Energy Conversion and Management 151 (2017) 53–62

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Efficient continuous biogas production using lignocellulosic hydrolysates as substrate: A semi-pilot scale long-term study

Chao Huang[a,b,c], Hai-Jun Guo[a,b,c], Can Wang[a,b,c], Lian Xiong[a,b,c], Mu-Tan Luo[b,d], Xue-Fang Chen[a,b,c], Hai-Rong Zhang[a,b,c], Hai-Long Li[a,b,c], Xin-De Chen[a,b,c,*]

[a] *CAS Key Laboratory of Renewable Energy, Guangzhou 510640, PR China*
[b] *Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences, Guangzhou 510640, PR China*
[c] *Guangdong Provincial Key Laboratory of New and Renewable Energy Research and Development, Guangzhou 510640, PR China*
[d] *University of Chinese Academy of Sciences, Beijing 100049, PR China*

A R T I C L E I N F O

Keywords:
Biogas production
Semi-pilot scale
Long-term performance
Continuous fermentation
Lignocellulosic hydrolysates
Industrial application

A B S T R A C T

Traditional solid-state biogas production from lignocellulosic biomass has some issues such as relatively low methane yield, instability of fermentation system, etc., and these might be solved by changing solid-state mode to completely liquid-state mode using lignocellulosic hydrolysates as substrate for biogas production. However, the potential and possibility of this new technology for industrial application is still unclear. In this study, semi-pilot scale long-term biogas production using various lignocellulosic hydrolysates (acid hydrolysates of bagasse, rice straw, and corncob) as substrate was carried out in a 100 L up-flow anaerobic bioreactor (internal circulation reactor, IC) for 76 days. During operation, biogas was generated almost immediately when the substrate was pumped into bioreactor and the start-up can be finished in short period. Throughout the fermentation process, most COD (> 85%) of lignocellulosic hydrolysates was utilized for biogas production. High biogas yield (0.549 ± 0.058 $m^3/kg_{\text{COD consumption}}$), methane yield (0.381 ± 0.043 $m^3/kg_{\text{COD consumption}}$) and CH_4 content in biogas (69.6 ± 5.6%) can be obtained respectively when the fermentation system was stable. Variations of inlet pH value and types of lignocellulosic hydrolysate showed little influence on the operation performance of this fermentation system. Overall, the fermentation scale, operation period, COD removal, biogas yield, CH_4 content in biogas, and operation performance with various inlet pH value and different kinds of substrate shows that this technology has great potential and possibility of industrialization.

1. Introduction

Biogas (methane), usually generated by anaerobic digestion, is considered as one important product to satisfy global energy need (applied for heating, stationary engine, vehicle fuel, natural gas grid, etc.) and offer various environmental benefits such as reducing greenhouse gas emission, organic waste disposal, and biogas linked agro-system [1,2]. Various low-cost raw materials such as sewage sludge [3,4], food wastes [5], municipal wastes [6], animal manure [7], waste animal carcasses [8], etc. can be substrate for biogas production. Compared with these raw materials, lignocellulosic biomass such as rice straw, corncob, bagasse, etc. seems a promising sustainable alternative for biogas production due to its various advantages such as low-cost, great availability in nature, and renewable characters [9,10]. Nowadays, solid-state anaerobic digestion is usually applied for biogas production from lignocellulosic biomass due to the high solid content of lignocellulosic biomass [11]. However, some critical issues exist for this technology such as relatively low methane yield and instability of fermentation system caused by inefficient mass transfer (because of high solid content) and poor biodegradability of some compounds present in lignocellulosic biomass, and therefore industrialization of solid-state anaerobic digestion for biogas production from lignocellulosic biomass is retarded [12]. Many methods such as pretreatment of lignocellulosic biomass [13–15] and co-digestion of lignocellulosic biomass and some additives such as manure [16–18] have been applied for improving the performance of biogas production from lignocellulosic biomass. However, these methods still do not change the substrate inlet mode (solid-state) of biogas production from lignocellulosic biomass, and the processes (hydrolysis, acidogenesis, acetogenesis, methanogenesis) for degradation of lignocellulosic biomass and generation of biogas are fulfilled by various microorganisms in anaerobic sludge simultaneously [10], therefore the issues of solid-state anaerobic digestion of lignocellulosic biomass cannot be solved completely.

Undoubtedly, if lignocellulosic biomass can be converted into water

* Corresponding author at: No.2 Nengyuan Road, Tianhe District, Guangzhou 510640, PR China.
E-mail address: cxd_cxd@hotmail.com (X.-D. Chen).

http://dx.doi.org/10.1016/j.enconman.2017.08.074
Received 30 May 2017; Received in revised form 3 August 2017; Accepted 27 August 2017

soluble fermentable components, the "liquid lignocellulosic components" can be much easier for utilization by anaerobic sludge and this completed liquid-state fermentation mode can increase the efficiency of biogas production greatly. Today, the hydrolysis technology especially acid hydrolysis of lignocellulosic biomass is mature for industrial application [19–22]. Different from pretreatment (usually one necessary step before hydrolysis) of lignocellulosic biomass which means the procedure to make biomass easier for degradation [23], hydrolysis of lignocellulosic biomass is the technology which can turn solid biomass into liquid components. Lignocellulosic hydrolysates (liquid product generated after hydrolysis of lignocellulosic biomass which contains fermentable components with certain COD) have been applied as substrate for production of many chemicals such as ethanol, butanol, and single cell oils [24–26]. Recently, it is proven that lignocellulosic hydrolysate (rice straw acid hydrolysate) can also be used as substrate for biogas production in batch fermentation with laboratory scale (1 L) short-term (5 days) experiments [27]. However, for industrial biogas production, continuous fermentation mode is applied mostly because it can guarantee sustainable supply of biogas and this mode is easy for automatic control. In addition, laboratory scale experiment cannot reflect the performance of mass transfer and biogas production in large scale. Moreover, industrial biogas production is usually long-term process with various complex fermentation environment and operation issues, and therefore short-term experiment is not enough for the evaluation on operation performance of this technology. Base on above reasons, the potential and possibility of industrial application of biogas production using lignocellulosic hydrolysates as substrate are still unclear.

For industrialization of biogas production using lignocellulosic hydrolysates as substrate, at least following three points should be considered carefully: 1. The start-up should be simple and efficient that biogas can be generated quickly and stably after operation; 2. The biogas yield and CH_4 content in biogas should be stable and suitable for industrial production; 3. The fermentation system should have excellent operation performance for different inlet environment (e.g. various pH value or different types of substrate). However, little research focuses on these important points to date. To evaluate the potential and possibility of industrialization for biogas production using lignocellulosic hydrolysates as substrate, semi-pilot scale long-term biogas production from various lignocellulosic hydrolysates (acid hydrolysates of bagasse, rice straw, and corncob) was carried out in a 100 L up-flow anaerobic bioreactor (internal circulation reactor, IC) for 76 days for the first time in this study (Scheme 1). For this bioprocess, the performance of start-up process, biogas yield and CH_4 content in biogas, fermentation system operation performance for various inlet pH value and types of substrate were systematically measured. This study can offer important information for industrial application of biogas production using lignocellulosic hydrolysates as substrate especially from the viewpoint of "application" and "operation".

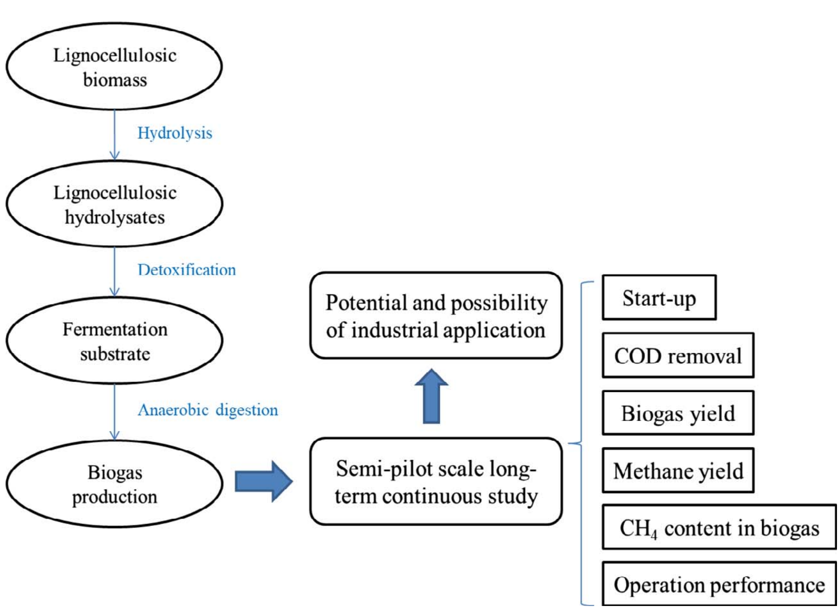
2. Experimental

2.1. Feedstock for fermentation

Granular anaerobic sludge was obtained from local chemical plant. Before anaerobic fermentation in this study, the granular anaerobic sludge has been in dormant state for about half a year. The volume of inoculated sludge was approximately 50% of the reactor operation volume (reaction part). Lignocellulosic hydrolysates (acid hydrolysates of bagasse, rice straw, and corncob) offered by ZHONGKE New Energy Technological Development Co., Ltd (Huai-An, China) were used as substrate for anaerobic fermentation. According to ZHONGKE New Energy Technological Development Co., Ltd, the hydrolysis of lignocellulosic biomass was carried out in a 50 L reactor containing diluted sulphuric acid (2% w/v) with 10% (w/v) solid/liquid ratio at 170 °C for 1 h, and then the lignocellulosic hydrolysates and solid residues after hydrolysis were separated by filtration or centrifugation. During later anaerobic fermentation process, no separation of liquid and solid was need. The lignocellulosic hydrolysates were detoxified by adding lime to adjust its pH value to around 6.0 and maintain at room temperature for 1 h. After that, the hydrolysates were recovered by vacuum filtration. The initial COD value of bagasse, rice straw, and corncob acid hydrolysates after treatment by lime were 73931 mg/L, 48359 mg/L, and 59127 mg/L, respectively. Before fermentation, the pH of detoxified lignocellulosic hydrolysates was further adjusted to around 9.0 by Na_2CO_3 in order to prevent possible acidification of fermentation system during operation and the hydrolysates were recovered by vacuum filtration again. Then, the hydrolysates were diluted to certain COD value by tap water. In addition, urea and KH_2PO_4 were added into the diluted lignocellulosic hydrolysates to adjust the COD: N: P (w/w) to 200: 5: 1 and finally the hydrolysates were used as the fermentation substrate.

2.2. Biogas production by anaerobic fermentation

Anaerobic fermentation was carried out in a 100 L up-flow



Scheme 1. Flow chart of biogas production using lignocellulosic hydrolysates as substrate.