IMPACT OF THE ANAEROBIC DIGESTION PROCESS CONFIGURATION ON THE SLUDGE DEWATERABILITY

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Anaerobic sludge digestion is an important tool for converting sludge into a renewable fuel - biogas. However, digested sludge can also be used as a fuel, and a fundamental parameter determining the energy value of digested sludge is as effective as possible dewatering. The main aim of the presented study was to evaluate how the anaerobic digestion (AD) technology and post-treatment technology can affect sludge dewaterability. Two technological alternatives of AD were evaluated: mesophilic (MAD) and thermophilic (TAD). In addition, also the effect of post-aeration of digested was evaluated. The dewaterability was assessed using two methods based on centrifugation and filter pressing. Finally, the sludge cake concentration of total suspended solids (TSS) was compared. The results showed the difference in sludge dewaterability for the tested sludges: The sludge cake concentration was similar or slightly higher for MAD compared to TAD sludge. Post-aeration of digested sludge increased sludge cake concentration.

Key words: Anaerobic digestion; biogas; dewaterability; mesophilic; post-aeration; thermophilic

Received 25. 08. 2021 Accepted 18. 09. 2021

1. Introduction

The importance of sludge dewaterability as a crucial qualitative parameter of stabilized sludge is growing simultaneously with growing application of thermal processes such as drying, incineration, pyrolysis etc. in the sludge management of wastewater treatment plants. The dewaterability is a complex parameter determined by many factors, which were still not sufficiently evaluated. The dewatering is generally defined as “the removal of enough of the liquid portion of the sludge so that it behaves as a solid [1].

From practical point of view it is important that the dewaterability brings an information about extent of water removable from sludge by mechanical processes because the energy requirements related to water removal by thermal processes (water evaporation) are much higher in comparison with mechanical processes (pressing, centrifugation, etc.). Therefore, any improvement of sludge dewaterability can have big effect on energy balance of the sludge management.

Many authors published the data indicating a relation between dewaterability and sludge composition: extracellular polymeric substances (EPS), VSS/TSS ratio, divalent ions, phosphate [2-7]. Temperature is also often reported parameter affecting properties of the sludge however, as regards dewaterability the conclusions are sometimes contradictory [8-10]. Some papers even shown that not only temperature but also thermal history of sludge can affect irreversibly the rheological properties of sludge [11].

However, many contradictory data are available regards effect of anaerobic digestion technology on the sludge dewaterability. Only exceptions are probably data about improvement of dewaterability after thermal hydrolysis of the sludge [12].

Another challenge of the research focused on the sludge dewaterability is the finding of appropriate method of dewaterability evaluation because mostly used capillary suction time (CST) measurement is often not suitable [13-14].

Therefore, the main aims of the presented research were the verification of the suitability of recently developed methods of sludge dewaterability assessment and the evaluation of the impact of operational temperature, mesophilic versus thermophilic and postaeration of digested sludge on the sludge dewaterability.

2. Materials and methods

2.1. Sludge sources

Samples of sludge for dewaterability testing were taken in several different places – postaeration pilot unit and full-scale anaerobic digesters.

<u>Postaeration pilot unit</u>

Digested sludge was pumped at regular intervals from the storage tank into a cylinder-shaped reactor of 1 m^3 (sludge volume 0.5-0.7 m^3) where it was continuously mixed by a slow-running paddle stirrer and aerated with a coarse-bubble aeration element connected to blower. The oxygen concentration and the pH value of the sludge were measured online using probes in the reactor. The sludge level was monitored by a level sensor connected to the pump for dosing the anti-foaming agent in case of excessive foaming. The amount of the sludge withdrawn and supplied depended on the tested HRT of 6 and 4 days. Samples: influent (INF), effluent (EFF)

<u>Sludge from full-scale anaerobic digesters</u>

Two digesters of typical municipal wastewater treatment plants with the digested sludge of similar TSS, VSS

concentrations and VSS/TSS ratio were selected for testing of sludge dewaterability at mesophilic and thermophilic conditions. Table 1 illustrates the tested sludge properties.
Samples: mesophilic (MAD), thermophilic (TAD)

Table 1 Basic parameters of tested sludges

Parameter (unit)	MAD	TAD
Operational temperature (°C)	40	55
VSS (g/L)	13.2-14.5	13.6-15.5
TSS (g/L)	23.4-25.6	24.8-27.1
VSS/TSS (-)	0.57-0.58	0.56-0.58

2.2. Flocculant samples

In this study, several types of flocculant were used in cooperation with colleagues from the company Sokoflok s. r. o. At the beginning, the powdered flocculant SOKOFLOK 55 GP, then also the liquid flocculants SOKOFLOK ZM CT and SOKOFLOK EM 440 were examined. They differ in the content of active ingredient – while the powdered one is 100% active, the liquid one is only 50% active. From these flocculants, the solution of 2.5 and 5 g/L were prepared using the tap water and mixed thoroughly until no lumps were observed. The solution was stored in room temperature or in the fridge for maximum two weeks.

2.3. Analyses

2.3.1 Centrifuge dewatering method

This method for sludge dewaterability determination is based on measuring the quantity of water removed by centrifugation and the quantity of sludge cake remaining at the bottom of the centrifuge tube. For centrifuge dewatering method, about 25 mL of the sludge was poured into a pre-weighed centrifuge tube and then weighed again. The sample was centrifuged at 13,000 rpm (equal to 18,928 g) for 10 min and the sludge liquor was decanted for further analysis. The quantity of removed water was calculated as the difference in weight of the sludge and the weight of the sludge cake. The sludge cake concentration was calculated from the volume of sludge cake and TS concentration.

2.3.2 Filter pressing method

The principle of this method is to form the flocs by adding the appropriate dose of flocculant into the certain amount of sludge and then separate the sludge liquor and flocculated sludge by pressing the suspension on a filter press (Figure 1). During the pressing, the constant pressure was applied and the test was finished when no sludge liquor was being released. Then the sludge cake was removed and dried at 105 °C for at least 12 hours. The sludge cake dry mass concentration was calculated as a ratio between the weight of the dried cake and the weight of the wet cake.

A)

B)

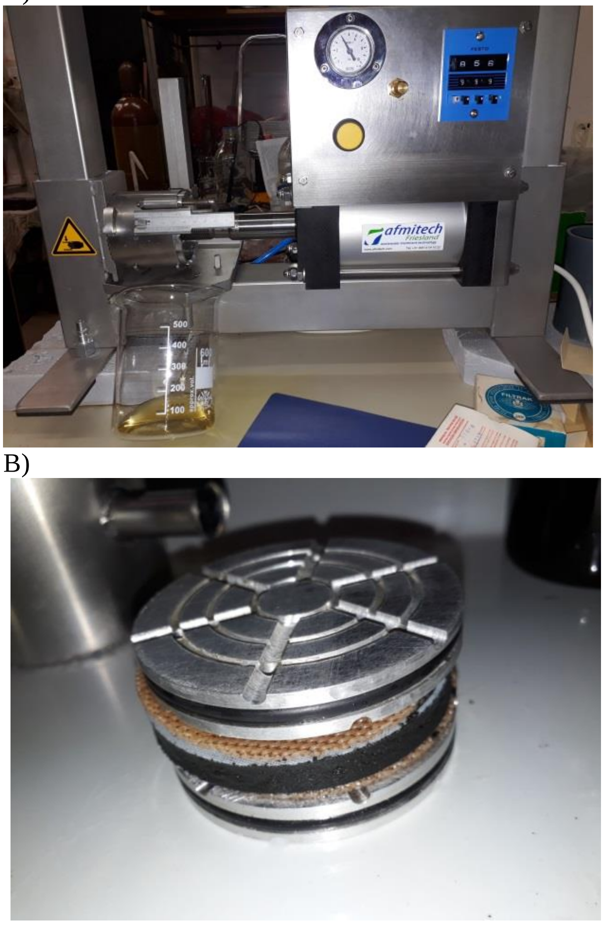

Fig 1 A- the machine Mareco minipress MMP-3/2 used during filter pressing method; B – sludge cake after pressing.

3. Results and discussion

3.1. Centrifuge dewatering method

3.1.1 Comparison of sludge from mesophilic (MAD) and thermophilic anaerobic digestion (TAD)

In the first period of experiments, the standard condition of the centrifugation dewatering method was examined in more detail. The aim was to find out how the change of the parameters, such as rotational speed and centrifugation time, could affect sludge dewatering efficiency. Another task was to verify whether the concentration of suspended solids in the sludge liquor can be supposed as negligible (according our experience bellow 1-2% of total amount of TSS).

Sludges were collected at different WWTPs with both mesophilic and thermophilic anaerobic stabilization. In addition to the standard procedure described in Chapter 2.3 in these experiments, all separated sludge liquor was poured and then filtered using pre-weighed 0.45 µm pore size glass fiber filters. The filters were weighed again after drying at 105° C and the weight of remaining suspended solids was calculated. Filtered sludge liquor was used to analyze total dissolved solids.

At a constant centrifugation time of 10 min, the effect of rotational speeds of 7,000; 10,000; 13,000 and 14,500 rpm were tested. As can be seen in Fig.2, with the increasing rotational speed, the sludge cake concentration also increased, but the increase was not so sharp. However quite huge effect had the rotational speed on the TSS concentration in sludge liquor and thus on the sludge separation efficiency which was especially for thermophilic sludge quite low at lower rotational speeds and can be significantly improved at higher ones - Fig.3.

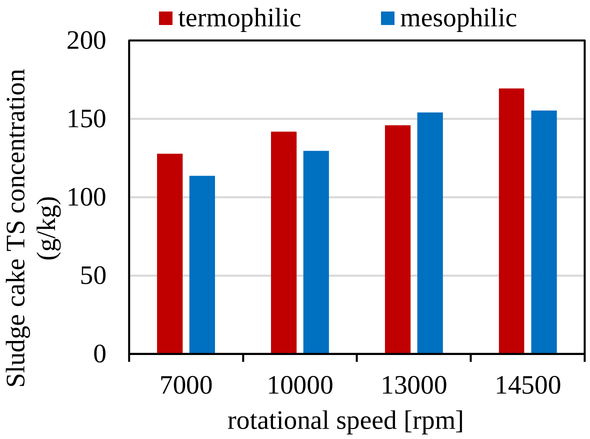

Fig 2 Comparison of sludge cake TS concentration of MAD and TAD at different rotational speed.

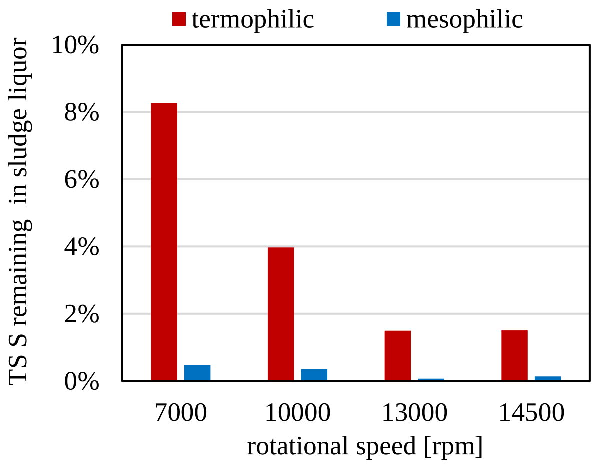

Fig 3 Comparison of remaining sludge in sludge liquor after centrifugation of MAD and TAD at different rotational speed.

At the standard testing conditions, the centrifuge dewatering method was used for evaluation of difference MAD and TAD dewaterability. Table 2 shows the results, which indicate slightly better dewaterability of MAD. Relatively low standard deviation confirms the suitability of centrifuge method for quick and simple dewatering evaluation.

Table 2 Evaluation of the centrifuge dewatering method for thermophilic (TAD) and mesophilic (MAD) digested sludge

Sludge type		Sludge cake TSS [g/kg]
TAD	average	161
	standard deviation	4
MAD	average	178
	standard deviation	3

3.1.2 Results for postaeration pilot unit

The same method was used also for evaluation of dewaterability change caused by postaeration of digested sludge at long-term operation of such technology.

Table 3: Sludge cake concentration of influent (INF) and effluent (EFF) sludge measured by centrifugation dewatering method during the postaeration experiment at different hydraulic retention times (HRT)

Day	HRT (d)	INF (g/kg)	EFF (g/kg)	Sludge cake conc. increase (%)
0	6	110	110	-
7	6	143	138	-3,5
14	6	132	146	10,6
21	6	128	140	9,4
35	6	138	142	2,9
42	6	131	132	0,8
49	6	133	143	7,5
56	4	129	126	-2,3
70	4	117	122	4,3
99	4	134	150	11,9

It was found that after an adaptation period the sludge cake concentration increased thanks to postaeration in average by 6.2 % (with standard deviation 4.2 %) at HRT 6 days and 8.4 % (with standard deviation 5.4 %) at HRT 4 days. If we will compare final amount of sludge for transport it is determined by final amount of TSS and by sludge cake concentration after dewatering. After post-aeration also final amount of TSS is significantly lower: 13 % at HRT 6 days and 9 % at HRT 4 days. We can estimate that total weight of sludge cake to be disposed decreased by 18 % at HRT 6 days and 16 % at HRT 4 days. It would have big impact on transportation costs if sludge is disposed out of wastewater treatment plant [15]. The degradation of sludge during post-aeration is probably related to enzymatic lysis, which take place during post-aeration [16].

3.1.3 Strong and week points of the dewatering method based on sludge centrifugation

Evaluating the suitability of centrifugation dewatering method as the main advantage can be stated:

- Absence of flocculant, which is therefore not affecting the original sludge behavior
- Simplicity and relatively low time consumption

- Good repeatability

As drawbacks of the method can me mentioned:

- Low sludge cake dryness / TSS sludge cake concentration in comparison with full scale results
- High portion of remaining solids in the sludge liquor after sludge separation, low separation efficiency for some types of sludge

3.2. Filter pressing method

3.2.1 Optimization of the method

Depending on the density of the sludge, fast stirring by magnetic stirrer was carried out for 20-40 s at 750-1000 rpm and slow stirring for 3-6 min at 250 rpm. Then the flocs and the cleanliness of the supernatant (sludge liquor) were visually assessed. In some cases, the suspension was formed by only one big floc – see Figure 4, which would make a problem in case of practical application since this floc could cause clogging of the dewatering device. Therefore, it was necessary to improve the mixing method [17]. A mechanical mixer was found as better solution. Then only the fast stirring was applied because the slow stirring did not improved flocs formation. Based on the density of the sludge, the rotation speed and time were found optimal between 500 and 700 rpm and from 2 to 3 min respectively. After mixing optimization, the pressing time 999 seconds started to be sufficient.

Fig 4 Illustration of non-optimal flocculation process.

3.2.2 Results for postaeration pilot unit

For all types of sludge, the powdered flocculant solution of 5 g·L^{-1} gave the best results despite initial problems with flocculation process.

Table 4: Sludge cake dry mass measured by filter pressing method during the postaeration experiment

	INF			EFF		
Day of operation	flocculant dose [g/kg TS]	pressing time [s]	sludge cake concentration [g/kg]	flocculant dose [g/kg TS]	pressing time [s]	sludge cake concentration [g/kg]
14	30	1998	347	30	999	372
49	35	999	363	35	999	354
56	35	3996	387	35	3996	339
70	35	1998	316	25	1998	336
92	35	999	345	25	999	360
99	35	999	375	25	999	373

Note: The double line in the table indicates the time from which the improved mechanical mixing during flocculation was applied.

Table 5 Statistical evaluation of the filter press dewatering method using at steady state postaeration operational period

Sludge type		sludge cake total solids [g/L]
Before postaeration (influent)	average	379
	standard deviation	21
After postaeration (effluent)	average	383
	standard deviation	13

Table 6 shows the results of the dewaterability comparison of mesophilic (MAD) and thermophilic sludge (TAD) from full-scale digesters. The average sludge cake TS concentration was slightly higher for TAD; however, the difference was not statistically significant.

What is extremely important from operational and economy point of view is the fact that flocculant dose for achieving of such results was about twice higher for TAD sludge.

Table 6: Sludge cake dry mass and flocculant dose at filter pressing method for TAD and MAD sludge

sludge type		sludge cake TS [g/L]	flocculant dose [g/kg TS]
MAD	average	354	15-25
	standard dev.	31	
TAD	average	370	35-45
	standard dev.	29	

However, it should be emphasized that the aim of this study is not to make general statements about mesophilic and thermophilic sludge dewatering, because besides the stabilization process temperature, there are many other parameters influencing sludge dewatering, sludge origin, mono- and divalent cation ratio, extracellular polymer concentrations, etc. [5, 8, 18].

Table 7 shows a comparison of the dewatering results evaluated in this study with results achieved during the full-scale operation of MAD and TAD.

Table 7: Sludge cake dry mass concentrations in mass percentage assessed by different methods

Dewatering method	MAD (%)	TAD (%)
Lab-scale centrifugation	17.8	16.1
Lab-scale filter pressing	35.4	37.0
Full-scale centrifugation	24-25	25-26

The comparison shows that lab-scale centrifugation cannot achieve full-scale sludge cake concentrations due to much lower centrifugal force. On the other hand, lab-scale pressing represents a method how to assess the potential maximum of dewatering.

3.2.3 Strong and week points of the filter pressing method

Evaluating the suitability of centrifugation dewatering method as the main advantage can be stated:

- Possibility to achieve sludge cake concentration which is close to full scale concentration sometimes even higher it means possibility to determine maximal achievable sludge cake concentration
- Good repeatability

As drawbacks of the method can me mentioned:

- The result is highly dependent on optimal flocculant choice and optimal flocculation process
- Risk of filter clogging and slow water release for some types of sludge

4. Conclusion

It has been shown that both the operational temperature of digestion and the post-aeration of digested sludge affect the sludge dewaterability.

The dewaterability of MAD sludge was slightly better in comparison with TAD when evaluated by centrifugation method and did not differ significantly when evaluated by filter press method; however, the flocculant dose needed for efficient dewatering of TAD sludge at filter pressing was significantly higher. The separation efficiency of sludge at dewatering was better for MAD in comparison with TAD.

Post-aeration improved sludge dewatering by about 6 to 8% using the centrifugation method and did not show a significant change in dewatering using the filter press method. However, the optimal doses of flocculant were significantly higher without post-aeration.

Both methods of dewaterability assessment are suitable for this purpose. The strong point of the centrifugation-based method is the characterization of only the sludge properties and the fact that it is not affected by the quality of the flocculant and the flocculation process. The strong point of the method based on filter pressing is the possibility to achieve a sludge cake concentration that is close to the full-scale concentrations, or close to the maximum achievable sludge cake concentrations.

Acknowledgments

The authors would like to acknowledge the Technology Agency of the Czech Republic for financing our project TJ01000138 Improvement of the quality of stabilized sludge by the postaeration.

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