Two-stage high pressure anaerobic digestion for biomethane production

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Introduction

Considering Germany's energy supply, there is a need to supplement the increasing share on volatile energy sources, such as wind and solar energy, by expanding demand power generation and developing new energy storage concepts. Biomethane production, in this case, has the potential to play a major role. As biomethane gas can be fed directly into the natural gas grid, it thus utilizes a large existing energy storage system. In May 2015, in the EU-28 a total underground gas storage capacity of 108.3 billion m³ was available; 7.4 billion m³ more were under construction and 29.3 billion m³ planned [GIE, 2015]. Biogas produced primarily consists of CH_4 (55 to 60%) [FNR, 2006] and CO_2 (40 to 45%), dependent on the fermentation process and on the converted initial substrates. However to achieve the same calorific value as natural gas before grid injection it must be purified, and furthermore compressed to the required pressure level. The current upgrading technologies, such as amine scrubbing, gas separation membranes, organic solvent scrubbing, pressure swing adsorption (PSA) and water scrubbing are highly energy consuming and by that expensive.

In a new, continuous two-stage high pressure anaerobic digestion system, the second process stage runs under increased pressure. The methanogenic bacteria in the methane reactor autogeneratively increase the pressure of the gas. This concept uses the higher solubility of CO_2 in liquid compared to CH_4 [Clever, 1987; Crovetto, 1991; Gevantman, 1992], providing an opportunity to discharge the CO_2 via the liquid stream from the methane reactor. Through that, it integrates biogas production, purification and pressure boosting within one process and results in a high-calorific biogenic gas gained from the methane reactor.

Previous research in this area has achieved CH_4 contents of up to 87% at operating pressures up to 10 bar in continuous operation, and of up to 95% at pressures up to 90 bar in batch tests [Lemmer et al., 2015; Lindeboom et al.; 2011].

Material and methods

This investigation examined the effects of different operating pressures in methane reactor (10, 25, 50 bar) on biogas quantity and quality, pH value and process stability. Three operating pressure levels (10 bar, 25 bar, 50 bar absolute pressure) were tested at a temperature of 37 °C in the pressure methane reactor. The used percolate for the methane reactor was produced in four parallel-operated acidogenesis-leach-bed-reactors with a volume of 50 L each [Chen et al., 2014], in which the supplied biomass (grass and maize silage) was degraded to organic acids and alcohols. The pressurized anaerobic filter system consisted storage tanks HP-T1 for the percolate, HP-T4 for the effluent, high pressure methane reactor as an upflow anaerobic filter with a total volume of 21 L and two flash tanks (Flash 1+2) with a total volume of 10 L each.

The chemical oxygen demand (COD) concentration in the percolate varied between 17.9 ± 0.4 g L^{-1} (10 bar) and 17.2 ± 0.6 g L^{-1} (50 bar). The organic loading rate related to COD was between 4.42 ± 0.44 kg m^3d^{-1} at 10 bar and 4.19 ± 0.09 kg m^3d^{-1} at 50 bar. The entire amount of liquid within the methane reactor was circulated in several intervals once hourly. No additional caustic chemicals were added for pH adjustment throughout this experiment. In addition, alcohols, alkaline buffer capacity, ammonium-nitrogen, chemical oxygen demand (COD), and volatile fatty acids were analysed.

Results and discussion

The analysis of the alcohols, alkaline buffer capacity, ammonium-nitrogen and volatile fatty acids clearly showed no inhibition of the processes (Table 1). Only the concentration of propionic and acetic acid had slightly increased for the experimental pressure level of 50 bar. The pH value varied between 6.65 ± 0.05 at 10 bar, 6.53 ± 0.04 at 25 bar and 6.55 ± 0.02 at 50 bar. The pH value at 10 bar was significantly higher in comparison to 25 bar and 50 bar experiments. The drop in pH value is caused by dissolution of CO_2 in the liquid.

Significant differences were observed in the biogas composition under different operating pressures (Figure 1). The methane content increased from 79.08 ± 1.01% at 10 bar to 90.45 ± 0.73% at 50 bar, while the carbon dioxide content decreased from 21.62 ± 1.28% at 10 bar to 7.86 ± 0.2% at 50 bar. At higher operating pressures the methane content in the gas raised.

Table 1 Chemical characteristics of the effluent from methane reactor operated at different pressure levels [Merkle et al., 2017].

	Effluent composition		
	10 bar	25 bar	50 bar
Acetic acid (g kg^{-1})	0 ± 0	0 ± 0	0.1 ± 0.1
Propionic acid (g kg^{-1})	0 ± 0	0 ± 0	0.4 ± 0.1
iso-Butyric acid (g kg^{-1})	0 ± 0	0 ± 0	0 ± 0
n-Butyric acid (g kg^{-1})	0 ± 0	0 ± 0	0 ± 0

The specific methane yield (SMY) in the methane reactor decreased from 0.33 ± 0.02 L g^{-1} COD_{input} at 10 bar to 0.26 ± 0.04 L g^{-1} COD_{input} at 50 bar. By increasing the pressure, more CH_4 was dissolved in the process liquid and transferred to the Flash 1, where this dissolved CH_4 was released due to the reduced partial pressure. Summarizing the CH_4 production of the whole anaerobic filter system including Flash 1, the SMY has increased to 0.34 L g^{-1} COD_{input} at 10 bar and 25 bar. A lower SMY of 0.3 L g^{-1} COD_{input} was observed at 50 bar.

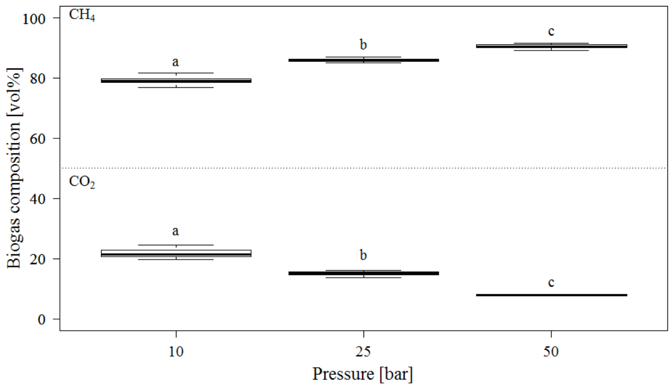

Figure 1 Methane and carbon dioxide content in the methane reactor measured at different pressure levels [Merkle et al., 2017].

Conclusions

With this investigation of two-stage high pressure anaerobic digestion integrating biogas production, purification and pressure boosting within one process, methane contents above 90% were obtained. In order to provide high conversion efficiency and a low methane slip, making the process feasible, operating pressures below 50 bar should be aimed according to the current study. The produced biomethane can be injected into the transnational gas grids without additional pressurization or can be used in the transportation sector [Merkle et al., 2017].

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