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About the hydrolytic and acidogenic stage in dry temperature phased anaerobic digestion: influence of temperature and retention time.

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Abstract

Temperature phased reactors are known to improve the global yield of anaerobic digestion. The present work focuses on the first stage – hydrolysis and acidogenesis. We addressed the effect of temperature (mesophilic, thermophilic or hyperthermophilic) and retention time (2, 3, 4 and 2+2 days) on the hydrolytic and acidogenic activity in the first stage of temperature phased dry digestion system treating cow manure with co-substrates (straw and grass silage). We showed dramatic changes of both hydrolytic and acidogenic activities depending on the temperature with 3d and 4d reactors. In 2+2 days series, the influence of temperature became weaker, while the splitting effect was strong.

Keywords

Hydrolysis, Acidogenesis, TPAD, Dry Anaerobic Digestion, Manure, Straw, Silage

INTRODUCTION

Temperature-phased anaerobic digestion (TPAD) is an interesting option for improving the efficiency of anaerobic digestion (Lv *et al.*, 2010). This configuration permits to separate the biochemical steps involved during AD in order to optimize each step. In two-phase systems for instance, the organic matter is degraded into soluble material and VFA in the first stage, which are then converted into biogas in the second stage. Using a higher temperature in the first stage may favour higher hydrolytic activity and global methane conversion efficiency (Ge *et al.*, 2011). We addressed this problematic by studying how the COD is converted in the first stage reactors with TS content ranging from 12% to 18% with agricultural wastes (manure). A better understanding of this hydrolysis and acidification phase can lead to reactors with optimized retention time and temperature in each stage. The present work supports the development of an industrial continuous dry-digestion TPAD process named ARKOMETHA™, developed by ARKOLIA Energies.

EXPERIMENTAL SETUP

We used 1L reactors with thermal regulation. Biogas production was measured continuously with milligas counters (Ritter) and the biogas composition was determined by gas chromatography (SRA micro-GC 3000). The reactors were fed once a day with the amount of biowaste required by the experimental condition (fixed by the retention time). The reactors were monitored for pH, total and soluble COD and Volatile Fatty Acids. Experiments lasted at least one month per condition.

Runs settings

Four runs have been performed and analysed for this study. For each run the temperatures, retention time and input changed as follows:

Run #1. The input was cattle manure (15% TS, 78% VS), the retention time used was 4 days. We used 3 reactors in parallel. The temperatures were 65°C, 55°C and 37°C.

Run #2. The input was cattle manure (15% TS, 67% VS), mixed with 2.5% straw (85% TS, 86% VS) as co-substrate. The final composition was 17% TS and 68% VS. The retention times tested were 3

and 4 days. The temperatures were 65°C, 55°C and 37°C (4 days retention time).

Run #3. The input was the same as for run #2 (18%TS, 71%VS), the retention times tested were 4 days, divided into two reactors being each 2 days. The temperatures were 65°C and 55°C, *i.e.* 2 lines in parallel (each line with 2 reactors in series).

Run #4. The input was a mixture containing a cattle slurry (7%TS, 76%VS), cattle manure (37%TS, 60%VS) and grass silage (26%TS, 91%VS). The input was prepared at 12%TS and 74%VS, with 37% of the TS and 44% of the VS brought by the silage. The temperatures tested were 55°C and 65°C, with retention times distributed with 2 days + 2 days, as in run 3.

Hydrolytic and acidogenic yields calculations

All mass balances and calculations are expressed on a COD basis. The hydrolysis and the acidogenic yields are determined according to equations 1 and 2, respectively.

$$Y_s = \frac{COD_{gas} + COD_{s-out} \times m_{out} - COD_{s-in} \times m_{in}}{COD_p \times m_{in}} \quad (1)$$

$$Y_A = \frac{COD_{gas} + COD_{VFA-out} \times m_{out} - COD_{VFA-in} \times m_{in}}{COD_p \times m_{in}} \quad (2)$$

In these equations, COD_{gas} is the amount of COD in the biogas produced during a given period (in g_{COD}) based on the CH_4 and H_2 content; COD_{s-in} and COD_{s-out} are the concentrations of soluble COD in the input and the digestate, respectively ($g_{COD}.kg^{-1}$); COD_p is the concentration of particulate (non-soluble) COD in the input ($g_{COD}.kg^{-1}$); COD_{VFA-in} and $COD_{VFA-out}$ are the concentrations of COD due to the VFA in the input and the digestate, respectively ($g_{COD}.kg^{-1}$); m_{in} and m_{out} are the input and output masses of matter during the period.

RESULTS

Biogas

The average biogas throughput measured in the different runs are displayed in Table 1. For each run, the biogas production at 65°C reactor was lower than that at 55°C.

Table 1. Average biogas production (all results expressed in $L_{STP}.d^{-1}$ per kg of reactor content).

	37°C	55°C				65°C			
	4d	2d	3d	4d	2+2d	2d	3d	4d	2+2d
Run #1	0.41	-	-	2.50	-	-	-	1.07	-
Run #2	1.63	-	4.29	4.31	-	-	0.61	0.51	-
Run #3	-	2.98	-	-	8.66	1.01	-	-	1.61
Run #4	-	-	-	-	-	2.25	-	-	2.73

The biogas composition (not shown here) varied depending on the operating conditions. In hyperthermophilic reactors, the methane concentration remained between 4 % and 34% depending on the runs, and between 48% and 54% at 55°C. In parallel, the carbon dioxide concentration was higher when methane was lower. Moreover, the hydrogen production was higher at 65°C compared to 55°C and 37°C ($7.2 mL_{STP}.d^{-1}.kg^{-1}$, $2.3 mL_{STP}.d^{-1}.kg^{-1}$, $1.8 mL_{STP}.d^{-1}.kg^{-1}$ in run #2 at 4 days HRT respectively). The presence of easily degradable matter (ground straw and grass silage) strongly increased the hydrogen production.

Volatile Fatty Acids

The compositions and concentrations of VFA during run#3 are shown on Figure 1. Under these conditions, two lines (55°C and 65°C) were operated in parallel with 2 reactors in series for each line. The predominant acid was acetic acid, followed by propionic acid to a fewer extent. The highest VFA content was obtained at 65°C (over 23g VFACOD.kg⁻¹ while the input VFA concentration was 10.5g VFACOD.kg⁻¹). We also observed that the VFA concentration decreased in the second reactor of the thermophilic series, while it kept increasing at 65°C. This is probably due to the important methanogenic activity observed in the second thermophilic reactor

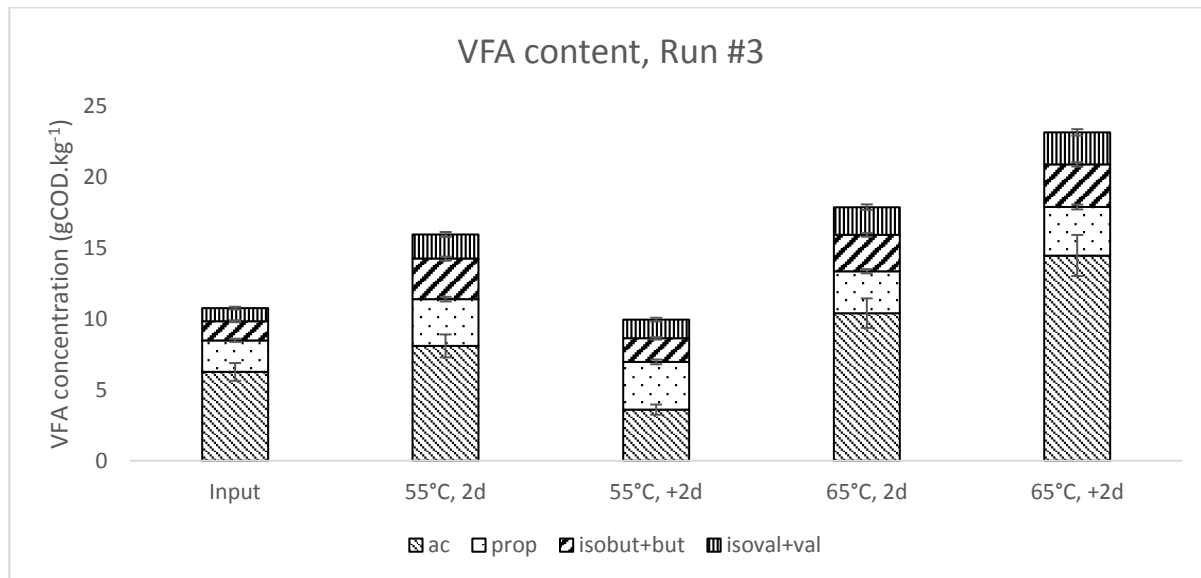


Figure 1. VFA content of run #3 reactors. For each temperature, two reactors with a 2 days retention time are used in series.

Hydrolysis and acidification yields

Hydrolysis and acidification yields are presented in the Table 2 and 3 for hydrolysis and acidogenesis, respectively. When the reactors were operated in series, the second stage had a lower hydrolytic activity (from 13% to 8% in run #3, 55°C, from 12% to 4% in run #3, 65°C, from 5% to 3% in run #4, 65°C). At 65°C, the second stage showed a lower acidogenic activity (6% to 3% in run #3, 65°C, 11% to 2% in run #4, 65°). At 55°C, the acidogenic activity is similar in both stages (6% and 8% along the series in run #3, 55°C).

In run #1, the hydrolytic and acidogenic activities were lowest in the reactor at 37°C (3% and 4% yields respectively) and the most active one was at 55°C (16% and 15% yields, respectively). With an input containing straw, the hyperthermophilic and mesophilic reactors had a similar hydrolytic activity (5-6%), while the acidogenic activity was higher at 37°C than at 65°C (8% vs 3% and 5%, depending on the retention time).

Table 2. Hydrolysis yields expressed in percentage of the particulate COD in the input.

	37°C	55°C				65°C			
	4d	2d	3d	4d	2+2d	2d	3d	4d	2+2d
Run #1	3%	-	-	16%	-	-	-	11%	-
Run #2	6%	-	10%	12%	-	-	6%	5%	-
Run #3	-	13%	-	-	8%	12%	-	-	4%
Run #4	-	-	-	-	-	5%	-	-	3%

Table 3. Acidification yields expressed in percentage of the particulate COD in the input.

	37°C	55°C				65°C			
	4d	2d	3d	4d	2+2d	2d	3d	4d	2+2d
Run #1	4%	-	-	15%	-	-	-	11%	-
Run #2	8%	-	8%	10%	-	-	5%	3%	-
Run #3	-	6%	-	-	8%	6%	-	-	3%
Run #4	-	-	-	-	-	11%	-	-	2%

DISCUSSION

The impact of the temperature on the VFA concentrations, biogas production and composition, hydrolysis and acidification yields, was found dominant compared to the influence of the retention times (runs #1 and #2) when the reactors were operated at 3 and 4 days HRT. A temperature as high as 65°C enabled a stronger VFA output concentration in the hydrolytic stage. However, the hydrolysis and acidification yields were found improved when an easily degradable compound (grass silage) was added.

When the 4 days HRT reactors were split into 2 reactors in series with 2 days HRT each, the hydrolytic activity was reinforced in the first stage. The effect of temperature was less obvious. According to Boe *et al.* (2008), the use of different stages not only increases the performance of the process, but also improves its resilience and stability. This highlights the relevance of the process segmentation into several tanks in series or plug flow mode, further than conventional TPAD, as we did in runs #3 and #4 for the hydrolysis.

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