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Coproduction of hydrogen and methane via anaerobic fermentation of cornstalk waste in continuous stirred tank reactor integrated with up-flow anaerobic sludge bed

Xi-Yu Cheng, Qian Li, Chun-Zhao Liu *

National Key Laboratory of Biochemical Engineering, Institute of Process Engineering, Chinese Academy of Sciences, Beijing 100190, PR China

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A B S T R A C T

A 10 L continuous stirred tank reactor (CSTR) system was developed for a two-stage hydrogen fermentation process with an integrated alkaline treatment. The maximum hydrogen production rate reached 218.5 mL/L h at a cornstalk concentration of 30 g/L, and the total hydrogen yield and volumetric hydrogen production rate reached 58.0 mL/g-cornstalk and 0.55–0.57 L/L d, respectively. A 10 L up-flow anaerobic sludge bed (UASB) was used for continuous methane fermentation of the effluents obtained from the two-stage hydrogen fermentation. At the optimal organic loading rate of 15.0 g-COD/L d, the COD removal efficiency and volumetric biogas production rate reached 83.3% and 4.6 L/L d, respectively. Total methane yield reached 200.9 mL/g-cornstalk in anaerobic fermentation with the effluents and alkaline hydrolysate. As a result, the total energy recovery by coproduction of hydrogen and methane with anaerobic fermentation of cornstalk reached 67.1%.

1. Introduction

With rising energy demands and increasing environmental pollution, interest in renewable hydrogen and methane production from organic wastes has grown (Cheng and Liu, 2010; Demirel et al., 2010; Park et al., 2010). Recently, bio-hydrogen production from various organic wastes has been the focus of research due to its advantages such as a high gravimetric energy density, a high efficiency of conversion to usable power, and the fact that it is environmentally-friendly (Das and Veziroglu, 2008). Lignocellulosic waste is an ideal resource for renewable hydrogen production due to its high annual production; however, it is quite difficult to produce hydrogen from lignocellulosic waste due to its recalcitrant structure (Levin et al., 2009; Lu et al., 2009).

Acid, alkaline, and steam explosion pretreatments are efficient ways to breakdown the structure of lignocellulosic biomass and enhance hydrogen production (Datar et al., 2007; Fan et al., 2008). The addition of external cellulase or cellulose-degrading microorganisms such as *Clostridium thermocellum* can augment the hydrolysis of lignocellulose (Li and Chen, 2007; Lo et al., 2008; Lu et al., 2009; Wang et al., 2010). Hydrogen can be produced by direct microbial conversion with *C. thermocellum* using natural lignocellulosic biomass as the substrate, but the overall conversion efficiency is significantly decreased due to the physical barrier created by lignin (Cheng and Liu, 2011; Liu et al., 2008; Magnusson et al., 2008). An alkaline pretreatment, which has advantages over steam explosion and acid treatments because steam explosion requires high temperatures and pressure and acid treatments require the use of acid-resistant vessels, has been regarded as an efficient method for the complete delignification and destruction of the lignocellulose microstructure (Rani et al., 1998). However, in the alkaline pretreatment process, a significant portion of the carbohydrate fraction is degraded to saccharinic acids, which are often toxic to microorganisms and may diminish substrate utilization ratios (Avgerinos and Wang, 1983).

In a two-stage system for the coproduction of hydrogen and methane, the production of hydrogen and methane from diluted molasses reached 27 L-H_2/L-molasses/d and 342 L-CH_4/L-molasses/d respectively, corresponding to energy recovery value of 0.3 and 12.9 MJ/L-molasses for the first hydrogen and second methane fermentation stage, respectively (Park et al., 2010). It is clear that the energy recovery ratio of single anaerobic hydrogen fermentation was quite low, and coproduction of hydrogen and methane from two-stage dark fermentation produced a remarkable increase in energy recovery (Park et al., 2010). The objective of the current study was to develop a two-stage thermophilic fermentation system of cornstalk by *C. thermocellum* integrated with alkaline treatment for improving hydrogen production in a continuous stirred tank reactor. The effluents of the two-stage hydrogen fermentation were used for continuous methane production in an up-flow anaerobic sludge bed (UASB), and the total energy recovery

* Corresponding author. Tel./fax: +86 10 82622280.
E-mail address: czliu@home.ipe.ac.cn (C.-Z. Liu).

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