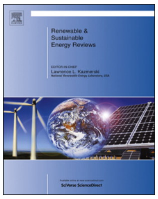
Renewable and Sustainable Energy Reviews 44 (2015) 824–834

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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



Challenges and strategies for solid-state anaerobic digestion of lignocellulosic biomass

Liangcheng Yang, Fuqing Xu, Xumeng Ge, Yebo Li*

Department of Food, Agricultural and Biological Engineering, The Ohio State University/Ohio Agricultural Research and Development Center,
1680 Madison Avenue, Wooster, OH 44691, USA

A R T I C L E I N F O

Article history:
Received 16 June 2014
Received in revised form
5 November 2014
Accepted 3 January 2015

Keywords:
Solid-state anaerobic digestion
Lignocellulosic biomass
Biogas yield
Inhibition
Transportation fuel

A B S T R A C T

Solid-state anaerobic digestion (SS-AD) has gained increasing attention in recent years, especially for digesting lignocellulosic biomass. Compared to liquid anaerobic digestion (L-AD), SS-AD handles feedstocks with higher total solids content, and therefore, performs more effectively at higher organic loading rates and has higher volumetric biogas productivity. Challenges facing SS-AD of lignocellulosic biomass are primarily related to its relatively low methane yield, potential instability, and low value end-products. These challenges are either due to the inherent limits of SS-AD (e.g. retarded mass transfer caused by high solid content) or can be attributed to the nature of lignocellulosic biomass (e.g. components recalcitrant to biodegradation). To address these challenges, a variety of methods, including pretreatment of feedstock, improvement of inoculation efficiency, co-digestion of multiple feedstocks, and upgrading biogas to higher-value transportation fuels, have been examined to enhance the performance of SS-AD and increase the value of the end products. This review summarizes these challenges in SS-AD of lignocellulosic biomass and discusses the mechanisms and feasibility of potential strategies for resolving them.

Contents

---

* Corresponding author. Tel.: +1 330 263 3855.
E-mail address: li.851@osu.edu (Y. Li).

http://dx.doi.org/10.1016/j.rser.2015.01.002
1364-0321/

1. Introduction

Recent studies about solid-state anaerobic digestion (SS-AD) have helped promote the development and application of this technology. It was reported that more than 60% of recently built anaerobic digesters in Europe adopted this technology [1]. Compared to liquid anaerobic digestion (L-AD), which is usually operated with less than 15% total solids (TS) content, SS-AD can handle high solid feedstocks and operate with higher than 15% TS. Consequently, SS-AD has a higher organic loading rate, smaller reactor volume, lower energy demand for heating, higher volumetric methane productivity, and less wastewater generation. A previous study also showed that biogas yield from SS-AD was comparable to that produced from L-AD for some lignocellulosic feedstocks such as switchgrass and corn stover [2]. Besides, the digestate of SS-AD has a lower moisture content than that in L-AD effluent, thus it is favorable for transportation and land applications. The principles and applications of SS-AD have been reviewed previously [3].

Lignocellulosic biomass, or plant biomass, is an abundantly available raw material from agricultural, forestry, and municipal sources [4]. It is mainly composed of cellulose, hemicellulose, and lignin, among which cellulose and hemicellulose are the principal biodegradable components, while lignin is recalcitrant [5]. Given its abundance and renewability, as well as the fact that it does not compete with food or feed production for land, there is wide interest in using lignocellulosic biomass as an AD feedstock. To-date, a variety of lignocellulosic biomass has been examined for biogas production, including miscanthus, switchgrass, corn stover, leaves, albizia and others [2,6–9]. Most previous studies employed L-AD to digest lignocellulosic biomass, but the nature of the high solid content of lignocellulosic biomass has spurred researchers to consider SS-AD, and some studies of it have been carried out in recent years. For instance, Xu et al. used SS-AD to digest corn stover that contained 22% TS, and achieved a maximum methane yield of 199.6 L/kg-volatile solid (VS) [10].

Current SS-AD practices using lignocellulosic biomass as feedstock have met with a few challenges, including relatively low methane yield, potential instability, and low end-product values [11,12]. Low methane yield can be caused by the recalcitrance of lignocellulosic biomass or retarded mass transfer in SS-AD, while the imbalance of nutrients and accumulation of digestion intermediates, such as ammonia and volatile fatty acids (VFAs), may lead to system instability. The two major end products from SS-AD, biogas and digestate, have value but need additional treatment prior to usage. These obstacles have caused decision makers in the U.S., to some extent, to be hesitant about developing large-scale SS-AD systems. As of 2010, there was no commercial scale SS-AD facility operating in the U.S., but a few pilot-scale systems were installed in California [3,13].

To resolve these challenges, efforts have been made by academic and industrial stakeholders to enhance biogas production and to improve the value of end-products. Commonly used approaches include pretreatment of feedstocks [4], co-digestion of different feedstocks [10], improvement of inoculation efficiency [14], and operation at thermophilic temperature (50–60 °C) instead of mesophilic temperature (35–40 °C) [11]. These approaches can be used alone or in combination. In addition, end products can be upgraded to transportation fuels and fertilizers to improve the economic feasibility of SS-AD of lignocellulosic biomass [15].

This review summarizes the major challenges in SS-AD of lignocellulosic biomass and discusses possible strategies for resolving them, with an emphasis on mechanism and feasibility; therefore, it provides useful guides for current and future SS-AD practices for enhanced biogas yield and value-added end products. Besides, future research on SS-AD inhibition management and system scale-up are envisaged, which would be beneficial for the development of large scale SS-AD systems.

2. Challenges in SS-AD of lignocellulosic biomass

2.1. Relatively low methane yield

2.1.1. Nature of lignocellulosic biomass

As an abundant organic material, lignocellulosic biomass has a good potential for biogas production. However, methane yields of lignocellulosic biomass in SS-AD are relatively low due to the recalcitrance of the plant cell wall to digestion. The average reported methane yield of woody biomass by SS-AD is about 50 L/kg, which is only 10% of its theoretical methane yield [16]. Plant cell walls are mainly composed of cellulose (9–80%), hemicellulose (10–50%), and lignin (5–35%) (Fig. 1) [17]. Cellulose is a polysaccharide of glucose. At the molecular level, glucose is linearly polymerized by β-1,4-glycosidic bonds creating cellulose chains, which are further connected by hydrogen bonds and van der Vaals force to form microfibrils. Amorphous cellulose is readily digestible, while crystalline cellulose is resistant to hydrolysis. Hemicelluloses are usually amorphous and randomly branched heterogenetic polysaccharides of various mono-sugars (xylose, arabinose, galactose, mannose, and rhamnose) and uronic acids

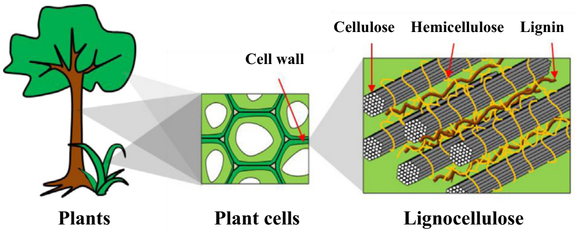


Fig. 1. Structure of lignocellulosic biomass in plant cell walls.