Inżynieria i Ochrona Środowiska 2016, 19(4), 447-453
Engineering and Protection of Environment
https://ios.is.pcz.pl/

p-ISSN 1505-3695
e-ISSN 2391-7253
DOI: 10.17512/ios.2016.4.1

Paweł WOLSKI
Czestochowa University of Technology, Faculty of Infrastructure and Environment
Institute of Environmental Engineering
ul. Brzeźnicka 60A, 42-200 Częstochowa
e-mail: pwolski@is.pcz.czest.pl

Rheological Parameters of Digested Sludge

Parametry reologiczne przefermentowanych osadów ściekowych

The paper presents the effect of the fermentation process on the values of shear stress in the sewage sludge pre-conditioned with ultrasonic field. The sludge samples were fermented in the glass flasks that represented the models of digester chamber. The values of shear stress and rheological models were determined for the fermented sludge. The study demonstrated an increase in shear stress values with the increase of velocity gradient. The highest values of these parameters were obtained for the sludge conditioned with the highest ultrasonic field intensity. The decrease of shear stress values was obtained after fermentation process.

Keywords: digested sludge, conditioning, fermentation, rheological parameters

Introduction

The process of proper disposal of sewage sludge involves the use of different methods of their preparation or conditioning. Rheological properties of the sludge have a substantial impact on different processes used in sewage treatment plants, such as fluid transport, mixing and diffusion of oxygen, anaerobic digestion or mechanical dewatering. Although the studies published in recent years have focused on the rheology of the sludge, it seems clear that further research is needed in this field [1, 2].

The most frequently used method of sewage sludge conditioning is to add chemical substances. Although the method improves the effectiveness of dewatering, dangerous chemicals may contaminate the environment. The use of physical methods of sludge conditioning offers an alternative to chemical methods of sludge preparation. The use of these methods before the stabilization process had a positive effect on COD and VFA values in the supernatant liquor and parameters of the degree of dewatering [3-5]. Therefore, the above methods affect the shape of the flow and viscosity curves, which has not been presented in the literature to date.

Pre-treatment with ultrasonic field affects the sludge structure and form of water sludge. The studies on improving the capability of sludge dewatering have been performed by many researchers [6, 7]. Capillary suction time, specific resistance, chemical oxygen demand have been studied extensively by various aiding factors, i.e. ultrasonic field energy or microwave [8].

The energy of microwave or ultrasonic field is used in the preliminary treatment of sewage sludge to improve its dewatering efficiency [9, 10]. The sonication process before fermentation intensifies the biogas output and improves chemical oxygen demand and volatile fatty acids indicator values [11]. Moreover changes of sludge structure are connected with the rheological parameters [12]. Knowledge of rheological parameters is essential during the design of pipelines for sewage sludge transport [13, 14]. They are also important parameters for control of such processes as stabilization or dewatering. Neglecting these parameters is likely to generate design errors and, consequently, difficulties in the operation of the whole system. The simplest mathematical rheological model used to describe the flow curve for these fluids is the Ostwald-de Waele power model:

$$\tau = k \cdot (\gamma)^n$$

where:
k - constant termed consistency coefficient, Pa·s,
n - exponent, termed yield exponent.

Both constant k termed coefficient of consistency and the exponent n, termed the yield exponent, are the rheological parameters determined empirically at a specific temperature. The coefficient of consistency is the measure of viscosity of a substrate (the higher the k value the more viscous the fluid). The flow coefficient n can point to the process of shear thinning ($n < 1$), shear thickening ($n > 1$) or a Newtonian fluid ($n = 1$).

There is a relationship between parameters of conditioning agent and values of shear stress. The analysis of the effect of conditioning agents on the rheological parameters of stabilized sludge has been poorly explored in the literature. Therefore further research is needed in this field.

The aim of this study was to evaluate the effect of fermentation process on the values of shear stress, viscosity and yield stress for sewage sludge conditioned with ultrasonic field.

1. Material and methods

The substrate studied was excess sludge derived from the treatment of municipal wastewater in mechanical-biological treatment plant with capacity of 90 000 m^3/d (314 835 population equivalent). The sludge conditioned with ultrasonic field before fermentation was mixed with fermented sludge with the ratio of 10:1. The sludge was characterized by the following parameters: dry mass of 13.43 ± 2.4 g/dm^3, organic dry mass 8.6 ± 2.4 g/dm^3, capillary suction time 52 ± 2 seconds, initial and final hydration 98.7 and 84.8%, respectively, specific resistance of sludge $2.96 \cdot 10^{12}$ m/kg.

Ultrasonic processor Sonic VCX-1500 was used for the sonication process of sewage sludge. Sonication process was carried out under static conditions. The intensity of ultrasonic field was: 2.7 (60%); 3.2 (80%); 3.8 (100%) W/cm^2. Time of sonication was 600 s. The maximum power output of this processor is 1500 watts. The vibration frequency of ultrasonic field generator is 20 kHz. The volume of sonicated samples was 500 cm^3.

Fermentation process of pre-conditioned samples of sludge was performed in the glass flasks that represented the models of digester chambers. Sludge samples were inserted to 10 laboratory flasks of 0.5 dm^3 volume. During each day of process one of the flask was pulled from incubator and the shear stress values and rheological models were determined.

Rheological parameters were determined using RC20 rheometer at a shear rate of 0÷200 s^{-1} for a period of 120 seconds. The rheometer was composed of the coaxial cylinders ended with the cone and plate design. The sample was placed in the ring gap between the internal and external cylinder. The device is controlled by the computer with the RHEO 2000 software. The rheometer is a device used to measure shear stress and viscosity at various velocity gradients. Measurement error is ±1% of maximal measurement value. Using the ultrathermostat, the measurements were carried out at fixed temperature of 20°C.

2. Results and discussion

After exposure of the sewage sludge to the ultrasound field, an increase in the value of yield stress was proportional to the intensity of the ultrasonic field. For the non-prepared sludge, its value was 0.122 Pa, whereas the use of the ultrasonic field energy of 3.8 W/cm^2 caused an increase in the yield stress to 0.286 Pa. Sludge stabilization caused a reduction in this parameter for each test on each day of the process, thus changing the flow capability of the sludge.

Table 1. **Effect of fermentation time on the yield stress of the sludge pre-conditioned with ultrasonic field (according to the model Ostwald)**

		Fermentation time, d										
		0	1	2	3	4	5	6	7	8	9	10
Non-conditioned sludge	Yield stress τ_0, Pa	0.122	0.052	0.051	0.046	0.041	0.035	0.033	0.031	0.026	0.024	0.023
Sludge+UD 2.7 W/cm^2	Yield stress τ_0, Pa	0.162	0.069	0.063	0.058	0.054	0.051	0.047	0.043	0.039	0.035	0.029
Sludge+UD 3.2 W/cm^2	Yield stress τ_0, Pa	0.208	0.206	0.122	0.077	0.055	0.055	0.053	0.049	0.045	0.041	0.037
Sludge+UD 3.8 W/cm^2	Yield stress τ_0, Pa	0.286	0.274	0.213	0.132	0.092	0.088	0.081	0.079	0.075	0.071	0.063

The use of the thermodynamic medium with higher ultrasonic field power increased the value of shear stress for higher velocity gradients (Fig. 1). At the highest shear rates (200 s^{-1}), the values of shear stress were: 0.758 Pa (2.7 W/cm^2), 0.829 Pa (3.2 W/cm^2) and 0.992 Pa (3.8 W/cm^2) respectively.

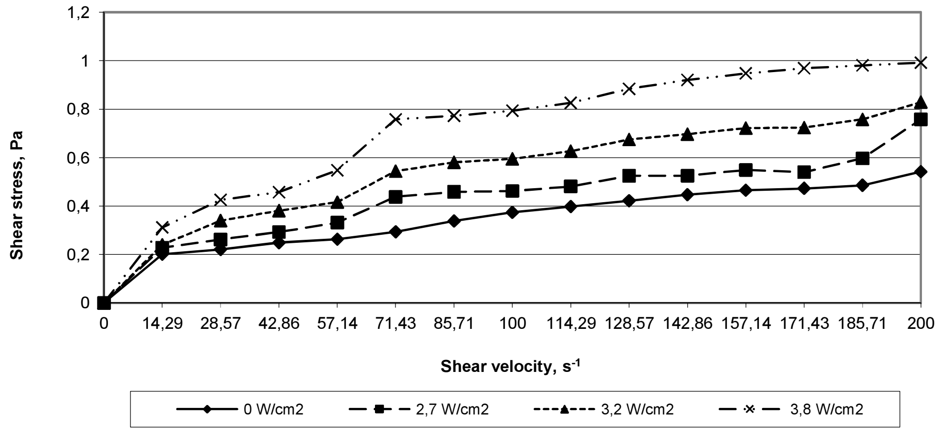

Fig. 1. Flow curves of sludge prepared with ultrasonic field

For fermented sewage sludge, the values of shear stress were reducing on consecutive days of the process (Fig. 2). On the 10th day of the stabilization, stress values for shear rate of 200 s^{-1} were as follows: 0.377 Pa (2.7 W/cm^2), 0.5 Pa (3.2 W/cm^2) and 0.742 Pa (3.8 W/cm^2). The reduction in shear stress followed by reduction in dry mass with increasing time of stabilization time is presented in Table 2. The lowest percentage of dry mass was obtained on the 10th day of the process for the sludge exposed to high intensity of ultrasonic field (3.8 W/cm^2).

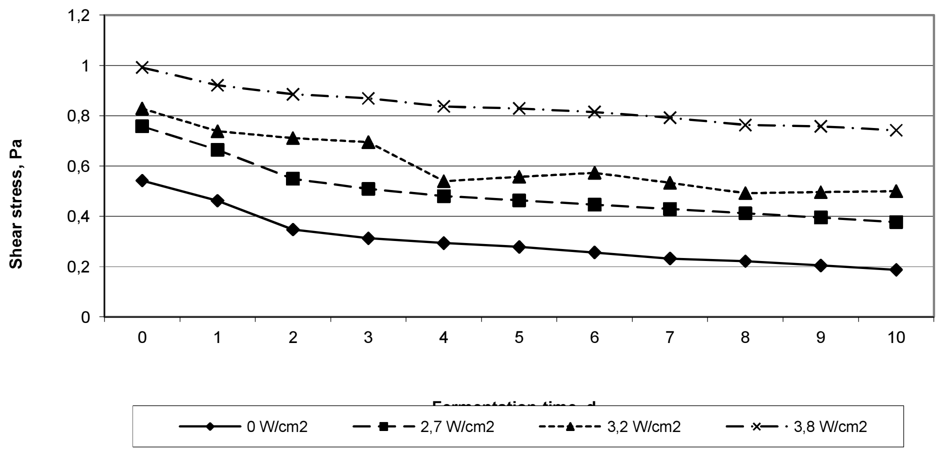

Fig. 2. The effect of fermentation time on the shear stress of sludge pre-conditioned with ultrasonic field (shear rate 200 s^{-1})

Table 2. **Effect of fermentation time on dry mass (g/dm³) of the sludge pre-conditioned with ultrasonic field**

	Fermentation time, d										
	0	1	2	3	4	5	6	7	8	9	10
Dry mass of non-conditioned sludge	13.43	13.32	13.22	12.96	12.76	12.66	12.51	12.4	12.37	12.3	12.31
Dry mass of Sludge+ UD, 2.7 W/cm²	11.87	12.14	11.02	10.72	10.42	10.34	10.29	10.02	9.5	9.25	8.96
Dry mass of Sludge+ UD, 3.2 W/cm²	11.87	12.03	11.03	10.81	10.77	10.41	10.17	9.99	9.42	9.18	8.87
Dry mass of Sludge+ UD, 3.8 W/cm²	11.87	11.67	11.04	10.87	10.78	10.52	10.09	9.97	9.34	9.08	8.73

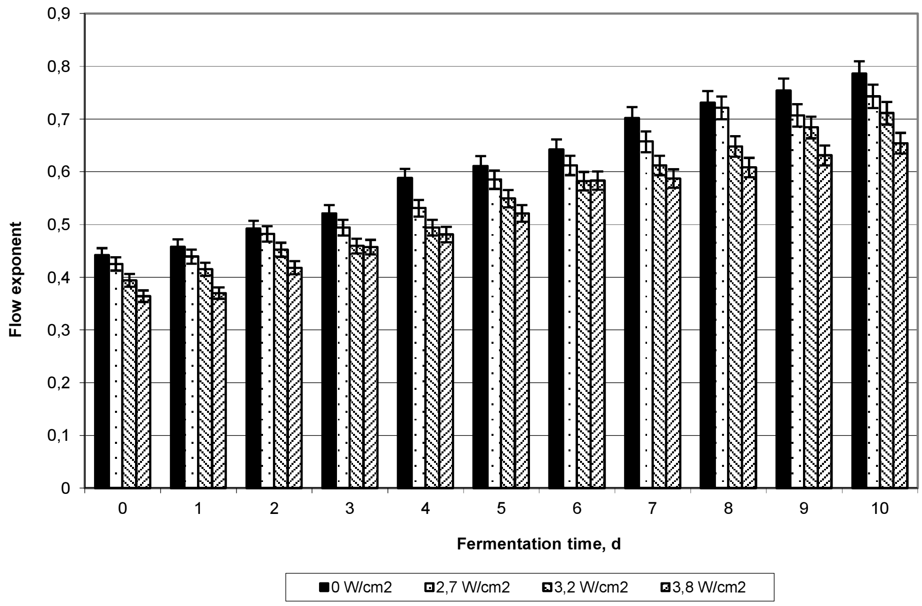

Fig. 3. Effect of fermentation time on the value of yield exponent n for the sewage sludge pre-conditioned with ultrasonic field

Determination of the rheological models of sewage sludge contributes to a more detailed description of the sludge and provides insights into the effect of the conditioning method on final parameters. Initial conditioning before the fermentation process affects rheological parameters of the sludge on each day of the stabilization process. Analysis of rheological models revealed the n values below 1 for three wavelengths, which suggests the process of shear thinning over the whole 10-day stabilization cycle. The coefficient of consistency k, which is a measure of viscosity, changes depending on the wavelength of the ultrasonic field and fermentation time and ranged from 0.07 to 0.03 Pas.

Conclusion

Capability of the sludge to release water and, consequently, to flow determines the methodology and procedure in the case of their final use. Sewage sludge is a non-Newtonian fluid. Flow curves and viscosity curves are determined in order to learn more about such fluids. Yield stress, viscosity and yield exponents are other rheological parameters that can be used for a direct evaluation of the flow capability for a fluid. Due to the number of factors that affect the rheological properties, there is no opportunity to evaluate them theoretically and the specific examinations are necessary.

There are a number of rheological models that describe non-Newtonian fluids. However, it is generally accepted that only the Ostwald-de Waele, Bingham and Herschel-Bulkley models are simple enough to be used for technological applications. With specific values of shear stress, the phenomenon of flow is observed. Determination of the yield stress may contribute to better characterization and provide more information about the substrate.

Analysis of the results obtained in the study showed that the values of shear stress in sewage sludge after conditioning with ultrasound field increase with the shear rate. Stress also rose for higher values of the ultrasonic field as a conditioning factor. The use of fermentation process for the initially modified sludge resulted in reduction in the value of stress and yield stress on consecutive days of stabilization. Values of stress and the yield stress were reducing until the final day of the stabilization process. Furthermore, fermentation caused an increase in the coefficient of consistency for the sludge. However, the value was in the range of shear thinning.

Acknowledgements

The financial support by Czestochowa University of Technology, Institute of Environmental Engineering (BS-PB-401/303/12) is gratefully acknowledged.

References

[1] Tang B., Zhang Z., Essence of disposing the excess sludge and optimizing the operation of wastewater treatment: Rheological behaviour and microbial ecosystem, Chemosphere 2014, 1-13.

[2] Ociepa-Kubicka A., Pachura P., Wykorzystanie osadów ściekowych i kompostu w nawożeniu roślin energetycznych na przykładzie miskanta i ślazowca, Annual Set The Environment Protection (Rocznik Ochrona Środowiska) 2013, 15, 2267-2278.

[3] Bień J., Wolny L., Zawieja I., Barański M., Worwąg M., Wpływ termicznej dezintegracji osadów nadmiernych na generowanie lotnych kwasów tłuszczowych, [In:] Oczyszczanie ścieków i przeróbka osadów ściekowych [in Polish: Effect of thermal disintegration of excess sludge on generation of volatile fatty acids, Sewage treatment and sludge processing.], ed. Z. Sadecka, Monograph, Zielona Góra 2010, 63-69.

[4] Małkowski M., Wolski P., Wpływ termicznego kondycjonowania na efektywność odwadniania osadów ściekowych poddanych stabilizacji beztlenowej [in Polish: Effect of thermal conditioning of sewage sludge after anaerobic stabilization], Inżynieria i Ochrona Środowiska 2010, 13, 2, 103-109.

[5] Zawieja I., Wolny L., Effect of sonicator power on the biodegradability of sewage sludge, Rocznik Ochrony Środowiska (Annual Set of Environment Protection) 2011, 13, 1, 1719-1730.

[6] Dieude-Fauvel E., Dentel S.K., Sludge conditioning: Impact of polymers on floc structure, Journal of Residuals Science and Technology 2011, 101-108.

[7] Wolski P., Zawieja I., Susceptibility of conditioned excess sewage sludge to biodegradation and dewatering, Environment Protection Engineering 2015, 41, 3, 5-17.

[8] Zhou C.H., Ling Y., Zeng M., Le X.Y., Influence of microwave and ultrasound on sludge dewaterability, Advanced Materials Research 2014, 2074-2079.

[9] Dong Y., Wang Y., Steady rheological characteristics of the concentrated water treatment residuals (CWTR), Acta Scientiae Circumstantiae 2012, 678-682.

[10] Wolny L., Wolski P., Zawieja I., Rheological parameters of dewatered sewage sludge after conditioning, Desalination 2008, 382-387.

[11] Zawieja I., Wolny L., Ultrasonic disintegration of sewage sludge to increase biogas generation, Chemical and Biochemical Engineering Quarterly 2013, 27, 4, 491-497.

[12] Travnicek P., Vitez T., Junga P., Krcalova E., Sevcikova J., Original research of rheological measurements of disintegrated activated sludge, Polish Journal of Environmental Studies 2013, 1209-1212.

[13] Dong Y., Wang Y., Steady rheological characteristics of the concentrated water treatment residuals (CWTR), Huanjing Kexue Xuebao/Acta Scientiae Circumstantiae 2012, 32(3), 678-682.

[14] Sozański M.M., Kempa E.S., Grocholski K., Bień J., The rheological experiment in sludge properties research, Water Science and Technology 1997, 36, 11, 69-78.

Streszczenie

Przedstawiono wyniki badań wpływu procesu fermentacji na wartości naprężeń stycznych wstępnie kondycjonowanych polem ultradźwiękowym osadów ściekowych. W procesie kondycjonowania wykorzystano trzy wartości natężenia fali pola ultradźwiękowego: 2,7; 3,2; 3,8 W/cm^2. Wstępnie przygotowane próbki osadów poddawano procesowi fermentacji w kolbach szklanych stanowiących modele komór fermentacyjnych. Proces fermentacji prowadzono przez 10 dób. Dla przefermentowanych osadów wyznaczano wartości naprężeń oraz modele reologiczne. Badania wykazały wzrost wartości naprężeń wraz ze wzrostem gradientu prędkości. Najwyższe wartości uzyskano dla osadów kondycjonowanych przy najwyższym natężeniu pola UD. Fermentacja wpłynęła na obniżenie wartości naprężeń stycznych.

Słowa kluczowe: **osady przefermentowane, kondycjonowanie, fermentacja, parametry reologiczne**