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PRIMARY AND ACTIVATED SLUDGE BIOGAS PRODUCTION: EFFECT OF TEMPERATURE

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Abstract

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Sewage sludge management is a problem of growing importance. Anaerobic sewage sludge stabilization is commonly used technology, where organic matter contained in primary and activated sewage sludge is converted into biogas, so both, pollution control and energy recovery can be achieved. The paper deals with the effect of process temperature (36 °C, 42 °C and 50 °C) on biogas production and quality during anaerobic stabilization of primary and activated sewage sludge generated during purifying process in low-loaded activated sludge process. Primary and activated sewage sludge samples were taken at the wastewater treatment plant Brno, Czech Republic. The characteristics of sludges (dry matter and organic dry matter content, pH, conductivity, redox potential) were dermined. Biogas production and quality was measured using 3 anaerobic systems, each of 8 batch anaerobic fermenters, at the 3 different temperature conditions 36 °C, 42 °C and 50 °C. Hydraulic retention time was 20 days. Hypothesis, which predicts that the fermentation of primary and activated sludge provides dissimilar methane quantity and quality under different temperature conditions (36 °C, 42 °C and 50 °C), was partially confirmed. Temperature 42 °C significantly increased biogas production from primary sewage sludge (by 60 % in comparison with production at 36 °C). For activated sewage sludge samples no significant influence of temperature on the biogas production was observed.

Keywords: sewage sludge, primary sludge, activated sludge, anaerobic stabilization, biogas production, temperature

INTRODUCTION

The quality of wastewater treatment in Europe is improving continuously. At present, about 71,000 municipal wastewater treatment plants (WWTPs) are operated in the 28 EU member states (EUROSTAT, 2015). One of the main challenges in wastewater treatment is the separation of solids from wastewater and its subsequent processing. The separated insolubles comprise particles trapped in the primary, mechanical treatment. Trapped are either inorganic (gravel, sand) or mixtures of organic and inorganic (screenings, primary sludge) substances. In the biological treatment, activated sewage sludge is produced (Tchobanoglous *et al.*, 2013). For separation of solids from wastewater, the basic physical principles of sedimentation, filtration and flotation are used. The sewage sludge represents the largest volume of suspended solids, which has to be processed. Sewage sludge is a concentrated, aqueous suspension of biodegradable, partially biodegradable and essentially non-biodegradable solids with associated sorbed and dissolved matter, exhibiting simile ranges of degradability characteristics (Hammer & Mason, 1987). Primary and activated sewage sludge is processed in sludge management, which is integral part of every wastewater treatment plant. Especially in large wastewater treatment plants (> 30,000 PE (population equivalent)) and in wastewater treatment plants equipped with a primary sedimentation tanks, anaerobic sewage sludge stabilization is used. In this technology, a mixture of primary and activated sewage sludge is stabilized under anaerobic conditions. Activated sewage sludge is characterized by lower biodegradability than primary sludge (Eskicioglu *et al*., 2008; Kavitha *et al*., 2014). During anaerobic stabilization either mesophilic (30–40 °C) or thermophilic (50–60 °C) conditions are used (Ahring, 1995; Buhr & Andrews, 1977; Ahring *et al*., 2002). Most of the anaerobic fermenters in Europe were started and is operated in mesophilic conditions (Baere, 2000). Thanks to massive support for the protection of the environment, a large number of wastewater treatment plants have been built or reconstructed in recent years. After reconstruction, changes in wastewater treatment plants operation and thus changes in the primary and activated sewage sludge quality are not usually taken into account. However, the composition of the sewage sludge is crucial for anaerobic stabilization. Economy of sludge management of wastewater treatment plants is related to the amount of biogas produced. Optimization of the anaerobic sludge stabilization process depends on a number of parameters. The temperature of the fermenter is one of the most important parameters. Generally, higher temperature in fermenter increases the metabolic activity of microorganisms as well as the rate of decomposition of the substrate and the biogas production. Additionally, higher temperature results shorter hydraulic retention time of the sewage sludge in fermenter, which allows process higher volume of sewage sludge (Nielsen & Petersen, 2000). Conversely, higher temperature in fermenter represents higher energy consumption to heat up the fermenter (Zupancic & Ros, 2003) and impaired process stability at thermophilic conditions (Buhr & Andrews, 1977; Braun *et al*., 1981; Metcalf & Eddy, 2003). The scope of the present study was to investigate the effect of process temperature on anaerobic fermentation of primary and activated sewage sludge. Hypothesis predicts that the fermentation of primary and activated sludge provides dissimilar methane quantity and quality under different temperature conditions (36 °C, 42 °C and 50 °C). The informations obtained are unique and can help to operators of wastewater treatment plants, who face a difficult decision, intensification of sewage sludge management.

MATERIALS AND METHODS

Primary and activated sewage sludge samples were taken at the wastewater treatment plant Brno, Czech Republic, 513,000 PE (population equivalent). Sewage sludge samples were collected from the primary sedimentation tank and activation tank at the wastewater treatment plant. Inoculum, thus mixed primary and activated sewage sludge, ratio 50 : 50 (v/v), was collected from anaerobic stabilization tank operated at mesophilic condition (38 °C) with hydraulic retention time 20 days. After the collection, the sewage sludge samples were transported to the laboratory immediately.

To determine the sewage sludge dry matter (DM) content, the laboratory oven EcoCELL 111 (BMT Medical Technology Ltd., Czech Republic) was used. Organic dry matter (ODM) content was determined by incineration of the samples in a muffle furnace LMH 11/12 (LAC Ltd., Czech Republic) at 550 °C ± 5 °C, according to the method developed by the U.S. Environmental Protection Agency. Sewage sludge pH, redox potential and conductivity were determined by using pH/Cond meter 3320 (WTW GmbH, Germany).

Biogas production and quality was measured using batch anaerobic fermenters at the three different temperature conditions 36 °C, 42 °C and 50 °C, according to VDI 4630. Temperatures 36 °C and 42 °C, were chosen based on the fact that most

I: *Experiment setup*

System No.		1	
Temperature		36 °C	
Fermenter No.	1–2	3–5	6–8
Substrate	Inoculum 3.0 dm³	Inoculum 2.5 dm³ Primary sludge 0.5 dm³	Inoculum 2.5 dm³ Activated sludge 0.5 dm³
System No.		2	
Temperature		42 °C	
Fermenter No.	9–10	11–13	14–16
Substrate	Inoculum 3.0 dm³	Inoculum 2.5 dm³ Primary sludge 0.5 dm³	Inoculum 2.5 dm³ Activated sludge 0.5 dm³
System No.		3	
Temperature		50 °C	
Fermenter No.	17–18	19–21	22–24
Substrate	Inoculum 3.0 dm³	Inoculum 2.5 dm³ Primary sludge 0.5 dm³	Inoculum 2.5 dm³ Activated sludge 0.5 dm³

II: *Sewage sludge characteristic*

	dry matter [%]	organic dry matter [%]	pH [-]	redox potential [mV]	conductivity [mS·cm^{-1}]
Inoculum	3.38 ± 0.2	58.62 ± 0.05	7.07 ± 0.3	–28.10 ± 0.3	7.60 ± 0.1
Activated sludge	0.99 ± 0.2	65.46 ± 0.07	6.83 ± 0.2	–13.90 ± 0.4	1.22 ± 0.1
Primary sludge	1.27 ± 0.3	60.98 ± 1.37	6.53 ± 0.3	2.60 ± 0.4	1.06 ± 0.1

of sewage sludge anaerobic stabilization systems are operated at mesophilic conditions. The temperature of 50 °C was chosen to verify the influence of thermophilic conditions on the stabilization process dynamics. Hydraulic retention time was set on 20 days, because most of anaerobic stabilization systems operate with retention time ranged between 15–21 days. For each temperature, one system, which consists of eight batch fermenters of volume 5 dm^3 each, was used. In each system, two batch fermenters were used as blank, with 3.0 dm^3 of inoculum. Three fermenters were filled up with 2.5 dm^3 of inoculum + 0.5 dm^3 of primary sewage sludge and three remaining were filled up with 2.5 dm^3 of inoculum + 0.5 dm^3 of activated sewage sludge, Tab. I.

The biogas produced was collected in wet gas meters over a defined period of 20 days and was measured daily. Methane (CH_4), carbon dioxide (CO_2) and hydrogen sulphur (H_2S) content was measured during the batch fermentation tests using gas analyzer COMBIMASS® GA-s (BINDER GmbH, Germany). Biogas production was converted to standard conditions (T_0 = 273 K, p_0 = 101,325 Pa).

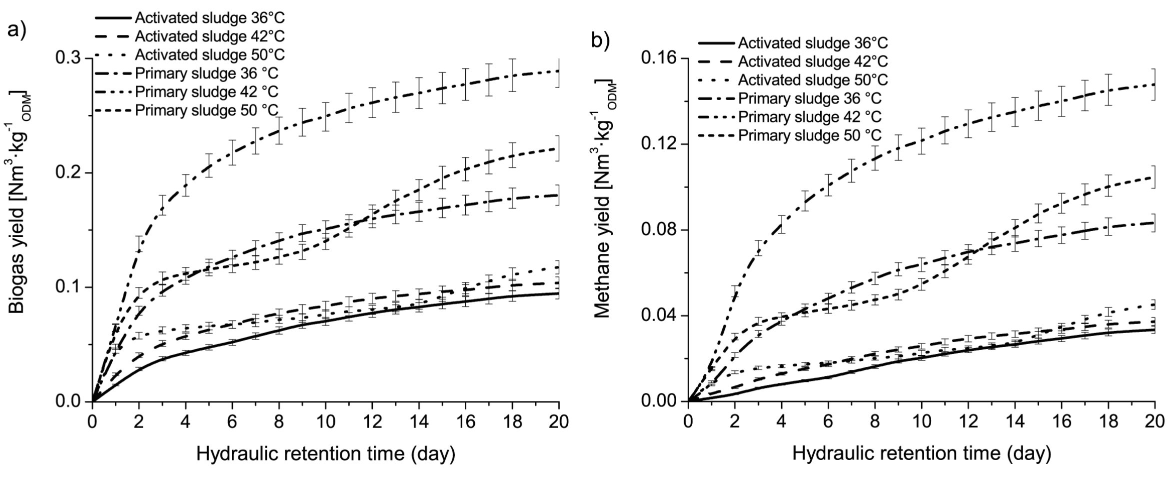
Significant differences among biogas (methane) yield and methane content for different sludge samples and different temperature regime were determined by analysis of variance (ANOVA) at $P < 0.05$ using the Tukey test. STATISTICA 12 software was used.

RESULTS AND DISCUSSION

The sewage sludge samples used for the batch anaerobic fermentation tests were specified by analysing the parameters; dry matter (DM), organic dry matter (ODM), pH, redox potential and the conductivity. The results are reported in Tab. II. The presented results meet the intervals published by other autors (Chobanoglous, 1987; McGhee, 1991; Tchobanoglous *et al.*, 2013).

During anaerobic fermentation of sludge, the biogas production was reported as the volume of biogas at standard conditions, 0 °C and 101,325 Pa, per kg ODM fed in Nm^3 biogas·kg$_{ODM}^{-1}$. Fig. 1a,b shows cumulative biogas (methane) yield course during experiments, when activated and primary sludge were fermented at temperatures of 36 °C, 42 °C and 50 °C.

The primary sewage sludge degradation rate at 42 °C was much faster than the degradation rate at temperature 36 °C and 50 °C (Fig. 1a,b). Trend in biogas (methane) production at 50 °C clearly proves the necessary acclimatization of microbial community to thermophilic conditions. The acclimatization was observed between the fourth and the twelfth day of fermentation test. As it can be seen in Fig. 1a,b the biogas (methane) production after 20 days of hydraulic retention time at different temperature differ significantly. The biogas production after 20 days of hydraulic retention time ranged from 0.181 Nm^3·kg$_{ODM}^{-1}$ at 36 °C to 0.289 Nm^3·kg$_{ODM}^{-1}$ at 42 °C. The methane production after 20 days of hydraulic retention time ranged from 0.083 Nm^3·kg$_{ODM}^{-1}$ at 36 °C



1: *Primary and activated sludge cumulative biogas yield (a) and cumulative methane yield (b) during experiments*

III: *Tukey test of the biogas and methane yield for various sludge and temperatures*

Cell No.	Sludge and process temperature	Biogas yield [Nm^3/kg_{odm}]	Methane yield [Nm^3/kg_{odm}]	1	2	3
1	Activated 36 °C	0.095 ± 0.003	0.033 ± 0.002	****		
2	Activated 42 °C	0.104 ± 0.020	0.037 ± 0.009	****		
3	Activated 50 °C	0.118 ± 0.005	0.045 ± 0.003	****		
4	Primary 36 °C	0.181 ± 0.020	0.083 ± 0.013		****	
5	Primary 50 °C	0.221 ± 0.020	0.105 ± 0.013		****	
6	Primary 42 °C	0.289 ± 0.007	0.148 ± 0.003			****

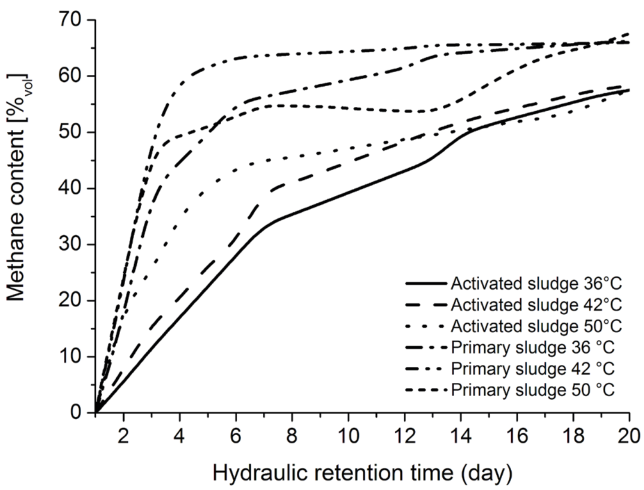
**** significant difference at P = 0.05 level

to 0.148 $Nm^3 \cdot kg_{ODM}^{-1}$ at 42 °C. Results in biogas and methane production when primary sludge is fermented are in correlation with results by Buhr & Andrews (1977) and Metcalf & Eddy (2003). The activated sludge degradation rate was similar for all temperatures 36 °C, 42 °C and 50 °C. As it can be seen in Fig. 1a,b, there was no significant difference in biogas and methane production. The biogas production after 20 days of hydraulic retention time ranged from 0.095 $Nm^3 \cdot kg_{ODM}^{-1}$ at 36 °C to 0.118 $Nm^3 \cdot kg_{ODM}^{-1}$ at 50 °C. The biogas production after 20 days of hydraulic retention time ranged from 0.033$Nm^3 \cdot kg_{ODM}^{-1}$ at 36 °C to 0.045 $Nm^3 \cdot kg_{ODM}^{-1}$ at 50 °C. Results in biogas production are in correlation with results by Buhr & Andrews (1977), Rehm *et al.* (2000) and Bolzonella *et al.* (2005). Tab. III shows the results of Tukey test. In Tab. III can be clearly seen, that there was no significant difference either in biogas or methane production, when activated sewage sludge was fermented. When primary sludge was fermented, significant difference in biogas and methane production was observed only when the sewage sludge was fermented at temperature 42 °C.

During the experiment, methane (CH_4) concentration was determined at [$\%_{vol}$]. The Fig. 2 shows that the temperature significantly influences the course of the methane content in biogas generated from primary or activated sludge.

Temperatures do not affect final methane content in biogas produced either from primary sewage sludge or from activated sewage sludge (Tab. IV). At the end of hydraulic retention time, biogas analysis showed the same methane content in all fermenters processed primary sewage sludge independently on process temperature. Similar situation was observed also in fermenters process activated sewage sludge. Comparable results were reported by Metcalf & Eddy (2003) and Turovskiy & Mathai (2006).

The results obtained show that the temperature in the fermenter significantly affected the production of biogas when samples of primary sewage sludge were fermented. For samples of activated sludge no significant difference in the biogas production at different temperatures was observed. Recently many pretreatment methods for disruption of microbial cell walls of activated sewage sludge were studied (Valo *et al.*, 2004; Hii *et al.*, 2013). Many of these pretreatment methods are showing increasing degradation and biogas production from treated sewage sludge. However, the massive deployment of these methods is hindered due to high investment and operating costs. Thermal pretreatment of the activated sewage sludge seems to be a promising



2: *Methane concentration in biogas generated during fermentation test*

IV: *Tukey test of the methane content in biogas generated after 20 days of experiment for various sludge and temperatures*

Cell No.	Sludge and process temperature	Methane content [$\%_{vol}$]	1	2
1	Activated 36 °C	57.50	****	
2	Activated 50 °C	57.57	****	
3	Activated 42 °C	58.30	****	
4	Primary 42 °C	66.00		****
5	Primary 36 °C	66.23		****
6	Primary 50 °C	67.60		****

**** significant difference at P = 0.05 level

method. Presented results show that temperature raising in the fermenter of anaerobic sewage sludge stabilisation is not promising direction. Taking into account, the results of Bolzonella *et al.* (2005), it is clear that the heating up of the fermenter content to a temperature above 40 °C is not realistic, due to energy balance. Additionally, raising the temperature did not prove the expected result in the higher biogas production from activated sewage sludge, which was confirmed by presented results. Certain way could be a short-term exposure (30 min) of the activated sewage sludge to temperatures of 70 °C–90 °C, with utilization of residual heat for the fermenter heating. This pretreatment is recently extensively studied by many operators of wastewater treatment plants.

CONCLUSION

Tightening legislation, possible future ban on the application of sewage sludge on agriculture land, the toxic substances content, these are problems that must the operators of wastewater treatment plants face with. Composition of sewage sludge has significantly changed in last years, due to changes in the operation of the biological stage of wastewater treatment plants. This fact reduced efficiency of anaerobic sewage sludge stablization. Scientists intensively look for ways to more efficient decomposition of sewage sludge during anaerobic stabilization. One of the perspective methods is thermal sewage sludge pretreatment. The effect of temperature 36 °C, 42 °C and 50 °C in fermenter on the anaerobic sewage sludge stabilization process was investigated. Temperature 42 °C significantly increased biogas production from primary sewage sludge. For activated sewage sludge samples, no significant influence of temperature on the biogas production was observed. Temperature rising in fermentors during the anaerobic sewage sludge stabilization is not real, when consider the operating costs.

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