SELECTED ASPECT OF RISK MINIMIZATION IN ENERGY RECOVERY SYSTEM

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ABSTRACT
The paper describes laboratory study conducted to estimate a technically feasible digestion time for raw sludge of a different composition. Additionally, the progress of a sludge digestion process was examined in the sludge samples collected at the Nowy Sacz WWTP. Results provided practical information to be used during the design of upgrading and extension of the existing sludge digestion system at the plant. Moreover, the results can serve as a tool in developing a technological guideline for design of a complete sludge processing system, including a new digester.
In this specific case it was found that mesophilic digestion of mixed sludge resulted in:

- A drop of organic fraction of dry sludge solids down to 54% of VSS; indicating that the sludge is biologically stable.
- Led to relatively moderate production of 590 liters of biogas per 1 kg of VSS removed.
- Rather high methane content (approx. 69-70% of CH_4) in biogas mass

It was also found that mixing of primary and waste activated sludge(WAS) at the 1:1 VSS ratio provides the optimum conditions for process performance; an increase of a WAS fraction (2:3) only slightly deteriorates the performance of the digestion process .

KEYWORDS
Sludge processing, sludge digestion, biogas, SRT, batch tests

INTRODUCTION

In the sludge digestion process a decrease of organic matter content (VSS) is achieved through a conversion of organic material, captured in raw sludge, to a mixture of methane and carbon dioxide. The process is conducted in anaerobic conditions. The mixture is commonly known as “digestion gas” or “biogas”. According to the literature data, the volume of biogas generated during anaerobic decomposition of 1 kg of organic material amounts to 900-905 dm^3. However, in the engineering practice this value can range between 500 -750 dm^3/kg VSS removed. The volume of biogas produced per 1 kg of VSS supplied to the system ranges from 400 to 600 dm^3. An average biogas volume, produced at the wastewater treatment plant is assumed as 480 dm^3/kg VSS removed. So-called „digestion module” determines the extent to which sludge undergoes digestion. According to the literature data, the sludge, coming from a well-designed and operated WWTP, is considered as biological stable if the digestion module exceeds 40%.

Biogas with a high methane content can be utilized as fuel for boilers and gas generators. This way, the overall energy costs at the WWTP can be substantially reduced. The volume of biogas produced during a mesophilic digestion phase as well as the methane content in the biogas can vary depending on the nature of the substrates delivered with raw (unstabilized) sludge.

The laboratory method selected for this study is described as the respirometric batch test. It appears to be the most precise method for determination of digestion parameters. The method focuses on biogas generation, which remains proportional to organic matter decomposition.

The objective of the laboratory study was to estimate a technically feasible digestion time for raw sludge of a different composition. Additionally, the progress of a sludge digestion process was examined in the sludge samples collected at the Nowy Sacz WWTP. The obtained results will provide valuable information that can be used during the discussion on upgrading and expansion of the existing sludge digestion system at the plant. Moreover, the results can serve as a tool in developing a technological guideline for design of a complete sludge processing system, including a new digester.

METHODS AND MATERIALS

Laboratory equipment for the respirometric test

The experimental instruments applied for tests on productivity of the digestion gas included:

- ANR-100 respirometer for anaerobic experiments, US made by the CHALLENGE Syst. Int.;
- Water bath with magnetic mixer
- Computer program for automatic data collection and processing

Assumptions for batch test investigation

Experimental methodology:	batch tests
Period of experiment:	ca. 30 d, this period is to be adjusted due to sludge acclimation
Temperature:	the incubation temperature: 35^{o}C.
Test stand:	a magnetic stirred system
Volume of samples:	500 mL glass vessels
Chemical analyses:	
- basic:	suspended solids (SS), volatile suspended solids (VSS)
- reference:	pH, alkalinity, COD, ammonium
Gas measured system:	anaerobic respirometer ANR-100
Determination of methane percentage of gas volume:	gas chromatographic analysis

Scope of investigation

Based on the batch tests under monitoring conditions and parameters the digestion ability of mixed sludges primary + WAS (secondary) was determined.

During the laboratory research the mixed samples of sludges were investigated:

- mixed sample of sludges: primary + WAS in proportion 1: 1 (1 g VSS of primary sludge per 1 g VSS of the WAS) – sample twice repeated
- mixed sample of sludges: primary + WAS in proportion 2:3 (2 g VSS of primary per 3 g VSS of the WAS) - sample twice repeated.

RESULTS OF TESTS ON DIGESTION – PROCESS PARAMETERS' DETERMINATION

Mixed sludges : primary and WAS (1:1 mass proportion)

A cumulative curves of the gas production is shown on Fig.1. The plotted curve was based on average results from independent tests on the same sludge mixture. The bold line shows total gas production while the lower, thin line reflects a methane gas production.

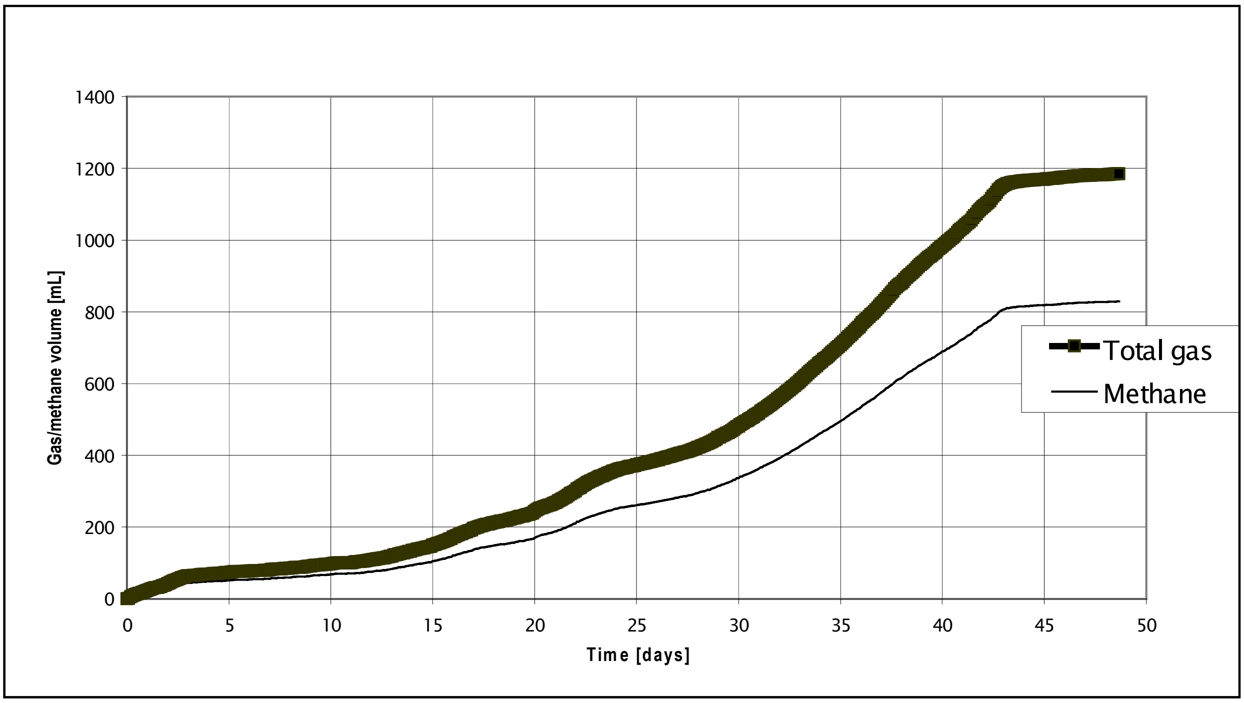


Figure 1. Gas production cumulative curve . Mixed sludge : primary + WAS , 1 : 1 proportion.

From the results on Fig 1, basic process parameters were calculated. The table 1 summarizes these results. First column shows results obtained during a start-up period i.e. during building up a biomass of methane producing microorganisms. Second one shows results for 'real' fermentation i.e. during effective digestion of an organic matter. The second column reflects real process conditions being usually applied for the design and/or decision making purposes.

Table 1. Results of tests on mixed sludge : primary + WAS , 1 : 1 proportion

Calculated process parameters	Start-up	Fermentation
TSS decomposition [%]	13%	27%
VSS decomposition [%]	18%	41%
Digestion gas production rate [L/day]	0.0149	0.0451
Gas production per 1g of removed VSS [L/kg VSS]	576	590
Gas production per 1 g of incoming VSS [L/ kg VSS]	103	240
Methane content in the digestion gas [%]	-	70% average
Digestion module	18%	41%

Mixed sludges : primary and WAS (2:3 mass proportion)

To estimate an influence of primary : WAS proportion on a total gas production and gas characteristics the same procedure as above was completed for 2:3 mass proportion. This showed some difference both in gas production and in a methane content in the gas obtained. The Fig.2. shows a cumulative curves of a digestion gas nad methane production as it has been described above for Fig.1.

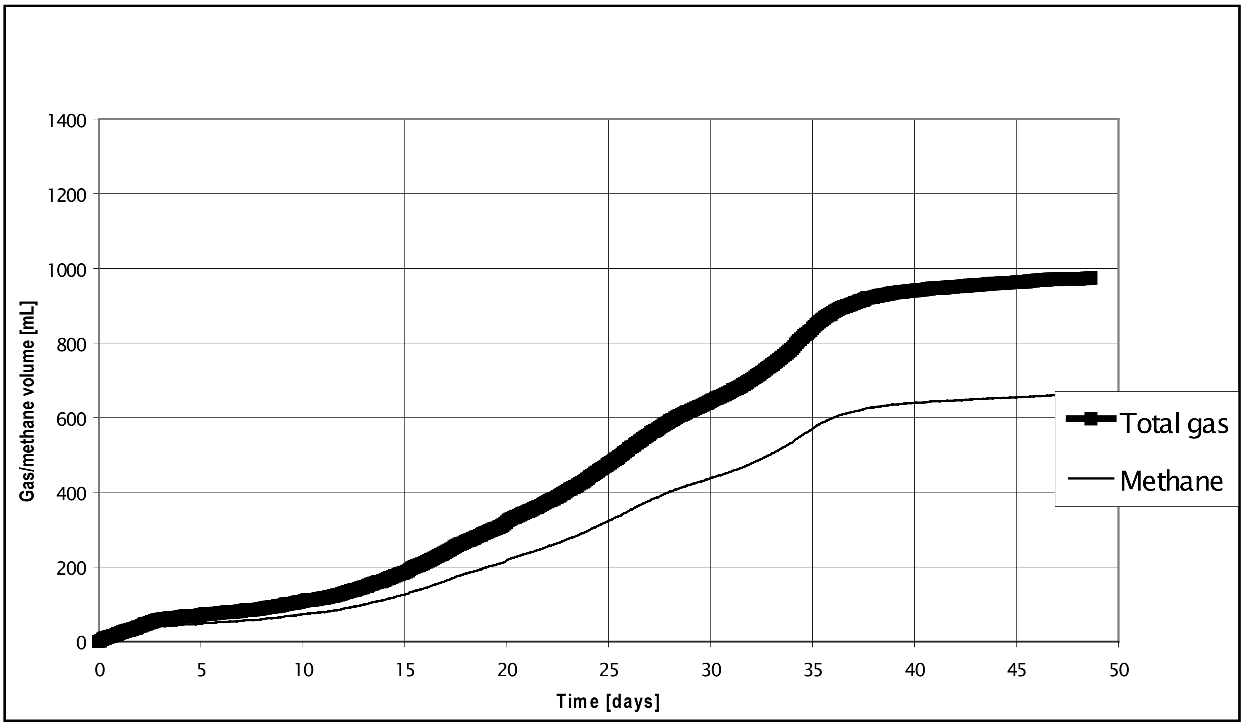


Figure 2. Gas production cumulative curve . Mixed sludge : primary + WAS , 2 : 3 proportion.

As it has been discussed previously, the table 2 summarizes obtained results, presented in two columns. One may note significant differences in the process rate with similar results in gas production per one gram of VSS removed. Difference in the methane content in total digested gas lays within a margin of incertainity (approx 1%).

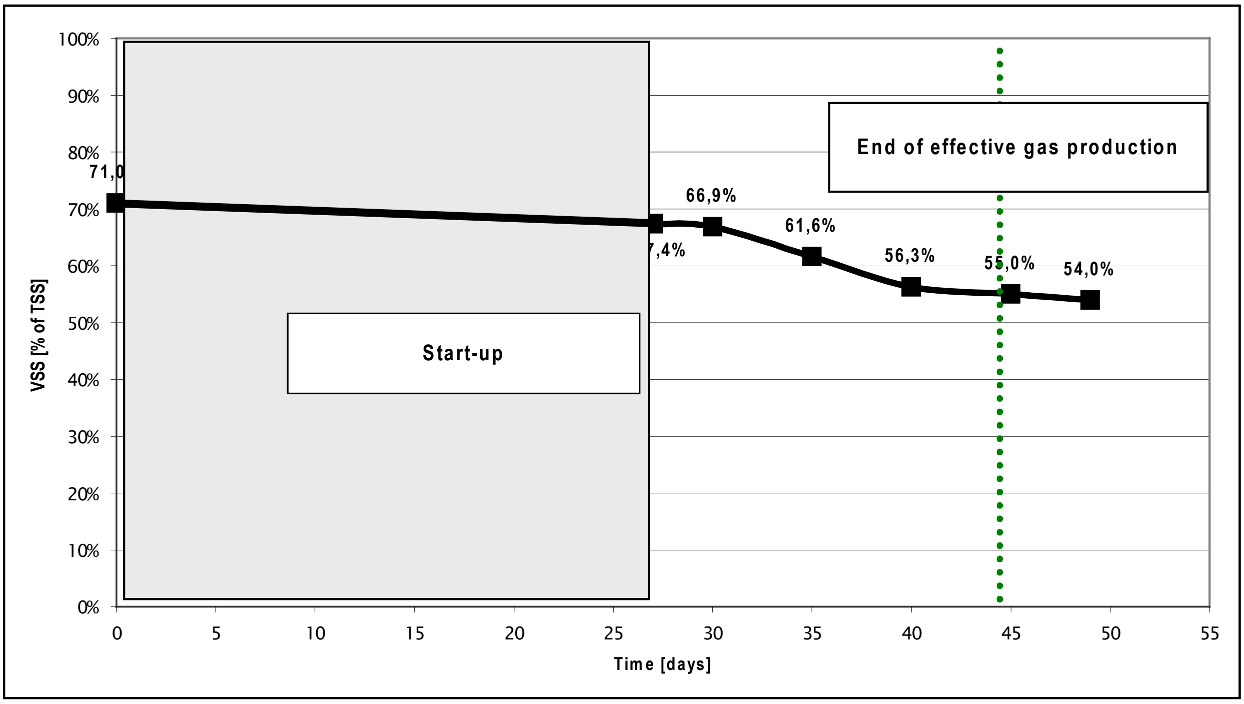
Table 2. Results of tests on mixed sludge : primary + WAS , 2 : 3 proportion.

Calculated process parameters	Start-up	Fermentation
TSS decomposition [%]	13%	29%
VSS decomposition [%]	15%	43%
Digestion gas production rate [L/day]	0.0120	0.0332
Gas production per 1g of **removed** VSS [L/kg VSS]	371	541
Gas production per 1 g of **incoming** VSS [L/ kg VSS]	55	232
Methane content in the digestion gas [%]	-	69% average
Digestion module	8%	42%

DECOMPOSITION DEGREE OF DIGESTED SLUDGES

Mixed sludges : primary and WAS (1:1 mass proportion)

A biogas production is one of intended effects of a digestion process at WWTPs. Decomposition of organic matter – effective way for sludge stabilization is at least of same importance. Design of the digestion chamber requires a knowledge concerning end of a stabilization process. Usually an assumption is made that the end of an effective digestion is when the VSS content curve reaches its lower stabilized level. The VSS content curve for mixed sludges (1:1 proportion) is shown on Fig.3.



Figur 3. VSS content curve (VSS vs. time). Mixed sludges : primary + WAS (1:1 proportion).

The VSS content curve vs time is made of three intervals. First represents a start-up phase with dominancy of an acidogenesis. Slight decrease of a VSS content has been observed (from 71%% down to 68%).It was observed since 1st to 27th day of tests. Since a beginning of a 'real' digestion period when a fermentation process caused an effective stabilization of sludge, significant decrease of a VSS contents was observed. During this period i.e. between 27th and 44th day of tests, a VSS content lowered from 68% to 55%. Further extension of digestion time to 50 days did not result in significant decrease of a VSS content. Such a sludge can be recognized as biologically stable.

The WAS used for this test was withdrawn from the WWTP with simultaneous aerobic stabilization (extended aeration). Such sludges processed with aerobic stabilization usually have a VSS content at 60% level. So the mixed sludge with 55% VSS level can be treated as stabilized one. While the WWTP is converted to digestion-only technology, the VSS content is expected to be even lowered.

Mixed sludges : primary and WAS (2:3 mass proportion)
Tests on mixed sludges of 2:3 mass proportion were completed as a reference to those of 1:1 proportion. Results are presented in Fig.4.

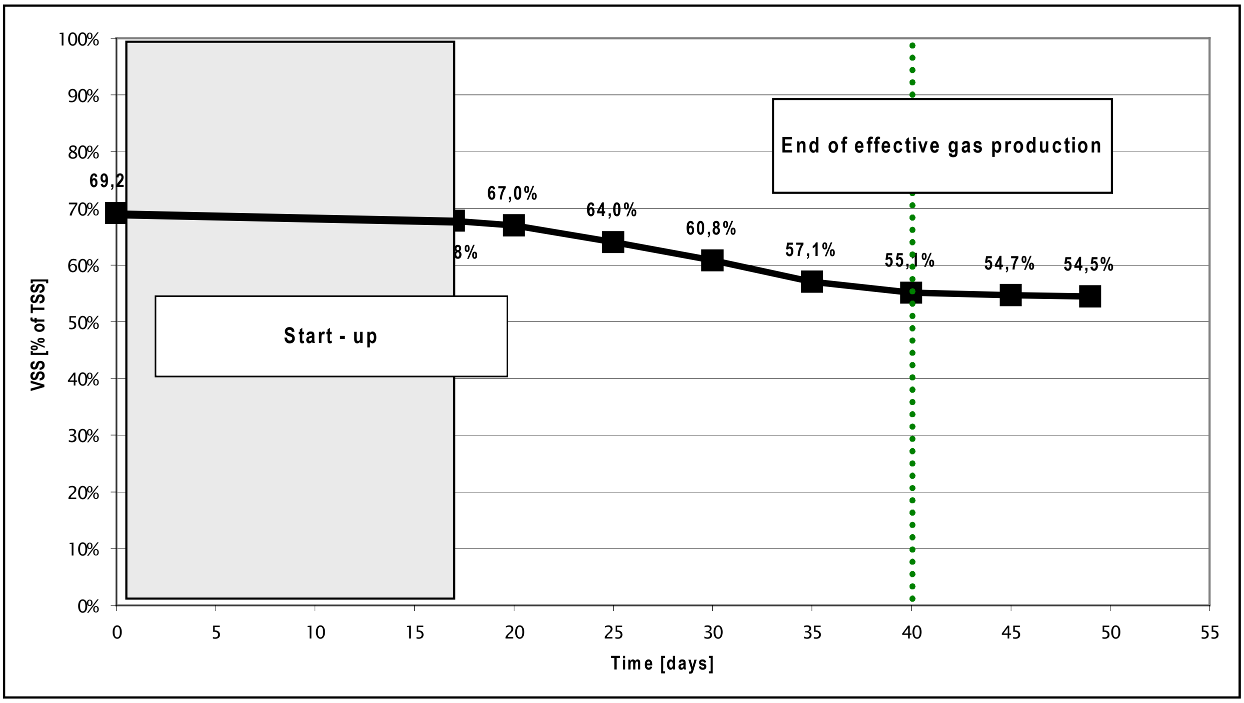


Figure 4. VSS content curve (VSS vs. time). Mixed sludges : primary + WAS (2:3 mass proportion).

At this stage of tests a decrease of a VSS content has been observed from 69.2% down to 67.8%). This period was shorter and ended in 17th day of tests. During period of effective digestion i.e. between 17th and 40th day of tests, a VSS content lowered from 67.8% to 55.1%. Further extension of digestion time to 50 days did not result in significant decrease of a VSS content. The difference between effective digestion phase between '1:1' and '2:3' tests is hardly visible.

DETERMINATION OF PROPER SRT

Determination of proper retention time in digestion chambers is a crucial point of design optimization of these facilities. A procedure of determination of these parameters has been proposed as a results of tests described in this paper. Determination of a retention time was based on cumulative curves of a gas production for digestion without an inoculation. Based on plotted curve 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. The procedure for mixed sludges (1:1 proportion) is shown in Fig. 5. for 2:3 proportion.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 a final point of an effective gas production period (see Fig. 3 and Fig. 4. respectively).

Mixed sludges : primary and WAS (1:1 mass proportion)
The procedure for this proportion was illustrated in Fig. 5. Length of start-up period was estimated as 27 days but it must be recognized that these tests were completed without an inoculation. If the inoculation was applied the shorter start-up period would have been expected . So in day-by-day routine operation this period tends to decrease.

The effective digestion period has been determined as 23,5 days. If the digestion time was extended over this value it did not resulted in better stabilization of sludges. One must remember that extension of digestion time without proper gas production results in lower methane production may adversely impact energetic efficiency of a sludge processing unit.

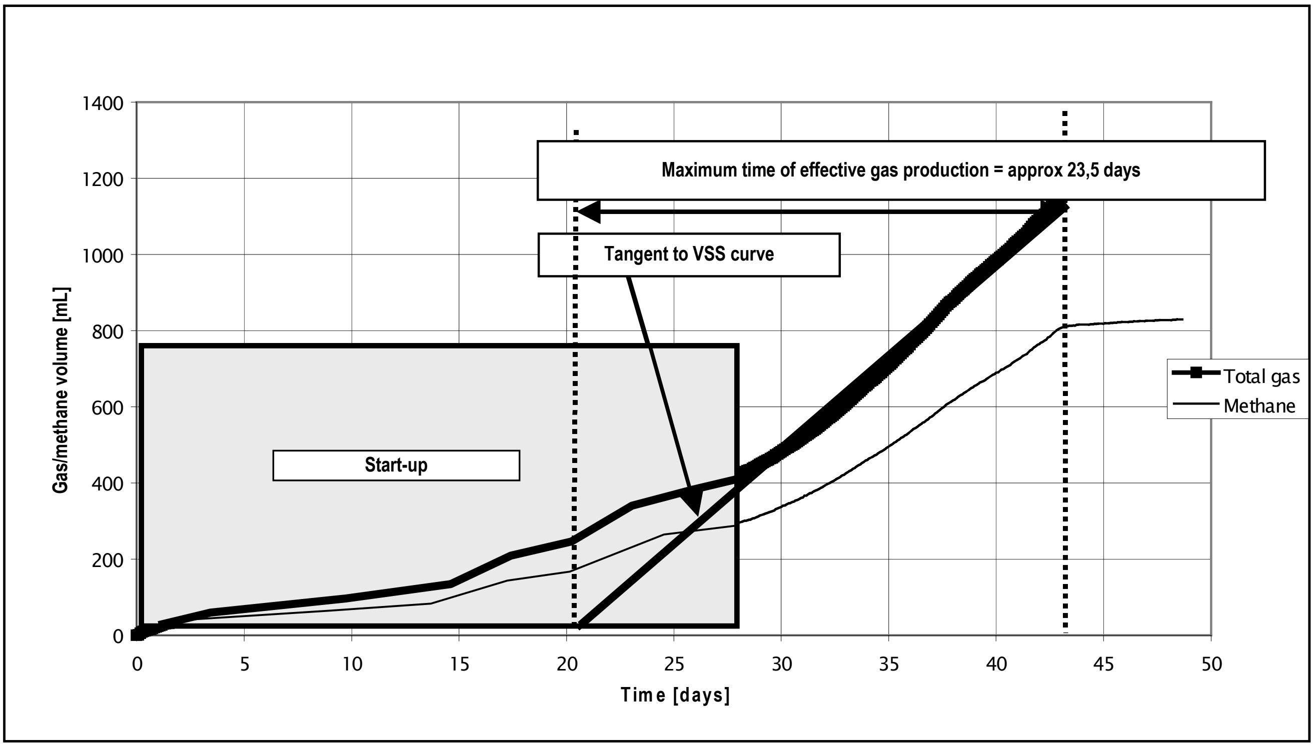


Figure 5. Determination of a retention time. Mixed sludges : primary and WAS (1:1 proportion).

Mixed sludges : primary and WAS (2:3 mass proportion)
The procedure for this proportion was illustrated in Fig.6. Length of start-up period was estimated as 17 days but at the same conditions as described above. The effective digestion period has been determined as 25 days, which is in practice close to results obtained for '1:1' sludge.

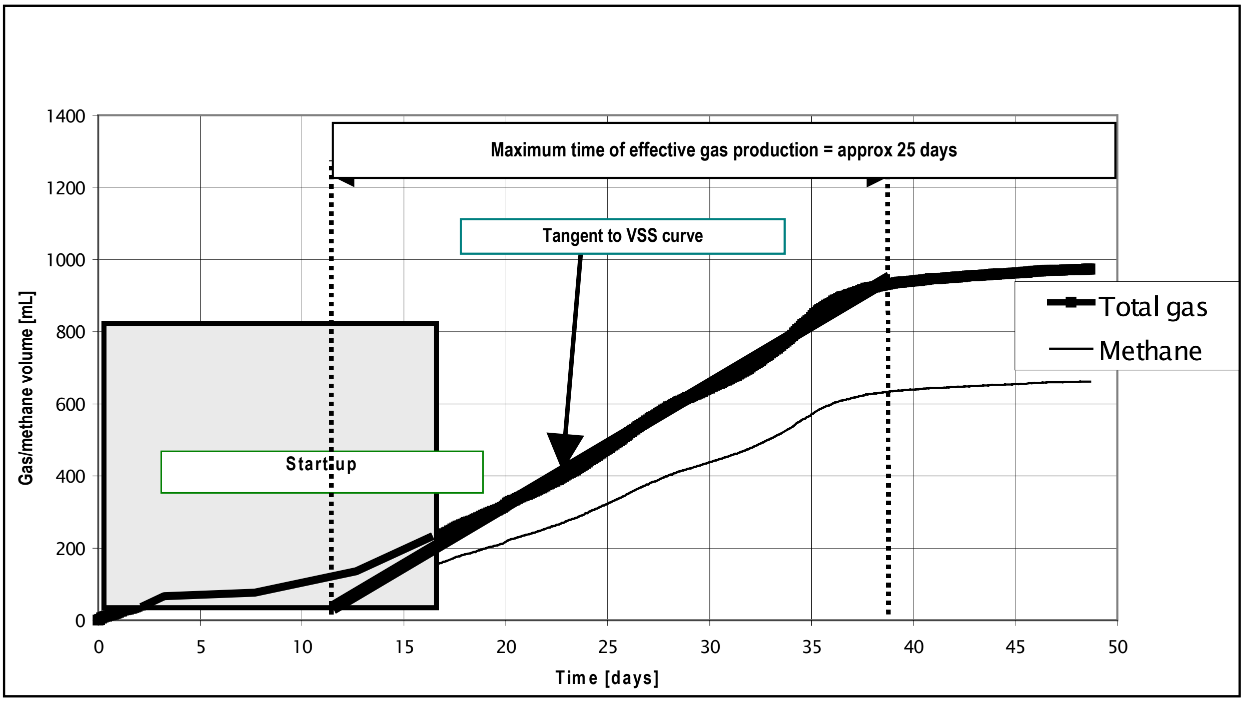


Figure 6. Determination of a retention time. Mixed sludges : primary and WAS (2:3 proportion).

CONCLUSIONS

In the laboratory studies, it was found that mesophilic digestion of mixed sludge resulted in:

- A drop of organic fraction of sludge dry solids from 70% down to 54%; it indicates that the sludge is biologically stable.
- Production of 590 liters of biogas per 1 kg of VSS removed. After further optimization of the wastewater treatment process (lowering of sludge age in the multiphase biological reactor) and primary sludge processing (optimization of an acid digestion phase ahead of an anaerobic digester) this value could even get higher.
- Rather high methane content in biogas, approx. 69-70% of CH_4 in biogas mass

Mixing of primary and waste activated sludge(WAS) at the 1:1 VSS ratio provides the optimum conditions for process performance; an increase of a WAS fraction (2:3) only slightly deteriorates the performance of the digestion process .

The analyzed sludge digests easily; it does not contain any inhibitory agents, which would affect biological decomposition of organic material

The digestion time is considered the main parameter for the prospective upgrading of the sludge processing line at existing plant i.e. the Nowy Sącz WWTP. The digestion time was found to be 23,5 d (for the 1:1 sludge mixture)

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