THE INFLUENCE OF MICROWAVE IRRADIATION ON THE INCREASE OF WASTE ACTIVATED SLUDGE BIODEGRADABILITY

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Abstract

The aim of the research project was to establish the most appropriate time of microwave exposure, which ensures effective sludge lysis. The assessment of the sludge disintegration was based on a release of organic (COD) and inorganic (PO_4^{3-}, NH_4^+, Ca^{2+}, Mg^{2+}) substances into liquid phase as well as the quantity and quality of the biogas produced. It was established that an increase in sludge biodegradability caused by a rise in COD, had a positive impact on the amount of biogas generated. Based on the results obtained, the optimum microwave exposure amounted to 4 min, and was correlated with the sludge temperature of 60°C for the power of 700W and 80°C for power of 900W. As compared to the amount of biogas generated with raw sludge, the optimum exposing time allowed to generate 49% and 60% more biogas at 700W and 900W respectively. Microwave treatment at both powers, did not have an influence on the CH_4 content in biogas produced.

Streszczenie

Celem badań przedstawionych w artykule było ustalenie najkorzystniejszego czasu oddziaływania mikrofal zapewniającego efektywną lizę nadmiernych osadów czynnych. Stopień dezintegracji osadu oceniano na podstawie zmian zawartości związków organicznych (ChZT) i nieorganicznych (PO_4^{3-}, NH_4^+, Ca^{2+}, Mg^{2+}) w cieczy nadosadowej oraz ilości i jakości wygenerowanego biogazu. Poprawa biodegradowalności osadów wskutek wzrostu stężenia związków organicznych (ChZT) wpłynęła pozytywnie na ilość wydzielanego biogazu. Jako optymalny czas oddziaływania mikrofal na analizowany osad ściekowy uznano czas wynoszący 4 minuty, który odpowiadał temperaturze osadu na poziomie około 60°C dla mocy mikrofal 700W oraz około 80°C dla mocy mikrofal – 900W. Dla czasu tego produkcja biogazu w odniesieniu do ilości biogazu wygenerowanego przez osad surowy wzrosła o 49% (700W) i 60% (900W). Wstępne preparowanie osadu mikrofalami nie wpłynęło na zawartość CH_4 w produkowanym biogazie.

Keywords: **Waste Activated Sludge; Biodegradability; Disintegration; Microwave Irradiation; Anaerobic Digestion; Biogas.**

1. INTRODUCTION

Anaerobic digestion for biogas production, whose major advantage is the potential to generate biogas, constitutes the most widely used sludge stabilization method in medium-sized and large wastewater treatment plants. The main purpose of the methane fermentation is sludge stabilization, whereby strongly hydrated, odorous and environment-unfriendly raw sludge is converted into a well-dewatering, digested sludge [1-2]. The digestion process is conditioned by the activity of a few types of bacteria, and is divided into four successive stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis. The phase which determines the course of the whole process is hydrolysis, whereby polymeric, insoluble compounds (proteins, fats, carbohydrates and their derivatives) are decomposed into less complex (such as amino acids, monosaccharides, alcohols, fatty acids). Due to complex particle structures and the existence of strong cell membranes, excessive activated sludge is difficult to biodegrade in anaerobic conditions. Accordingly, the main purpose of its disintegration is to disrupt cell membranes and thus lysis microorganism cells. Both lead to a release of polymeric substances in a soluble form into liquid phase [3-7].

As regards different disintegration methods, positive effects on waste activated sludge were recorded when the following methods were used: thermal treatment [8-11], ultrasonic energy [12-13], mechanical mincing [14-15], chemical oxidation [16-20], high pressure [21-25] as well as the application of enzymes [26].

Microwaves are a type of electromagnetic waves within the range between 0.3-300 GHz, and the wave length of 0.01-1 m. Microwaves can be absorbed by matter in two different ways. Firstly, through dielectric polarization. As a result of exposure to microwaves, chemical particles which are dipoles, spin and heat neighboring particles and thus pass the energy gained onto them. The other mechanism is based on ions conductivity. Ions while moving in line with the direction of the electromagnetic field collide into other particles and thus cause heat to spread through the matter [27-30].

Microwave irradiation is successfully applied in chemical engineering industry as a factor increasing and facilitating the rate of chemical reactions, e.g. polymerization [31]. Microwaves have also been used in the process of sewage sludge hygienization, dewatering and drying. The studies concerning the sludge pre-treatment by means of microwave irradiation before anaerobic digestion mostly concern influence of microwaves on the conversion of organic matter into easily-accessible substances for fermentative microorganisms. The conversion of organic matter contained in the sludge flocs is usually reflected by the increased value of SCOD/TCOD ratio. The most favorable values of the ratio quoted in literature fluctuates between 0.14 and 0.24 [28, 32-34]. For similar temperature range of sludge treated by microwave irradiation, higher COD values were recorded if the sludge was treated by waves of lower power [34-35]. A similar relationship was observed in the work [28], which indicated that the amount of COD released is mainly conditioned by the temperature of sludge treated as well as the length of microwave irradiation. If the sludge is treated with microwaves of lower power, the same effects can only be reached if the length of exposure is prolonged [35]. The disintegration of cell membranes leads also to the release of enzymes located in protoplasma, which are responsible for hydrolytic decomposition of organic nitrogen and phosphorus compounds, and thus in turn causes both – ammonia and phosphates release into a liquid phase [36]. The maximum concentrations of ammonia-nitrogen are usually released at the sludge temperature of 70-80°C. A further increase in the time of microwaves exposure leads to a significant decrease in NH_4^+ concentration, which is ascribed to the impact of high temperature. High temperature causes a partial conversion of NH_4^+ into gas form (NH_3) and subsequently its release into the atmosphere [28, 30].

The increase of easily-accessible organic substances for fermentative microorganisms usually results in higher biogas production in the process of methane fermentatation.The increase of biogas production after microwave irradiation quoted in literature fluctuates between 6% and 31%. The values however refer experiments conducted under differing conditions and pertaining to different amounts of digested sludge used as an inoculum. Acclimatization to microwave conditions plays the most important role. In case of non-acclimated sludge, the increase of biogas production was negligible [29, 37-38].

The application of microwave irradiation to facilitate the process of sludge anaerobic digestion is a relatively novel method and is not thoroughly described in literature. Especially, the current literature showed that there is little information concerning the influence of microwave power on the degree of sludge disintegration. The aim of the research project was to establish the most appropriate time of microwave exposure, which ensures effective sludge lysis. It was assumed that the level of microwaves power is behind a factor impacting the effects of sludge disintegration. The assessment of the sludge disintegration was based on an increase of organic (COD) and inorganic (PO_4^{3-}, NH_4^+, Ca^{2+}, Mg^{2+}) substances in the liquid phase. The influence of different microwave exposure times on the quantity and quality of the biogas generated was evaluated.

Table 1.
Characteristics of the research material

Indicator	Unit	Sewage Sludge	
		Range of values	Average value
pH	-	5.9÷6.6	6.3 (0.3)
Total solids (TS)	%	5.17÷5.41	5.27 (0.17)
Volatile solids (VS)	%	3.63÷3.83	3.71 (0.16)
C_{org}	% TS	32.80÷33.31	33.05 (0.38)
N_{og} (Kjeldahla)	% TS	4.88÷5.01	4.96 (0.11)
COD	mgO_2/dm^3	102÷430	247 (122)
Ammonia-nitrogen	$mgNH_4^+/dm^3$	11.4÷19.8	15.8 (5.9)
Phosphates	$mgPO_4/dm^3$	103.2÷200.8	145.5 (32.6)
Calcium	$mgCa^{2+}/dm^3$	42.5÷74.5	58.5 (9.5)
Magnessium	$mgMg^{2+}/dm^3$	20.6÷42.4	26.5 (7.5)

() – standard deviation

2. MATERIALS AND METHODS

Waste activated sludge (WAS) was used as a research material. The sludge was taken after thickening from a full scale municipal treatment plant, based on Enhanced Biological Nutrients Removal (EBNR), operated on activated sludge method. The plant treats domestic as well as industrial wastewater. The industrial fraction constitutes up to the 10% of the total influent and is pre-treated before mixing with domestic wastewater. Table 1 presents the physical and chemical properties of the waste activated sludge, used as a research material.

The disintegration was conducted by means of a microwave oven of 700 and 900W (2450 GHz). Microwave irradiation was applied to sludge samples of 500 cm^3, i.e. the volume which corresponded to the sludge layer of 4 cm. The time of microwave exposure was gradually increased by 30s within the range of 0-8 min. The disintegration process was repeated 5 times and the presented results represent averages.

The scope of the analyses conducted encompassed: pH value measurement and determinations of total solids (TS), volatile solids (VS), chemical oxygen demand (COD), ammonia (NH_4^+) and total Kjeldahl (TKN) nitrogen, phosphates (PO_4^{3-}), organic carbon (C_{org}) as well as calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions [39-40]. The temperature of the sludge treated was taken immediately after microwave exposure, by means of a portable multi-parameter meter produced by the company WTW. Whilst images of sludge structures were taken by means of a Nikon Alphaphot microscope, coupled with a digital camera.

The influence of microwave irradiation on the amount of biogas produced was based on the cumulative biogas production tests, conducted in static conditions. The recorded amounts of biogas were adjusted to the volume at standard temperature (0°C) and pressure (1 atm). The process was terminated when the intensive biogas production came to an end (approx. 30 days). Digested sludge extracted from continuous mesophilic process, acclimated to microwave conditions, was used as an inoculum. The acclimatization lasted over a period of 3 months, during which 20% of the bioreactor contents were replaced with the same amount of irradiated sludge on a weekly basis. The power of microwave irradiation used for acclimatization amounted to 700 or 900 W, while the exposure time amounted to 4 min. The sludge irradiated by means of microwaves of 700 W and 900 W was inoculated with sludge acclimated to microwaves of 700 W and 900 W respectively. The inoculum constituted 20% of the digestion feedstock.

3. RESULTS AND DISCUSSION

The exposure to microwaves, causes the heat to spread, which leads to a temperature increase of the treated material. The higher the power of microwaves applied, the higher the temperature of the sludge treated until reaching the boiling point. Figure 1 presents the influence of microwave power and exposure time on the temperature of the sludge irradiated.

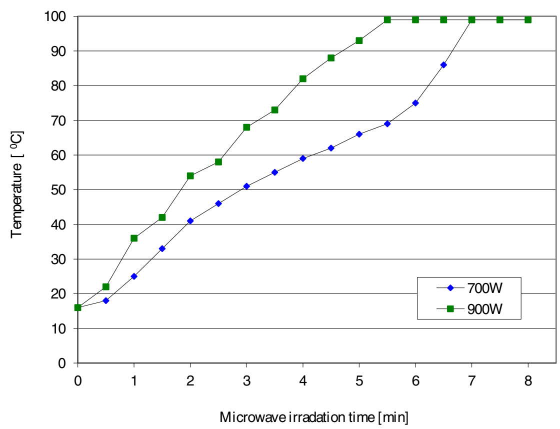

Figure 1.
Influence of the microwave irradiation on the temperature of the sludge treated

Cell membranes disintegration leads to a release of organic matter into liquid phase. Figure 2 presents the influence of microwave irradiation on the COD content in the liquid phase. For both values of microwave power, the maximum level of COD release was not strongly correlated with the value of microwave power applied. The values of maximum COD release were comparable for both microwave powers used and amounted to 8250 mgO_2/dm^3 for 700W and 7760 mgO_2/dm^3 for 900W. The values were recorded after 7.0 and 5.5 min of sludge irradiation respectively. The sample of sludge irradiated with microwaves of 700W, exhibited a COD value higher by about 6%, which was accounted by the fact that the sludge was exposed to microwaves action for 90s longer. When the temperature of the sludge increased to ~100°C, microwaves were not recorded to have a positive impact on the COD release. An intensive boiling of the sludge was observed, which might have led to a partial release of organic substances into the atmosphere. As a result, a slight decrease in COD concentration was observed (Fig. 2).

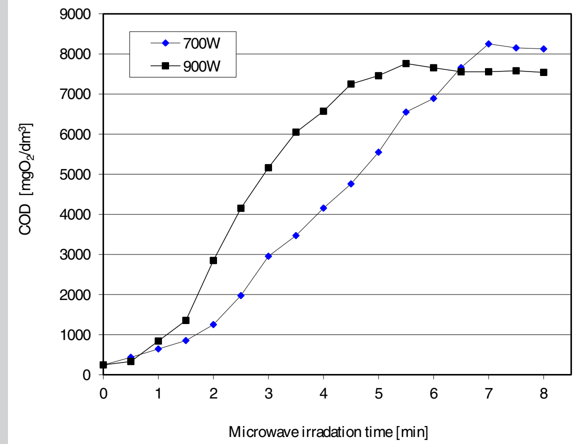

Figure 2.
Influence of microwave irradiation on the amount of organic substances (COD) released into the liquid phase

Effective destruction of sludge flocs results in the release of ammonia-nitrogen and phosphates. Ammonia is mainly released during decomposition of amino acids and proteins. The concentration of ammonia recorded during the experiment was depicted in Figure 3. As with CODs, the concentration of NH_4^+ released was not correlated with the value of microwave power applied. Comparable values of maximum NH_4^+ concentration (104÷106 mg/dm^3) were achieved at the sludge temperature of 70°C, which corresponded to microwave exposure of 5.5 min at 700W and 3.5 min at 900W. A further increase in the time of exposure led to a significant decrease in NH_4^+ concentration, which was ascribed to the impact of high temperature.

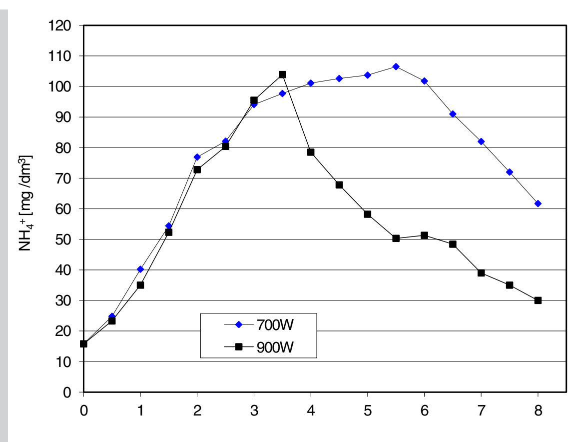

Figure 3.
Influence of microwave irradiation on the amount of NH_4^+ released into the liquid phase

Besides, the application of bacteria accumulating phosphorus in quantities exceeding their energetic needs, increases the contents of phosphorus in the sludge flocs [41]. The influence of the microwaves power on the amount of phosphates released is presented in Figure 4. The highest value of phosphates was noticed for microwaves of higher power (900W) and amounted to 650 mgPO_4^{3-}/dm^3. The value was achieved at the exposure time of up to 3.5 min, which corresponded to the sludge temperature of 70°C. Exposure of microwaves exceeding 3.5 min did not have a positive impact on the amount of phosphorus released (620-635 mgPO_4^{3-}/dm^3). Whereas, for sludge treated with 700W microwave power, the concentration of phosphates increaesd further. The highest value amounted to 725 mgPO_4^{3-}/dm^3 and was achieved for the exposure of 4.5 min, at the sludge temperature of 60°C. The value is higher by 12% than the equivalent value obtained when the sludge was treated with microwave power of 900W.

A coherent flock structure is conditioned not only by hydrogen bindings and hydrophobic interactions but also by divalent ions, such as Ca^{2+} and Mg^{2+} constituting a component of phospholipids [32, 42]. Hence, an increase in the amount of divalent ions in the liquid phase after disintegration is a proof of effective flocs disintegration. Figure 5 shows the influence of microwave irradiation on the release of Ca^{2+} and Mg^{2+} ions. About 10% greater Ca^{2+} concentration was recorded for the whole length of microwave exposure, when the power was higher (900W). The level of microwave power, however, did not impact on the release of Mg^{2+} ions.

Effective destruction of sludge flocs was additionally confirmed by microscopic observations, conducted before and after disintegration. As show in Figure 6, microwave irradiation has a significant impact on the sludge flocs structure and causes their disruption. As mentioned before, effective microorganisms disintegration leads to the release of their inner contents, which is reflected by an increased concentration of organic and inorganic substances in liquid phase.

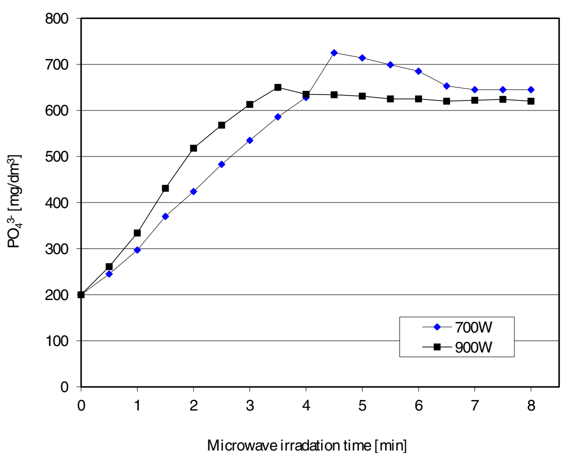

Figure 4.
Influence of microwave irradiation on the amount of phosphates released into the liquid phase

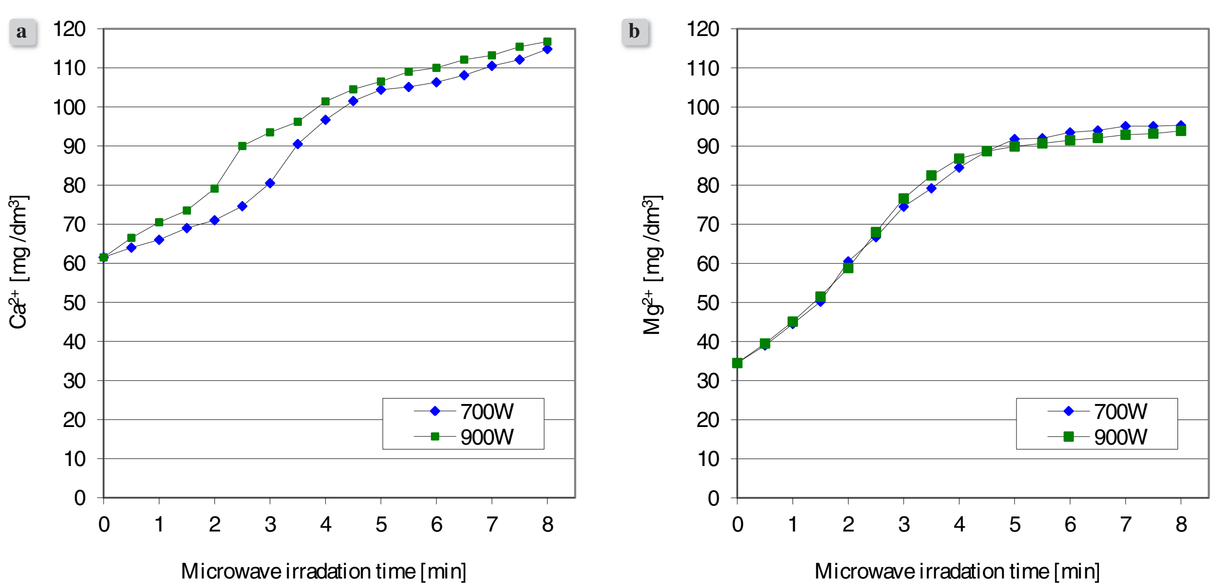

Figure 5.
Influence of microwave irradiation on the amount of calcium (A) and magnesium (B) released into the liquid phase

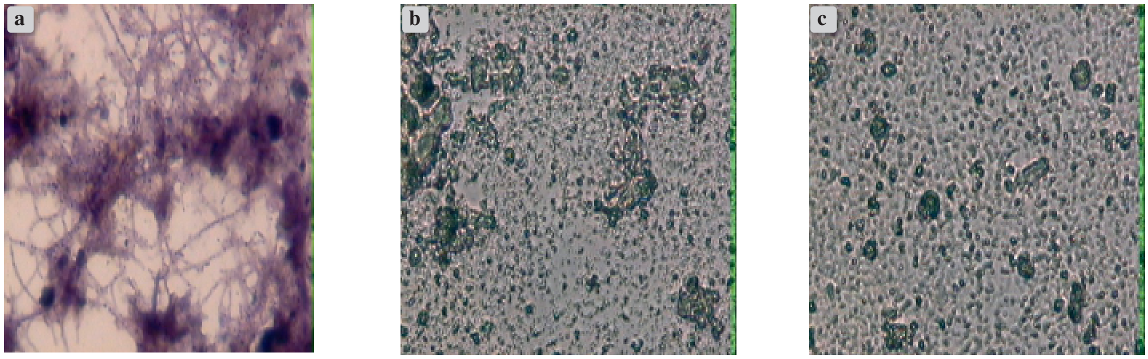

Figure 6.
Microscopic images of waste activated sludge (x100), A – raw sludge, B – sludge exposed to microwave power of 700W for 4 min, C – sludge exposed to microwave power of 900W for 4 min

Further stages of the research were focused on biogas production. The quantity and quality of biogas generated during the experiment is presented in Figure 7. The longer the microwave exposure time, the greater the amount of biogas produced. Even short exposure time led to a significant increase of biogas production. At the exposure time of 4 min, biogas production reached 4.62 dm^3 (700W) and 4.95 dm^3 (900W). Compared to the untreated sludge, the values increased by 49% and 60% respectively. Further exposure to microwaves did not have such a significant impact on the amount of gas produced; still higher power allowed gain about 4-8% more biogas than microwave power of 700W, under the same conditions. The CH_4 content in the biogas amounted to 54-56% and was similar for both, – raw sludge and pre-treated with microwave irradiation.

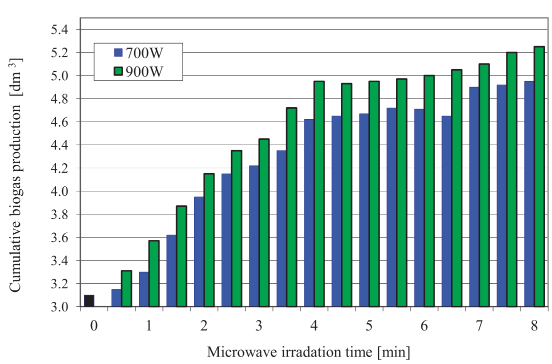

Figure 7.
Influence of microwave irradiation on the biogas production

4. CONCLUSIONS

1. Considering the fact that the secondary sludge generated at municipal wastewater treatment plants exhibits a relatively low susceptibility to biodegradation in anaerobic conditions, initial treatment – meant to improve its biodegradability becomes ever more important and justified in technological terms. Disintegration of the secondary sludge by means of microwave irradiation is a relatively recent method which has not been extensively published on.
2. The method allowed to effectively disrupt the sludge flocs, which was confirmed by increased concentrations of organic (COD) and inorganic (NH_4^+, PO_4^{3-}, Ca^{2+}, Mg^{2+}) substances. The effectiveness of the process was also confirmed by microscopic observations.
3. The power of microwave irradiation did not have a significant impact on disintegration effects, however, slightly higher COD and PO_4^{3-} concentrations after disintegration by means of microwaves of lower power (700W) were ascribed to a longer exposure times.
4. An increase in sludge biodegradability caused by a rise in COD matter, had a positive impact on the amount of biogas generated. The optimum microwave exposure amounted to 4 min, and was correlated with the sludge temperature of 60°C for the microwave power of 700W and 80°C for power of 900W. As compared to the amount of biogas generated with raw sludge, the optimum exposing time allowed to generate 49% and 60% more biogas at 700W and 900W respectively. Microwave treatment at both powers, did not have an influence on the CH_4 content in biogas produced. Knowing that sludge disintegration requires signif-

icant amounts of energy, it seemed uneconomical to increase the exposing of microwaves on the analysed sludge beyond 4 min.

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