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Improving Biogasfermentation of Sludge and Cosubstratesby Combining Acidification with Disintegration Systems

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2. Keywords

Acidification; Disintegration; Anaerobic digestion

1. Abstract

A semi-scale acidification batch reactor (700 litres) was installed at the domestic wastewater treatment plant Hof (Germany) and feed with thickened sludge and treated with electroporation and hydrodynamic induced cavitationwith exposure times up to 6 hours. Inoculation from the large-scale sludge digester improved acidification significantly.Investigations were carried out with sludge from the treatment plant, domestic biowaste and *Silphie*after silage fermentation as cosubstratesto observe the effects of combined acidification with disintegration to biogas production.Lab-scale fermentation of the treated substrates showed an increase in biogas formation of about 19 % by impact of electroporation, hydrodynamic induced cavitation lead to an increase of app. 21 % biogas formation and the combination of electroporation with hydrodynamic induced cavitation lifted the biogas formation even up to app. 31% at an exposure time less than 2 hours. Moreover, the rheology of the treated substrates improved significantly thepumping characteristics, offering an additional optimisation potential.

3. Introduction

Anaerobic industrial wastewater treatment leads to much higher biogas formation rates compared to domestic treatment plants. Especially the installation of an acidification reactor improves biogas formation rates in industrial applications. The separation of hydrolysis and acidogenesis from acetogenesis and methanogenesis stabilizes anaerobic fermentation processes significantly and reduces the risk of over-acidification[1]. Depending on the COD-load the residence time inside an acidification reactor is usually in the range of 6–12 hours. Investigations of Weiland &Wulfert(1986)with potato grain showed the formation of higher organic acids exceeding residence times of more than 24 hours, inhibiting anaerobic digestion.Moser (2002) reached stable process conditions at residence times of 2–3 days for citric acid production by additional inoculation of the acidification reaction with sludge from the anaerobic digester.In domestic sludge treatment these technologies are almost unknown (DWA working group, 2012)but offer a great potential for process optimisation[2]. Report from optimized residence time in the range of 72 h for waste activated sludge. Further improvements can be realised by the installation of disintegration systems to increase the specific area of solid particles and enable cell wall breakupfor higher degradation rates of the substrates [3-5].

Applying electroporation, a high voltage electrical field is generated, leading to massive cell deformations and can even break up the cell wall to release the cell content to the broth [6,7]. Large-scale application at the anaerobic sludge digester of the wastewater treatment plant Landshut (Germany) increased the biogas production rate more than 15%[8].

Hydrodynamic induced cavitation inside a nozzle leads to imploding cavities with high local temperature and pressure peaks, stressing any solid material and the cell wall of microorganisms. Imploding cavities generate micro jets, lifting the fluid velocity close tothe imploding bubble up to 700 m/s and causes fluid hammers up to 5000 N/m^2[9,10]. Under low surrounding pressure conditions, secondary and tertiary imploding cavities can be formed, improving the overall yield of disintegration. Besides mechanical stress on solid particles and cell walls, water molecules get disrupted and generate free radicals (HO•, H• and HO_2•). Derived $H_2O_2$and free radicals lead to an additional chemical impact towards the substrate [6, 11, 12].Investigations in technical scale, treatingmethyl-tert-butylethereven lead to complete mineralisation by the exposure of hydrodynamic induced cavitation(Schmid, 2010). Using a rotor-stator-system to generate hydrodynamic cavitation[13]. Showed in semi-scale an increase

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of biogas formation rates in the range of about 30% for sidahermaphroditesilage. The investigations of [14].Revealed an increase in biogas formation by 12.7% for activated sludge pre-treatment by a rotor-stator system to generate cavitation.

4. Material and Methods

A batch acidification reactor with a volume of 700 litres was fed with thickened sludge from the domestic wastewater treatment plant Hof (300 000 residents). The reactor content was recirculated by passing an electroporation device(INNOVUM GmbH) with an electrical power of 35 Watts and a voltage of 100 kV or alternatively a hydrodynamic induced cavitation reactor (length 1 m) with a power input of 2 kW and an inlet pressure of 2 bars (experimental setup according to previous study (Schmid, 2010)). The experiments with diverse substrates were carried out without disintegration as a reference value, compared with the two disintegration systems run separately or in combination (**Figure 1**). Additionally, the residence time inside the acidification reactor was varied in a 30 minutes interval up to a maximum of 6 hours to find an optimum of the biogas production rate for each investigated substrate. 10 litres inoculation of anaerobic microorganisms from the existing large-scale sludge digester assured a high concentration of hydrolytic and acidogenic microorganisms inside the acidification reactor for each experiment.

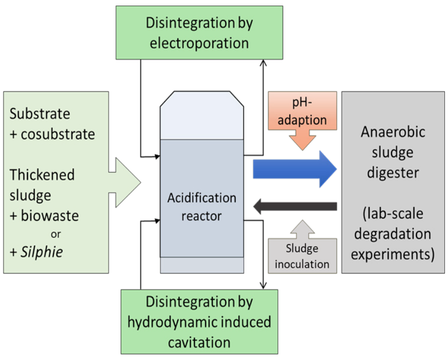

Figure 1: Experimental setup of semi-scale acidification reactor.

After leaving the acidification reactor 1 litre samples were taken, the pH was adapted to pH=7 and the biogas formation was measured in a 2 litres anaerobic reactor after 7 days of fermentation as triplicate measurements (deviation less than 5%). The samples were inoculated by 1 litre of anaerobic sludge from the large-scale fermenter.The rate of disintegration A_{COD} was determined accordingequ[1]. After chemical dissolution under 22 hours with 1 molar NaOH in the relation 1:1,the maximum of released COD_{NaOH} was analysed (ATV working group, 2000). Centrifugation of the pre-treated samples at 10 000 g (10 minutes) and following membrane filtration (0.45 µm) the COD_{disint} was analysed. COD_u represents the COD-concentration of untreated samples after membrane filtration.

$$A_{COD} = \left[\frac{COD_{disint} - COD_u}{COD_{NaOH} - COD_u}\right] \cdot 100\,[\%] \qquad (1)$$

Domestic biowaste and Silphieafter silage fermentation (renewable plant from agriculture) were mixed with thickened sludge in the proportion 1:10 to investigate acidification and disintegration on biogas formation rates.

5. Results and Discussion

The rate of disintegration A_{COD} increased with time of exposure in the acidification reactor (**Figure 2**).After 4 hours acidification with disintegration the A_{COD}-values rose up to 3%-6% using thickened sludge only; whereas added biowaste lead to A_{COD}-values of almost 12%. But high rates of disintegration did not necessarily lead to high biogas formation rates.

Following tables show the optimum of each variation experiment. The best results were derived when the residence time inside the acidification reactor is in the range between 30 minutes to 2 hours in combination with disintegration systems, which is much shorter than data published elsewhere[15, 16, 17]. Table 1 show the changes of acidification in comparison to untreated substrates.The biogas formation rate for thickened sludge can be lifted up to 12%-14% at a residence time of app. 1 hour. Using biowaste as cosubstrate, an increase of 8% biogas formation was observed. Applying *Silphie* as cosubstrate, no significant changes were detected.

Imposing electroporation as disintegration system in combination with acidification, additional improvements had been observed (**Table 2**).

Applying hydrodynamic induced cavitation on thickened sludge at a residence time inside the acidification reactor of app. 3 hours lead to improvements of biogas formation in the range of app. 21% (see **table 3**). Due to the small diameter inside the cavitation nozzle (6 mm for the semi-scale device) Cosubstrates (biowaste as well as *Silphie*) blocked the disintegration systems.

The combination of hydrodynamic induced cavitation with electroporation for thickened sludge lifted up biogas formation to app. 31% at a residence time of less than 2 hours (**Table 3**).

During the investigations the viscosity of the thickened sludge declined drastically, especially by the impact of electroporation (**Figure 3**). Even after 15 minutes of operation the viscosity fell down from initially 4000 mPas to 200 mPas. Applying hydrodynamic induced cavitation, it took about 3 hours to meet a similar small value of viscosity[18]. Report from similar effects, when applying ultrasound on waste activated sludge as a pre-treatment step.

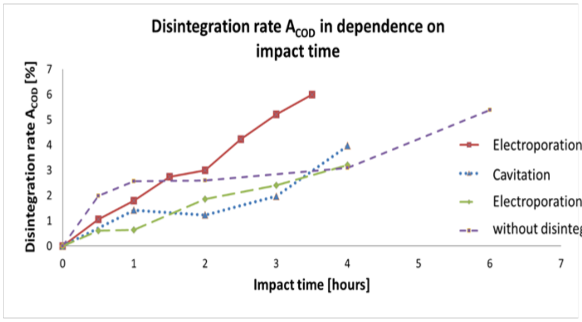

Figure 2: Disintegration rates ACODof thickened sludge by acidification and disintegration.

Table 1: Improving biogas formation by acidification only.

Substrate Parameter	Thickenedsludge	Thickenedsludge + 10% biowaste	Thickenedsludge + 10% *Silphie*
Optimum residence time	1 hour	1 hour	2 hours
Energy consumption*	2,1 kWh/m³	2,1 kWh/m³	4,2 kWh/m³
Increaseofbiogasformation	+ 12%to 14%	+ 8%	+ 1%

*Energy consumption by mixing device

Table 2: Improving biogas formation by acidification in combination with electroporationin comparison to acidification only.

Substrate Parameter	Thickenedsludge	Thickened-sludge + 10% biowaste	Thickenedsludge + 10% *Silphie*
Optimum residence time	1 hour	1 hour	30 minutes
Energy consumption	2,2 kWh/m³	2,2 kWh/m³	1,1 kWh/m³
Increaseofbiogasformation	+ 10%	+ 8%to 18%	+ 4%

Table 3: Improving biogas formation by acidification in combination with cavitation and additionally with electroporationin comparison to acidification only.

Substrate Parameter	Thickenedsludgewith-cavitation	Thickened sludge with cavitation and electroporation	Cosubstrates
Optimum residence time	3 hours	30 minutes - 2 hours	-*
Energy consumption	3,1 kWh/m³	1,6 to– 6,5 kWh/m³	-
Increaseofbiogasformation	+ 21%	+ 13%to 31%	-

*Blockage of cavitation nozzle by large particles of cosubstrates

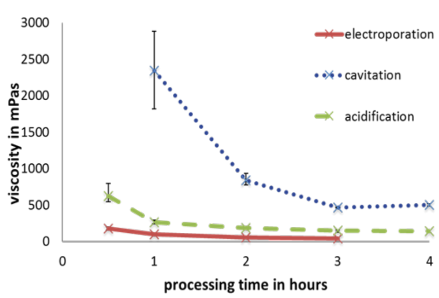

Figure 3: Reduction of viscosity of thickened sludge by impact of electroporation and cavitation.

Measurements of particle size distribution showed a reduction in size of app. 15% for large particles, whereas small and medium sized particles didn't show any changes in size.

6. Conclusions

The semi-scale investigations show a significant increase of biogas formation by the impact of acidification in combination with disintegration systems on different substrates. Using silage fermented substrates (*Silphie*), acidification only did not lift up biogas production - an additional disintegration step is necessary. Whereas domestic biowaste and thickened sludge respond significantly to acidification and even more, when combined with disintegration systems. Increase of biogas formation up to app. 31% was reached at a residence time less than 2 hours which is much lower than published data (Weiland &Wulfert, 1986; Moser, 2002, Yang et al., 2013). Higher residence times lead to lower biogas formation rates due to degasification of CO_2 and H_2.The specific energy consumption was in the range of 2-6 kWh/m³ and can be compared with other cavitation disintegration techniques, like e.g. ultrasound which needs 3-15 kWh/m³ to lift up biogas formation towards 20 %(Nickel &Neis, 2013) or orifice plates[19]. To generate more reliable data, semi-scale experiments in continuous flow operation including an anaerobic fermenter are strongly recommended. This technology has been patented by the University of Applied Sciences Hof[20].

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