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Desalination 222 (2008) 374–381

DESALINATION

www.elsevier.com/locate/desal

Influence of excessive sludge conditioning on the efficiency of anaerobic stabilization process and biogas generation

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Received 4 January 2007; accepted 13 January 2007

Abstract

In the paper the problem of excessive sludge anaerobic stabilization process intensification by combined pretreatment method i.e. alkaline hydrolysis and ultrasonic field active action was discussed. Combination of the mentioned methods, base on different mechanisms of action allow to obtain high pretreatment efficiency i.e. essential increase of sludge disintegration degree and the course of sludge anaerobic stabilization process.

The fermentation processes having periodical character were conducted in the laboratory scale in the mesophilic conditions in the eight laboratory bulbs being models of fermentation chamber as well as in the fermentation chamber of Applikon. Process of alkaline pretreatment was conducted in the ambient temperature, in the time of 24 h and in the hermetic plastic bottles of 5 dm^3 volume. The following solid hydroxides were applied: $Mg(OH)_2$, $Ca(OH)_2$, KOH and NaOH. The supersonic disintegrator UD–20 (TECHPAN Warsaw, Poland) was used, with a ceramic transducer and power output of 180 W. The used waves has the frequency of ca. 22 kHz. Applied sonification time was of 30 ÷ 480 s and the vibration amplitude was of 8 ÷ 16 μm.

In anaerobic stabilization process of excessive sludge after alkaline pretreatment aided with ultrasonic field for about 2-time increase of volatile solids reduction was obtained. Sludge pretreatment intensified the biogas production of about 4-time, as compared to untreated sludge. The connection of alkaline hydrolysis and active ultrasonic field action has influence on the high effectiveness of excessive sludge stabilization process.

Keywords: Excessive sludge; Alkaline conditioning; Ultrasonic field; Anaerobic stabilization; Biogas

1. Introduction

To increase anaerobic stabilization, excessive sludge is subjected to processes of initial conditioning, which rely on different mechanisms of action. The common feature of different methods of preparing is their influence on structure changes as well as sewage sludge physicochemical transformations, determining the increase of sludge biodegradability rate.

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Presented at the conference on Desalination and the Environment. Sponsored by the European Desalination Society and Center for Research and Technology Hellas (CERTH), Sani Resort, Halkidiki, Greece, April 22–25, 2007.

doi:10.1016/j.desal.0000.00.000

The rate of excessive sludge biodegradability is particularly slow and hydrolytic reactions are considered as limiting factor of decomposition of organic matter included in sludge [1].

The results of actually conducted research indicate that the rate of transformation in anaerobic stabilization process depends on the sort and accessibility of substrate submitted to stabilization.

According to Zielewicz-Madej and Fukas-Plonka as well as Choi and others [2,3] an increase of organic matter accessibility yield to biochemical decay is the factor, which influences an anaerobic stabilization efficiency.

Excessive sludge pretreatment contributed to the essential increase of their susceptibility to biodegradation.

Ultrasonic field conditioning of excessive sludge causes, besides biomass break-up, destroying microbial cell walls and cytoplasm releasing as well as cell enzymes. These substrates in the liquid and colloid state become available to anaerobic degradation [4].

The increase of total organic dissolved solids concentration indicates better accessibility for microorganisms responsible for decay of organic matter, which results in reduction of the following phases of fermentation process time occurrence [5–7].

According to Marcinkowski [8] during the process of chemical pretreatment, in the result of proceeding reaction changes, the modification of prepared medium is observed.

Reagents introduced to the sludge during chemical pretreatment, which are involved in chemical reactions with organic compounds, contributing to the changes of physicochemical features of sludge. Among existing chemical methods of preparing, excessive sludge conditioning with suitable alkalis deserves attention. The supernatant of sludge submitted to alkaline pretreatment process is characterized with the significant increase of organic dissolved solids concentration in reference to supernatant of unprepared sludge. The increase of organic matter concentration in the dissolved form is the result of processes of hydrolysis and digestion of such compounds as: proteins, lipids, carbohydrates occurring during chemical pretreatment. In the alkaline pretreatment medium, reactions such as saponification of uronic acids and acetyl esters, reactions occurring with free carboxylic groups and neutralization of various acids formed from the degradation of particular materials take place [9]. According to the theory of Baldwin [10] reactions of hydrolysis catalyzed by enzyme can be conducted in the similar way by means of diluted bases.

2. Materials and methods

The periodical methane fermentation processes were conducted in the laboratory scale, in the mesophilic conditions in eight laboratory flasks, which were models of fermentation tanks, as well as in the sludge digestion chamber.

The ultrasonic pretreatment process of sewage sludge was conducted with the usage of ultrasonic disintegrator with immersing concentrator of “sandwich” type. The ultrasonic generator, of the maximum output power 180 W, produced frequency of ca. 22 kHz for the constant field intensity.

The volume of pretreated sample was 0.5 dm^3 and ultrasonic conditioning took place in the non-flowing system. The following parameters of sonification were applied:

- vibration amplitude $A = 8, 10, 12, 14, 16$ µm;
- time of exposition $t = 30 \div 480$ s.

The alkaline pretreatment process of sewage sludge was conducted in the ambient temperature, in the time of 24 h and in the hermetic plastic bottles of 5 dm^3 volume. To conduct the alkaline pretreatment of sewage sludge the following analytically pure hydroxides in the solid state, such as: $Mg(OH)_2$, $Ca(OH)_2$, KOH, NaOH in the powdery and granular form were applied.

Sewage sludge was taken from the waste water treatment plant of the daily inflow of sewage about 65,000 m^3.

Excessive activated sludge, which was the main substrate of research, was taken from the pipeline transporting the sludge into the mechanical thickener. Digested sludge which fulfilled the role of *inoculum* was taken from the pipeline transporting sludge from separated closed digestion chamber to separated open digestion chamber.

The general characteristic of investigated sewage sludge was shown in the Table 1.

To simplify the comparison and assessment of obtained results the following determination were introduced:

- M — mixture of excessive and digested sludge,
- A — alkaline pretreatment of sludge with sodium hydroxide,
- UD — ultrasonic pretreatment of sludge,
- A + UD — alkaline pretreatment of sludge aided with ultrasonic field.

On the basis of initial research concerning only alkaline conditioning as well as the alone ultrasonic conditioning determined the best conditions of preparing. For the most effective vibration amplitude, in the case of effective ultrasound field action, the amplitude of $A = 16$ μm and the 300 s time of exposition was chosen. In the case of alkaline conditioning among reagents (taking into consideration range of doses 0.1 ÷ 1.8 g/g VS) sodium hydroxide of 0.6 g/g VS dose was considered as the most effective. During the next stage of research, the excessive sludge, in was prepared with sodium hydroxide in the range of doses of 0.1 ÷ 0.6 g/g VS. It was done to assess the aiding action of ultrasonic field on the efficiency of alkaline conditioning.

Therefore, for the all conducted processes of the methane fermentation the following mixtures of excessive and digested sludge, respectively in the volume ratio 10 to 1, were created:

- $M_{(8)}$ — nontreated sludge submitted 8-day anaerobic stabilization,
- $M_{(28)}$ — nontreated sludge submitted 28-day anaerobic stabilization,
- $M_{(8)}A_{0.1 \div 0.6}$ — sludge after alkaline pretreatment with doses 0.1 ÷ 0.6 g NaOH/g VS and stabilized anaerobically for 8 days,
- $M_{(28)}A_{0.1 \div 0.6}$ — sludge after alkaline pretreatment with doses 0.1 ÷ 0.6 g NaOH/g VS and stabilized anaerobically for 28 days,
- $M_{(8)}UD$ — ultrasonic-pretreated sludge submitted 8-day anaerobic stabilization,
- $M_{(28)}UD$ — ultrasonic-pretreated sludge submitted 28-day anaerobic stabilization,
- $M_{(8)}A_{0.1 \div 0.6}$ + UD — sludge pretreated with combined method i.e. alkaline pretreatment respectively in the range of doses 0.1 ÷ 0.6 g NaOH/g VS aided with ultrasonic field submitted 8-day anaerobic stabilization.
- $M_{(28)}A_{0.1 \div 0.6}$ + UD — sludge pretreated with combined method i.e. alkaline pretreatment respectively in the range of doses 0.1 ÷ 0.6 g NaOH/g VS aided with ultrasonic field submitted 28-day anaerobic stabilization.

Table 1
The general characteristic of investigated excessive and digested sludge

Kind of sludge	Indicators and parameters			
	Hydration (%)	Dry matter (g/dm^3)	Organic dry matter (g/dm^3)	Mineral dry matter (g/dm^3)
Excessive sludge	98.64 ÷ 98.87	11.35 ÷ 13.65	8.09 ÷ 9.52	3.26 ÷ 4.13
Digested sludge	97.43 ÷ 98.09	19.11 ÷ 25.71	12.51 ÷ 16.2	6.6 ÷ 9.51

Table 2
The influence of sodium hydroxide dose on concentration organic matter in the supernatant of excessive sludge pretreated with combined method i.e. alkaline aided with ultrasonic field

Dose NaOH	$COD_{nonprepared}$	$COD_{prepared\ NaOH+UD}$	$COD_{nonprepared}/COD_{prepared\ NaOH+UD}$
g NaOH/g VS	mgO_2/dm^3	mgO_2/dm^3	mgO_2/dm^3
0.1	112	2858	1/26
0.2	112	3730	1/33
0.3	112	4765	1/43
0.4	112	5578	1/50
0.5	112	5979	1/53
0.6	112	6033	1/54

3. Results and discussion

The operational parameters of associated method conditioning were selected on the basis of preliminary tests results concerning the choice of the most advantageous parameters of alkaline and ultrasound conditioning. During alkaline pretreatment aided with ultrasonic field with the usage of sodium hydroxide in the range of doses 0.1 ÷ 0.6 g NaOH/g VS respectively for mentioned doses, about 26-time, about 33-time, about 43-time, about 50-time, ok. 53-time as well as about 54-time increase of organic matter concentration in the supernatant of excessive sludge prepared with the combined method in the relation to the initial concentration was obtained (Table 2).

In the case of the investigated combined method the confirmation of intensified action of ultrasonic field on the changes of chemical oxygen demand (COD) value was obtained. COD increase in the supernatant of sludge, in the relation to the result obtained during only alkaline pretreatment, equal respectively for the dose 0.1 g NaOH/g VS about 38%; for 0.2 g NaOH/g VS about 33%; for 0.3 g NaOH/g VS about 27% and for 0.4 g NaOH/g VS about 24%, whereas for 0.5 g NaOH/g VS about 12% was noticed.

It was found that the efficiency of combined preparing method by the sodium hydroxide dose equal 0.5 g/g VS, which was determined on the basis of COD increase, corresponded with the efficiency of that method obtained for the sodium hydroxide dose equal 0.6 g/g VS. As the result, combined preparing method with the usage of dose 0.5 g NaOH/g VS, was recognized, on this stage of research, the most effective conditioning method (Table 3).

The changes of COD values appearing in the result of sludge submitted alkaline pretreatment as well as alkaline pretreatment aided with ultrasound were shown in Fig. 1.

Table 3
The comparison of alkaline and alkaline aided with ultrasonic field pretreatment efficiency expressed by ratio of COD of nontreated sludge supernatant to COD of sludge supernatant prepared with investigated methods

Dose NaOH	$COD_{nonprepared}$/ $COD_{prepared\ NaOH}$	$COD_{nonprepared}$/ $COD_{prepared\ NaOH+UD}$
g NaOH/g VS	mgO_2/dm^3	mgO_2/dm^3
0.1	1/16	1/26
0.2	1/22	1/33
0.3	1/31	1/43
0.4	1/38	1/50
0.5	1/47	1/53
0.6	1/54	1/54

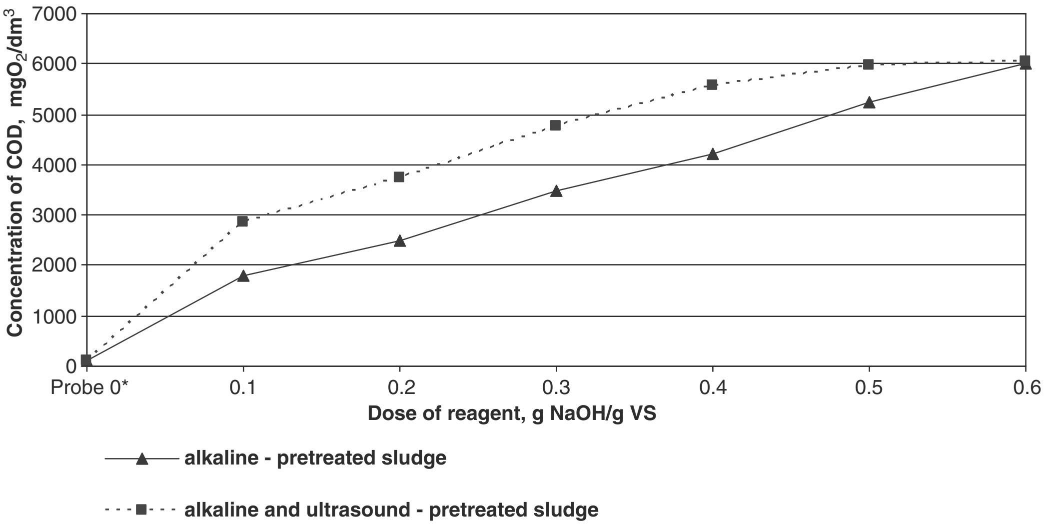

Fig. 1. The influence of sodium hydroxide dose during alkaline as well as combined method i.e. alkaline pretreatment aided with ultrasonic field, on the changes of COD value in the sludge supernatant.

During the next stage of the research it was noticed that for conducted fermentation process of conditioned sludge with $M_{(8)}A_{0.1 \div 0.6}$, $M_{(8)}UD$ and $M_{(8)}A_{0.1 \div 0.6}$ + UD methods the essential increase of volatile fatty acids (VFAs) was observed (Fig. 2).

It was noticed that with the dose of sodium hydroxide increase the growth of VFAs generation in the following days of fermentation process of excessive sludge ($M_{(8)}A_{0.1 \div 0.6}$) was obtained.

Comparing the production of volatile fatty acids (VFAs) from nonprepared sludge ($M_{(8)}$) as well as submitted ultrasonic conditioning ($M_{(8)}UD$) it was observed significant concentration growth of this parameter, in the following days of prepared sludge anaerobic stabilization process. Thus, during stabilization of ($M_{(8)}UD$) the intensified influence of ultrasound active action on VFAs concentration was noticed. In the day eight of anaerobic stabilization of nonprepared sludge ($M_{(8)}$) and sludge prepared with ultrasonic field about 3-time and 10-time increase of volatile fatty acids concentration was observed, in relation to initial value of this parameter.

In the case of preparing excessive sludge by the combined method, connected alkaline and ultrasonic pretreatment, for the sludge conditioning with sodium hydroxide in the range of doses 0.1 ÷ 0.3 g/g VS ($M_{(8)}A_{0.1 \div 0.3}$ + UD) intensified action of ultrasonic field on changes of volatile fatty acids (VFAs) concentration was noticed, in comparison with the concentration changes of this parameter during anaerobic stabilization of sludge pretreatment with mentioned doses. During the eight day of anaerobic stabilization, in the case of sludge prepared with sodium hydroxide, about 10-time, 13-time and 19-time increase of volatile fatty acids concentration was observed, in relation to initial value of this parameter. Whereas in the case of sludge prepared combined method for the dose 0.1 g NaOH/g VS about 16-time and both for the doses of 0.2 g NaOH/g VS and 0.3 g NaOH/g VS about 25-time increase of volatile fatty acids concentration was noticed.

Moreover during the methane fermentation of sludge pretreatment combined method for the doses 0.4 ÷ 0.6 g NaOH/g VS, in comparison with the fermentation of alkaline pretreatment

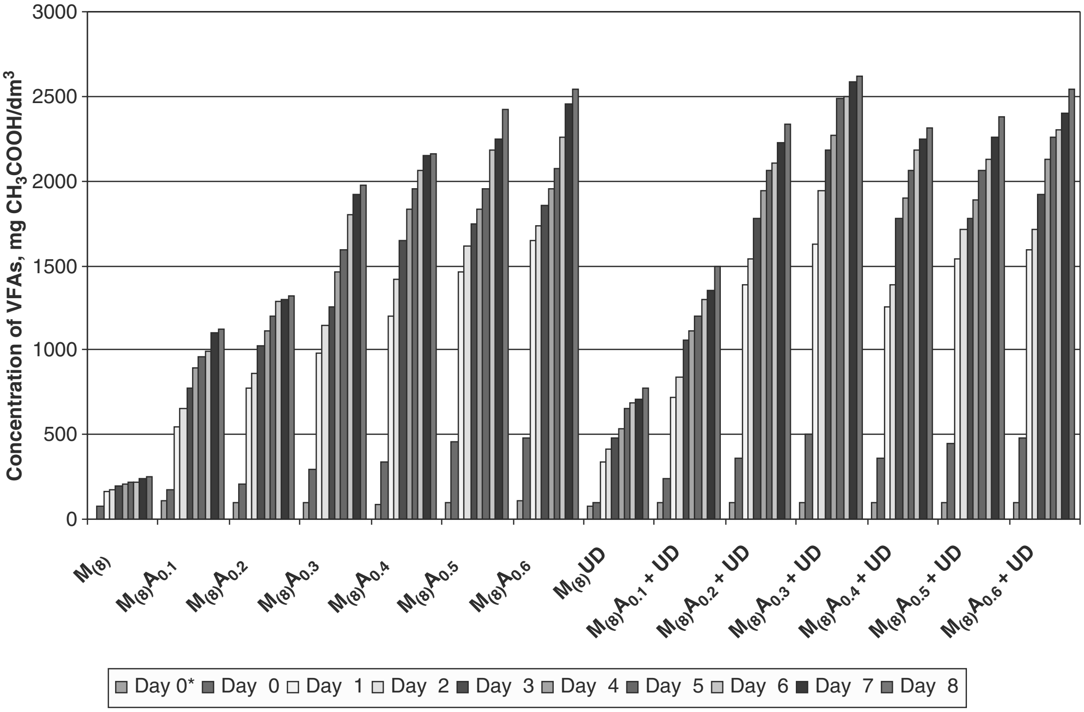

Fig. 2. The changes of volatile fatty acids concentration in the following days of anaerobic stabilization process of $M_{(28)}$, $M_{(28)}A_{0.1 \div 0.6}$, $M_{(28)}UD$ and $M_{(28)}A_{0.1 \div 0.6}$ + UD mixture.

sludge, by mentioned doses, the insignificant differences in VFAs concentration was observed. So in this case the aiding ultrasonic field action on increase of VFAs concentration was not noticed.

On the basis of biogas production observed during the methane fermentation process it was noticed that sludge preparing with the chosen methods, in the case of all mixtures, the intensification of biogas generation was obtained (Fig. 3). The lowest efficiency of biogas production was observed in the case of $M_{(28)}$ as well as $M_{(28)}UD$ mixture. Whereas, in the case of alkaline conditioned and alkaline — aided ultrasonic field sludge i.e. $M_{(28)}A_{0.1 \div 0.6}$ and $M_{(28)}A_{0.1 \div 0.6}$ + UD, the lowest intensity of biogas production was obtained for $M_{(28)}A_{0.2}$.

The simultaneously increase of sodium hydroxide doses caused the higher biogas production, which was shown in Fig. 3. Moreover some regularity concerning active ultrasonic field action, as a disintegrated factor, on the growth of alkaline pretreatment efficiency was noticed. Referring to stabilization process of $M_{(28)}A_{0.1 \div 0.3}$ and $M_{(28)}A_{0.1 \div 0.3}$ + UD mixtures the considerable increase of biogas production was obtained. During anaerobic stabilization of mixtures $M_{(28)}A_{0.1 \div 0.3}$ the yield production of biogas equal suitable 0.86; 1.18 and 1.47 dm^3/g VS. The biogas production, in the case of mixtures $M_{(28)}A_{0.1}$ + UD equal 1.35 dm^3/g VS and for the mixtures $M_{(28)}A_{0.1}$ + UD as well as for $M_{(28)}A_{0.2}$ + UD — 1.80 dm^3/g VS. The degree of volatile solids reduction of alkaline pretreatment sludge, for mentioned doses of sodium hydroxide equal respectively 66%, 72% as well as 75% and for sludge pretreatment combined method 73%, 81%, 79%. Whereas in the case of anaerobic stabilization of mixtures $M_{(28)}A_{0.4 \div 0.6}$ and

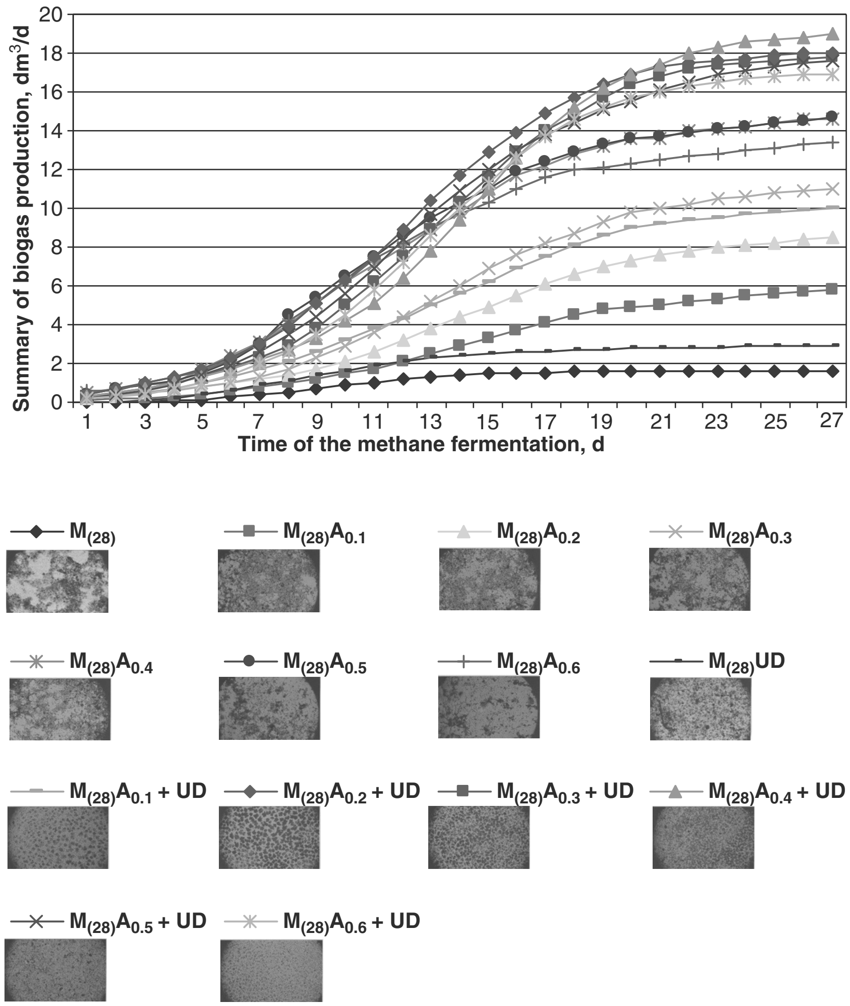

Fig. 3. Summary biogas production observed during the anaerobic stabilization process of $M_{(28)}$, $M_{(28)}A_{0.1 \div 0.6}$, $M_{(28)}UD$ and $M_{(28)}A_{0.1 \div 0.6}$ + UD mixture.

$M_{(28)}A_{0.4 \div 0.6}$ + UD the similar intensification of biogas production was observed. The confirmation of this fact, for mentioned mixtures was the yield production of biogas in the range of 1.78 ÷ 1.83 dm^3/g VS and the degree of volatile solids reduction equal 79 ÷ 81%.

4. Summary and conclusions

The excessive sludge conditioning before fermentation process was resulted in the efficiency of anaerobic biotransformation of organic matter to volatile fatty acid. The investigation confirm the efficiency of combined conditioning method i.e. alkaline conditioning with sodium hydroxide aided with ultrasonic field.

On the basis of the investigation the following conclusions were formulated:

- The investigated methods of sludge conditioning i.e. alkaline, ultrasonic field and alkaline with ultrasonic field influenced on its disintegration and chemical oxygen demand in the supernatant increase.

- The most efficiency was combined method i.e. alkaline — aided with ultrasonic field and the dose of sodium hydroxide decrease.
- The alkaline conditioning with sodium hydroxide (a dose of 0.2 g/g VS) aided with ultrasonic field influenced the efficiency increase of $M_{(28)}A_{0.2}$ + UD during anaerobic stabilization process.
- As the result of excessive sludge conditioning with associated method it was observed for $M_{(8)}A_{0.2}$ + UD mixture about 8-time increase of volatile fatty acids concentration in comparison to nontreated excessive sludge, defined as $M_{(8)}$. Moreover for the $M_{(28)}A_{0.2}$ + UD mixture after anaerobic stabilization it was obtained about 2-time increase of volatile solids reduction and about 4-time increase of yield biogas generation as compared to $M_{(28)}$.

Acknowledgement

The research was funded by the BS-401/301/00 resources.

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