Bioresource Technology 248 (2018) 79–87

Contents lists available at ScienceDirect

Bioresource Technology

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

Review

Biohydrogen production from food waste: Current status, limitations, and future perspectives

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HIGHLIGHTS

- Critical reviews on dark fermentation of food waste (FW).
- Current status of dark fermentation with strategies applied for enhancement.
- Technical and economical limitation of dark fermentation performance of FW.
- Strategies to increase H_2 yield and gain more energy.
- Integrated system converting fermentation effluent to various fuels and chemicals.

ARTICLE INFO

Article history:
Received 30 April 2017
Received in revised form 19 June 2017
Accepted 20 June 2017
Available online 23 June 2017

Keywords:
Food waste
Dark fermentation
Hydrogen
Economic assessment
Integrated system

ABSTRACT

Among the various biological routes for H_2 production, dark fermentation is considered the most practically applicable owing to its capability to degrade organic wastes and high H_2 production rate. Food waste (FW) has high carbohydrate content and easily hydrolysable in nature, exhibiting higher H_2 production potential than that of other organic wastes. In this review article, first, the current status of H_2 production from FW by dark fermentation and the strategies applied for enhanced performance are briefly summarized. Then, the technical and economic limitations of dark fermentation of FW are thoroughly discussed. Economic assessment revealed that the economic feasibility of H_2 production from FW by dark fermentation is questionable. Current efforts to further increase H_2 yield and waste removal efficiency are also introduced. Finally, future perspectives along with possible routes converting dark fermentation effluent to valuable fuels and chemicals are discussed.

Contents

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http://dx.doi.org/10.1016/j.biortech.2017.06.107
0960-8524/

1. Introduction

Food waste (FW) is one of the most abundant and problematic organic solid wastes, accounting for 15–63% of total municipal solid wastes worldwide (Asian Institute of Technology, 2010; Jang et al., 2015). Unless properly managed, it releases odor and leachate during collection and transportation due to its high volatile solids (VS: 85–95%) and moisture content (75–85%). However, as FW has high energy content, the generation of fuels and chemicals while reducing waste seems ideal (Breunig et al., 2017). In particular, it could be more valuable if clean fuel (also it could be a raw material for chemical processing), hydrogen (H_2), is recovered during the treatment process.

Currently, H_2 is almost exclusively made by physico-chemical methods that split fossil fuels. However, it is an environmental contradiction that a clean fuel is generated from polluting and limited sources under high temperature pressure condition, emitting significant greenhouse gases (Ewan and Allen, 2005). Therefore, it is important to use other sources and methods to obtain H_2 in a renewable, sustainable, and environmentally friendly way. Biological H_2 production processes are more environmentally friendly and less energy consumptive than physico-chemical ones. They include a wide range of approaches to generate H_2, including direct biophotolysis, indirect biophotolysis, photo-fermentation, and dark fermentation (Kim and Kim, 2011). Among them, dark fermentation is considered the most practically applicable method since it does not require external energy, and its H_2 production rate is much faster than other processes. In addition, when combined with the treatment of waste such as FW, it can solve two problems simultaneously: the reduction of environmental burden and production of clean energy.

Since FW has higher carbohydrate content and biodegradability than other organic wastes, high H_2 production potential and rate are generally achievable. Dark fermentation performance has been maximized through various pretreatment techniques, the optimization of operation parameters, and the employment of various reactor types. However, from engineering and economical point of views, there are still doubts as to whether this process is ready to be practically applied. In this review article, first, the current status of H_2 production from FW by dark fermentation and the strategies applied for enhanced performance are briefly summarized. Then, the technical limitation of low H_2 yield from FW by dark fermentation is mentioned, and the economic feasibility is discussed. Finally, current efforts to further increase H_2 yield and waste removal efficiency along with future perspectives on dark fermentation of FW are covered.

2. Current status

2.1. Batch operation

H_2 production performances under batch operation and the strategies applied are arranged in Table 1. The main purpose of

Table 2
Typical glucose degradation reactions in dark fermentation.

Reactions	
H_2 production	Glucose + $2H_2O$ → 2Acetate + $2CO_2$ + $4H_2$ Glucose + H_2O → Acetone + $3CO_2$ + $4H_2$ Glucose → Butyrate + $2CO_2$ + $2H_2$
No relation	Glucose → 2Lactate Glucose → Butanol + $2CO_2$ + H_2O Glucose → 2Ethanol + $2CO_2$
H_2 consumption	Glucose + $2H_2$ → 2Propionate + $2H_2O$ Glucose + $2CO_2$ + $2H_2$ → 2Succinate + $2H_2O$ H_2 + CO_2 → Formate

Table 1
Batch H_2 production performance from food waste by dark fermentation (The H_2 yield value indicated here was obtained under optimal condition).

Substrate concentration	Temp.	H_2 yield per added substrate	Strategy to enhance performance	References
30 g Carbo. COD/L	35 °C	2.26 mol H_2/mol hexose	Heat-treatment (90 °C for 20 m)	Im et al. (2012)
30 g Carbo. COD/L	35 °C	153.5 mL H_2/g VS	Heat-(90 °C for 20 m), acid-(pH 1 for 1 d), and alkali-treatment (pH 13 for 1 d)	Kim et al. (2009)
30 g Carbo. COD/L	35 °C	1.74 mol H_2/mol hexose	Acid-treatment (pH 1.0–4.0)	Kim et al. (2014)
30 g Carbo. COD/L	37 °C	162 mL H_2/g VS 1.71 mol H_2/mol hexose 133 mL/g COD	Alkali-treatment (pH 9–13, 6 h)	Jang et al. (2015)
30 g Carbo. COD/L	35 °C	1.92 mol H_2/mol hexose	Initial pH change (5.0–9.0)	Kim et al. (2011a)
N.A.[a]	37 °C	77.0–79.1 mL H_2/g VS	Initial pH change (5, 6, 8)	Xiao et al. (2013)
5–80 g Carbo. COD/L	35 °C	1.71 mol H_2/mol hexose	Substrate concentration change (5–80 g Carbo. COD/L)	Kim et al. (2014)
30 g Carbo. COD/L	35–60 °C	1.79 mol H_2/mol hexose	Temperature change (35–60 °C)	Kim et al. (2011c)
30 g carbo. COD/L	35 °C	2.11 mol H_2/mol hexose	Co-digestion (FW:SWS[a] = 10:0–10:4, 0:10),	Kim et al. (2011b)
N.A.[a]	37 °C	102.63 mL H_2/g VS	Co-digestion (FW + SWS[b]) at different C/N ratios (10:1, 20:1, 30:1, 40:1, and 50:1)	Sreela-or et al. (2011)
5–50 g VS/L	35 °C	1.05 mol H_2/mol hexose	Co-digestion at various substrate concentration (FW:SWS[b] = 0:100–100:0),	Kim et al. (2004)
N.A.[a]	37 °C	76 mL H_2/g COD 165 mL H_2/g VS 1.84 mol H_2/mol hexose	Co-digestion (FW + PS[c] + WAS[d])	Zhou et al. (2013)

[a] N.A. = Not available;
[b] SWS = Sewage sludge;
[c] PS = Primary sludge;
[d] WAS = Waste activated sludge.