Bioresource Technology 232 (2017) 72–78

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Influence of pressures up to 50 bar on two-stage anaerobic digestion

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HIGHLIGHTS

- The influence of pressure on anaerobic digestion up to 50 bar was examined experimentally.
- Increasing pressure decreases pH value in the methane reactor until 6.53.
- Increasing pressure increases methane content over 90%.
- Increasing pressure decreases specific methane yield until 0.26 L g^{-1} COD_{added}.
- The pressurized methane reactor operates very stable.

ARTICLE INFO

Article history:
Received 24 November 2016
Received in revised form 30 January 2017
Accepted 3 February 2017
Available online 8 February 2017

Keywords:
Anaerobic digestion
High pressure
Two-stage
Biogas
Biomethane

ABSTRACT

The concept of pressurized two-stage anaerobic digestion integrates biogas production, purification and pressure boosting within one process. The produced methane-rich biogas can be fed into gas grids with considerably less purification effort. To investigate biogas production under high pressures up to 50 bar, a lab scale two-stage anaerobic digestion system was constructed including one continuously operated pressurized methane reactor. 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. By increasing operating pressures in methane reactor, the pH value decreased from 6.65 at 10 bar to 6.55 at 50 bar. Simultaneously, methane content increased from 79.08% at 10 bar to 90.45% at 50 bar. The results show that methane reactors can be operated up to 50 bar pressure continuously representing a viable alternative to commonly used gas upgrading methods because of reduced purification effort.

1. Introduction

Considering Germany's energy supply, there is a need to supplement the increasing expansion of volatile energy sources. In 2015, wind and solar energy had a share of 86.6% on the installed capacity for renewables-based electricity generation in Germany (AGEE-Stat, 2016). This challenge can be mastered by expanding demand power generation and developing new energy storage concepts. The production of biomethane as a renewable energy source, in this case, has the potential to play a major role. As biomethane gas can be fed directly into the public natural gas grid, therefore utilizes a large existing energy storage system and furthermore decouples the gas production and its utilisation in terms of time and space (Niesner et al., 2013; Barchmann et al., 2016). In 2014, the total upgrading capacity of 310,000 m^3 h^{-1} raw biogas was contributed by 178 biomethane plants in Germany and 189 plants from rest of Europe (EBA, 2016).

One concept for biomethane production combining biogas production, purification and pressure boosting in one process is the pressurized two-stage anaerobic digestion system (Wonneberger et al., 2011; Chen et al., 2014a, 2014b; Lemmer et al., 2015a) Through this, energetic efforts for grid injection could be significantly reduced. In commonly applied non-pressurized two-stage anaerobic digestion processes found in literature (Lehtomäki and Björnsson, 2006; Parawira et al., 2007; Muha et al., 2013; Lindner et al., 2015), the degradation steps of hydrolysis/acidification and acetogenesis/methanogenesis are spatially separated to ensure optimum environmental conditions for each group of microorganisms (Muha et al., 2013; Lemmer et al., 2015a; Lindner et al., 2015). In contrast, in the pressurized two-stage anaerobic digestion process, methanogenic bacteria autogeneratively increase the pressure of gas in the second stage. Besides, this applied process makes use of the fact that CO_2 is more soluble in liquid than

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http://dx.doi.org/10.1016/j.biortech.2017.02.013

methane (Clever and Young, 1987; Crovetto, 1991; Gevantman, 1992), allowing CO_2 discharge from the methane reactor with liquid stream. Therefore this system represents an alternative to commonly used post upgrading technologies pressure swing adsorption (PSA), gas separation membranes, amine and water scrubbing (Niesner et al., 2013). Previous studies in continuous two-stage high pressure fermentation indicated that high CH_4 contents of over 80% are possible at operating pressures of up to 9 bar (Chen et al., 2014a,b; Lemmer et al., 2015a,b). Other studies with batch systems up to 100 bar showed no inhibition of methanogenic bacteria, still producing biogas under high pressures (Lindeboom et al., 2011; Merkle et al., 2016).

For future applications, even higher operating pressures of 60 to 125 bar (Chandra, 2006) are possible, for e.g. biomethane transportation via transnational gas grids. These pressure levels were not yet achieved in former studies under continuous pressurized two-stage anaerobic digestion process. Therefore, a continuously operating pressurized methane reactor was build. The aim of this study was to investigate the effect of high operating pressures up to 50 bar on pressurized two-stage anaerobic digestion by testing three different operating pressure levels (10 bar, 25 bar and 50 bar) in the methane reactor. The effects on biogas quantity and quality, pH value and process stability were investigated using a lab-scale pressurized two-stage anaerobic digestion system at the University of Hohenheim. The accompanying modelling work was conducted by the Deutscher Verein des Gas- und Wasserfaches e. V. (DVGW) Research Centre at the Engler-Bunte-Institute of Karlsruhe Institute of Technology (KIT).

2. Materials and methods

2.1. Reactors

The design of the two-stage high pressure anaerobic digestion system without first stage is shown in Fig. 1. The first stage hydrolysis-acidification was performed in four parallel-operated acidogenesis-leach-bed-reactors with a volume of 50 L each (Chen et al., 2014a), in which the supplied biomass was degraded to organic acids and alcohols. An internal circulation of liquid was used to leach out organic acids and alcohols produced.

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 percolate was pumped with P-1, a piston diaphragm pump, (PROMINENT, Type HP3A) from HP-T1 into high pressure methane reactor in order to convert the organic fraction into biogas. The liquid in methane reactor was circulated by a separate circulation gear pump (GATHER Industrie, Type 1MA-A/12-11/X-SS/Q/K100/) to guarantee a homogeneous distribution of organic acids and provide uniform temperatures in the reactor. The fixed bed consisted of randomly packed polyethylene fillers (STÖHR, Type HX09: surface area 861 m^2 m^{-3}, porosity 83%) as a carrier material to aid in immobilizing the microorganisms and biofilm development. The fillers had an effective packing surface of 24.38 m^2.

The aim of high pressure fermentation system was to have an autogenerative increase in reactor pressure by microorganisms

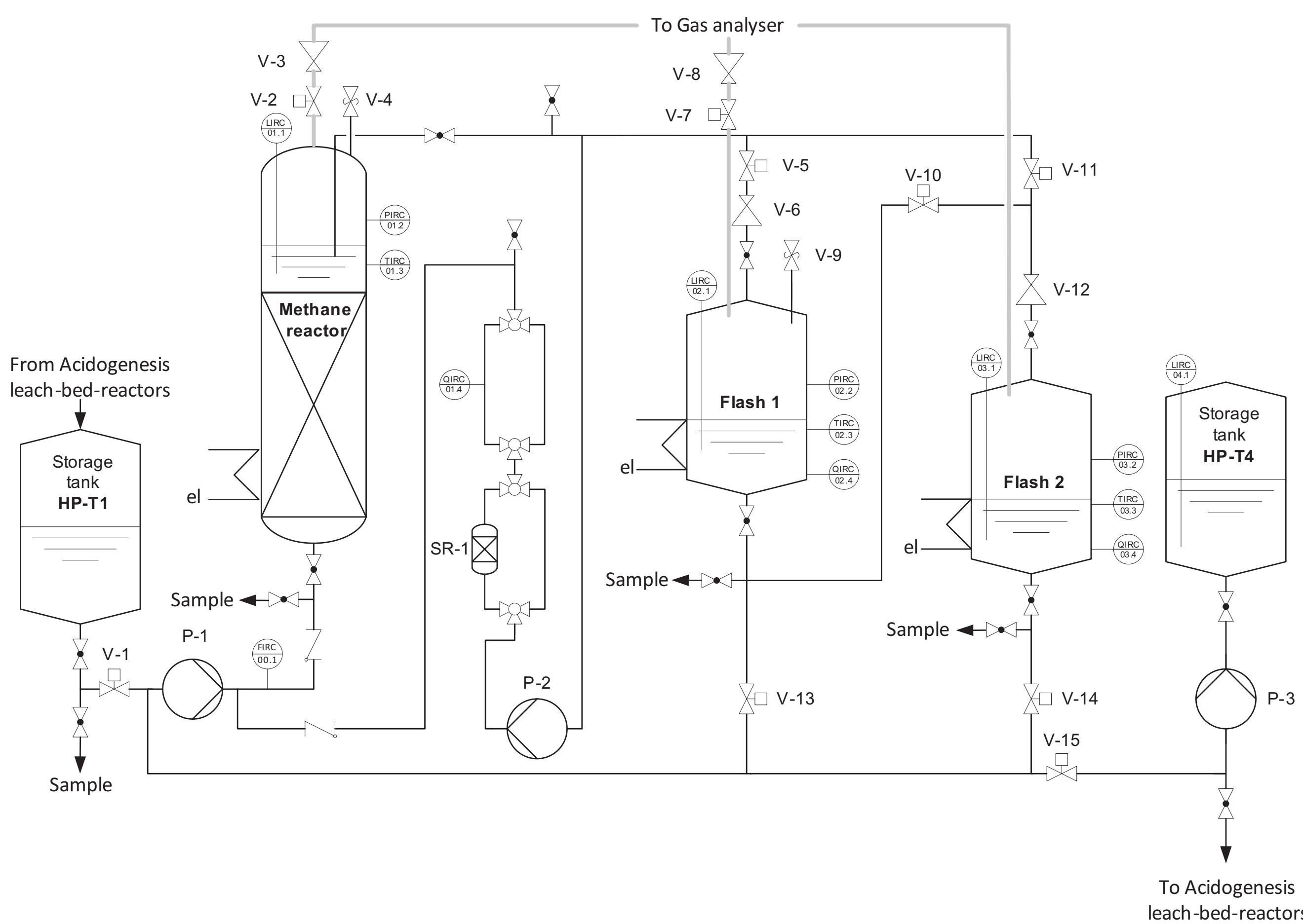

Fig. 1. Schematic diagram of the pressurized anaerobic filter system without the first stage