-sufficient (in heat and electricity) hygenization method. The results showed an increase in the gas production from 430 dm³/kg VSₐ to 610 dm³/kg VSₐ by adding the thermophilic step. This increase gave an energy balance with an excess of both heat and electricity. Sludge hygenization was sufficient with the method and another important result is the significant decrease digestate volume.

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Keywords: mesophilic digestion; thermophilic digestion; hygenization

Nomenclature

CST Capillary Suction Time,
VFA Volatile Fatty Acids
WWTP Waste Water Treatment Plant
SEPA Swedish Environmental Protection Agency
CHP Combined Heat and Power

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1. Introduction

Many modern municipal wastewater treatment plants (WWTP) are today still consumers of heat and electricity. In Swedish WWTP aeration basins and various forms of pumping are the largest electricity consumers and the heating of sewage sludge in the anaerobic digestion is the largest heat consumer [1]. To possibly decrease this net consumption it is desirable to extract more biogas from the sewage sludge. The increased biogas production can be achieved by arranging a two stage temperature phased system with the digestion in serial operation or using a higher operational temperature [2]. The higher operational temperature will increase the heat consumption and it is therefore important to build a process system where the net heat consumption still is decreased.

Today the use of sewage sludge on arable land is regulated in the European Union directive 86/278/EEC and the SEPA regulation 1994:2. SEPA was commissioned by the Swedish Government in February 2012 to conduct a study on a sustainable recycling of phosphorus and other nutrients from sewage sludge and other waste fractions. The purpose of the study was to give background material on a new national legislation proposal for the use of these rest products. Since many of the products contain potential pathogenic contaminants the investigation concluded that improvements in technology for hygienization are needed [3]. To meet these possible future demands the WWTP owners in Sweden have to start investing in hygienization methods to be able to use sludge as fertilizer on arable land in the future. According to the SEPA investigation [3] some hygienization methods can be preapproved for systematic use in the treatment of sewage sludge in fullscale. Two possible systems are pasteurization (70 °C, 30 min) before digestion and thermophilic digestion (55 °C) with 8 h of exposure time [3]. The first system was investigated for its feasibility as pre-treatment step for mesophilic digestion at a WWTP in Uppsala, Sweden. The investigation showed that the heat consumption was high and that a more energy efficient method needs to be found [4].

The purpose of this study was to evaluate a possible process solution with the second described preapproved hygienization system [3]. The aim was to show the possibility to develop a hygienization method with thermophilic secondary digestion that produces excess heat and electricity. The study was performed as a pilot experiment where the mixed sewage sludge from the existing mesophilic full-scale anaerobic digestion plant was thickened and digested at thermophilic conditions in 55 °C. In addition the change in dewaterability of the sludge was monitored and subsequent an intermittent aeration experiment was performed to evaluate if the dewaterability of the digested material was enhanced.

2. Material and Methods

The thermophilic digestion was investigated by running two pilot plants of each 35 dm³ during 15 weeks according to figure 1. Digesters 1 and 2 were loaded once a day with 5 dm³ and 2.5 dm³ of thickened mesophilic digested sludge resulting in a hydraulic retention time of approximately 10 days for digester 1 and 20 days for digester 2. The organic loading rate for digester 1 was 5.1 kgVS/m³,d and 2.5 kgVS/m³,d for digester 2. During the test period the gas production was monitored continuously with a gas flow meter of the type Ritter MGC-1 v 3.0. The quality of the produced biogas with respect to methane and carbon dioxide was investigated once a week with the gas analyzer instrument Multitec Sewerin 540. Other operating parameters monitored on the digestate once a week were ammonium, sequenced VFA, total alkalinity, bicarbonate alkalinity and pH.

From the data of the pilot study an energy balance for a possible full-scale system solution was made. The balance calculations included production of heat and electricity via a CHP-system and heat and electricity consumption from thickening of the sludge, storage volume for sludge before the digestion, inlet pumps
of sludge to the digester, circulation pumps in the digester, stirrers in the digester, heating of incoming sludge with outgoing sludge via water-based heat exchangers and cooling water from the CHP-system, heat maintenance of the sludge inside the digester and airblowers for the sludge aeration after the digestion.

A CST-experiment was also performed to compare the dewaterability of the thermophilic digested sludge with the sludge from the original digestion process. The same type and amount of polyelectrolyte was used for the thermophilic digested sludge as for the mesophilic digested sludge in the fullscale plant.

![Diagram](image)

Fig. 1. Experimental setup with thickening and subsequent thermophilic digestion with 10 and 20 days hydraulic retention time

In the end of the test period an experiment with intermittent aeration was performed on the sludge from digester 2 during an operation time of seven days. A temperature regulated reactor with 10 dm³ of the material was used. Additional sludge was not added to the reactor during the trial period. The aeration period was 1 h and the not aerated period 0.5 h. The goal was to keep the oxygen content during the aerated phase above 0.5 mg O₂/l and the temperature in the reactor close to 30 °C throughout the test period. Daily sampling was conducted for the analysis of O₂, temperature, pH, ammonium, nitrite and nitrate. After the aeration test the remaining material was sampled and the dewaterability was tested once more in a second CST-experiment.

Since thermophilic digestion (55 °C) with 8 h of exposure time is a preapproved hygenization method according to the SEPA investigation [3] no studies on the hygenization effect was made.

3. Results and discussion

The results of the 15 weeks study showed that it was possible to enhance the total gas production with a thermophilic digestion of the thickened mesophilic digested sludge to 610 dm³/kg VS_in (Table 1) The methane content in the thermophilic digestion was lower than the mesophilic digestion, which gives lower energy potential in the gas. Despite this fact the heat and electricity balance in the study gave an excess of both heat and electricity including the aeration step after the thermophilic digestion (Table 1). During the operational period the calculated ammonia levels in digester 1 and 2 were 400 and 800 mg/dm³ respectively. Several previous studies have indicated that high levels of ammonia (<100 mg/dm³) can give inhibitory effect on the digestion [5, 6]. The accumulation of VFA that was caused in both digester 1 and 2 in the end of the operating period can therefore be explained by high ammonia levels. The pH in both
reactors were 8.1±0.1 during the operational period and the total alkalinity 12 500 mg HCO₃⁻/dm³ in digester 1 and 13 500 mg HCO₃⁻/dm³ in digester 2. The CST-experiments showed that the dewaterability of the sludge was deteriorated with the thermophilic digestion but was enhanced again after aeration. This is in accordance with the results by Kevbrina et al. [7].

Table 1. Mean values of measured parameters for the two reactors and ordinary mesophilic digesters with standard deviations in parentheses and calculated values for excess heat and electricity from the results of digester 2

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Digester 1</th>
<th>Digester 2</th>
<th>Mesophilic digester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic loading [kgVS/m³.d]</td>
<td>5.1</td>
<td>2.5</td>
<td>2</td>
</tr>
<tr>
<td>Gas production [dm³/kgVSₐ]</td>
<td>140 (38)</td>
<td>180 (20)</td>
<td>430</td>
</tr>
<tr>
<td>Methane content [%]</td>
<td>56 (7)</td>
<td>60 (4)</td>
<td>62-65</td>
</tr>
<tr>
<td>Excess heat [MWh]</td>
<td>317</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excess electricity (MWh)</td>
<td>195</td>
<td></td>
<td></td>
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</tbody>
</table>

4. Conclusions

The results from the pilot-plant study showed that thermophilic digestion after a mesophilic digestion of sewage sludge can be a self-sufficient (in heat and electricity) hygenization method. Both heat and electricity was enough for the operation of a new full scale plant and the dewaterability of the sludge could be maintained with an aeration of the thermophilic digested sludge.

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References