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DIMENSIONING OF DIGESTION CHAMBER AT WASTEWATER TREATMENT PLANT FOR INCREASING GAS RECOVERY

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Abstract: The paper describes practical results of four-year laboratory studies completed to estimate technically feasible conditions of upgrading an existing sludge disposal system. A minimization of sludge mass and volume together with an energy recovery improvement were main goals of these activities. The way from lab studies and simulations to full scale investments has been shown with a special emphasis on application of respirometric procedure being applied by authors. Proposed was authors' procedure for an estimation of a digestion time prediction for sludge of specific composition. Investigations completed at existing wastewater treatment plant resulted in practical implementation to be used during the design of upgrading and extension of the digestion and energy recovery system at the plant. It was proved that proposed changes provide close to optimum conditions for process performance and the application of proposed calculation procedures was adopted by design team.

INTRODUCTION

Contemporary demand for sustainability of municipalities incorporates increasing interest in recovery of energy carrier from wastewater sludge processing [8, 12]. It puts more emphasis on enhancing an efficiency of anaerobic digestion of treatment sludge (biosolids) widely recognized as an efficient way of methane production. The methane-rich gas may be relatively easy converted into electrical and heat energy. A reference wastewater treatment plant (WWTP) was designed for municipal wastewater treatment, servicing a community of approx. 90,000 inhabitants. The process layout was originally based on an modified UCT (MUCT) system with primary sludge digestion and aerobic stabilization of wasted activated sludge (WAS). The main reason for this study was to check whether a change of process from combined stabilization – aerobic (for WAS) and anaerobic (for primary sludge) to proposed anaerobic digestion of whole sludge would lead to increase in energy carrier production. The plant is equipped with acid fermentation tank ('pre-fermenter') to improve biological nutrients' removal by increasing short chain fatty acids (SCFA) concentration. This pre-fermenter allows to hydrolyze part of primary sludge prior to its discharge to a digestion unit.

Design parameters of the plant and required quality of treated wastewater have been presented in Table 1.

Table 1. Basic description of reference wastewater treatment plant

PARAMETER	Unit	Value
Design population equivalent	p.e.	90 000
Average daily flow	m^3/d	30 000
Dry wether flow – average	m^3/h	1250
Dry wether flow – maximum	m^3/h	2275
Maximum flow	m^3/h	4000
BZT_5 – load	kg/d	7500
Tot N (as N) – load	kg/d	1400
Tot P (as P) – load	kg/d	420
Total suspended solids	kg/d	6000

The main authors' assumption was that common digestion of a WAS and primary sludge ('mixed sludge') would result in long term increase in a methane-rich gas production. A proper way of estimation of sludge stabilization and an energy carrier recovery from mixed sludge was found to be a crucial point of the entire program. Authors decided to use a respirometer test stand to grow a culture of anaerobic bacteria then measure a gas yield and an organic matter decomposition in 50 days' periods. Determination of proper retention time in an anaerobic digestion chambers is of crucial importance in design optimization of these facilities. It is especially difficult during design procedure, when there is no 'real sludge', for example in the case of change in sludge processing mode. Conservative methods of dimensioning such as assumption of solid retention time (SRT) may lead to over dimensioning of sludge digestion chambers [5, 7, 9]. Previous attempts towards prediction or assessment of design parameters did not result in universal reliable design method [10, 11]. Other proposed methods are suitable for general description of the phenomena rather than for engineering purposes [6, 12, 13].

METHODS AND MATERIALS

Reference wastewater treatment plant

In the first six years of the plant operation the original sludge processing was as follows:

- primary sludge was passing through a pre-fermenter (used for SCFA generation) to a gravity thickener where it reached 3.5–5% of total suspended solids (TSS) content, then it was pumped to a digester operated in mesophilic condition. The stabilized sludge was dewatered by centrifuge to 25% TSS;
- waste activated sludge was aerobically stabilized in the activated sludge reactors, then thickened mechanically in drum screen; final dewatering was done by a centrifuge to approx. 18% TSS;

Calculations and investigations presented formerly by authors [2, 3] showed that separate processing of sludge have appeared to be not effective, especially due to problems with dewatering of aerobically stabilized WAS. It was noticed that an aerobic stabilization had caused net consumption rather than generation of energy.

To verify that the fermentation residue is adequately stabilized a degree of decomposition (DDec) of organic matter was determined for all samples. It is calculated as the relative decrease in the concentration of volatile suspended solids (VSS) [1] according to equation (1):

$$DDec = \frac{VSS_{RAW} - VSS_{DIGEST}}{VSS_{RAW}} \ [\%] \tag{1}$$

where:

VSS_{RAW} – volatile suspended solids in sludge before digestion [g/L]
VSS_{DIGEST} – volatile suspended solids in sludge after digestion [g/L]

Decomposition degree of stabilized mixed sludge usually ranges between 40% and 60%.

Application of respirometry for determination of design parameters

The objective of the laboratory study was to find proper digestion time for raw sludge of different proportions between primary and wasted activated sludges.

The laboratory method supporting the study and later a design process has been a respirometric batch test, which appeared to be the most precise method for determination of digestion parameters [2, 3, 4]. The method applied a biogas generation, which remained proportional to organic matter decomposition. Moreover, the results appeared to be suitable as a tool in developing a technological guideline for design of a complete sludge processing system, including a new digester. The measurements of the amount of methane-rich gas being produced during the fermentation process were conducted from reaction vessels filled with three different mixtures, each was representing different 'design scenario' (i.e. proportion of mixed sludges). For the purpose of this paper only three – most typical scenarios – were discussed:

- Anaerobic biomass, taken from existing digestion chamber – as a control sample
- Mixed sample of sludges: primary sludge (PS) + WAS in proportion 1:1 (1 g volatile suspended solids (VSS) of primary sludge per 1 g VSS of the WAS) – sample twice repeated
- Mixed sample of sludges: PS + WAS in proportion 2:3 (2 g VSS of primary per 3 g VSS of the WAS) – sample twice repeated.

Test stand

Laboratory digestion of WAS and primary sludge was performed in the tests stand consisting of:

- Respirometer AER-208 (manufactured by Challenge Inc USA),
- Computer system with data recording programs,
- Water bath with magnetic stirrer,

The respirometer was composed of two basic parts: a gas measurement unit and an interface which stored data and was sending a digital signal to a computer. The test stand allowed for simultaneous performance of digestion of eight samples of different composition.

The samples were placed in 500 mL gas tight vessels of the AER-208 respirometer tests stand, working in an anaerobic mode. Test vessels were immersed in a water bath with magnetic stirrers to ensure complete mixing and provide conditions matching the actual operation. The incubation temperature was 35°C. Gas produced in vessels passed through the measuring cells and its total volume was continuously measured every two hours, at the standardized pressure. The measurement data were stored in the computer at the test stand. Due to the sensitivity of methanogenic microorganisms to pH, this parameter was rigorously controlled and ranged from 7 to 7.4. A chromatographic analysis of gas quality was carried out for each sample separately. A control analysis of samples for chemical oxygen demand (COD), SCFA, TSS and VSS concentration as well as pH were performed. Each of the three experimental series consisted of two tests completed parallely for each of three substrate proportions.

RESULTS AND DISCUSSION

Assessment of digestion chambers' design parameters

Based on the amount of the gas produced during the batch test and chromatography analyses of methane content, cumulative methane production curves were plotted to determine dynamics of methane production (Figure 1).

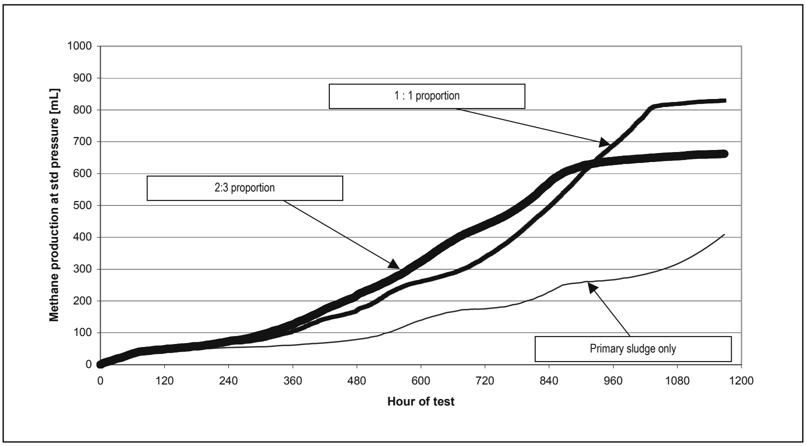

Fig. 1. Methane production cumulative curves for different substrate composition – run 2 (example) [3]

Basing on plotted curve of VSS content vs. time, the net length of the start-up ('yield') phase was estimated, similarly a length of effective gas production phase ('decay') was estimated. Figure 2 shows laboratory test results for digestion of sludges PS+WAS in 1:1 proportion while Figure 3 illustrates results for 2:3 proportion, respectively.

Estimation of SRT

The maximum theoretic effective gas production period was estimated as an interval between intersection point of tangent to a VSS content curve with a time-axis and

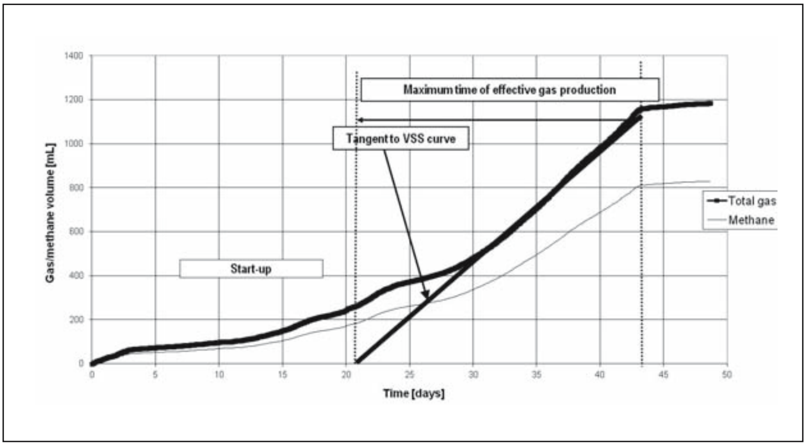

Fig. 2. Determination of a retention time for design purposes. Mixed sludges : PS and WAS (1:1 proportion)

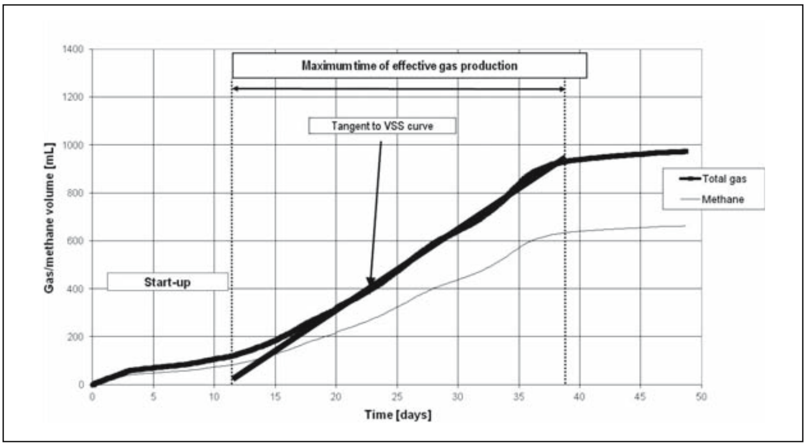

Fig. 3. Determination of a retention time for design purposes. Mixed sludges : PS and WAS (2:3 proportion)

a final point of an effective gas production period (see Figures 2 and 3) , which led to general SRT values adopted for design purposes. In this specific case it was proved that an effective digestion period, for this case study, has been determined as high as 23,5 days. This relatively high value was used for a real full-scale design, and it resulted in significant improvement of the WWTP overall energetic balance. At present, over 90% of electric energy demand is covered by combined heat and energy production using a biogas generated in upgraded digestion chambers. It should be noted that application of 'conservative' SRT (around 15 days) would result in incomplete process. If the digestion time had extended over determined value it neither resulted in better stabilization of sludge nor higher biogas production. Table 2 summarizes most important results of experimental data for scenarios presented in this paper.

Table 2. Example results of respirometric tests for assessment of a digestion chamber SRT

PARAMETER	Unit	PS+WAS proportion 1:1		PS+WAS proportion 2:3	
		Raw	Digested	Raw	Digested
TSS	g/L	4.8±0,6	3.5±0,3	4.6±0,4	3.35±0,2
VSS	g/L	3.2±0,5	1.9±0,3	3.0±0,6	1.8±0,4
Organic mass decay	percent		49±6		46±3
Unit biogas production (average)	Stdm^3/kgVSS (removed)		0.81		0,75
Assessed SRT	d		22		24

Energy recovery improvement

Figure 4 compares a biogas production (with minimum 70% methane content) for a 6 month period before upgrading the system with a biogas production in the same period length after an improvement. Some 10% of this improvement in an overall biogas production may be credited to increased load of wastewater inflowing to the WWTP, remaining gain is caused by the system upgrading. These 'improved' values reflect possible biogas production from the same amount of sludge as in the analyzed period, but assuming use of upgraded system designed in accordance with the procedure proposed in this paper. Rough estimation shows that process optimization based on changing mode of operation and increase of the digestion chamber's volume may lead to increase of an energy recovery. In reference case a yield of about 55% as compared with initial value was obtained.

Unit production of a digestion gas was observed on level varying around 0.80 Std m^3/1 kg VSS$_{removed}$ for 1:1 proportion and 0.75 Std m^3/1 kg VSS$_{removed}$ for 2:3 proportion

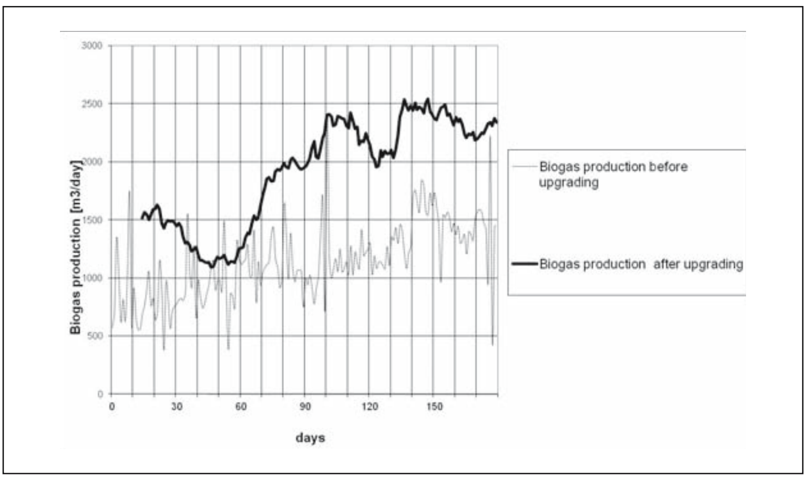

Fig. 4. Biogas daily production before (dotted line) and after upgrading (solid line) first half of a year

respectively, which was higher than unit gas production before changing the system (0.60 0.80 Std m^3/1 kg VSS$_{removed}$), but lower than expected 1.0 Std m^3/1 kg VSS$_{removed}$ (Table 2). This slightly lower than expected unit gas production was credited by authors to the SCFA generation from primary sludge.

Lower organics' content in digested sludge

Decomposition of an organic matter is required for stabilization of sludges. The decomposition of VSS observed during tests varied slightly:

- For PS to WAS 1:1 proportion VSS decomposition varied from 41% to 48%,
- For PS to WAS 2:3 proportion VSS decomposition varied from 43% to 47%.

CONCLUSIONS

Application of respirometric tests may be a valuable tool for a digestion chamber dimensioning, especially in the case when the content of sludge is unknown; this is especially valuable while changing a general concept of sludge processing.

Digestion of sludge from enhanced nutrient removal treatment plants in some cases requires slightly longer SRT than usually assumed in a case study as long as 23 day were required to complete the process.

Proposed design procedures allow to perform exact calculation of a digestion time which is considered the main parameter for the dimensioning of the sludge processing line at existing plant.

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WYMIAROWANIE WYDZIELONEJ KOMORY FERMENTACYJNEJ PRACUJĄCEJ NA OCZYSZCZALNI ŚCIEKÓW DLA ZWIĘKSZNIA UZYSKU GAZU

Artykuł opisuje praktyczne wyniki trwających cztery lata badań laboratoryjnych ukierunkowanych na wyznaczenie technicznie wykonalnych zasad modernizacji istniejącego systemu przeróbki osadów. Podstawowymi zadaniami tych prac były minimalizacja masy i objętości osadu przy jednoczesnym zwiększeniu stopnia uzysku biogazu - nośnika energii. W artykule pokazano sposób przejścia od wyników badań laboratoryjnych i symulacyjnych do inwestycji pełnoskalowej przy czym autorzy szczególną uwagę poświęcili zastosowaniu testów respirometrycznych. Wynikiem prac aplikacyjnych jest zaproponowana procedura szacowania czasu fermentacji osadów w zależności od ich składu. Wyniki prac badawczych zostały zastosowane w procedurze projektowej modernizacji istniejącej oczyszczalni, czego rezultatem jest podniesienie efektywności systemu odzyskiwania energii w trakcie eksploatacji oczyszczalni. Wykazano tym samym, że proponowane zmiany pozwalają na wskazanie metod projektowania bardziej precyzyjnych niż obecnie stosowane metody wymiarowania komór.