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Biohythane production from sugarcane bagasse and water hyacinth: A way towards promising green energy production

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ABSTRACT

The present study embarks the concept of developing continuous biohythane (biohydrogen followed by biomethane) production from renewable energy sources. Combination of sugarcane bagasse and water hyacinth were used to reduce the use of costly chemicals for fermentation process. The lignin content of sugarcane bagasse was reduced using alkaline hydrogen peroxide pretreatment. The maximum lignin reduction of 89 ± 3% (w/w) was observed at 50 °C and 150 min pretreatment time. Scanning electron microscopy, X-ray diffraction and Fourier transform infrared spectroscopy analysis were performed to confirm the lignin removal after pretreatment. Further, the influence of the hydraulic retention time on two stage biohythane production was studied by using combination of pretreated sugarcane bagasse and water hyacinth (1:2 ratio) (soluble COD, 30 ± 2 g/L) in continuous stirrer tank bioreactor. The suitable hydraulic retention time for biohydrogen and biomethane production were found to be 8 h and 10 d, respectively, which gave the maximum hydrogen and methane yield of 303 mL/g COD and 142 mL/g COD, respectively. The continuous biohythane production process increased the overall substrate conversion efficiency up to 86% with the maximum gaseous energy recovery of 8.97 kJ/g COD.

1. Introduction

In the conventional anaerobic digestion (AD) process, the decomposition of organic materials takes place by a series of bacteria in the oxygen free environment to produce biogas. During AD process various kinds of extracellular hydrolytic enzymes (cellulases, hemicellulases, lipases, proteases, amylases etc.) are produced which have ability to hydrolyse the complex substrates into their simpler form. The hydrolysed materials are subsequently utilized by the acidogenic bacteria to produce hydrogen (H_2) and carbon dioxide (CO_2) along with volatile fatty acids (VFAs). Further, the CO_2 and H_2 dissolved in the medium are used as energy source by hydrogenotrophic methanogens to produce methane (CH_4), whereas acetoclastic methanogens convert acetic acid (CH_3COOH) to CH_4 and CO_2 (Eqs. (1) and (2)) (Fig. 1) (Sikora et al., 2017). Since, the hydrogenotrophic methanogens are H_2 scavengers the overall yield of H_2 decreased in the AD process. Hence, the AD process can be oriented towards dark fermentation where H_2 and CO_2 are produced instead of CH_4 by inhibiting the methanogens and enriching the acidogenic bacteria (Nath and Das, 2004). Further, the spent medium of dark fermentation which contains VFAs (mainly acetic acids, butyric acids and propionic acid), ethanol and other compounds can be used for methane production using methanogenic bacteria (Pakarinen et al., 2009). The two stage process (dark fermentation followed by biomethanation) has several advantages over single stage biomethanation process (Kumari and Das, 2015).

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O \qquad (\Delta G^o = -131\ \text{kJ/mol}) \tag{1}$$

$$\text{CH3COOH} + \text{H2O} \rightarrow \text{CH4} + \text{CO2} + \text{H2O} \quad (\Delta G^o = -36\ \text{kJ/mol}) \tag{2}$$

H_2 energy seems to be attractive because of its high energy density (142 kJ/g) as compared to other fuels (Wang et al., 2016). It is easy to transport and produce no greenhouse gases after combustion (Ntaikou et al., 2010). After H_2, CH_4 is the 2nd highest energy content (55.5 kJ/g) gas (Pakarinen et al., 2009). Mixture of H_2 (5–20%) and CH_4 (80–95%) is called “Hythane®” and the production of hythane through biological process can be collectively called under the eponym of “Biohythane” (Liu et al., 2013). Under “Biohythane concept” the 2nd stage biomethane could be used separately as a fuel or could be mixed with biohydrogen in a certain ratio to make it suitable for IC (Internal combustion) engines. Also, the burning of hythane is cleaner than methane alone (Ueno et al., 2007).

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Notation list

AD	Anaerobic digestion
AHP	Alkaline hydrogen peroxide
APHA	American public health association
CH_4	Methane
CH_3COOH	Acetic acid
C/N	carbon to nitrogen ratio
CO_2	Carbon dioxide
COD	Chemical oxygen demand
CrI	Crystallinity index
D	Dilution rate
DBT	Department of Biotechnology
F	Flow rate
FTIR	Fourier transform infrared
GC	Gas chromatography
H_2	Hydrogen
HCl	Hydrogen chloride
H_2O_2	Hydrogen peroxide
HPR	Hydrogen production rate
HRT	Hydraulic retention time
IIT	Indian Institute of Technology
MMT/Y	Metric million ton/year
MNRE	Ministry of new and renewable energy
MPR	Methane production rate
NaOH	Sodium hydroxide
NREL	National renewable energy laboratory
OLR	Organic loading rate
P	Hydrogen production potential
PSCB	pretreated sugarcane bagasse
R_m	Rate of H_2 production
R^2	Correlation coefficient
S	Substrate concentration
S_o	Initial substrate concentration
SCB	Sugarcane bagasse
SCOD	Soluble chemical oxygen demand
SEM	Scanning electron microscopy
TS	Total solids
V	Volume of reactor
VFAs	Volatile fatty acids
VS	Volatile solids
WH	Water hyacinth
XRD	X-ray Diffractometer
YE	Yeast extract
X	Biomass concentration
λ	Lag phase

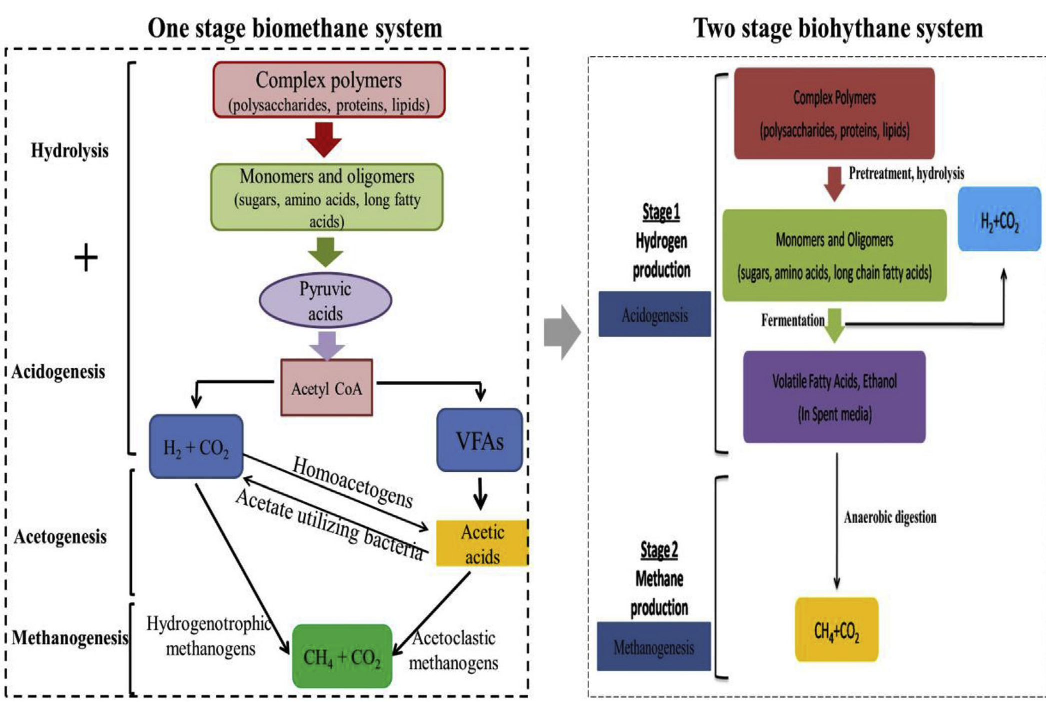

Fig. 1. Schematic diagram of one stage biomethane and two stage biohythane process.

Continuous biohythane production has to be explored for the commercialization of gaseous energy. It has several advantages over batch process which includes, high productivity, no down time, can operate under steady state condition, can hold a particular phase of fermentation process for a longer period of time etc. (Chen et al., 2012a). Moreover, there are several factors affecting the continuous process viz. pH (Alexandropoulou et al., 2018), temperature (Alibardi and Cossu, 2016), reactor configuration (DiStefano and Palomar, 2010), organic loading rate (OLR), hydraulic retention time (HRT) etc. (An Carrillo-Reyes et al., 2016) HRT is the most important parameter to determine the activity of acidogenic and methanogenic bacteria inside the bioreactor. It may affect the metabolic route of microorganism and also influence the composition of subdominant microorganism (Dareioti and Kornaros, 2014). Moreover, the composition of soluble metabolites and product yield (H_2 and CH_4) may be controlled by