Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2014.884685

52 (2014) 3725–3731
May

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Hybrid conditioning before anaerobic digestion for the improvement of sewage sludge dewatering

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Received 21 March 2013; Accepted 20 August 2013

ABSTRACT

So far, the most common method of conditioning to increase the efficiency of sludge dewatering is by adding chemicals (polyelectrolytes). This method effectively increases dewatering, thus causing the possibility of getting into the environment of hazardous chemicals. The use of physical conditioning methods (thermal, ultrasonic field) or a combination one (so-called hybrid conditioning) is an alternative to chemical methods for sludge preparing. A preliminary modification of excess sludge before the fermentation process affects the stabilization process, thereby changing the parameters characterizing the efficiency of sewage sludge dewatering. The article presents a study determining the impact of pre-conditioning of excess sludge before anaerobic stabilization on the final efficiency of their dewatering. Sludge conditioning methods of thermal and ultrasonic pre-treatment and combination of these two methods (hybrid conditioning) were used. The ability of sludge dewatering was determined on the basis of the capillary suction time, the effectiveness of their compaction and microscopic observation of the structure.

Keywords: Sewage sludge; Thermal conditioning; Ultrasonic pre-treatment; Methane fermentation; Dewatering

1. Introduction

Sewage sludge is the main waste which remains from sewage treatment in wastewater treatment plants. Depending on the source of sewage and treatment methods, it might differ with its composition and character. Its hydration is an essential factor, which impacts on dewatering technologies and, consequently, on total costs of the process [1–3]. In order to intensify the process of dewatering, the sludge is subjected to conditioning, which causes the changes in its structure. Chemical conditioning is the most popular method of sludge modification before its final dewatering. The chemical factor, however, might impact on the secondary environmental pollution, which contributes to searching and applying other methods which intensify the process of dewatering [4,5]. The examples of

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Presented at the 11th Scientific Conference on Microcontaminants in Human Environment. 25–27 September 2013, Wisla, Poland
Organized by Department of Chemistry, Water and Wastewater Technology,
Faculty of Environmental Engineering and Biotechnology, Czestochowa University of Technology

the methods which are currently gaining popularity in industry are thermal conditioning and the use of ultrasound field energy [6–9]. These methods, used before the process of stabilization, which is the most frequently used method of sludge treatment, demonstrated a positive effect on the levels of COD and VFA in the supernatant liquid and the parameters which characterize the degree of dewatering [10–14]. Knowing the positive effect of ultrasound field energy and temperature on physical, chemical and biological properties of the sludge, the investigations presented in this paper focused on a combination of both methods called hybrid conditioning. Ultrasonication and thermal pre-treatment cause the dispersion of the structure of sewage sludge and intensifies the methane fermentation process [15–19]. Intervention in the course of the process of stabilization through modification of sludge affects their final susceptibility to dewatering.

The aim of the study was to determine the effect of pre-treatment (thermal, ultrasonic or hybrid methods) of sewage sludge on the final effect of its dewatering through determination of capillary suction time (CST), degree of densification and microscope observations of the structure.

2. Methodology

The substrate used for the investigations was excess sludge from a combined mechanical and biological municipal wastewater treatment plant with an average capacity of 40,000 m^3/d. The inoculum was provided by the fermented sludge which was 10% of the total amount of sludge used for the investigations.

In order to ensure the initial conditioning of excess sludge, physical methods were employed: thermal heating, exposure to ultrasound fields and a combination of these two methods (hybrid conditioning). Thermal pre-treatment was carried out in a water bath for 1.5 h at temperatures: 60 and 80°C. Exposure to ultrasound field was obtained using ultrasound processor with power of 1,500 W, frequency of 20 kHz and wavelength of 39.42 μm (which corresponded to the amplitude of 100%). The ultrasound field conditioning was carried out with an amplitude of 80% and sonication time of 5 min. Both the temperatures and the sonication parameters were selected based on preliminary tests [8,17]. Hybrid conditioning consisted in the combination of thermal conditioning with the ultrasound field, which was used for preparation of the excess sludge.

The initial investigations in terms of selection demonstrated that sewage sludge exhibits improved effectiveness of dewatering if it is first conditioned with ultrasound field and then subjected to heating in a water bath.

Both the non-conditioned sludge and the sludge pre-conditioned with different methods were subjected to fermentation in 10 laboratory flasks ($V = 0.5$ dm^3) for a period of 10 d. In order to ensure the temperature which is optimal for mesophilic fermentation (±35°C), the flasks were placed in a laboratory thermostat. On each day of the process, dry matter amount, CST time and effectiveness of densification were determined (for both the conditioned and non-conditioned sludge) and the microscope structure observations were carried out.

Measurements of CST were carried out according to the methodology by Baskerville and Galle, based on the measurement of transition of the boundary layer of filtrate as a result of suction forces in the used paper (Whatman 17).

Gravitation densification was carried out in measurement cylinders with a volume of 100 ml for 120 min. Based on the measurements of the volume of the sludge sedimented in time, the densification curves were obtained.

The observation of sewage sludge structure was carried out by means of an Olympus BX41 microscope. The photographs were taken with 100x magnification by means of a C-7070 Olympus digital camera.

3. Results

Subjecting excess sludge to initial conditioning caused an increase in the value of CST compared to the non-conditioned sludge (Fig. 1). The highest levels of CST were observed for the sludge exposed to an ultrasound field (1,331 s), whereas the lowest values were found for the sludge conditioned at a temperature of 60°C (130 s). CST for the non-conditioned sludge was 34 s. The sludge subjected to the process of stabilization showed gradual reduction in the value of CST on consecutive days of the process. On the sixth day of fermentation, both in the thermally conditioned sludge and the sludge conditioned with an ultrasound field, the values of CST were found similar to those for the non-conditioned sludge. Stabilization of the sludge effectively affected the sludge modified with an ultrasound field for which CST was 40 times higher compared to the non-conditioned sludge on the first days of the process. However, the next few days of fermentation caused a successive decline in the value of this parameter, reaching the value of 113 s on the sixth day.

Similar relationships were observed for the excess sludge which was conditioned with the hybrid method (ultrasound field + temperature). The CST

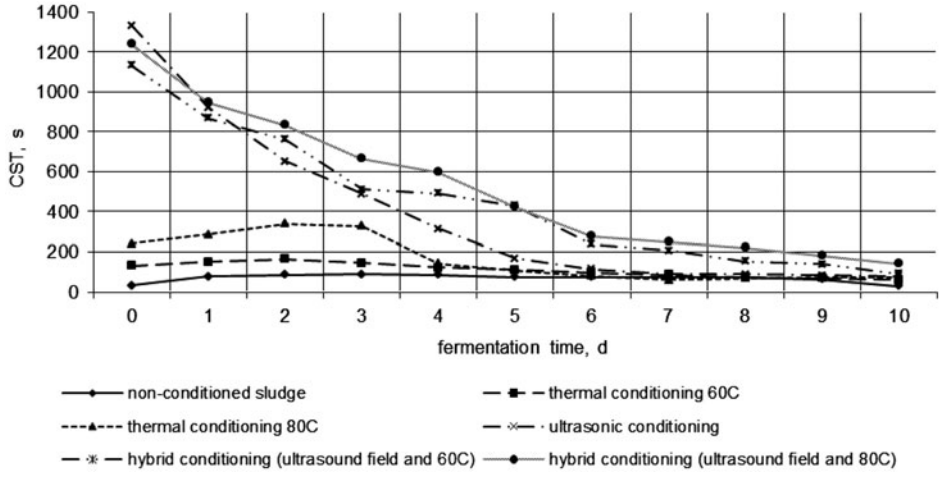

Fig. 1. Effect of conditioning and fermentation time on CST of sewage sludge.

values for non-stabilized sludge modified using the combined methods amounted to 1,133 s (ultrasound field + 60˚**C**) and 1,240 s (ultrasound field + 80˚**C**). Fermentation caused a gradual decline in CST, reaching the values of 92 and 142 s on the tenth day of the process.

The initial modification of excess sludge positively affected the process of gravitational densification. The best sedimentation was found for the sludge subjected to modification with hybrid methods, which gave values by 20 ml (ultrasound field and 60˚**C**) and 45 ml (ultrasound field and 80˚**C**) lower compared to the non-conditioned sludge after 30 min of densification. Also for the sludge conditioned with the combined methods, subjected to fermentation, the highest effectiveness of sedimentation was observed in consecutive days of the process, which was particularly noticeable after 2 d of fermentation. These findings are confirmed by the results of densification presented in Fig. 2. Effective sedimentation was also observed for the sludge exposed to an ultrasound field, which gave a 50% reduction in the volume of the sludge (compared to the volume of the non-conditioned sludge), observed on the third day of the process of stabilization after 30 min of densification.

During the process of stabilization, a decline in dry matter was observed, which is connected with biodegradation of the studied sludge (Fig. 3). The highest (35%) degree of reduction in dry mass, between 0 and 10th d of the process, was observed for

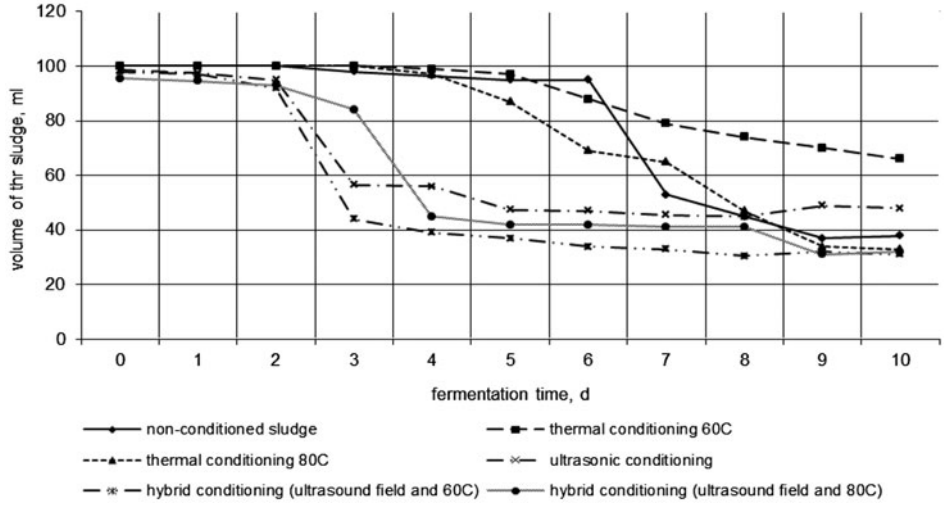

Fig. 2. Effect of conditioning and fermentation time on the thickening of sludge after 30 min of sedimentation.

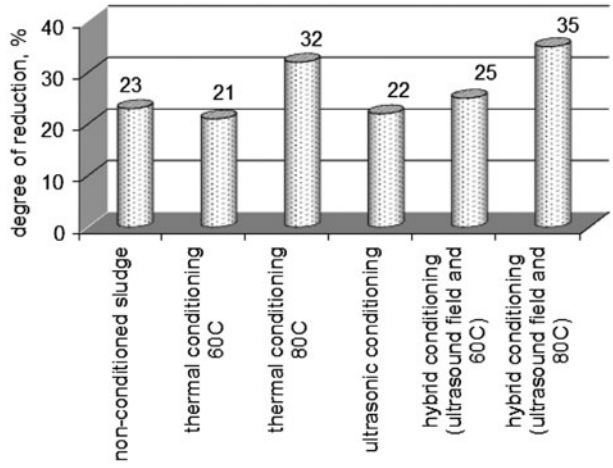

Fig. 3. Effect of conditioning on the degree of reduction in dry mass of examined sludge.

hybrid-conditioned sludge (ultrasound field + 80˚C). High degree of reduction (32%) was also found for the initially thermally conditioned sludge (80˚C). During other tests, this level was 23% for the non-conditioned sludge, 21% for the thermally conditioned sludge at 60˚C and 22% of the hybrid-conditioned sludge (ultrasound field + 60˚C). The changes in the degree of dry mass reduction were correlated with the values of CST, effectiveness of densification and the structure of the sludge.

In order to determine the changes which occur in the structure during conditioning and stabilization of the sludge, microscope observations were carried out for each sample. The non-fermented sludge (Fig. 4), both non-conditioned and initially modified were characterized by the compact structure. The sludge evenly filled the field of vision, whereas free water was not observed (Fig. 5).

On consecutive days of fermentation, the structure of sludge was loosened and created individual clusters of sludge particles. For the higher temperature of thermal conditioning (80˚**C**), the structure of the sludge was more defragmented (Fig. 6). A similar relationship was observed for the sludge conditioned with an ultrasound field. Sonication caused an appearance of free water with individual clusters of sludge with an elongated shape (Fig. 7).

The initial hybrid conditioning of sewage sludge subjected to fermentation considerably affected the structure of the sludge samples with respect to other methods of conditioning (Figs. 8 and 9). The clusters of sludge increased on each consecutive day of the process of stabilization. The structure became looser, less compact and the space between solid phase particles were filled with free water.

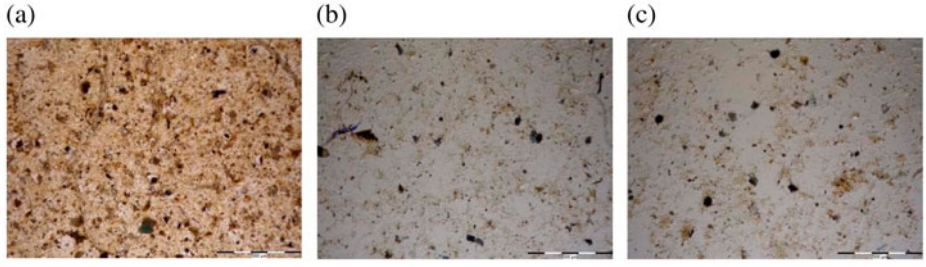

Fig. 4. The structure of non-prepared sewage sludge submitted anaerobic stabilization, (a) 0 d of fermentation, (b) 5 d of fermentation and (c) 10 d of fermentation.

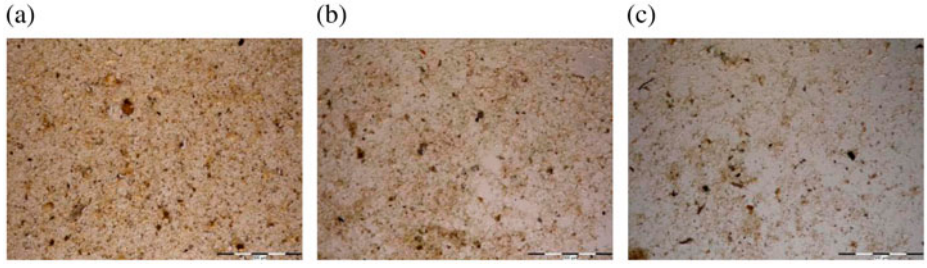

Fig. 5. The structure of thermally conditioned (60˚**C**) sewage sludge submitted anaerobic stabilization, (a) 0 d of fermentation, (b) 5 d of fermentation and (c) 10 d of fermentation.

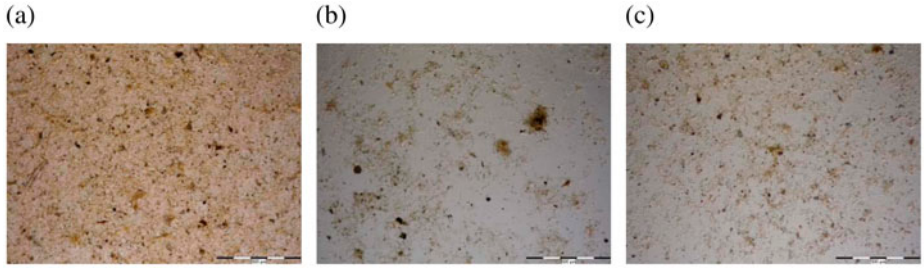

Fig. 6. The structure of thermally conditioned (80°C) sewage sludge submitted anaerobic stabilization, (a) 0 d of fermentation, (b) 5 d of fermentation and (c) 10 d of fermentation.

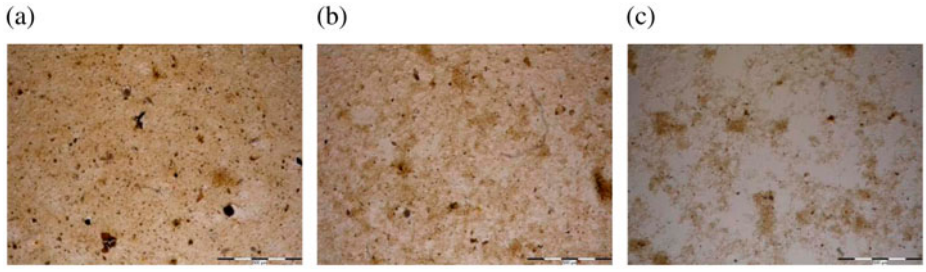

Fig. 7. The structure of ultrasonic conditioned sewage sludge submitted anaerobic stabilization, (a) 0 d of fermentation, (b) 5 d of fermentation and (c) 10 d of fermentation.

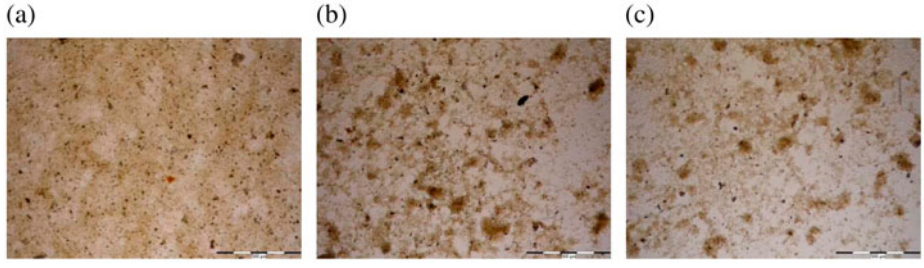

Fig. 8. The structure of hybrid conditioned (ultrasonic field + 60°C) sewage sludge submitted anaerobic stabilization, (a) 0 d of fermentation, (b) 5 d of fermentation and (c) 10 d of fermentation.

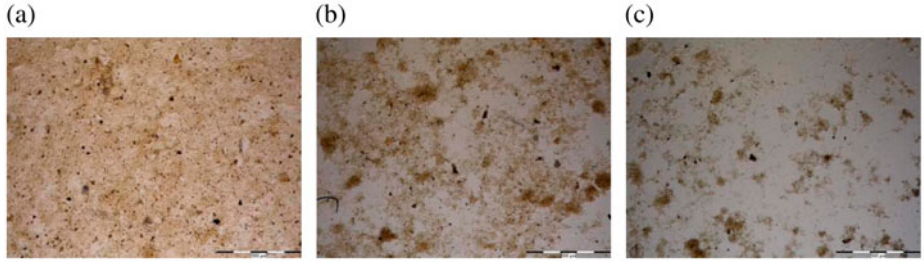

Fig. 9. The structure of hybrid conditioned (ultrasonic field + 80°C) sewage sludge submitted anaerobic stabilization, (a) 0 d of fermentation, (b) 5 d of fermentation and (c) 10 d of fermentation.

4. Summary and conclusions

The study demonstrated that each intervention in the structure of sewage sludge impacts on a change in its physical and chemical properties. The initial thermal conditioning, exposure to an ultrasound field or hybrid modification of sewage sludge subjected to stabilization affects the final effect of its dewatering [20].

The study revealed that the application of an initial physical modification of sludge causes an increase in the level of CST with respect to non-conditioned sludge. The elongation of CST in conditioned sewage sludge was caused by the dispersion of the particles, which consequently impacted on pore clogging in filtration paper, thus reducing filtration capacity in the studied medium. When subjecting initially, conditioned sewage sludge to stabilization, it showed a reduced value of CST, which was clearly noticeable for the sludge after the process of hydrolysis. According to Na et al. [11], the increase in the ultrasound energy causes an increase in the effectiveness of dewatering of sewage sludge after the process of fermentation.

As results from the study, thermal conditioning, ultrasound field energy and hybrid modification of sewage sludge improve the effectiveness of the process of densification with respect to the non-conditioned sludge. The increase in sedimentation capacity of the conditioned excess sludge was caused by the changes in its structure, which was observed in the presented photographs. The fragmented particles of sludge were packed more effectively, thus releasing the excess of free water.

Observations of the structure of sludge subjected to fermentation for different methods of conditioning confirmed its relationship with the effects of sludge dewatering. During 2 h of sedimentation, the sludge was sedimented to a different degree. Unlike the initially modified sludge, the process of densification in the non-conditioned sludge occurred more slowly.

There is a plethora of information in the literature on physical and chemical methods of sludge conditioning. However, no information was found about combined (hybrid) methods of sludge preparation subjected to dewatering and the obtained results are satisfactory and suggest further explorations in this area.

The following conclusions can be drawn based on the investigations:

(1) Initial thermal conditioning, ultrasound field and hybrid conditioning of excess sludge cause an increase in the value of CST. The highest values of CST were found for the sludge conditioned using hybrid methods which were nearly 40 times higher than the values of the non-conditioned sludge.
(2) The process of anaerobic stabilization impacted on the increase in the ability of sludge to release water. The values of CST were reduced on consecutive days of fermentation, which was accompanied by increasing densification capacity of the sludge. The best sedimentation was observed for the sludge conditioned with hybrid methods (ultrasound field + 60˚C). The changes in the effectiveness of sludge dewatering were correlated with the changes in its structure.
(3) During the process of fermentation carried out in initially conditioned sludge, a reduce in the degree of reduction in dry mass was observed. The highest (35%) degree of reduction was found for the sludge conditioned with the combined methods (ultrasound field + 80˚C).

Acknowledgement

The research was funded by the project No. BS-PB-401/303/12.

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