Possible Co-fermentation of Water and Sewage Sludge

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Abstract. The article describes problems related to intensification of energy production at a wastewater treatment plant. The authors analyzed anaerobic co-digestion of sludge from both water treatment plant and sewage treatment plant. Water sludge is produced during coagulation, ozonation and backwashing of rapid anthracite filters. Its characteristic and properties depend on a raw water quality, treatment methods as well as types of chemicals used and their doses. According to the Polish Act of 4 December 2012 (Journal of Laws from 2013, item 21) the water sludge should be treated as hazardous waste. An alternative way to dispose water sludge and reduce its volume may be sludge reuse. The authors suggested a research methodology and analyzed the preliminary results, which showed that co-digestion of sewage and water sludge enhanced biogas production. The authors assume that the results of the study will provide a basis for development of methodology for sludge control and disposal.

1 Introduction

During water treatment (surface water in particular) a large amount of sludge and wastewater are produced. According to the waste classification (the Act of 14 December 2012 on waste [1]) sludge generated during water treatment processes should be treated as hazardous or other then hazardous waste. In Poland, management of this type of sludge has been significantly influenced by the legal requirements involving the country's membership in the European Union. This resulted in a ban on the storage of sludge, beginning from January 1, 2016. Therefore, we are forced to limit production of this type of waste or to seek other alternative ways of its elimination, with the possibility of its reuse as a raw material [2, 3].

The literature offers many publications on water sludge, in which its composition is described [4–7] as well as the methods of its cultivation and utilization [8–12]. Water sludge is mostly used as coagulant and phosphorus recovery from wastewater, as a coagulant in wastewater treatment, for heavy metal immobilization, production of ceramics or cement, land reclamation, sludge dewatering and also as a fertilizer in farming and forestry [8–10].

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In contrast, there is little information on co-fermentation of water sludge and sewage sludge. Płonka [13] in her study used water sludge in co-fermentation with sewage sludge. The results showed that a higher amount of water sludge in samples resulted in a lower fermentation gas production. The presence of water sludge hindered the digestion process. However, it can be noted that the presence of water sludge improved wastewater sludge dewaterability. On the other hand, the authors' study [14] showed that co-fermentation of these two types of sludge increased a biogas production from 20 to 140% (depending on the sewage sludge/water sludge ratio in the samples), if compared to the digested sludge samples. Though, water sludge demonstrated a negative effect on filtration properties of sewage sludge.

The article tried to investigate a possibility of co-fermentation of water and sewage sludge as well as evaluate filtration properties of the sludge mixture. The study consisted of three phases:

- respirometric comparative analysis of biogas production,
- respirometric study of methanogenic activity,
- dewaterability - capillary suction time and specific resistance to filtration.

2 Methods

2.1 Respirometric test

Respirometric tests have been used for energy research to analyze both quantity and quality of a fermentation gas. Therefore, a respirometer and biogas production measurements were conducted to describe and evaluate biodegradability or activity in anaerobic processes. The respirometers used in anaerobic processes measure gas production as a gas volume determined either at a constant pressure or at a constant sample volume. Methane was selected as an indicator of the anaerobic process efficiency mostly due to its energetic properties, but also to its physical and chemical characteristics [15]. The test stand consisted of:

- Respirometer for aerobic-anaerobic tests (AER-208, manufactured by CHALLENGE SYSTEM),
- Water bath,
- Heating/cooling unit,
- Computer for online data processing (gas volumes measured every 2h).

Measurements were carried out over 20 days at mesophilic (35°C) conditions in three separate runs. Compositions of samples were selected based on the dry organic solids content and included water and digested sludge with a volume of samples: 1 dm^3. Co-substrate concentrations ranged from 3.0 to 6.0 g $VSS \cdot dm^{-3}$. To ensure the appropriate process conditions pH of samples was adjusted to 7.0 with NaOH. Before measurements, the sample were purged for three minutes with technical nitrogen. The laboratory analysis included: dry solids (VS), volatile suspended solids (VSS), chemical oxygen demand (COD), alkalinity, pH, total phosphorus (TP), total nitrogen (TN) and ammonia nitrogen (N_{NH4}).

2.2 Methanogenic activity test

Methanogenic activity was calculated based on the amount of methane produced from the sludge during the respirometric tests, and expressed in g COD_{CH4} g VSS^{-1} d^{-1} [15–18]. The maximum methane production and the R factor (as $ml_{CH4} \cdot h^{-1}$) were determined based

on the graphs showing the volume of methane produced per time unit. Fig. 1 shows the way R was determined for the digested sludge.

Table 1. Chemicals used during respirometric tests to determine the methanogenic activity.

Substrate concentration		Enrichment of samples – neutralized mixture of samples (pH 7.0): acidic and butter acids; COD of sample: 3.0 – 5.5 $gO_2 \cdot dm^{-3}$
Minerals	Solution 1	NH_4Cl (170 $g \cdot dm^{-3}$), $MgSO_4 \cdot 4H_2O$ (9 $g \cdot dm^{-3}$), KH_2PO_4 (37 $g \cdot dm^{-3}$), $CaCl_2 \cdot 2H_2O$ (8 $g \cdot dm^{-3}$)
	Solution 2	$FeCl_3 \cdot 4H_2O$ (2000 $mg \cdot dm^{-3}$), $(NH_4)_6Mo_7O_2 \cdot 4H_2O$ (90 $mg \cdot dm^{-3}$), $CoCl_2 \cdot 6H_2O$ (2000 $mg \cdot dm^{-3}$), $Na_2SeO_3 \cdot 5H_2O$ (100 $mg \cdot dm^{-3}$), $MnCl_2 \cdot 4H_2O$ (500 $mg \cdot dm^{-3}$), $NiCl_2 \cdot 6H_2O$ (50 $mg \cdot dm^{-3}$), $CuCl_2 \cdot 2H_2O$ (30 $mg \cdot dm^{-3}$), EDTA (1000 $mg \cdot dm^{-3}$), $ZnCl_2$ (50 $mg \cdot dm^{-3}$), HCl 36% (1cm^3), H_3BO_3 (50 $mg \cdot dm^{-3}$), resazurin (500 $mg \cdot dm^{-3}$)
Yeast extract		0.2 ($g \cdot dm^{-3}$ of sludge sample)

The methanogenic activity of biomass was calculated according to the equation:

$$AKT = (R \cdot 24)/(W \cdot V \cdot VSS) \quad (1)$$

where:
AKT – methanogenic activity of sludge [g $COD_{CH4} \cdot g\ VSS^{-1} \cdot d^{-1}$],
R – parameter determined from the curve of the methane production [$CH_4 \cdot h^{-1}$],
W – conversion factor [ml $CH_4 \cdot COD^{-1}$] (assumed 418 ml $CH_4 \cdot COD^{-1}$ at 35°C),
V – volume of the sample [dm^3],

VSS – volatile suspended solids in the sample [g $VSS \cdot dm^{-3}$].

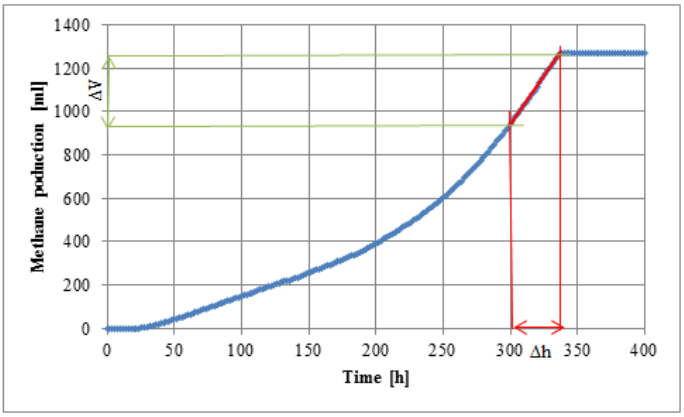


Fig. 1. Determination of the R factor from a methane production chart for digested sludge. The factor is determined as the ratio of the increase in methane production (ΔV) and time (Δh).

2.2 Filtration properties

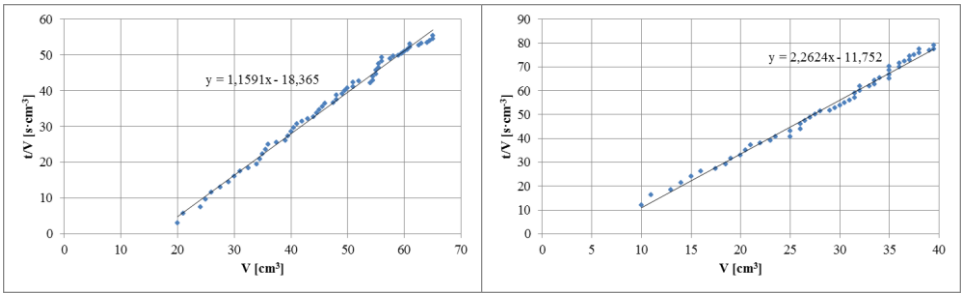
A capillary suction time (CST) and specific resistance to filtration are the main sludge characterization techniques. CST measurements were conducted according to the Polish standards PN-EN 14701-1:2007 [19]. This parameter evaluates how easy moisture can be removed from the sludge cake; when a capillary suction time is small, the sludge easier (faster) releases liquid.

On the other hand, the specific resistance to filtration (SRF) is defined as the pressure required to make filtrate flow through the sludge cake, having unit mass of dry solids per unit area of filtration surface while a filtrate viscosity equals 1. The measurement of the

specific resistance to filtration was carried out on the basis of the PN-EN 14701-2: 2013 [20]. The specific resistance to filtration (SRF) is calculation as follows:

$$SRF = (2 \cdot \Delta p \cdot A^2 \cdot b)/(\mu \cdot m) \quad (2)$$

where:
SRF – specific resistance to filtration [m·kg^{-1}],
Δp – pressure drop across the filter [Pa],
A – filtration area [m^2],
b – slope of the linear part of the curve obtained by plotting t/V vs. V [s·m^{-6}], b factor determined as in Fig. 2,
μ – viscosity of filtrate at the sludge temperature [Pa·s],
m– mass of solids deposited on the filtering medium per unit volume of filtrate [kg·m^{-3}].



a) b)

Fig. 2. Results for b factor in digested sludge, a – before fermentation, b – after fermentation.

3 Results and discussion

The sludge samples (sewage sludge (D), water sludge (W)) were collected at the municipal water and wastewater treatment plants in Southern Poland. Water sludge was produced as a result of coagulation (PAX 19, XL 10, PAX 16), ozonation, dosing of powdered activated carbon and sand filters backwashing. The samples have been taken directly from sludge drying beds at the water treatment plant.

Table 2. Characteristic of sludge samples before and after digestion (preliminary research).

Parameters		Before digestion				After digestion			
		D	**W**	**1:0.5**	**1:0.3**	**D**	**W**	**1:0.5**	**1:0.3**
pH	[-]	7.15	7.02	7.05	7.40	6.94	6.82	7.11	7.25
Alkalinity	[mg$CaCO_3$·dm^{-3}]	511	186	279	349	1029	755	653	618
VS	[gsm·dm^{-3}]	7.81	18.40	9.74	7.72	5.56	17.31	8.70	6.96
VSS	[gsmo·dm^{-3}]	4.69	4.65	4.04	3.65	3.35	3.99	3.58	3.42
*tCOD	[mgO_2·dm^{-3}]	7910	4980	6470	6630	7498	3971	4655	4759
**sCOD	[mgO_2·dm^{-3}]	214	107	199	185	153	65	147	140

*tCOD – chemical oxygen demand of total organic suspensions, **sCOD – chemical oxygen demand of soluble organic compounds

Initially, only 3 series of preliminary studies were run to set right ratios of water sludge to sewage sludge; the proportion of sewage sludge to water sludge has been determined based on the organic content in the sludge. The results of physic-chemical analysis of the mixtures before and after digestion are shown in Table 2. The first test was performed for

the sewage sludge (D), water sludge (W) and mixed sludge containing 50% (1:0.5) and 30% (1:0.3) of sewage and water sludge.

Biogas is produced as a result of anaerobic decomposition of organic compounds during methane digestion. Its volume and a production rate indicate the efficiency of the digestion process and signal any process limitations. Fig. 3 shows the biogas production in sewage sludge, water sludge and the samples that contained 50% (1:0.5) and 30% (1:0.3) of water sludge. In this study, biogas production varied depending on the ratios of sewage/water sludge though intensity of biogas production for both sludge (D) and (W) was very low at the beginning. After over 20 days of digestion, the produced biogas volumes were 0.26 $m^3 \cdot kgVSS^{-1}$ and - 0.17 $m^3 \cdot kgVSS^{-1}$, for sewage and water sludge, respectively. However, in the mixture with water sludge biogas production was much higher and reached 0.33 $m^3 \cdot kgVSS^{-1}$ for Sample 1:0.5 and 0.43 $m^3 \cdot kgVSS^{-1}$ for Sample 1:0.3. The sample mixed at a ratio of 1:0.3 produced the highest volume of biogas; it was about 65% higher than the value for sewage sludge only. It shows that water sludge has a stimulating effect on the biogas production. It should also be noted that a smaller amount of water sludge added to sewage sludge results in higher biogas volumes.

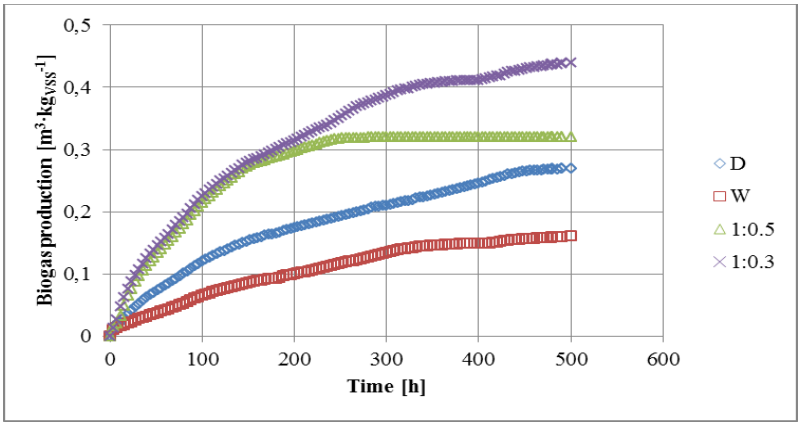


Fig. 3. The biogas production (preliminary research).

Another series of tests were performed for the mixed sludge containing 30% (1:0.3), 20% (1:0.2) and 10% (1:0.1) of water sludge and sewage sludge (D). The test results are shown in Table 3. After 20 days of digestion, the dry solid removals in the mixed sludge samples were as follows: 1:0.3–8.5%, 1:0.2 14% and 1:0.1–7.5%, while in the sewage sludge samples they exceeded 21 %. In the case of organic removal (COD), the mixed sludge showed up to 41% removal of sCOD, while in sewage sludge it was only 16%. Intensity of biogas production during the digestion process varied depending on the ratio of sewage sludge to water sludge. The highest production of biogas was observed, as in the preceding series, for the samples mixed at a ratio of 1:0.3 - 0.51 $m^3 \cdot kgVSS^{-1}$ (Fig. 4). In the sewage sludge samples (D) biogas production was the lowest (0.20 $m^3 \cdot kgVSS^{-1}$); it was about 60% lower than in Sample 1: 0.3.

During the study also some measurements of methanogenic activity (AKT) were made to investigate sludge digestion. The test results are shown in Tab.4. On the basis of the results it was stated that when water sludge was used to intensify the biogas production, the methanogenic activity increased from 5 to 122%, depending on the sludge mixing ratio. Methanogenic activity values to a large extent refer to the volume of biogas generated - the AKT value is the highest for Sample 1: 0.3, and the lowest for the samples D and 1: 0.1.

Table 3. Characteristic of sludge samples before and after digestion.

Parameters		Before digestion				After digestion			
		D	**1:0.3**	**1:0.2**	**1:0.1**	**D**	**1:0.3**	**1:0.2**	**1:0.1**
pH	[-]	7.51	7.16	7.22	7.21	6.89	6.89	7.04	6.98
Alkalinity	[$mgCaCO_3 \cdot dm^{-3}$]	1000	980	860	810	1100	1090	900	910
VS	[$gVS \cdot dm^{-3}$]	9.06	11.89	9.65	8.13	7.33	10.89	8.31	7.52
VSS	[$gVSS \cdot dm^{-3}$]	5.39	5.15	4.53	4.23	4.47	4.88	3.92	3.86
tCOD	[$mgO_2 \cdot dm^{-3}$]	7033	6227	4908	4469	6009	5740	3857	3677
sCOD	[$mgO_2 \cdot dm^{-3}$]	388	173	216	144	327	123	128	85
TP	[$mgP \cdot dm^{-3}$]	255	295	257	241	266	291	246	234
TN	[$mgN \cdot dm^{-3}$]	538	504	470	493	594	549	538	571
N_{NH4}	[$mgN_{NH4} \cdot dm^{-3}$]	266	154	126	126	291	224	258	224

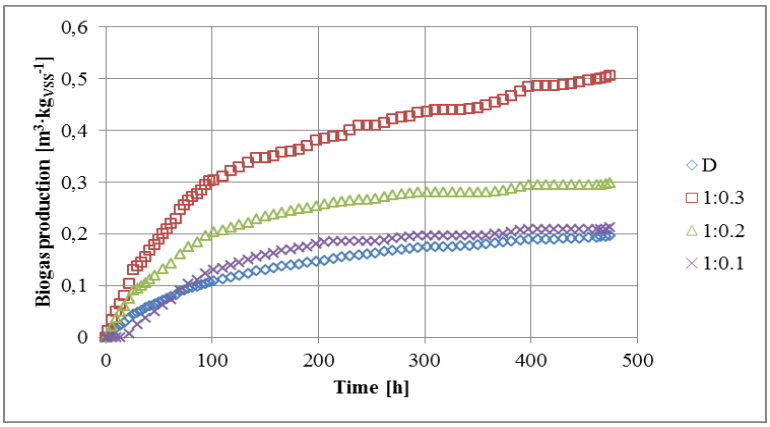


Fig. 4. The biogas production.

Table 4. Methanogenic activity test.

Parameters		D	1:0.3	1:0.2	1:0.1
Initial VSS	[$gVSS \cdot dm^{-3}$]	9.32	10.73	9.53	9.07
Final VSS	[$gVSS \cdot dm^{-3}$]	5.39	7.83	6.55	5.41
Initial sCOD	[$mgO_2 \cdot dm^{-3}$]	4911	4509	4018	3973
Final sCOD	[$mgO_2 \cdot dm^{-3}$]	1752	1581	1396	1731
R	[$mlCH_4 \cdot h^{-1}$]	7.43	12.07	9.88	7.21
AKT	**[g $ChZT_{CH4} \cdot g^{-1} \cdot VSS^{-1} \cdot d^{-1}$]**	**0.108**	**0.240**	**0.190**	**0.113**

Table 5. Filtration properties of sludge.

Parameters			D	1:0.3	1:0.2	1:0.1
Before digestion	CST	[s]	98	106	106	110
	SRF	[$m \cdot kg^{-1}$]	$2.43 \cdot 10^{13}$	$2.18 \cdot 10^{13}$	$2.21 \cdot 10^{13}$	$1.94 \cdot 10^{13}$
After digestion	CST	[s]	204	196	196	191
	SRF	[$m \cdot kg^{-1}$]	$2.85 \cdot 10^{13}$	$2.80 \cdot 10^{13}$	$3.13 \cdot 10^{13}$	$2.68 \cdot 10^{13}$

Corresponding to the tests, an analysis of capillary suction times (CST) and the specific resistance to filtration (SRF) were conducted. Since sludge generated during the treatment process has a very high moisture therefore, it must be thickened and dewatered. Measures such as CST and SRF determine whether sludge is susceptible to the above-mentioned processes. The value of SRF determines sludge permeability; the higher specific resistance, the lower efficiency of the dewatering process. On the other hand, CST determines

a moisture release rate from the sludge; sludge that strongly holds water back has a higher CST.

Comparing the values of the filtration measures before and after digestion (Table 5) it can be concluded that anaerobic digestion significantly worsened dewaterability of sewage and mixed sludge. The value of CST after digestion were two times higher than before the process, while SRF increased by 17 - 42%. It is worth mentioning that both CST and SRF do not vary with the sludge mixing ratio, so if water sludge is used as a co-substrate in sewage sludge digestion the filtering characteristic of sewage sludge is not significantly affected.

4 Conclusions

1. The results of the research work showed that digestion of both water sludge and sewage sludge increased a biogas production. The biogas production for mixed samples was greater than for sewage sludge only by 15-60%, depending on the mixing ratio. The highest biogas production was observed for 1:0.3 sample – about 60% higher than for sewage sludge.
2. Methanogenic activity can help to evaluate the digestion process. The measurements confirmed the above conclusions. Analysis of this parameter showed the growth of methanogenic activity from 5 to 122% for mixed sludge, if compared to sewage sludge. The highest methanogenic activity was observed for Sample 1:0.3 - 0.240 g $ChZT_{CH4}\cdot g^{-1}\cdot VSS^{-1}\cdot d^{-1}$, while for sewage sludge is was 0.108 g $ChZT_{CH4}\cdot g^{-1}\cdot VSS^{-1}\cdot d^{-1}$.
3. Analysis of CST and SFR showed no effect of water sludge on the filtration characteristic of sewage sludge. However, digestion significantly worsened dewaterability of both mixed and sewage sludge.

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