

Application of ultrasonic disintegration to waste activated sludge for increasing of biogas production by anaerobic digestion

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Proceedings Paper

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Abstract

The municipal wastewater treatment is the source of significant amounts of primary and secondary sludge, which is under the present legislation referring to quality and management aspects. It is estimated that half of wastewater treatment plant costs are due to the sludge management. Anaerobically sludge stabilization, capitalization as an energy source, to diminish the costs and sludge volume decreasing, are the aims of the main operational steps of sludge treatment, as a part of wastewater treatment plant. The improvement of sludge anaerobically stabilization process must be possible by acting in the rate-limiting step - hydrolysis to rise the organic carbon solubilization. The increase of soluble carbon can be possible by adding a pretreatment step of waste biological sludge, ultrasonic disintegration being one option. This paper emphasized the experimental results regarding anaerobically stabilization of the thickened waste biological sludge by ultrasonication taking into account the results of the blank test, without ultrasonication. Experimental tests show that ultrasonic disintegration of the sludge having initial dried substances content (d.w) 2.72% and soluble organic load COD of 598 mg O₂/L led to soluble COD concentration of 4950-6710 mg O₂/L after sonication with a specific energy in the range of 3.06 - 14.24 kWh/kg d.w. Anaerobically stabilization during 25 test days at 36°C of the mixture 40% disintegrated biological sludge and 60% digested sludge (inoculum) mixture led to 30-38.6% increase of biogas production comparing with parallel test with non-sonicated sludge.

Keywords: waste activated sludge, ultrasonic disintegration, anaerobically sludge digestion, biogas production

INTRODUCTION

Large amount of sludge is generated by municipal wastewater treatment plants (MWWTPs) as primary and waste activated sludge from primary and secondary sedimentation steps.

The MWWTP sludges have 95-99% water content, the heterogeneous mixture having both solids in suspensions and colloidal system. The solids substances of these sludges are 65-75% organics being fermentable in aerobic or anaerobic conditions [1].

The treatment of MWWTP sludge must be done to diminish pathogens, strong odours, the volume/weight, to improve dewatering properties and to generate energy from biogas production, after anaerobically sludge digestion treatment phase [2, 3].

Anaerobically digestion with biogas generation is the best option in case of medium and big wastewater treatment plants. Anaerobically

stabilization is the process of biodegradable organic matter transformation into CH₄ (60-70%) and CO₂ [4]. Anaerobically fermentation consists of four main steps: hydrolysis and solubilization of organic matter, acidogenesis, acetogenesis (transformation of acidogenesis product into acetate) and methanogenesis (biogas generation from acetates, 65-75% of biogas production, and from H₂ + CO₂ reaction) [3, 5].

The biogas production can be improved if the sludge is pre-treated before anaerobic digestion. The main pre-treatment methods of the sludge are as following [6, 7]:

- thermal: by heating the sludge to 90°C (approx. 1 h) and cooling it after to the digestion selected temperature;
- chemical or electrochemical: Fenton oxidation leads to better nitrogen removal and higher biogas production as well as

alkaline digestion [8];

- mechanical: improve the solubilization of organic matter and dewatering properties;
- ultrasonic: very efficient for organics solubilization because of mechanical (ultrasonic waves) and chemical oxidation effects (ultrasonic cavitation/sonolysis);
- hybrid methods: put together the advantages of above-mentioned methods (e.g. ultrasonics + Fenton oxidation).

Most of the sludge organic matter is insoluble and cannot be assimilated by specific microorganism in the anaerobic digestion step. Ultrasonication is one of the sludge pretreatment methods for organic load (COD or/and BOD indicators) solubilization with direct influence in biogas production increase

EXPERIMENTAL PART

The experimental tests were performed to establish the influence of ultrasonic energy to biogas production after anaerobic fermentation.

There were two experimental stages:

- ultrasonication of thickened waste activated sludge into ultrasonic reactor model SONICS Vibra Cell (Fig.1);



Fig. 1. Ultrasonic reactor

The main operational conditions for ultrasonic pretreatment were as following:

- sludge samples were mixtures of thickened waste activated sludge (BS) and fermented sludge (FS noculum):
 - BS: $COD_{\text{homogeneous}} = 29040 \text{ mg O}_2/\text{L}$, $COD_{\text{dissolved}} = 598 \text{ mg O}_2/\text{L}$, dried substances

[4, 9].

Ultrasonic pre-treatment of the sludge can be done directly or after pH correction (alkaline ultrasonic method) [3, 10].

The main parameters of ultrasonic pretreatment process are sludge composition (solid substances content, COD and BOD of heterogeneous phase and dissolved phase, metals, ammonia etc), ultrasonic frequency, ultrasonic energy and amplitude, sonication time, ultrasonication equipment (tank with an ultrasonic source inside the walls, tank with multiple ultrasonic probes) pH and temperature control system [1, 4].

The following experimental will demonstrate the effect of sludge ultrasonic disintegration to anaerobically digestion efficiency.

- anaerobically digestion of three ultrasonicated sludge samples and one blank sample (non-ultrasonicated) using a battery tests equipment model Puls Flow Respirometer PF 8000 placed inside the incubator - shaker (Brunswick Scientific - Innova 44, Fig. 2).



Fig. 2. Anaerobically digestion battery tests

(d.w.) content = 2.72%, volatile substances content = 72.3%

- FS: $COD_{\text{homogeneous}} = 22000 \text{ mg O}_2/\text{L}$, $COD_{\text{dissolved}} = 554 \text{ mg O}_2/\text{L}$, dried substances (d.w.) content = 2.13%, volatile substances content = 61.3%

- ultrasonic frequency was constant for all

samples: 20 kHz;
 - ultrasonic amplitude was constant for all samples: 100%;
 - specific ultrasonic energy applied: 3.06÷14.24 kWh/kg d.w.;

Anaerobically fermentation was performed to 36°C with continuous shaking (800 rpm) during 25 days and the operational parameters are presented below:

- bioreactor M (1 L) - blank test: 0.4 L BS (non-ultrasonicated) + 0.6 L of FS,

- bioreactor B1 (1 L) - test: 0.4 L BS after ultrasonication to 11016 kJ/kg d.w. (3.06 kWh/kg d.w.) + 0.6 L of FS,

- bioreactor B2 (1 L) - test: 0.4 L BS after ultrasonication to 22 032 kJ/kg d.w. (7.12 kWh/kg d.w.) + 0.6 L of FS,

- bioreactor B3 (1 L) - test: 0.4 L BS after ultrasonication to 44 024 kJ/kg d.w. (14.24 kWh/kg d.w.) + 0.6 L of FS.

RESULTS AND DISCUSSION

The influence of ultrasonic energy to organic load solubilization and biogas production was investigated.

The influence of ultrasonic energy on dissolved COD

The ultrasonic effect to COD solubilization and volatile substances of biological sludge (BS) consists of a significant increase of COD_{dissolved} along with decreasing of volatile substances (v.s.) content (Table 1).

The organic load (COD) in soluble form

increase constantly with ultrasonic energy doubling being 6700 mg O₂/L in case of US3 sample (over 11 times higher with initial BS). The decrease of dried and volatile substances content was about 9 and 8%, respectively.

Table 1. The influence of ultrasonic energy on dissolved organic load (COD_{dissolved}), dried and volatile substances content in ultrasonication stage

Sample	Specific US energy (kWh/kg d.w.)	COD _{homogeneous} (mg O ₂ /L)	COD _{dissolved} (mg O ₂ /L)	d.w. (%)	v.s. (% x d.w.)
BS	0	29 040	598	2.72	72.33
US1	3.06	22 900	4950	2.56	67.30
US2	7.12	21 950	6040	2.53	66.70
US3	14.24	19 800	6710	2.48	66.47

The influence of ultrasonic energy on biogas production

Ultrasonic pretreatment of biological sludge acts to hydrolysis step to dissolve solid organic matter. The specific microorganism can eat organic matter only in dissolved phase so, ultrasonic pretreatment increases the access to a concentrated “soup” leading to a more performant anaerobically digestion and in consequence, a higher volume of biogas.

Table 2 shows the organic load, dried and volatile substances levels before and after anaerobically digestion of ultrasonicated sludge mixture (40% ultrasonicated biological sludge +

60% inoculum) - bioreactors B1, B2, B3, and one non-sonicated sample of M bioreactor.

The dissolved organic load decrease after anaerobic digestion for each bioreactor having pretreated biological sludge (B1-B3) because of transformation into biogas. This transformation involved 10.5 - 28.5% of dissolved matter as COD soluble. The same evolution was for dried and volatile substances concentrations, where the decrease were about 12 and 11%, respectively.

Table 2. The influence of ultrasonic energy on dissolved organic load (COD_{dissolved}), dried and volatile substances content in anaerobically digestion stage

Bioreactor	Specific US energy (kWh/kg d.w.)	Initial COD _{dissolved} (mg O ₂ /L)	Final COD _{dissolved} (mg O ₂ /L)	Initial d.w. (%)	Final d.w. (%)	Initial v.s. (% x d.w.)	Final v.s. (% x d.w.)
M	0	570	1496	2.35	2.01	64.48	57.80
B1	3.06	2310	2068	2.30	2.01	63.71	56.85
B2	7.12	2750	2156	2.29	2.01	63.48	56.70
B3	14.24	3014	2156	2.27	1.99	63.38	56.35

Table 3 and Figure 3 emphasized the increase of biogas production and decrease of volatile substances amount after anaerobic digestion.

Table 3. The influence of ultrasonic energy on dissolved organic load (COD_{dissolved}) and volatile substances amount in anaerobically digestion stage

Sample	Volatile substances diminishing (%)	Biogas production (mL)	Specific biogas production, m ³ /kg v.s. diminishing	Increase of biogas production toward M bioreactor (%)
M	23.33	3326	1.045	0
B1	22.02	3946	1.359	30.04
B2	21.60	3958	1.400	33.97
B3	22.06	4136	1.448	38.56

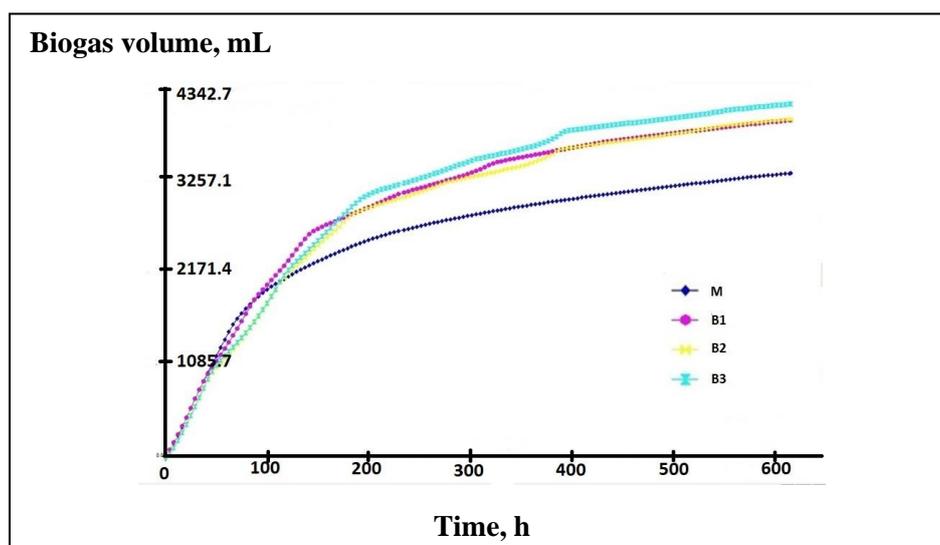


Fig. 3. The evolution of biogas production during 25 days of anaerobic fermentation

The analyses of experimental data highlighted the following:

- the amount of the volatile substance decreases with 22-23 %, for all bioreactors,
- the biogas production (from 1 L initial sludge mixture) was higher than M reactor for all the bioreactors having initial ultrasonic pretreated sludge content (40 %); bioreactor B3 produced 24% more biogas (4 136 mL) than M reactor (3 326 mL),
- specific biogas production for B1-B3 test reactors was in the range of 1.36-1.45 m³/kg comparing with 1.04 in case of blank reactor M,
- the increase of biogas production for B1-B3 referring to M was 30% for B1 - the lower specific ultrasonic energy (3.06 kWh/kg d.w.) and 38% for B3 - the highest specific ultrasonic energy (14.24 kWh/kg d.w.).

CONCLUSIONS

Experimental tests were performed to quantify the influence of ultrasonic pretreatment of waste activated sludge to the efficiency of the following sludge treatment step - anaerobically digestion. Three main parameters have been chosen to describe the experimental results: organic load as chemical oxygen demand (COD) indicator (especially in soluble phase), dried and volatile substances content (d.w. and v.s.) and the biogas volume generated during 25 days of anaerobic digestion.

These process indicators were feasible instruments to describe both ultrasonic pretreatment stage (ultrasonication with three different specific US energies (3.06÷14.24 kWh/kg d.w.) and anaerobically digestion steps.

The biogas production was 30% higher in case of bioreactor having biological sludge with lower applied specific ultrasonication energy 3.06 kWh/kg d.w. comparing with blank bioreactor (no ultrasonication before fermentation). 38% higher was the biogas production for the highest ultrasonic energy (14.24 kWh/kg d.w.) but can be considered that 8% more biogas doesn't justify this higher energy consumption.

These preliminary tests prove that ultrasonic disintegration appears as a promising waste activated sludge pretreatment method for biogas production increase by anaerobic digestion, but a cost-benefit analysis is necessary to prove its feasibility.

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