Modern Biogas Generation Method Based on Ultrasonic and Anaerobic Fermentation of Municipal Wastewater Biological Sludge

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Classical biogas generation during the municipal wastewater treatment flow is based on anaerobically fermentation of biological sludge.The efficiency of organic matter conversion into higher biogas volume depends on organic load (COD/BOD) of active biological sludge, especially in soluble form. Soluble COD amount can be rise by non-conventional pretreatment methods as ultrasonic application. Ultrasonic pretreatment of biological sludge increases the amount of biogas from anaerobic digestion phase comparing with traditional process. This paper shows the influence of ultrasonic field on biological sludge fermentation. Ultrasonic treatment step was performed in a field, in a medium size wastewater treatment plant, at industrial pilot scale level using biological sludge, before anaerobic fermentation phase. Laboratory fermentation tests have proved that ultrasonic pretreatment lead to biogas higher production with 84%.

Keywords: ultrasonic, wastewater treatment plant, biological sludge, anaerobic, biogas

The management of biological sludge is a very important part of any municipal wastewater treatment plant activity. There are two main ways for biological sludge stabilization: aerobic method which is usually used in case of small waste water treatment plants and anaerobic fermentation [1]. Anaerobic fermentation is applied in medium and large municipal wastewater treatment plant for biogas production [2, 3]. The volume and the quality of biogas are very important during the year depending on biological sludge quality, season, processes previously applied for wastewater treatment.

In this context, ultrasonic treatment represents a feasible method to improve the biological sludge quality before anaerobic digestion [4, 5].

The main effect of ultrasonic field on biological sludge is solubilization of organic content because of mechanical and cavitation processes. This is very important for anaerobic digestion because after ultrasonic treatment the microorganism developed in the fermentation tank have a better organic "soup" in order to develop and to generate biogas. Previously experiments prove that solubilization degree (SD) and disintegration degree (DD), as a measure of ultrasonic action on COD sludge evolution, increase and depend on ultrasonic parameter, reaction time and biological sludge composition [6,7].

This paper represents the results of ultrasonic pre-treatment tests of biological sludge using an industrial ultrasonic pilot installation followed by anaerobically digestion phase in a laboratory pilot installation.

Experimental part

Ultrasonic pilot installation was used for biological sludge pretreatment. The main characteristics were: ultrasonic constant frequency 20 kHz, flow rate 0.35 m^3/h, energy power 1 kW, sludge tank volume 1 m^3, automatic control, and possibility to recirculate de sludge in order to assure selected energy values. Figures 1 shows the ultrasonic treatment unit located very close to the sludge thickener of wastewater treatment plant.

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Fig. 1. Ultrasonic mobile pilot installation

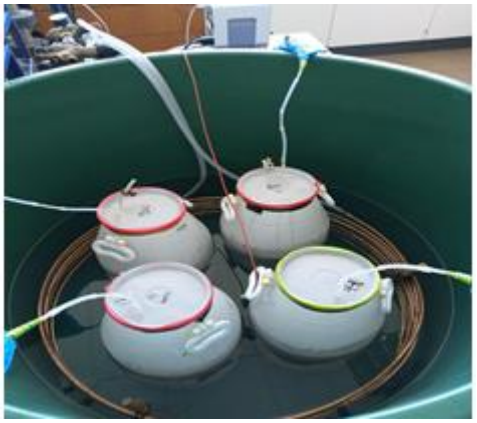

Fig. 2 Laboratory pilot for anaerobically fermentation of biological sludge

The efficiency of ultrasonic pretreatment was evaluated based on organic load (COD), solubilization degree - SD (eq. 1) and disintegration degree - DD (eq. 2). Dry matter (d.m.) and volatile matter (v.m.) content were also motorized.

$$SD = \frac{(soluble\ \ COD\ after\ US - soluble\ COD\ before\ US)}{homogeneous\ phase\ COD\ before\ US} x100 \quad (1)$$

$$DD = \frac{(soluble\ \ COD\ after\ US - soluble\ COD\ before\ US)}{homog.\ \ COD\ before\ US - soluble\ COD\ before\ US} x100 \quad (2)$$

Only biological sludge was ultrasonicated. For anaerobically digestion experiments (Fig. 2), a mixture of ultrasonicated biological sludge (USS) - for three ultrasonicated sludge - USS1 (1672 kJ/kg dry matter), USS2 (10033 kJ/kg dry matter), USS3 (20066 kJ/kg dry matter) and non-ultrasonicated biological sludge - just for blank fermentation test (BS), primary sludge (PS) and already anaerobically digested sludge (DS - for laboratory bioreactors seeding). The ratio between these types of sludge was similar to real ratio, inside the fermentation tanks of wastewater treatment plant.

The experimental conditions for ultrasonic pilot treatment tests were as following:

-ultrasonication of biological sludge (BS) samples, pH ~ 6.7;

-ultrasonic frequency: 20 kHz (constant for all samples);

-ultrasonic total energy: 836÷20066 kJ/kg d.m.;

-ultrasonic amplitude: 100% (constant)

The operational conditions for anaerobically sludge digestion for 4 anaerobically digestion tests (table 1) were: 29 days of anaerobically digestion tests; bioreactor temperature control, 36-37 ^{0}C; daily sampling of biogas for methane concentration determination and biogas collection/remove for volume measurement.

Table 1

THE BIOREACTORS SLUDGE COMPOSITION AND CORRESPONDING ULTRASONIC ENERGY

Bioreactors	Ultrasonic specific energy, kJ/kg d.m.	Sludge mixture
M (blank)	no ultrasonic pretreatment	9 L BS + 3 L PS + 3 L DS
F1	1672	9 L USS1 + 3 L PS + 3 L DS
F2	10033	9 L USS2 + 3 L PS + 3 L DS
F3	20066	9 L USS3 + 3 L PS + 3 L DS

Results and discussions

Two classes of experimental test are performed, such as: ultrasonic treatment and anaerobically digestion tests.

Ultrasonic pre-treatment of biological sludge

Previously laboratory tests emphasized that ultrasonic energy is the main operating parameter of organic load solubilization. Table 2 and Figure 3 show the variation of soluble and total organic load (COD) and SD/DD evolution with ultrasonic energy increase.

Table 2
ULTRASONIC ENERGY INFLUENCE OF DISSOLVED ORGANIC LOAD

Sample	Ultrasonic specific energy, kJ/kg d.m.	SD, %	DD, %
BS (initial)	-	-	-
1	836	5.16	5.36
2	1672	11.29	11.74
3	3344	20.32	21.14
4	10033	34.83	36.24
5	20066	36.87	38.35

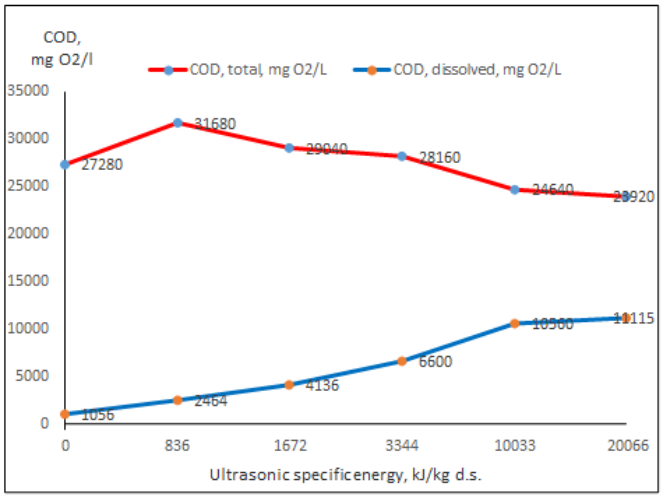

Fig. 3. Ultrasonic energy influence of organic load solubilization

These experimental data lead to the few main conclusions which were determinant for the pretreatment of sludge samples before anaerobically digestion phase:

-dissolved organic load increases with one magnitude order for samples 4 (COD 10560 mg O_2/L) and 5 (COD 11115 mg O_2/L) in case of higher ultrasonic energies 10033 and 20066 kJ/kg d.m.;

-dissolved COD at 20066 kJ/kg d.m. ultrasonic energy (sample 5) is two times higher than 3344 kJ/kg d.m., close to 10560 value which corresponding to 10033 kJ/kg d.m. (sample 4);

-disintegration degree and solubilization degree increase with ultrasonic energy approximately 7 times higher to 20066 kJ/kg d.m. (SD = 37%, DD = 38%) comparing with lower energy of 836 kJ/kg d.m..

Anaerobically digestion tests

The goal of anaerobically fermentation tests was to confirm the efficiency of ultrasonic pre-treatment of biological sludgy for the biogas production. New biological sludge volume was ultrasonic pre-treated before anaerobically digestion, taking into account previously ultrasonic tests.

Three pre-treated biological sludge samples were selected for anaerobically digestion. The main characteristics of test sludge samples are synthesized in table 3.

Table 3
BIOLOGICAL SLUDGE CHARACTERISTICS AFTER ULTRASONIC PRETREATMENT

Sample	Ultrasonic specific energy, kJ/kg d.m.	COD homogeneous, mg O_2/L	COD dissolved, mg O_2/L	d.m., %	v.m., %
BS	-	22000	1038	2.37	72.23
USS1	1672	22880	3212	2.32	71.09
USS2	10033	23760	7304	2.31	71.62
USS3	20066	24230	9680	2.29	71.48

These four treated sludge samples were put into bioreactors: BS-bioreactor M, USS1-bioreactor F1, USS2-bioreactor F2, USS3-bioreactor F3. Table 4 shows the main characteristics of biological sludge mixture at the beginning of anaerobically fermentation and table 5 after anaerobically fermentation.

Table 4
SLUDGE MIXTURE CHARACTERISTICS BEFORE ANAEROBICALLY FERMENTATION

Bioreactor	COD homogeneous, mg O_2/L	COD dissolved, mg O_2/L	d.m., %	v.m., %
M	32720	1892	3.05	72.78
F1	33440	2816	3.14	71.63
F2	34320	5016	3.09	71.15
F3	34895	6248	3.06	70.74

Table 5
SLUDGE CHARACTERISTICS AFTER ANAEROBICALLY FERMENTATION

Bioreactor	COD homogeneous, mg O_2/L	CODdissolved, mg O_2/L	Total methane production, L	d.m., %	v.m., %
M	26830	4576	48.3	2.23	60.33
F1	27280	5280	48.0	2.38	60.22
F2	28160	7744	85.6	2.36	61.67
F3	29040	8096	89.1	2.19	60.10

After 29 days monitoring of biogas volume and methane content in each test bioreactors (ultrasonic pretreatment) and blank reactor M the main observations are:

-the higher level of dissolved organic load was in case of F2 an F3 bioreactors: 7744 mg O_2/l and 8096 mg O_2/l twice higher than M reactor (4576 mg O_2/L);

-the volatile substances conversion into biogaz was ~ 10%;

-the volume of methane production was higher for higher energy corresponding to 10033 kJ/kg d.m. and 20066 kJ/kg d.m. respectively;

-the methane volume was with 84% higher in case of ultrasonicated sludge sample (bioreactor F3) than non-sonicated sample (bioreactor M).

Conclusions

Ultrasonic pretreatment of biological sludge for increase the biogas/methane production in anaerobically digestion process (treatment step of biological sludge of medium and big wastewater treatment plants) has the main advantages taking into account energy saving of classical municipal wastewater treatment plant:

- dissolved organic load (dissolved COD) increase with one magnitude order after ultrasonic pre-treatment of biological sludge in case of 10033 - 20066 kJ/kg d.m. applied ultrasonic energy;

- as a consequence of ultrasonic pre-treatment, the biogas production increase with 77-84% in anaerobically biological digestion phase, if the sludge was treated before with ultrasonic field with energy domain 10033-20066 kJ/kg d.m..

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