Bioresource Technology 131 (2013) 6–12

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

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

Kinetics of psychrophilic anaerobic sequencing batch reactor treating flushed dairy manure

Jingwei Ma [a], Liang Yu [a], Craig Frear [a], Quanbao Zhao [a], Xiujin Li [b], Shulin Chen [a,*]

[a] Department of Biological Systems Engineering, Washington State University, Pullman, WA 99164, USA
[b] Center for Resources and Environmental Research, Beijing University of Chemical Technology, Beijing 100029, China

HIGHLIGHTS

- A new biomass retention strategy for solids containing influent was presented.
- Influent solids were used as natural biofilm support media for high rate digestion.
- The technology showed a good performance despite short HRT and low temperature.
- There is free of clogging hazard in biofilm support media caused by manure fiber.
- Four microbial growth kinetic models were compared for biofilm kinetics study.

ARTICLE INFO

Article history:
Received 2 October 2012
Received in revised form 29 November 2012
Accepted 30 November 2012
Available online 12 December 2012

Keywords:
Psychrophilic
Kinetics
ASBR
Anaerobic digestion
Dairy manure

ABSTRACT

In this study, a new strategy, improving biomass retention with fiber material present within the dairy manure as biofilm carriers, was evaluated for treating flushed dairy manure in a psychrophilic anaerobic sequencing batch reactor (ASBR). A kinetic study was carried out for process control and design by comparing four microbial growth kinetic models, i.e. first order, Grau, Monod and Chen and Hashimoto models. A volumetric methane production rate of 0.24 L/L/d of and a specific methane productivity of 0.19 L/gVS_{loaded} were achieved at 6 days HRT. It was proved that an ASBR using manure fiber as support media not only improved methane production but also reduced the necessary HRT and temperature to achieve a similar treating efficiency compared with current technologies. The kinetic model can be used for design and optimization of the process.

1. Introduction

Livestock farms in US produce a total of about two billion tons of manure each year (Gillespie and Flanders, 2010), which accounts for 8% of the total US anthropogenic bio-methane emissions (USEPA, 2010). Anaerobic digestion (AD) is an alternative to livestock waste management that offers economic and environmental benefits. Besides alleviating manure-associated greenhouse gas (GHG) emissions and farm-generated odors, AD of animal waste provides fertilizers rich in nutrient, and biogas as renewable energy.

Wider adoption of AD for animal manure management has been limited primarily by economics. This is especially true in some applications where the wastewater is relatively dilute such as in flushing dairies. Flushed manure handling systems are widely employed within large-scale dairy farms due to their reduced labor and mechanical failures (Powers et al., 1997). However, flushing systems produce a waste stream with total solids of 1–2%, negatively impacting conventional AD treatment processes due to the fact that diluted manure increases digester size and heating requirements. Anaerobic digestion at psychrophilic temperature can alleviate this concern, if corresponding reduction in biogas production rates due to the lower utilized temperature can be overcome through high microbial accumulation (Kashyap et al., 2003). By inference, assuming adequate psychrophilic operation, the main concerns with using an anaerobic digester for dilute manure treatment is the challenges in achieving higher solids retention time (SRT) required to retain microbial biomass and reducing required size. Typical designs such as continuous stirred-tank reactor (CSTR) or plug flow (PF) digesters cannot accomplish such decoupling of SRT and HRT (hydraulic retention time) (Zaher et al., 2008).

Many efforts have been made to increase microbial biomass retention with different digester configurations, such as fixed-bed and hybrid reactors (Borja et al., 1994; Demirer and Chen, 2005; Umana et al., 2008; Wilkie et al., 2004; Zaher et al., 2008), and have been successfully applied at low temperature

* Corresponding author. Tel.: +1 509 335 3743; fax: +1 509 335 2722.
E-mail address: chens@wsu.edu (S. Chen).

0960-8524/$ - see front matter © 2012 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.biortech.2012.11.147

Nomenclature

μ	specific microbial growth rate (/d)	K	dimensionless kinetic parameter of Chen and Hashimoto model
μ_m	maximum specific microbial growth rate (/d)	Y	growth yield coefficient
r_m	microbial growth rate (g/L/d)	c	contois coefficient
X_0	influent biomass concentration (g/L)	B	volume of methane produced under standard condition per gram of substrate loaded (L CH_4 STP/gVS$_{loaded}$)
X	effluent biomass concentration (g/L)	B_0	volume of methane produced under standard condition per gram of substrate loaded at infinite retention time (L CH_4 STP/gVS$_{loaded}$)
V	digester working volume (L)	M	volumetric methane production rate (L CH_4/L/d)
Q	flow rate (L/d)	P	specific methane productivity (L CH_4/gVS$_{loaded}$)
S_0	influent substrate concentration (g/L)	L	organic loading rate (gVS$_{loaded}$/L/d)
S	effluent substrate concentration (g/L)		
θ	hydraulic retention time (d)		
b	endogenous decay constant (/d)		
k	maximum specific substrate utilization rate (gVS/g/d)		
k'	first order rate constant (/d)		
K_s	half-saturation constant (gVS/L)		

(Siggins et al., 2011; Zhang et al., 2012). A variety of external artificial biofilm support media, such as spherical plastic trickling filter media, floating support media, automobile tires, and zeolite have been employed in anaerobic biofilm digesters to enhance biomass retention. The addition of artificial support media occupies substantial digester volume, which automatically lowers the digester efficiency. Moreover, the artificial biofilm support media are vulnerable to clogging caused by manure fiber, which impedes commercialization.

A concept of biofilm retention with influent solids was presented in the authors' previous studies (Frear et al., 2010; Wang et al., 2011). It was reported that anaerobic microorganisms have a strong affinity to manure fiber, which can serve as natural biomass support media in a high rate digester. Biomass retention using manure fiber as natural support media seems a promising approach for anaerobic treatment of flushed dairy manure. In virtue of no artificial biofilm support media, the concern regarding mechanical failure caused by media clogging is removed. Along with low maintenance, the required digester size and cost are reduced. Anaerobic sequencing batch reactors (ASBRs) are known to be capable of uncoupling HRT with SRT for biomass retention with a particular sequence of operation of ASBR exerting selection pressures to microbes for immobilization (Liu et al., 2005; Wang et al., 2011). Wang et al. (2011) showed that an ASBR digester, which retained high concentration of biomass in the form of fiber-attached biofilm by selection pressure, exhibited comparatively high methane yield and production rate. However, applications of this technology require technical information for process design and optimization.

Although simple, the ASBR operation involves complex processes whose design and optimization can be facilitated using mathematical models. Kinetic modeling, being a useful tool in process analysis, design, and system control can be established by precise determination of kinetic coefficients. Process kinetics also details the effects of operational factors and reaction environment on the substrate utilization rates. A variety of kinetic models have been developed to describe microbial growth kinetics. A first order model is the simplest model for microbial growth with the assumption of first-order degradation, which has been used often to describe hydrolysis limited digestion with respect to particulate substrate (Gavala et al., 2003). Monod model is the most widely used kinetic model which was developed as a result of empirical analysis (Monod, 1949). Grau et al. (1975) and Chen and Hashimoto (1978) improved the Monod model by predicting that effluent substrate concentration is proportional to influent substrate concentration. However, it was assumed that microbial growth kinetics in anaerobic biofilm reactors followed Monod or first-order models in most literature (Batstone et al., 2002; Buffière et al., 1998; Huang and Jih, 1997; Rittmann and McCarty, 2001). The lack of appropriate models in the literature though shows that improvements can still be made. For example, it has been hypothesized that the Chen and Hashimoto model is capable of characterizing biofilm growth kinetics with an improved performance, compared to the Monod model, due to its dependence on influent substrate concentration.

The main objective of this study was to evaluate the performance and kinetics of the new biomass retention strategy during psychrophilic ASBR digestion of flushed dairy manure. A kinetic model with aim to find a more appropriate biofilm growth model was derived and assessed for substrate utilization and methane production. Both HRT and OLR (organic loading rate) are considered as the most important parameters for digester operation. Hence, the effects of HRT and OLR on methane production were the primary output of the kinetic model.

2. Methods

The aforementioned biomass retention technology for treating flushed dairy manure at psychrophilic temperature were evaluated in five lab scale digesters operated in sequencing batch mode. Kinetic properties of psychrophilic ASBR digesters were then analyzed and a kinetic model was derived for system optimization.

2.1. Feedstock and seed

Fresh dairy manure was collected from the Washington State University Dairy Center in Pullman, WA, USA and stored at 4 °C prior to use. Before addition to digesters, manure was diluted with tap water to mimic flushed dairy manure, which resulted in mixed liquor containing 9.1 g/L total solids (TS) and 7.6 g/L total volatile solids (VS). Anaerobic sludge containing a microbial community of hydrolyzing, acid producing, acetate producing and methane producing microbes was sampled from an anaerobic digester in the Pullman Wastewater Treatment Facility with TS of 17.1 g/L and VS of 11.7 g/L.

2.2. Experimental setup and operation

Five digesters (64 cm in height and 10 cm in diameter), each with working volume of 6 L, were operated as ASBR at respective cycle times of 2, 4, 6, 8 and 10 days while the other operation conditions remained constant (50% exchange ratio, 5 min settling time