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REDUCTION OF HEAT CONSUMPTION IN MESOPHILIC DIGESTION OF SEWAGE SLUDGE – A FULL-SCALE STUDY

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ABSTRACT

This combined lab-scale and full-scale study investigated how the anaerobic digestion process of sewage sludge was affected in the lower mesophilic temperature range (32°C). The aim of the study was to achieve a more positive heat balance by reducing the operational temperature in the full-scale mesophilic digesters in a Swedish WWTP with a preserved methane production.

The effect on methane yield and degradation rate were examined by a BMP-experiment with three different temperatures (32, 34.5, 37.5°C). The BMP-experiment showed no significant difference between 37.5°C and 34.5°C in methane yield or degradation rate. At 32°C the production of biogas was decreased by 11% compared with 37.5°C.

Consequently, the temperature in the full-scale digesters was gradually adjusted from 37.5°C to 35°C during two months. The heat balance for the reactors was calculated and revealed that it is possible to save up to 13% in heat consumption per year with an operational temperature of 35°C compared to 37.5°C. No change in the production of biogas could be observed during and after the temperature adjustment.

Keywords: renewable energy, biogas, heat reduction, mesophilic digestion, Wastewater Treatment Plant

NONMENCLATURE

Abbreviations

AD	Anaerobic Digestion
BMP	Biochemical Methane Potential
OLR	Organic Loading Rate
TS	Total Solids
VS	Volatile Solids
WAS	Waste Activated Sludge
WWTP	Wastewater Treatment Plant

Symbols

Y(t)	Cumulative methane yield [$Nm^3\ kgVS^{-1}$]
Y	Methane potential [$Nm^3\ kgVS^{-1}$]
Rm	Maximum production rate [$Nm^3\ kgVS^{-1}\ day^{-1}$]
e	Euler's number = 2.7182
λ	Lag phase [day]
t	Digestion time [day]
E_{sludge}	Energy heating of sludge [$kWh\ day^{-1}$]
Q_{in}	Incoming sludge flow [$m^3\ day^{-1}$]
ρ	Sludge density [$kg\ m^{-3}$]
c_p	Specific heat capacity [$kWh\ kgK^{-1}$]
T	Digester temperature [K]
T_{in}	Temperature of raw sludge [K]
$E_{heat\ loss}$	Energy heat losses [$kWh\ day^{-1}$]
A	Surface area [m^2]
U	Heat transfer coefficient [$W\ m^{-2}\ K^{-1}$]
T_a	Ambient temperature [K]

1. INTRODUCTION

Biogas is a renewable energy source with low greenhouse gas emissions. It can be used for production of heat, electricity, and vehicle gas [1]. In many countries, approximately 30-45% of the methane production comes from anaerobic digestion (AD) of sewage sludge in municipal wastewater treatment plant (WWTP) [2]. The residue can be used as fertilizer and thereby combine waste management with nutrient recovery and production of renewable energy [1].

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Mesophilic digestion is a common and stable process at WWTPs. The temperature ranges from 25-40°C but most processes have an operational temperature between 35-42°C [3]. Temperature has proven to have a large impact on the process and there is substantial research on temperatures between mesophilic and thermophilic (46-60°C) processes [4-6]. The research exploring the lower mesophilic temperatures however is limited. Previous studies have shown that even minor temperature adjustments within the mesophilic range have an impact on the gas production [7, 8].

A higher temperature often leads to a higher gas production but on the downside, it needs more energy for heating and it is therefore important to look at the total heat balance when evaluating the process temperature [8]. Heating of sludge for AD is one of the largest heat consumers at WWTPs [9] and reducing the operational temperature can save a lot of heat consumption each year. A lower heat demand reduces cost and makes it possible to use more of the produced gas for vehicle fuel or production of electricity. If it is possible to lower the operational temperature and still maintain the same production of biogas a reduced heat demand and a more efficient process can be achieved.

Earlier research about temperature changes within the mesophilic range has been conducted at batch or semi-continuous conditions [7, 8]. The purpose of this study was to investigate if the production of biogas was affected by a lower operational temperature at a full-scale digester. Furthermore, the study aimed to answer how much heat that can be saved with a lower temperature. This was done on a full-scale WWTP in Sweden. The aim of the study was to evaluate the effects on biogas production within the lower mesophilic range and reduce the heat demand needed for biogas production.

2. MATERIAL AND METHODS

2.1 Batch experiment

A batch experiment was made using a BMP-test (Biochemical Methane Potential) in order to indicate how the temperature affects the production of biogas. The study was performed at three different temperatures, 32°C, 34.5°C and 37.5°C using the AMPTS II – system [10]. A modified Gompertz growth equation (eq. 1), which describes the methane production at AD, determined the effect on reaction rate.

$$\mathrm{Y(t)} = \mathrm{Y} \cdot \exp\left\{-\exp\left[\frac{\mathrm{R_m} \cdot \mathrm{e}}{\mathrm{P}}(\lambda - \mathrm{t}) + 1\right]\right\} \quad \text{(eq. 1)}$$

The equation was fitted to the data from the BMP-experiment and the kinetic parameters for production rate (R_m) and lag phase (λ) was estimated [10].

2.2 Full-scale study

A full-scale study was made at a municipal WWTP in Sweden where two digesters with an active volume of 5600 m^3 are operated. Primary sludge is digested in series in reactor 1 and 2. Waste activated sludge (WAS) from the biological treatment is only digested in the second reactor. The ratio between primary sludge and WAS is approximately 3:1. Organic loading rate (OLR) is approximately 4 kgVS m^{-3} day^{-1} for the first reactor and approximately 3 kgVS m^{-3} day^{-1} for the second, giving a total OLR for both reactors of 2.4 kgVS m^{-3} day^{-1}. Total solids (TS) and volatile solids (VS) for primary sludge is 4.9±0.5% and 80.5±1.8%TS and for WAS 3.5±0.8% and 76.3±3.4%TS.

The temperature in the digesters were adjusted from 37.5°C to 35°C during a total period of two months. In the first step the temperature was reduced to 36°C. After monitoring the process for two months, the temperature was reduced further to 35°C.

To evaluate how the temperature affected the production of biogas, process parameters such as VS-reduction, amount of biogas and methane content were studied. Other parameters such as OLR, VFA (volatile fatty acids), alkalinity and total nitrogen were monitored to ensure the process stability. Analyzes of the sludge were taken once a week. Flow measurements for the sludge and produced biogas were sampled approximately every second minute and a daily mean was calculated.

2.3 Energy balance

In order to quantify the heat reduction with lower operational temperature a heat balance for the reactors was calculated [10]. The calculations were based on the heat needed to increase the sludge temperature to the chosen level (eq.2) and the heat losses from the reactors (eq.3). To calculate the heat losses the digester was divided into parts depending on the material and ambient temperature and then summarized to a total heat loss [10].

$$\mathrm{E_{sludge}} = \mathrm{Q_{in}} \cdot \rho \cdot \mathrm{c_p} \cdot (\mathrm{T} - \mathrm{T_{in}}) \quad \text{(eq. 2)}$$

$$\mathrm{E_{heat\ loss}} = \sum \mathrm{A} \cdot \mathrm{U} \cdot (\mathrm{T} - \mathrm{T_a}) \quad \text{(eq. 3)}$$

3. RESULTS AND DISCUSSION

The BMP-experiment showed no significant difference between 37.5°C and 34.5°C, neither on methane yield nor degradation rate (Tab.1). This

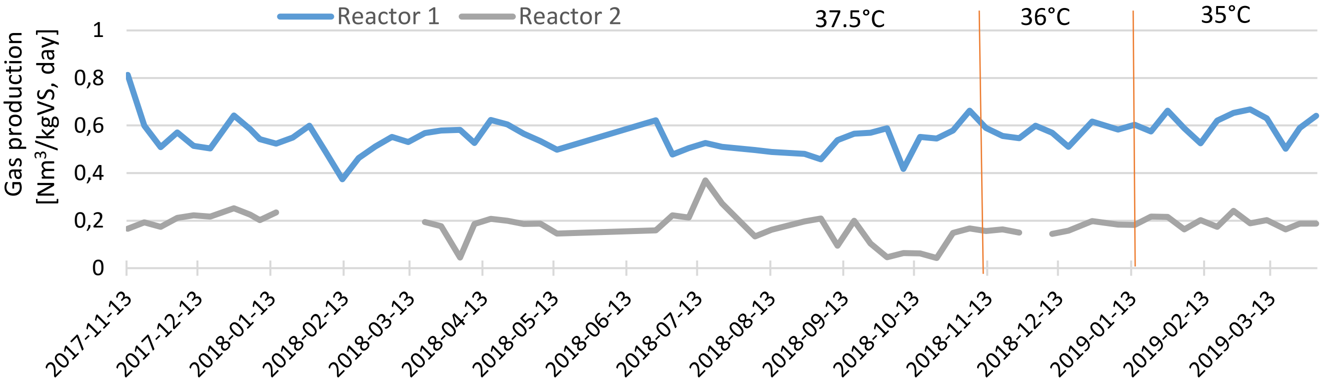

Fig. 1 Production of biogas during the testperiod

indicates that the production of biogas was not affected by a temperature change to 34.5°C. At 32°C, the production of biogas was decreased by 11% compared to 37.5°C but the degradation rate was maintained.

Tab. 1 Methane yield and kinetic parameters from the BMP-test. R^2-coefficient represents how well the equation fitted the data

	37.5°C	34.5°C	32°C
Methane yield [Nm^3 $kgVS^{-1}$]	274±7	271±10	243±7
R_m [Nm^3 $kgVS^{-1}$ d^{-1}]	80.6	82.7	75.7
λ [d]	0	0	0
R^2	0.998	0.995	0.989

The methane yield was slightly lower than the average yield in previous studies but was still within the standard deviation [11]. Compared to Olsson et al. [12] and Yoon et al. [13] the production rate was slightly higher but the lag phase was approximately the same. The availability of organic material is probably higher for primary sludge compared to WAS. This could explain the higher production rate compared to Olsson et al [13] who had a lower proportion of primary sludge.

No direct impact on the production of biogas could be observed with the temperature change in the full-scale study (Fig. 1). The process stability was maintained and there was no significant difference regarding the VS-reduction between the different temperatures. The amount of biogas was slightly higher at the lower temperatures but the methane content was slightly lower (Tab. 2).

The reason for a higher gas production could be a lower flow in to the digester, which consequently gives a higher retention time (Tab. 2). Reactor 1 was emptied for cleaning and control during the test period, which could have influenced the data at 37.5°C resulting in a higher methane content. Possible errors in the flow measurement makes it difficult to say if the small difference is due to the temperature change or the measurement.

Tab. 2 Average values of process parameters for the first reactor during the test period.

	37.5°C	36°C	35°C
No of samples	45	8	12
Biogas [Nm^3 $kgVS^{-1}$]	0.545	0.571	0.605
Methane content [%]	63.43[1]	63.46	62.96
VS-reduction	56.0	54.9	55.1
TS [%]	4.64	4.60	4.92
Amount of sludge [m^3 d^{-1}]	309	297	272
OLR [kgVS $m^3 d^{-1}$]	4.08	3.91	3.85
HRT [d]	9.1	9.4	10.2

[1] No of samples = 18

The heat consumption for both full-scale reactors was calculated to 2.8 GWh/year with an operational temperature of 37.5°C (Fig. 2). In contrast from Nielsen et al. [9] where the heat losses was almost negligible the calculated heat losses was approximately 12-13% of the total heat consumption. With an operational temperature of 35°C it is possible to save up to approximately 13% of heat energy compared to 37.5°C.

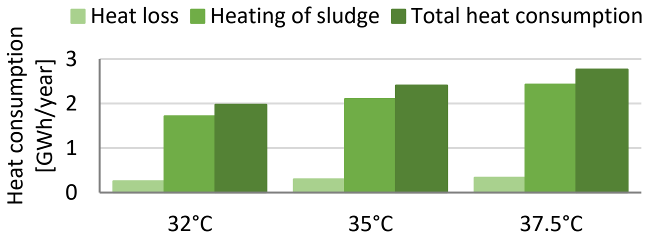

Fig. 2 Heat consumption for the reactors at Uppsala WWTP calculated for different temperatures

4. CONCLUSIONS AND FUTURE STUDIES

Many mesophilic digesters in WWTPs operates in temperatures between 35-42°C. This full-scale study has shown that it is possible to get a successful production of biogas at lower temperatures without reducing the biogas-production or reaction rate. The energy needed for heat consumption can vary between digesters and on the contrary from previous studies the heat losses has proven to have an impact on the total heat consumption. It is therefore important to adapt the values according to the plant design when evaluating the total energy balance. By reducing the temperature of the reactors by 2.5°C, approximately 13% of the heat energy can be saved per year.

Further research within the lower mesophilic range should be made in order to validate the temperature effect on different substrates. Another interesting thing to evaluate is the temperature effect with an increasing OLR since the loading rate often is a limiting factor. Additionally the temperature effect on the dewatering process at WWTP should be further evaluated, since it often represents a major part of the expenditure at a WWTP.

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