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Microwave and thermal pretreatment as methods for increasing the biogas potential of secondary sludge from municipal wastewater treatment plants

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HIGHLIGHTS

- ▶ Microwave irradiation and thermal heating as methods for sludge pre-treatment.
- ▶ Microwave irradiation turned out to be superior over thermal pre-treatment.
- ▶ 900 W irradiation showed to be less energy demanding compared to 700 W.
- ▶ Pre-treatment at 70 °C allowed to achieve the highest energy profit.
- ▶ Microwave pre-treatment ensured high degree of sludge sanitation.

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ABSTRACT

In the present study, the sludge was pretreated with microwave irradiation and low-temperature thermal method, both conducted under the same temperature range (30–100 °C). Microwave pretreatment was found to be superior over the thermal treatment with respect to sludge solubilization and biogas production. Taking into account the specific energy demand of solubilization, the sludge pre-treated at 60–70 °C by microwaves of 900 W was chosen for further experiments in continuous mode, which was more energetically sustainable compared to lower value (700 W) and thermal treatment. Continuous biogas reactor experiments indicated that pre-treated sludge (microwave irradiation: 900 W, temperature: 60–70 °C) gave 35% more methane, compared to untreated sludge. Moreover, the results of this study clearly demonstrated that microwave pretreated sludge showed better degree of sanitation.

1. Introduction

Treatment of wastewater in municipal treatment plants (WWTP) is removing the majority of the organic matter, and a part of the organic matter is ending up as sludge. It contains a significant amount of water, organic matter, un-degradable particles and living organisms. Primary sludge consists of the easily-biodegradable matter, which is a suspended particle. While secondary sludge, which is mainly microbial cell biomass, formed by aerobic bioconversion of organic matter in the activated sludge process. The latter process is commonly used as a core process in a majority (approx. 90%) of municipal wastewater treatment plants (WWTP) (Bordeleau and Droste, 2011; Tyagi and Lo, 2011). It is estimated that in WWTPs located in European Union, about 10 million tons of sludge dry matter is generated annually (Tyagi and Lo, 2011). Sludge is a burden to society and methods for its disposal and treatment are of high priority. Among the various treatment methods, anaerobic digestion (AD) is the most frequently used. By anaerobic treatment not only stabilization of the sludge but also utilization of the residual organic matter for production of biogas is achieved. In this process, organic matter (lipids, proteins and carbohydrates) is microbiologically converted under anaerobic methanogenic conditions into biogas (Angelidaki et al., 2011; Mata-Alvarez et al., 2000). The secondary sludge has low biodegradability, as it consists microbial cells agglomerated by extracellular polymeric substances (EPS) and cations resulting in compact flocs. On the contrary, primary sludge is relatively easily biodegradable. Hydrolysis is widely regarded as the rate-limiting step of degradation of particulate organic matter in the secondary sludge. Pre-treatment is required in order to disrupt cell membranes and thus lyse microbial cells in the sludge (Tang et al., 2010; Tyagi and Lo, 2011).

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The application of microwave pre-treatment as a means of improving waste activated sludge: solubilization (Eskicioglu et al., 2009; Park et al., 2010; Park and Ahn, 2011), biogas production (Eskicioglu et al., 2009; Park and Ahn, 2011) and sanitation, i.e. destruction of pathogens (Eskicioglu et al., 2009; Hong et al., 2006) has been mostly investigated in separate studies. According to our knowledge, there is lack of reports describing the influence of microwave pretreatment on both the sludge solubilization/sanitation and efficiency of the subsequent continuous anaerobic digestion, conducted in the same conditions. In addition, efficiency of microwave pre-treatment over thermal treatment to facilitate the biodegradability has not been thoroughly evaluated in the literature. Case studies comparing sludge pre-treatment by means of microwave irradiation and thermal low-temperature treatment are very scarce and usually differ significantly in process conditions. For example, Eskicioglu et al. (2006) achieved twice more biogas after thermal heating, as compared to microwave pre-treatment. However, the increase was ascribed to the 16-fold longer exposure time of oven heating compared to microwave irradiation. In case of long retention times of microwaves, the increase in process effectiveness is considered to be caused by temperature itself, rather than the action of microwaves (Park et al., 2010; Yu et al., 2010). Moreover, the sludge contains diverse microorganisms and among them significant amount of pathogens, such as *Giardia* spp., enteroviruses, helminthes or bacteria (*Escherichia coli*, *Salmonella* spp. or *Campylobacter* spp.) (Gantzer et al., 2001; Rimhannen-Finne et al., 2004). Pathogens, present in sewage, are frequently transferred to sludge during treatment processes, where their concentration can be even higher, as compared to raw sewage (Lasobras et al., 1999). It is commonly known that AD process conducted in mesophilic conditions usually does not ensure complete elimination of pathogens. Therefore, both, raw and digested sludge are considered as potential sources of pathogens. That is the reason why sludge sanitation should also be taken into account, for assessing the sludge pre-treatment method. The microwave pre-treatment turned out to be an effective method of coliforms removal (Dańczuk and Łomotowski, 2010; Hong et al., 2006); however, its impact on heat-resistant *Clostridium perifingers* after following continuous AD, to our knowledge, has never been studied.

Therefore, the aim of this study was to assess the effectiveness of sludge pre-treatment by means of microwave irradiation and low-temperature treatment, both conducted at the same temperature range (30–100 °C) with respect to release of organic and inorganic substances as well as their efficiency in increasing the methane potential. The assessment of the most appropriate conditions for pre-treatment was mainly based on the sludge solubilization relative to energy consumption and energy demand/profit of the process conducted in batch tests. To verify the increased digestibility achieved in batch tests, the sludge was anaerobically digested in continuous reactor experiments. The impact of the pre-treatment as means of increasing the methane potential as well as ensuring higher sludge sanitation (*Salmonella* spp., *E. coli* and *Clostridium perifingers*) was evaluated.

2. Methods

2.1. Feedstock

The waste activated sludge (WAS) was taken after thickening from a full scale municipal plant treating domestic and industrial wastewaters (Silesian district, Poland), based on enhanced biological nutrients removal (EBNR) and operated on activated sludge method. The industrial wastewater fraction constitutes up to the 10% of the total influent and is mechanically pre-treated before mixing with domestic wastewater. The feedstock has been taken eight times in total; five samples between April and July 2011 (no. 1–5) and three times between August and September (no. 6–8). The samples no. 1–5 were used for pre-treatment, while samples no. 6–8 for digestion conducted in continuous tests. Table 1 presents the physical and chemical properties of the waste activated sludge.

2.2. Pre-treatment methods

The microwave sludge treatment (MW) was performed using a laboratory unit equipped with 700 W and 900 W power generators; frequency of 2.45 GHz. Thermal pre-treatment method (TM) was performed in closed steel vessels, equipped with a heating coil (900 W). Inside the pre-treatment vessels, a probe installed could monitor the actual temperature of the sludge treated. The volume of sludge treated in one run amounted to 1 dm^3 (5×200 ml). The temperature of the sludge was gradually increased by 10 °C in the range of 20 °C to ~100 °C. After the samples had reached the wished temperature, they were cooled down to about 10 °C and used as a feedstock. The sludge pre-treatment was replicated five times in case of each method (microwave 700 W, microwave 900 W, thermal method). The exposure times of pre-treatment agents were expressed as mean values ($n = 5$) with standard deviations. Table 2 presents applied exposure times of pre-treatment agents.

Table 1
Characteristics of the feedstock (mean values, ±standard deviation).

Parameter	Unit	Sewage sludge	
		Sample no. 1–5	Sample no. 6–8
pH	–	6.3 ± 0.3	6.2 ± 0.2
TS	%	5.27 ± 0.17	5.30 ± 0.11
VS	%	3.71 ± 0.16	3.72 ± 0.12
VFA	mg/dm^3	655 ± 168	352 ± 72
TKN	% TS	4.96 ± 0.11	n.d.
NH_4^+	mg/dm^3	15.8 ± 3.5	13.5 ± 1.3
PO_4^{3-}	mg/dm^3	145 ± 33	165 ± 20
SCOD	mgO_2/dm^3	247 ± 52	226 ± 24
TCOD	mgO_2/dm^3	22520 ± 1890	21602 ± 942
Soluble protein	mg/dm^3	122 ± 22	128 ± 15
Ca^{2+}	mg/dm^3	58.5 ± 4.5	n.d.
Mg^{2+}	mg/dm^3	26.5 ± 3.5	n.d.

n.d. – not determined.

Table 2
Exposure times of pre-treatment methods applied (mean values $n = 5$, ±standard deviation).

Temperature, °C	Microwave treatment (MW) 700 W	Microwave treatment (MW) 900 W	Thermal treatment (TH) 900 W
	Exposure time (s)		
30	75 ± 4	58 ± 3	95 ± 5
40	128 ± 7	87 ± 5	145 ± 6
50	184 ± 5	122 ± 5	225 ± 7
60	254 ± 5	171 ± 6	292 ± 8
70	341 ± 7	212 ± 5	365 ± 8
80	393 ± 6	252 ± 6	445 ± 9
90	413 ± 5	283 ± 6	476 ± 8
~100	429 ± 6	311 ± 5	493 ± 7