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Semi-continuous solid substrate anaerobic reactors for H_2 production from organic waste: Mesophilic versus thermophilic regime

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Abstract

We evaluated the influence of the operation temperature (mesophilic vs. thermophilic regime) of semicontinuous, acidogenic solid substrate anaerobic digestion (A-SSAD) of the organic fraction of municipal solid waste (OFMSW) at lab scale. The H_2 percentage was higher in the thermophilic regime than in the mesophilic operation (58% and 42%, respectively). The H_2 yield of thermophilic A-SSAD was significantly higher than in our mesophilic reactors (360 vs. 165 NmL H_2/g VS_{rem}) and other studies reported in the literature (range of 62–180 mL/g VS). Mesophilic A-SSAD showed a yield of 37% of the maximum yield based on 4 mol H_2/mol hexose, while thermophilic A-SSAD exhibited a yield of 80% of the maximum yield. This result is similar to works with pure cultures of extremophile microorganisms where H_2 yields of 83% of the maximum were reported. We found higher concentrations of acetic acid in the digestates of thermophilic A-SSAD, while butyrate was in higher proportion in mesophilic A-SSAD spent solids. The moderate-to-high yields obtained with the semicontinuous process used in this work are in disagreement with previous reports claiming that batch and semicontinuous processes are less efficient than continuous ones.

Keywords: Acidogenic fermentation; Biological hydrogen production; Organic wastes; Semi-continuous; Temperature

1. Introduction

During the past 10 years there has been a renewed interest in new technologies that could supply energy in an environmentally friendly, sustainable way [1]. From an environmental viewpoint, there is an urgent need for appropriate management of municipal solid wastes (MSW). Nearly 1600 million tonne/year of MSW are generated worldwide with up to 43% contributed by Asia and Oceania and 28% contributed by North America and the European Union [2]. On average, almost 50% of the MSW of underdeveloped countries consists of a fermentable, biodegradable fraction.

The anaerobic digestion of the organic fraction of municipal solid waste (OFMSW) for generation of methane and a soil amender has received increased interest in the last 15 years [3–9]. Yet, even the use of methane as a fuel could be debatable, due to the production of CO_2 known to

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Nomenclature

A-SSAD	Semi-continuous solid substrate acidogenic fermentation
COD	carbon organic demand
HAF	hydrogenogenic anaerobic fermentation
HRT	Hydraulic retention time
HSP	Heat-shock pretreatment
M-SSAD	Methanogenic solid substrate anaerobic digestion
NmL	Biogas volume in milliliters at 0 °C and 1 atm
OFMSW	Organic fraction of municipal solid waste
TS	Total solids
VS	Volatile solids

Sub indices

rem	removed
wmr	wet mass reactor

Greek characters

α	ratio between intermediate alkalinity-to-partial alkalinity

contribute to the greenhouse effect [10]. Hydrogen is a clean fuel since its combustion with oxygen does not generate polluting emissions. According to energy experts, hydrogen is safe, versatile and has a high energy content, high utilization efficiency and is the best option for transport applications [11–13]. Hydrogen can be produced chemically, electrochemically, as a by-product of oil/coal processing or by the use of microorganisms. There are two main approaches to microbial H_2 production, namely, photochemical and fermentation. The first uses photosynthetic microorganisms such as algae and photosynthetic bacteria [14,15]. The second approach is carried out by fermentative H_2-producing microorganisms, such as facultative anaerobes and obligate anaerobes [16,17].

Some advantages of H_2 production by anaerobic fermentation (HAF) are that many fermentative bacteria are capable of high hydrogen generation rate and H_2 is produced throughout the day and night at a constant rate since it does not depend on energy provided by sunlight. HAF production has been investigated using pure cultures in sterile conditions and undefined mixed cultures in nonsterile conditions [18]. Moreover, some authors have shown that this valuable fuel can be produced from OFMSW and industrial wastes [19–23].

Some advantages of using mixed cultures over pure cultures in HAF are lower operational costs (savings in asepsis), operational control based on differential kinetics of microbial subgroups is possible, and septic organic wastes can be used as substrate. Yet, some limitations regarding process development still remain to be solved, such as suppression of hydrogen-consuming microbial subgroups, long-term process feasibility of continuous and semicontinuous processes has not been fully demonstrated, there is limited knowledge of community profile-biochemical performance, acclimation is often required to minimize lag times, etc. [1].

Most HAF-related processes rely on the disruption of the hydrogen uptake of methanogenic archaea since the latter are recognized to be the most significant hydrogen-consumer microbial group in anaerobic consortia [24,25]. Several approaches have been attempted and reported for achieving this goal, e.g., the use of chemical inhibitors such as acetylene and bromoethane sulfonic acid [19,23]; heat shock pretreatment (HSP) of inocula [20–22,26,27]; and keeping the pH of the cultures in the acidogenic range (5.8–6.5) [28,29]. HSP relies on the killing or thermal suppression of methanogenic archaea and nonsporulating eubacteria whereas the culture is enriched in sporulating, hydrogen-producing bacteria such as Clostridia.

At lab scale, HSP usually consists of heating the inocula in a boiling water bath for periods from 15 min to 2 h [1]. HSP has been shown to be effective for batch processes, although its feasibility for semicontinuous or continuous processes seems to be questionable [30,31]. On the other hand, the acidogenic operation of continuous anaerobic reactors has been demonstrated at pilot-plant and commercial levels [32,33], although the purpose of this early research was not directed to hydrogen production but to sludge and waste treatment. In this approach, methanogenic archaea are inhibited by the low pH prevalent in the reactor [34–36]. Low pH is the consequence of the overloading of the reactor that leads to an overproduction of organic acids and other metabolites from the incoming substrate. Thus, we can refer to this as “kinetic” control of the pH although some care has to be exercised in order to keep the pH in a range favorable for hydrogen accumulation [28,29,37].

Ueno et al. [38] evaluated the effect of hydraulic retention time (HRT) on the production of hydrogen from sugar-industry wastewater by anaerobic microflora in chemostat culture. Anaerobic microflora was cultured at 60 °C during 212 days of operation; pH of the cultures was kept at about 6.8. A maximum hydrogen yield of 14 mmol H_2/g carbohydrate removed (2.6 mol H_2/mol hexose) was obtained at an HRT $= 0.5$ day. Lay [39] found a hydrogen production of 1600 L/m^3 day at an HRT 17 h and pH 5.2 in his studies of hydrogen production from soluble starch in a complete mixed reactor. The reactor was started with an HSP anaerobic-digested sludge and incubated at 37 °C for 60