Bioresource Technology 100 (2009) 5934–5940

Contents lists available at ScienceDirect

Bioresource Technology

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

Mono fermentation of grass silage by means of loop reactors

Konrad Koch [a,*], Marc Wichern [b], Manfred Lübken [a], Harald Horn [a]

[a] Institute of Water Quality Control, Technische Universität München, Am Coulombwall, 85748 Garching, Germany
[b] Institute of Environmental Engineering, Ruhr-Universität Bochum, Universitätsstraße 150, 44780 Bochum, Germany

ARTICLE INFO

Article history:
Received 20 February 2009
Received in revised form 2 June 2009
Accepted 5 June 2009
Available online 3 July 2009

Keywords:
Anaerobic digestion
Biogas technology
Loop reactor
Grass silage
Hydrolysis kinetics

ABSTRACT

A loop reactor was operated for mono fermentation of grass silage without manure addition under mesophilic conditions (38 °C). An averaged specific biogas production of 0.50 m_N^3 per kg volatile solids (VS) with a methane concentration of 52% at an organic loading rate of up to 3.5 $kg_{VS}/(m^3\ d)$ was obtained. The retention time varied from 440 days at 1.0 $kg_{VS}/(m^3\ d)$ to 50 days at 3.5 $kg_{VS}/(m^3\ d)$. The degradation level was more than 60% based on VS and 75% based on COD. The first-order hydrolysis rate constant of the process was estimated to be 0.6 d^{-1}. Despite the relative high ammonium concentration of up to 4 g/l, the system worked stable for an operation period of 310 days. In particular the TS content in the fermenter was found to be a key parameter and should not exceed 12% in order to avoid instabilities.

1. Introduction

In order to achieve the ambitious environmental protection goals declared in the Kyoto Protocol in 1997, a diversified mix of different forms of renewable energy is needed. Besides water and wind power, energy conversion based on biomass makes nearly half of all renewable energy production worldwide and will soon rise (Caillé et al., 2007). Considering the current debate on concurrence of energy crops and food production, biogas technology should mainly focus on residues from agriculture and other sources. Especially in landscape conservation (parks, nature reserves, fallow land, etc.) grass is often a waste product and composted by emitting the stored energy as heat. Such treatment strategies are not conforming to the closed loop recycling management and additionally, valuable energy is needlessly wasted.

Grass has a high potential as energy crop for biogas production. In order to guarantee a conservation and availability during the whole year, ensilage or haylage is inalienable. Usually, compacting to extrude enclosed air and a plastic coverage is sufficient for conservation of fresh grass. Sometimes, ensilage substances like lactic acid bacteria are added, but that is only necessary to ensure highest quality for livestock farming (Mukengele and Oechsner, 2007). Haylaging offers the advantage of long-time storing because of less humidity, which ensures that only digestible material is stocked. Normally, the live stock of the farm defines the way of conservation.

Up to now, grass silage is mostly used as co-substrate in biogas plants based on cattle, pig or chicken manure because of its inappropriate high nitrogen content (Distel et al., 2005; Nousiainen et al., 2003; Rodriguez et al., 2005; Speckmaier et al., 2005; Yan and Agnew, 2004) of about 14% of total solids (TS). The influence of ammonia on anaerobic digestion in terms of process inhibition was studied by several researcher (e.g. Mignone, 2005; Sterling et al., 2001; Strik et al., 2006; Van Velsen, 1979). However, several authors proved that mono digestion of grass silage is possible, although both applied systems and experimental conditions differ occasionally significant. Wichern et al. (2009) described laboratory reactors with an averaged specific biogas production of 0.6 m_{BG}^3/kg_{VS} with an averaged methane concentration of 50–60% by means of CSTR. Zielonka et al. (2007) applied a two stage bioleaching process with a specific biogas production of 0.75 m_{BG}^3/kg_{VS} at 44% methane. Yu et al. (2002) described a two phase digestion system producing 0.15 m^3 of methane per kg of grass, but with a hydraulic retention time of 190 days. Batch leach bed reactors were operated by Lehtomäki et al. (2008), where up to 0.2 m^3 CH_4/kg volatile solids were obtained. By means of a percolation system, Kusch (2007) achieved 0.465 m^3 CH_4/kg_{VS} with an averaged methane content of 53%. As biogas production is in particular influenced by both organic loading rate (OLR) and retention time (RT), Table 2 gives an overview of the applied systems and the achieved methane productions of the different authors in the overall context.

It is often assumed that the rate-limiting step in anaerobic digestion is the hydrolysis of particular matter to soluble substances, which is expressed by the first-order hydrolysis rate constant k_h. Its calculation was subject of different research projects. Pavlovstatis and Giraldo-Gomez (1991) composed a critical review

* Corresponding author. Tel.: +49 89 289 13700; fax: +49 89 289 13718.
E-mail address: wga@bv.tum.de (K. Koch).

0960-8524/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biortech.2009.06.020

Nomenclature

ADM1	Anaerobic Digestion Model No. 1
COD	chemical oxygen demand (mg_{O_2}/l)
CSTR	completely stirred tank reactor
$F_0 \cdot G$	maximum methane yield (l_{CH_4})
GC/FID	gas chromatograph with flame ionization detector
k_{dis}	disintegration constant (d^{-1})
k_h	hydrolysis constant (d^{-1})
OLR	organic loading rate ($kg_{VS}/(m^3\ d)$)
RT	retention time (d)
TS	total solids (%)
TVFA/alkalinity	stability criterion
VS	volatile solids (%)

on hydrolysis of particulate organic matter with emphasizes on pure substrate and cultures; therefore the range of k_h is quite extensive. Veeken and Hamelers (1999) measured the hydrolysis rates of different biowaste components and found a k_h of 0.266 d^{-1} for grass at 40 °C. Hu and Yu (2005) applied rumen microorganism to enhance anaerobic fermentation of corn stover and estimated k_h to be 0.94 d^{-1} at 40 °C. They concluded that this hydrolysis rate constant was quite high, which might attributed to the high cellulolytic activity of the rumen microorganism applied. Myint et al. (2007) modelled the hydrolysis of cattle manure at 37 °C and established a maximum rate of hydrolysis of 1.4 d^{-1} for hemicellulose and 0.09 d^{-1} for cellulose. In consideration of the particular share of hemicellulose and cellulose within grass silage, k_h is varying between both values. Lübken et al. (2007) simulated the anaerobic digestion process of manure and cow fodder under mesophilic conditions (38 °C) and calculated a k_h of 0.31 d^{-1} using the Anaerobic Digestion Model No. 1 (ADM1, Batstone et al., 2002). Song and Clarke (2009) found a k_h of 0.45 d^{-1} by investigating the hydrolysis of cellulose by a mixed culture enriched from landfill waste in a continuous reactor at 38 °C. Wichern et al. (2009) modelled the mono fermentation of grass silage under mesophilic conditions with ADM1 and specified the disintegration constant k_{dis} to be 1.0 d^{-1} (manually calibrated) and 0.26 d^{-1} (genetic algorithm calibrated).

In general, both k_h and k_{dis} can be used for parameter estimation, because in every case the rate-limiting step is described.

Besides the benchmarking of the mono fermentation of grass silage, the paper shows the application of loop reactors, which are already used for treatment of sludge from waste water treatment plants, biological wastes and manure. For the study presented, the system has been adapted to its new goals. Producing biogas from energy crops is often connected to the main problem of unsatisfying mixing, which results in punctual peaks of substances, lack of biogas stripping and formation of scum layers (Buffiere et al., 1998; Chanakya et al., 1999; Koller, 2004). The traditional system of blowing in produced biogas for mixing is substituted by a motor driven screw, that enforces a downward flow within a narrow inner cylinder and hence a slower upward flow within the larger outer ring. Consequently, on the one hand an intensive mixing of all components in the inner cylinder is guaranteed. On the other hand, exceeding shear stress has a negative effect on the symbiotic community of acetogenic and methanogenic bacteria, wherefore a slow flow in the outer ring is very important. So far, experiences in mono fermentation of grass silage without manure addition and especially by means of loop reactors are rare, even through a boom of biogas plants using energy crops cannot be dismissed. In particular on account of absence of manure, which contains bacteria, micro elements and buffer capacity, inhibition or deficiency effects are expected.

The aim of this study was to evaluate the suitability of loop reactors for methane production from grass silage in comparison to other systems. Operation shows opportunities and drawbacks

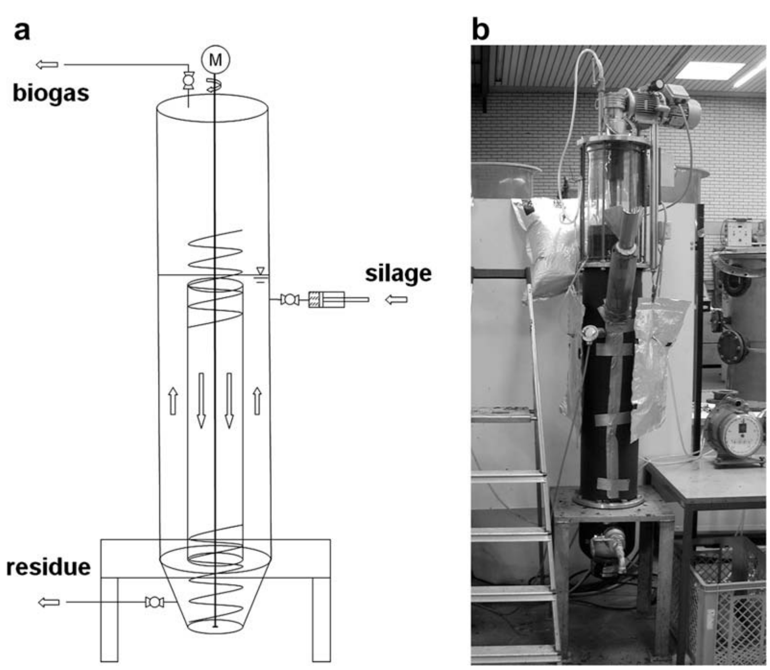

Fig. 1. Simplified drawing and photo of loop reactor.