

Role of Primary Sludge Hydrolysis in Energy Recovery from Municipal Wastewater Sludge

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Abstract

Laboratory experiments supported by full-scale operational observations have been utilized to assess the possible yield of methane-rich biogas via decomposition of COD and volatile fatty acids (VFAs) from organic matter trapped and settled in a municipal wastewater treatment plant. The impact of operational conditions (mainly solids' retention time) on VFAs and methane-rich gas generation was estimated by fractionation of COD in sludge and supernatant. Assessment of efficiency of this process was done by steady state measurements of COD solubilization. Full-scale investigations supported by laboratory tests enlightened some specific operational problems that may occur in wastewater treatment plants with an intensive acidic hydrolysis. Relatively high consumption of biodegradable carbon is usually one of adverse and unfavorable effects.

Keywords: sludge processing, renewable energy sources, wastewater treatment, EBNR

Introduction

Demand for sustainability of municipalities which was launched on a global level, includes, among other things, great interest in recovery of energy carrier from sludge processing [1-3]. This usually leads to more emphasis on enhancing the overall efficiency of anaerobic digestion of treatment sludge widely recognized as an efficient way of methane production. The methane-rich fermentation gas may be relatively easily converted into electrical and heat energy. Primary sludge digestion is widely recognized and successfully applied in routine operations, but a wasted activated sludge (WAS) is still of minor importance in methane-rich digestion gas production [4, 5]. The main reason for this study was to determine the importance of primary sludge hydrolysis before anaerobic (primary) stabilization. A reference wastewater treatment plant (WWTP) was designed for municipal wastewater treatment, serving a community of approx. 120,000 inhabitants. Process layout is based on a modified UCT (MUCT) system. This process scheme is recognized as a well-tested

enhanced biological nutrient removal (EBNR) system for municipal wastewater [6].

Effects expected to be obtained were: decomposition of primary sludge components into soluble carbonaceous matter (possible easily biodegradable) form and increase of an electron donors for denitrification and biological phosphorus removal reactions. Determination of proper retention time in primary fermentation chambers was 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 an assumption of solid retention time (SRT), may lead to over-dimensioning of units [2, 7]. Numerous attempts to predict or assess design parameters did not result in a universal reliable design method [5, 8, 9]. Other proposed methods are more suitable for general description of the phenomena than for engineering purposes [7, 10-12].

The overall efficiency of sludge hydrolysis could be indirectly expressed by the increment of soluble COD (SCOD) concentrations by the incoming wastewater, and the design becomes dependent on the quality of this wastewater. When wastewater quality is poor in terms of readily

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Table 1. Experimental set-up of laboratory hydrolysis and raw sludge characteristics.

Series of experiment		WI01	WI02	SP03	SP04
Parameter	unit				
SRT	days	1-6	1-6	1-8	1-8
Temperature	°C	14.1	15.1	16.1	15.2
COD initial	mgO ₂ /l	31000	32000	29900	26900
TSS initial	mg/l	22000	22600	21050	19000
VSS initial	% of TSS	65	71	73	69
PO ₄ soluble	mg/l	7.1	6.3	6.4	5.8
Sludge pH	-	6.14	5.98	6.02	6.11

biodegradable (RBCOD), some substrate can be added to serve as electron donors for biochemical reactions associated with an EBNR, such as, for example, molasses, alcohol, acetic acid, or degradable substrates from infrastructure (e.g. the remains of de-icing liquid from airports).

Another way of solving this problem, suitable for treatment plants with primary treatment, is hydrolysis of primary sludge. But when primary treatment is followed by sludge digestion to produce biogas, hydrolysis of primary sludge will diminish the biogas yield [6]. As an alternative to the addition of substrate and to primary sludge hydrolysis, an anaerobic hydrolysis of return activated sludge, taking a side stream of the return sludge from the clarifier and letting it undergo anaerobic hydrolysis. [13-15]. Activities described in this paper are focused on primary sludge hydrolysis. The reference WWTP that the primary sludge was taken from is not applying pre-precipitation. Such a choice was supported by previous investigations [16, 17], showing that pre-precipitated sludge tended to solubilize less efficiently than sludge without precipitation.

Materials and Methods

Laboratory Investigation on Solubilization of Primary Sludge

Basic experimental conditions were:

Temperature: during the hydrolysis tests the temperature was kept at a constant 15°C (equal to average in real-term operation).

Test stand: A mechanically stirred system was applied to ensure a full mixing of samples.

Substrate and sludge concentration: Primary sludge was kept in 0.5-liter continuously stirred reactors (flasks) at a constant temperature for 7 days.

Nitrogen gas was introduced to a gas volume of the flask in order to ensure strictly anaerobic conditions and minimize measurement error [18, 19]. As a comparison sample, settled sludge from municipal wastewater (without pre-precipitation) withdrawn before the bar screens was hydrolyzed in the same type of reactor at 15°C, which was

recognized as average temperature of wastewater sludge in reference wastewater treatment plant. Initial concentration of sludge was approximately 25,000 mg/l of total suspended solids (TSS), sludge was not diluted for this experiment. Samples were collected from the reactors every day and analyzed for pH, VFA, COD, and PO₄. The degradability of the organic matter was also examined by fractionation of select samples with respect to easily biodegradable COD fraction (RBCOD).

Analysis Methods

The test stand was located at the Kraków University of Technology Research Laboratory, Poland. A spectrophotometer was used in all COD measurements. All measurements of COD, VFA, and orthophosphate were carried out for filtered samples. Cellulose filters No. 1002 with a filtering rate of 250±25 ml/min were used for all filtration of samples. COD were analyzed using Dr Lange LCK 114 tests and phosphates were measured with spectrophotometer (molybdenovanate method). TSS and VSS were analyzed according to Standard Methods. The total amount of fatty acids was measured by titration at pH 5 and pH 4 with 0.1 M HCl [20]. Specific single SCFAs were determined by gas chromatography. A WTW 320 pH-meter was used for all measurements of pH. RBCOD measurements were done according to the OUR-based test. Based on a daily grab sample withdrawn from reactors, soluble COD fraction and a VFA concentration were calculated. Table 1 summarizes results obtained in four series completed in winter (WI01 and WI02) and spring (SP03 and SP04) with respect to conversion of VSS to soluble COD.

Results of Laboratory Experiments

Results of laboratory tests were presented in Fig. 1 as a proportion between filtrated COD and total COD in sample, and this graph shows that up to 32% of COD could be converted into soluble form. For the sludge (without precipitation), the most efficient phase of sludge hydrolysis was found for the first two days, but on the other hand no signif-

Table 2. Laboratory results.

Series of experiment		WI01	WI02	SP03	SP04
Parameter	unit				
Maximum yield	mg COD _{fil} /gVSS	360	322	380	379
Maximum yield	COD _{fil} /COD _{tot} [%]	26	23	27 (28)	29 (30.5)
SCFA/COD _{fil}	%	48	38	51	48
RBCOD (grab sample after 2 days)	% of total COD	8.7	7.6	11	9.6
Initial hydrolysis rate	mgCOD _{fil} /(gVSS×h)	0.95	1.05	1.24	1.3

icant effect was found for solid retention time longer than 5 days. This result corresponds with references and was not innovative. Measurements showed, however, that maximum yield expressed as mg soluble COD per total COD were higher than expected, up to 32%. This might be explained by higher concentration of total COD, which favored hydrolysis during the first days of the process in an experiment described (compared with lower COD in reference experiments). On the contrary, initial hydrolysis rate was slightly lower than expected, which to some extent could be credited to local specifics, but overall requires further investiga-

tion. No seasonal changes were found, mainly due to a mostly separated type of sewer system delivering wastewaters, but this is the subject of the next stage of investigation.

Table 2 summarizes experimental results for each of the test series with respect to possible use of the product. To compare SCFA production with a COD concentration a calculation factor of 1.42 g COD per g VSS was used for re-calculation [19, 21]. Maximum yield was calculated for the sixth day of observation, data for SP03 and SP04 series in brackets were estimated for the eighth and final day of these longer series. It was noted that the intensity of hydrolysis (expressed as COD soluble to COD total ratio) reached approx. a 20% value at SRT = 2.5 days, which was a period recognized by the author as the longest SRT that does not adversely impact methanogenesis in a sludge digestion chamber [6, 21]. The specific composition of supernatant with respect to the SCFA showed that almost the same fraction of soluble COD was acetate (30%) and propionate (29%).

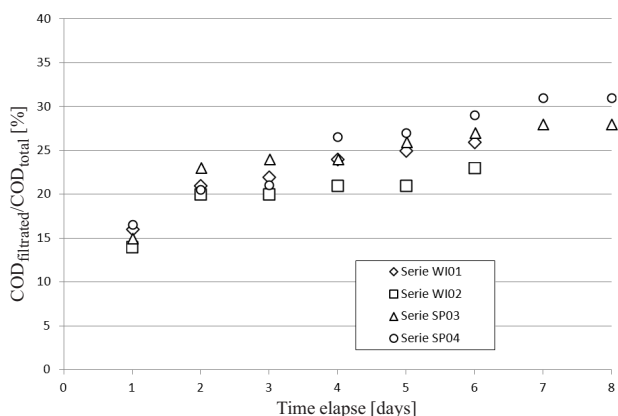


Fig. 1., Production of soluble COD expressed as COD (filtrated) to COD (total) proportion. Unprecipitated sludge, initial temperature 15±1.5°C.

Full-Scale Investigations at a Wastewater Treatment Plant

There are two main ways to arrange primary sludge hydrolysis, as shown in Fig. 2. In the original [22] 'in line' layout, primary sludge is kept in the primary settling tanks (clarifiers) for a longer time so that a sludge layer is created at the bottom of facilities (in most cases but the reference one in sludge hopper).

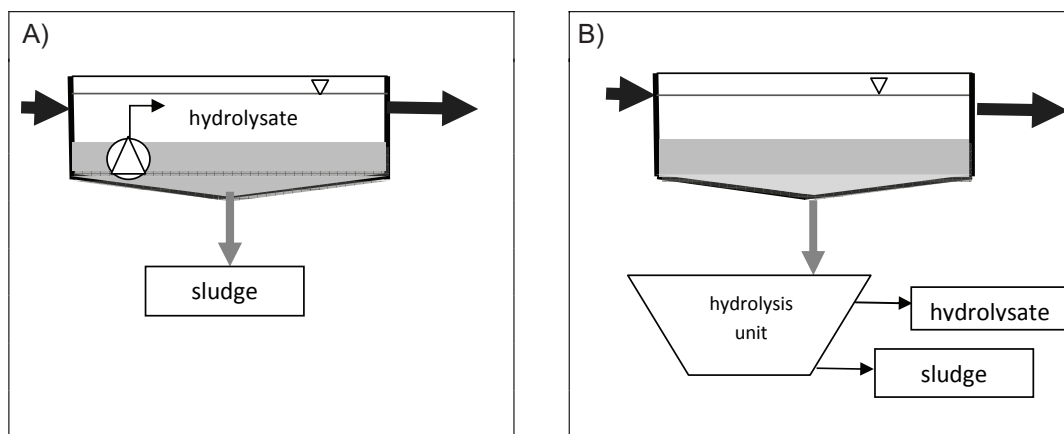


Fig. 2. In line (A) and side-stream (B) configuration of sludge hydrolysis units in contemporary WWTPs.

Table 3. Average monthly, unit biogas yield after side stream hydrolysis, full scale operation.

Month	January	February	March	April	June	July
Unit biogas yield [std m ³ /kg VSSrem]	0.76	0.72	0.69	0.82	0.69	0.59

Anaerobic conditions prevail in the sludge layer, allowing hydrolysis to take place. In order to separate the formed soluble COD out of the sludge, the sludge is lifted to just below the water surface by a pump. The SCFA-rich soluble COD follows the water to the bioreactor, where it is used as an electron donor for denitrification and Bio-P processes. The insoluble fraction – the sludge – settles again. The disadvantage of this method is that separation of the recirculated suspended solids never is ideal, which usually leads to an increased load of inert, solid fraction to biological reactors. Another alternative, which was applied in reference WWTP for experiments being described in this paper, is side-stream hydrolysis. In this case, primary sludge is pumped to a pre-fermenter, a separate tank for hydrolysis.

After this operation, which takes 1 to 4 days, the formed soluble COD is separated from the sludge by gravity thickeners or by centrifugation and directed to a biological treatment train as a supernatant liquid. Side-stream hydrolysis is more efficient to control than in line systems, as it is operated independently of the wastewater flow [16, 19, 21, 22].

In such a way the intracellular matters, including proteins, polysaccharides, lipids, etc., are released into the supernatant and go to the treatment train. This process also results in reduced residual sludge production.

The general assumption is usually made that the discharge of SCFA-rich supernatant is dosed precisely to the needs of the biological processes, while remaining easily biodegradable carbon is utilized in sludge processing train for gas production (if anaerobic digestion is applied).

Results and Discussion of Full-Scale Investigations

Full-scale measurements were performed at a wastewater treatment plant being operated in MUCT mode with side-stream sludge hydrolyzers, and phase separation of supernatant was supported by gravity sludge thickeners following the hydrolyzers. The measurements were completed in the first seven months of 2012 on a day-by-day basis. 36 grab samples were collected to establish TSS, VSS, SCFA, and filtrated COD values to assess performance of sludge hydrolysis in real, full-scale operation. Assumed SRT in the hydrolyzing unit was 1.5 days followed by 1 day in a gravity thickener. These periods were chosen to avoid a decrease in biogas production [21, 22]. Fig. 3 shows real SRT in consecutive units during investigations, when real values were relatively closed to assume proving that this phase of investigation was based on laboratory results described above. Fig. 4 illustrates the proportion between SCFA expressed as acetic acid concentration and filtrated COD concentration in daily supernatant samples. This parameter varied between

21 and 71% with average value 38%, which is lower than that observed in a laboratory for 2.5 days hydrolyzed SRT (42–47%), this difference can be recognized as an acceptable decrease of efficiency between the laboratory and real conditions. Measurements of methane-rich biogas production showed that biogas unit production was not adversely reduced by a deficiency of RBCOD after hydrolysis. The monthly average biogas production unit is presented in Table 3.

Conclusions

- Primary sludge hydrolysis can be used in routine operation of wastewater treatment plants to produce a readily biodegradable carbon source to be used in biological processes for nutrient removal (denitrification and Bio-P processes).

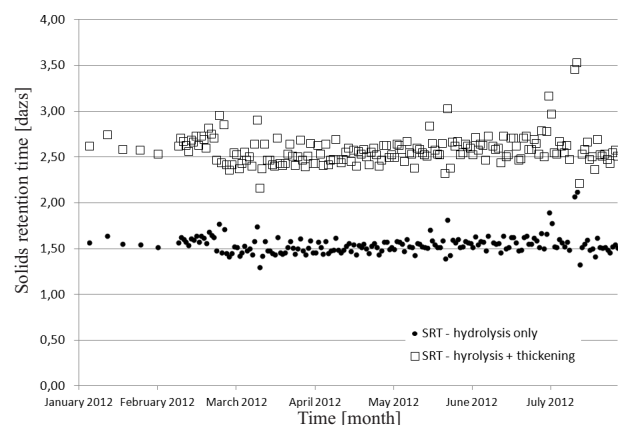


Fig. 3. SRT in hydrolyzing and thickening facilities during full-scale operation.

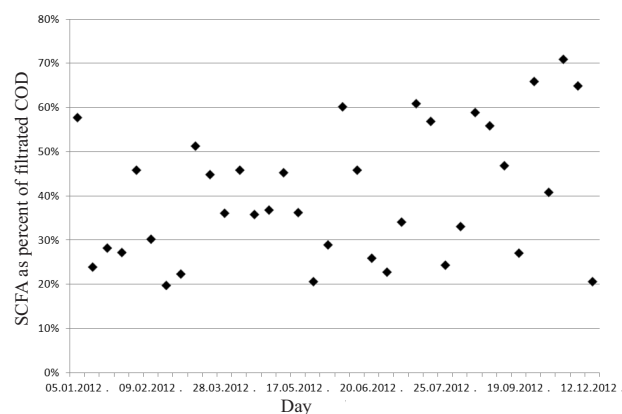


Fig. 4. Proportion between SCFA expressed as acetic acid concentration and filtrated COD concentration in daily supernatant samples.

- Proper adjustment of solid retention time in hydrolyzed units may ensure proper load of readily biodegradable carbon sources simultaneously with efficient biogas recovery, while too long retention may decrease the efficiency of this process.
- Laboratory tests supported by full-scale experiments showed that 50% efficiency of hydrolysis can be reached, expressed as SCFA proportion to filtrated COD after properly controlled hydrolysis.
- Results from these methods can be incorporated into design procedures of wastewater treatment plants addressed toward avoiding a decrease of methane rich biogas production.

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