Using household food waste extract for continuous bio-hydrogen production through dark fermentation

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Keywords: food waste, household food waste, hydrogen, dark fermentation.

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Introduction

Biohydrogen is a promising CO_2- neutral biofuel, which is nontoxic and may be derived from a wide variety of raw, renewable materials. Fermentative hydrogen production of food waste can contribute to both food waste minimization and energy recovery.

In this study, the long term, continuous, fermentative biohydrogen production, was investigated, using household food waste (biowaste) (rotten fruits and vegetables like carrots, beetroot, oranges, tomatoes, lettuce etc.). The biowaste was squeezed and used as the substrate in a CSTR – type lab- scale bioreactor of 0.4 L working volume, which operated at 35.5ºC under different operational conditions. Initially, the effect of hydraulic retention time (HRT) (12, 18 and 24 h) and feed substrate concentration (20, 30 and 40 g of carbohydrates /L), was assessed, when the organic loading rate (OLR) was maintained at 40 g carbohydrates /L.d, and when the OLR increased (40, 50 and 60 g of carbohydrates /L.d), through maintaining the HRT at 24 h and increasing the feed substrate concentration (40, 50 and 60 g of carbohydrates /L) and was correlated to the hydrogen yields and the distribution of the metabolic products generated in the reactor.

Materials and Methods

Biowaste extract

Biowaste was collected from two local, open markets in Patras, Greece. It was squeezed in a domestic juicer, so as the initial carbohydrates concentration of the extract was 79.1 ± 2.2 g/L and the initial chemical oxygen demand (COD) concentration was 86.8 ±2.5 g/L. Then the extract was properly diluted with tap water and used as feed in the CSTR.

Hydrogen production process

The experiments were performed in a CSTR – type lab- scale bioreactor, described in Alexandropoulou et al. (2018). The biowaste extract, properly diluted, also supplemented with NaOH and KH_2PO_4 was used as the feeding substrate, which was inserted in the reactor via a peristaltic pump. During start-up, the reactor, was filled with the biowaste extract and operated anaerobically in a batch mode for 24 h, in order to activate the indigenous microbial species, as proposed in Antonopoulou et al. (2008). Following the start-up, the operation of the reactor was switched to continuous mode, with initial substrate concentration, in terms of carbohydrates as 20 g/L and with an HRT of 12 h, corresponding to an OLR, 40 g/L.d. Subsequently, and upon achievement of steady state, a) both the substrate concentration and the HRT were gradually increased and b) the HRT was maintained stable, increasing only the substrate concentration (Table 1). The reactor's performance (biogas production rate and composition in H_2, carbohydrates, volatile fatty acids (VFAs)), COD was monitored and characterized according to Alexandropoulou et al. (2018).

Table 1: Operational characteristics of the CSTR

HRT (h)	Initial carbohydrates concentration (g/L)	OLR (g/L.d)
12	20	40
18	30	40
24	40	40
24	50	50
24	60	60

Results and discussion

The CSTR operated for almost 110 d, during which three different HRTs (12, 18, 24 h at OLR 40 $g_{carbohydrates}$/L.d) and OLRs, (40, 50, 60 g/L.d) were tested. The produced biogas consisted mainly of hydrogen and carbon dioxide and it was free of methane, indicating that there was no methanogenic activity in the reactor. The biogas and hydrogen production rates as well as the concentration of VFAs, is depicted in Figure 1, while the main characteristics of the steady states are presented in Table 1.

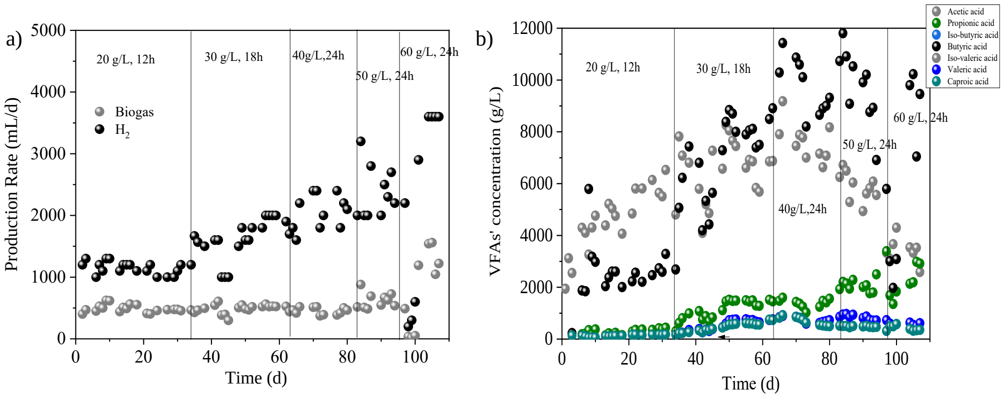

Figure 1: (a) The hydrogen and biogas production rates and (b) the VFAs concentration throughout the CSTR operation

The experimental results showed that the increase of the OLR to 60 g/L.d enhanced hydrogen production rates and yields, leading to 4.47 m^3 $H_2/m^3_{biowaste\ extract}$ and 0.44 mol H_2/mol $_{consumed\ carbohydrates}$. High concentrations of acetic and butyric acids were detected in the reactor, which in general favour hydrogen production upon dark fermentation.

Table 1: The main characteristics of the reactor at steady states

	20 g /L HRT= 12 h	30 g /L HRT= 18 h	40 g /L HRT= 24 h	50 g /L HRT= 24 h	60 g /L HRT= 24 h
H_2 (%)	42.99 ± 4.43	27.23 ± 0.73	23.51 ± 2.57	25.85 ± 2.40	37.27 ± 3.44
pH	6.40 ± 0.17	6.28 ± 0.05	6.19 ± 0.03	6.01 ± 0.15	6.30 ± 0.24
L $H_2/L_{reactor}$/d	1.17 ± 0.02	1.33 ± 0.04	1.19 ± 0.10	1.50 ± 0.22	3.35 ± 0.63
$Y_{H2/feed}$ (L H_2/L feed)	0.59 ± 0.01	1.00 ± 0.03	1.19 ± 0.10	1.50 ± 0.22	3.35 ± 0.63
$Y_{H2/extract}$ (m^3 H_2/m^3 biowaste extract)	2.35 ± 0.04	2.65± 0.08	2.38 ± 0.22	2.40 ± 0.36	4.47 ± 0.83
Carbohydrates removal efficiency (%)	97.4	98.8	97.0	96.1	94.6
$Y_{H2/Su}^{mol}$ (mol H_2/mol consumed carbohydrates)	0.22± 0.01	0.25± 0.01	0.23± 0.01	0.23 ± 0.01	0.44 ± 0.02

Conclusions

- Fermentative hydrogen production of biowaste extract was investigated in a CSTR at different HRTs and OLRs
- High hydrogen rates and yields were achieved in high OLRs, indicating lower dilution with tap water and maximum exploitation of the biowaste, generated by open markets (rotten fruits and vegetables).
- The experimental results from the CSTR showed that the OLR of 60 g /L.d (HRT of 24 h and initial carbohydrates concentration of 60 g/L) led to the higher hydrogen production rates and yields which were accompanied by high butyrate and acetate production.

Acknowledgements

This work was funded by the European Union's Horizon Europe research and Innovation programme under SYMSITES project, No 101058426.

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