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IMPACT OF ULTRASONIC FIELD ON THE EFFICIENCY OF LANDFILL LEACHATE CO-TREATMENT IN ANAEROBIC DIGESTION – REVERSE OSMOSIS SYSTEM

WPŁYW POLA ULTRADŹWIĘKOWEGO NA EFEKTYWNOŚĆ WSPÓŁOCZYSZCZANIA ODCIEKÓW W UKŁADZIE ZINTEGROWANYM FERMENTACJA BEZTLENOWA – ODWRÓCONA OSMOZA

Abstract: The results of a research project pertaining to the specification of the influence of the ultrasonic, US field on the efficiency of landfill leachate co-treatment in the process of anaerobic digestion associated with reverse osmosis were presented. The biological process – methane fermentation – was conducted in the bioreactor equipped with submerged membrane module (MBR reactor). The concentration of the anaerobic sludge granules was maintained at the fixed level of 10 g/m^3. The samples both after and before ultrasonic disintegration underwent the digestion process. Hydraulic retention time was varied within the range of between 1 and 3 days, which allowed to increase the OLR (Organic Loding Rate) value from 1.3 kg COD/m^{3}d to 4.0 kg COD/m^{3}d. It was established that ultrasonic disintegration reduced the HRT value from 2 to 1.5 days, as compared with non-disintegrated samples. What is more, ultrasonic, US-facilitated samples exhibited a higher COD reduction as well as the overall biogas production, on average by 10 % and 11 %, respectively. Since the biologically treated effluent in both analysed modes (MBR and MBR+US) exhibited a high degree of contamination – which did not allow to release the effluent into the natural water – an attempt was made to post-treat it by means of a high-driven membrane process, ie reverse osmosis. The application of reverse osmosis enabled a high degree of pollutants reduction. However, the final volumetric permeate flux (in both cases, ie MBR and MBR +US) exhibited an excessive concentration of ammonia nitrogen, which did not allow to release the effluent into receiving water. It was suggested that further experiments should additionally be based on nitrogen ammonia removal processes, eg ammonia stripping.

Keywords: landfill leachate**,** anaerobic digestion, membrane reactor (MBR), reverse osmosis (RO), ultrasonic field

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By far the largest proportion of municipal solid waste (MSW) generated in Poland as well as in other countries is still disposed of by means of landfilling. Moreover, depositing municipal solid waste even at properly designed and serviced dumping sites constitutes a threat to the natural environment, in particular, to groundwaters. Generally, landfill leachate is caused by atmospheric precipitation percolating through the landfill bed as well as organic and inorganic substances – often toxic – leaching from the landfill bed [1–3]. Leachate chemical composition as well as its amount vary and depend on a number of factors, ie season of the year; type of landfilled waste; age of the landfill site as well as landfilling method used [4]. Additionally, in a number of dumping sites, anaerobic conditions results in the production of explosive gases, as well as vapor-phase volatile organic compounds. Taking into account the limited biodegradability of organic compounds in the leachate, their treatment requires the classic biological method to be augmented by additional processes, mainly physical or/and chemical.

The aim of the research project

The main objective of the research project was to establish the influence of the ultrasonic (US) field on the efficiency of landfill leachate and synthetic wastewater co-treatment. In particular, an attempt was made to establish if the treatment of landfill leachate – especially that generated in long existing landfill sites – involving digestion in an MBR reactor after ultrasonic disintegration (US) and subsequent treatment in the reverse osmosis process (RO), is a promising solution to the problem of leachate treatment or not.

Research material and methods

The research project is based on samples collected from the regional landfill site in Sobuczyny near Czestochowa, which has been in operation since 1987. Experiments were conducted on samples consisting of: raw leachate – 20 % vol. and synthetic wastewater – 80 % vol. The adopted proportion was considered optimal taking into account results from the early stages of the research project. Table 1 presents the physical and chemical parameters of raw landfill leachate.

Table 1

Characteristics of the raw landfill leachate

Parameter	Unit	Range of value
pH	[-]	8.2–8.4
COD	mgO_2/dm^3	3200–4600
BOD/COD	[-]	0.11–0.2
NH_4^+	mg/dm^3	800–1000
Cl^-	mg/dm^3	1800–2500

Samples both after and before ultrasonic disintegration underwent the digestion process – a methane fermentation in the reactor equipped with submerged membrane module. The concentration of sludge granules was maintained at the fixed level of 10 g/m^3. Hydraulic retention time was varied within the range of between 1 and 3 days, which allowed to increase the OLR (Organic Loading Rate) value from 1.3 kg COD/m^{3}d to 4.0 kg COD/m^{3}d. The ultrasonic field parameters applied: disintegration time: 300 s and amplitude of resonance – 25 m were specified during the early stages of the research project implementation. Samples after anaerobic digestion were transferred to the reverse osmosis module. The reverse osmosis process was conducted applying the following parameters: cross-flow velocity of 2 m/s and transmembrane pressure of 3 MPa.

Discussion

The core of the project focused on the determination of the most appropriate operating parameters of anaerobic digestion process, such as hydraulic retention time (HRT) and organic loading rate (OLR) of the bioreactor. Samples after anaerobic digestion were treated in the process of reverse osmosis with the aim to receive a high degree of pollutant removal.

The treatment of landfill leachate in an MBR reactor

Hydraulic retention time (HRT) initially adopted was 3 days, which was tantamount to 1.3 kg COD/kg$_{d.m.}$d of bioreactor organic loading rate (OLR). Under the conditioned specified, the leachate treated exhibited the COD value of 620 mgO_2/dm^3. In this case, COD reduction amounted to 84.5 %. Whilst samples treated in the same reactor without ultrasonic disintegration exhibited the COD value of 780 mgO_2/dm^3 and the COD reduction at the level of 80.5 %.

The HRT value was subsequently reduced by 12 hours and the corresponding COD changes recorded. Figure 1 presents COD values as well as COD reduction of the leachate samples in relation to the HRT value.

Firstly, the reduction of HRT value from 3 days to 2.5 days caused the OLR value to increase from 1.3 to 1.6 kgCOD/m^{3}d as well as positively effected the degree of COD reduction both with reference to disintegrated and non-disintegrated samples – Fig. 1.

Secondly, when the HRT was reduced to 2 days, the COD removal increased significantly and amounted to 87.2 % and 84 % for the US-facilitated and non--facilitated samples, respectively.

Thirdly, the application of HRT of 1.5 was associated with an increase in OLR value to 2.6 kgCOD/m^{3}d. Under such conditions, the degree of COD removal increased to 88 % for the US-facilitated sample. In case of non-disintegrated sample, the recorded degree of COD removal was lower and amounted to 81 %.

Finally, when the HRT was reduced the most to 1 day, and the corresponding OLR value amounted to 4.0 kgCOD/m^{3}d, degree of COD reduction for ultrasonically treated

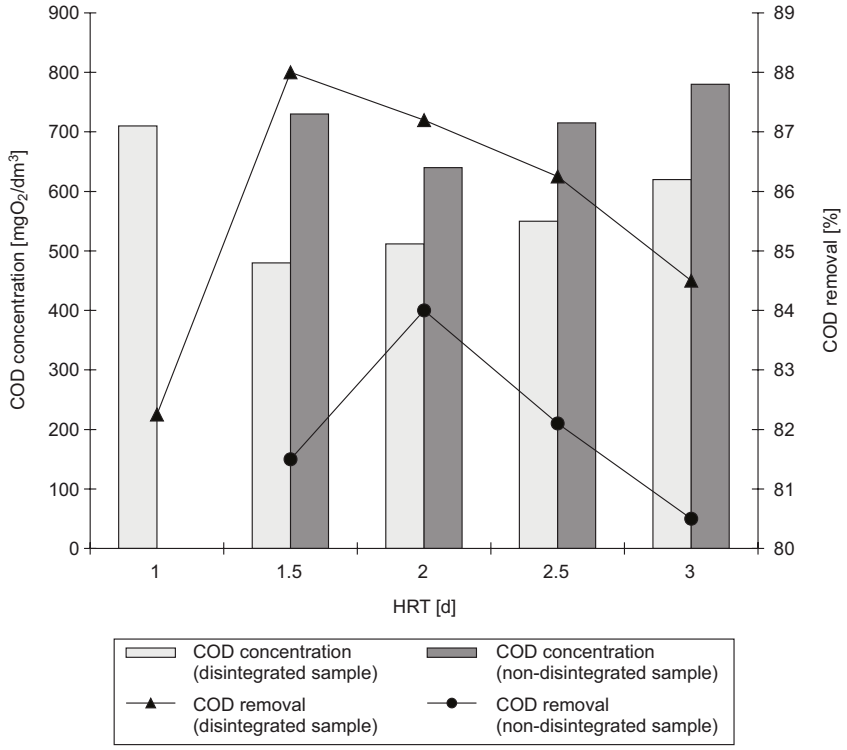

Fig. 1. Dependency of COD concentration as well as COD removal on HRT value in samples treated in MBR reactor

samples amounted to around 82.2 % and was lowered by 6 %, as compared with samples treated at HRT 1.5.

As the samples were undergoing digestion, the amount of biogas generated was recorded. It was observed that the reduction of HRT value lead to an increase in the amount of biogas generated. For, example, at the HRT of 3 days, the daily amount of biogas was about 14.8 and 13.5 dm^3 for US-facilitated and non-facilitated sample, respectively. Whilst at the HRT of 1 day, in both cases the amount of biogas generated increased by about 3 times. In comparison with the process which was not augmented by ultrasonic disintegration, the amount of biogas produced increased by 11 % on average. Figure 2 presents the amount of biogas generated at various HRT values for both conditioned and non-conditioned samples.

The results presented above allowed to specify the optimum HRT as well as the OLR value of the membrane reactor for both ultrasonically disintegrated and non-disintegrated samples. When the methane fermentation was conducted at 2.6 $kgCOD/m^3d$ and HRT of 1.5, the recorded degree of COD removal was the highest and amounted to 88 % in the MBR reactor coupled with ultrasonic disintegration. In the case of non-disintegrated process, the highest degree of COD removal, ie 84 % was recorded for the HRT of 2.0. It should be highlighted that the application of US-field allowed to

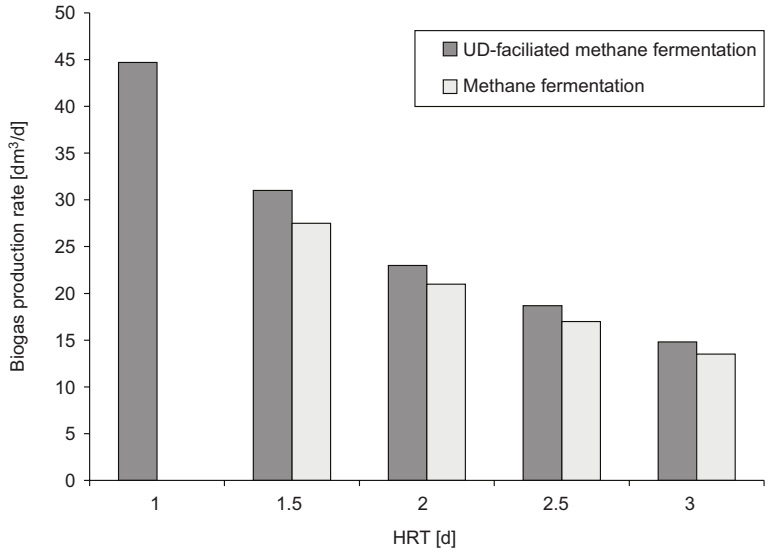

Fig. 2. The amount of biogas generated at various HRT values for both conditioned and non-conditioned samples

decrease the HRT value by 12 hours. What is more, US-facilitation positively impacted the overall biogas production – Fig. 2.

Post-treatment of landfill leachate in the process of reverse osmosis

Leachate samples treated in the process of anaerobic digestion, both disintegrated and non-disintegrated underwent the reverse osmosis process. In the beginning of the

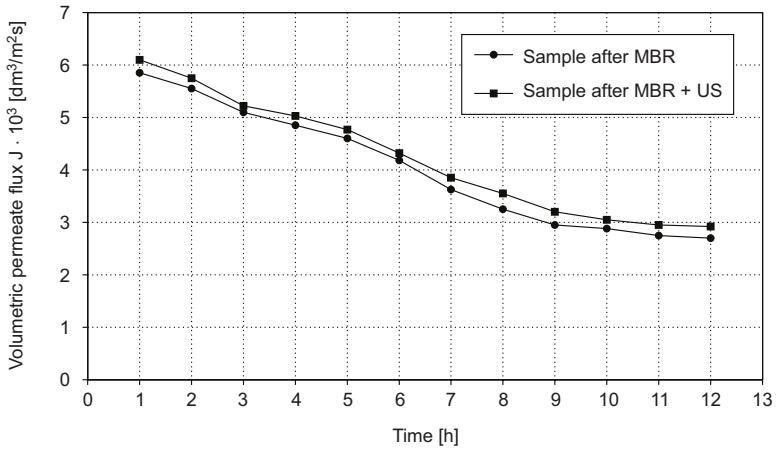

Fig. 3. Dependency of the volumetric permeate flux on the length [in hours] of the process

process, both volumetric permeate fluxes exhibited the same value of 8.13×10^{-3} dm^3/m^2s. After 12 hours of the process their value decreased significantly and amounted to 2.7 dm^3/m^2s for non-US facilitated sample and 2.9 dm^3/m^2s for UD-facilitated sample – Fig. 3.

As it was expected, the process of reverse osmosis turned out to be very effective. The COD and BOD values of samples after ultrasonic disintegration decreased by 97.5 % and 92.6 %, respectively. Whilst the concentration of chlorides and ammonia nitrogen was reduced by 90 % and 86 %, respectively, all compared with the values obtained after biological treatment. Likewise, posttreated samples which had been treated by means of anaerobic digestion without ultrasonic disintegration, allowed to receive a high degree of pollutant reduction. The values of COD and BOD decreased by 90.8 % and 96.2 %, respectively. The application of US field did not exert a positive influence on chlorides and ammonia nitrogen concentration, as compared with the values recorded for samples, which did not undergo US-facilitation. Table 2 presents the comparison of chemical parameters of the leachate treated in the MBR as well as MBR + US mode.

Table 2

Comparison of physical and chemical parameters of the leachate treated in the MBR and MBR+US mode

Indicator	Raw sample	Samples after anaerobic digestion		Samples after anaerobic digestion and reverse osmosis		Maximal discharge limits [5]
		MBR HRT = 2d	MBR + UD HRT = 1.5d	MBR +RO HRT = 2d	MBR + UD + RO HRT = 1.5d	
COD [mgO_2/dm^3]	4000	640	480	24	12	125
BOD_5 [mgO_2/dm^3]	1350	186	135	17	10	25
NH_4^+ [mg/dm^3]	280	207	207	20	29	10
Cl^- [mg/dm^3]	2500	2250	2300	209	210	1000

Conclusions

The application of the MBR reactor associated with a reverse osmosis process (RO) turned out to be effective for the treatment of the analyzed landfill leachate. It was established that ultrasonic disintegration reduced the HRT value from 2 to 1.5 days, as compared with non-disintegrated samples. Moreover, the COD removal as well as biogas production for each HRT value adopted was on average by 10 % and 11 % higher, respectively. However, landfill leachate after anaerobic digestion in both modes,

ie MBR and MBR+US, exhibited an excessive amount of contamination, which did not allow to discharge it into receiving water.

Post-treatment by means of reverse osmosis ensured a high degree of pollutant removal for both US-facilitated and non-facilitated modes. However, posttreated leachate exhibited an excessive amount of ammonia nitrogen – exceeding the discharge limits [5]. In order to overcome the problem, it was suggested that the leachate might subsequently undergo the process of ammonia stripping. It will be taken into consideration in the further stages of the research project.

Acknowledgements

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Abstrakt: Przedstawiono wyniki badań dotyczące określenia wpływu pola ultradźwiękowego (UD) na efektywność współoczyszczania odcieków ze ściekami syntetycznymi w procesie fermentacji metanowej skojarzonym z odwróconą osmozą. Oczyszczanie ścieków metodą biologiczną realizowano w beztlenowym bioreaktorze z zanurzonym modułem membranowym (MBR), w którym stężenie osadu granulowanego utrzymywano na poziomie 10 g/dm^3. Czas zatrzymania w reaktorze zmieniano w zakresie wartości od 3 do 1 d, uzyskując dzięki temu wzrost obciążenia reaktora ładunkiem zanieczyszczeń od 1,3 do 4,0 kgChZT/m^{3}d. Stwierdzono, że kondycjonowanie odcieków w polu UD pozwoliło na skrócenie z 2 do 1,5 d hydraulicznego czasu zatrzymania mieszaniny współoczyszczanych ścieków w reaktorze MBR w porównaniu z procesem fermentacji prowadzonym dla odcieków nie poddawanych nadźwiękawianiu. Odnotowano również średnio o 10 % większy stopień usunięcia ChZT oczyszczonych ścieków dla każdego z przebadanych HRT i o 11 % większą objętość generowanego biogazu. Z uwagi na fakt, że ścieki po procesie beztlenowej biodegradacji w obu przebadanych układach (MBR i MBR+UD) nadal charakteryzowały się dużym ładunkiem zanie-

czyszczeń uniemożliwiającym ich bezpośrednie odprowadzenie do odbiornika naturalnego, podjęto próbę ich doczyszczania metodą odwróconej osmozy. Pomimo bardzo dużej retencji ładunku zanieczyszczeń, w otrzymanym permeacie stężenie azotu amonowego pozostało nadal na zbyt wysokim poziomie. W celu obniżenia pozostałego azotu amonowego poniżej wartości umożliwiającej odprowadzenie do odbiornika naturalnego zaproponowano, aby w kolejnych etapach badań włączyć do badanego układu proces odpędzania amoniaku.

Słowa kluczowe: odcieki ze składowisk odpadów komunalnych, fermentacja metanowa, reaktor membranowy (MBR), odwrócona osmoza (RO), pole ultradźwiękowe