Available at www.sciencedirect.com

ScienceDirect

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

Effect of organic loading on a novel hydrogen bioreactor

Hisham Hafez [a], *George Nakhla* [a,b,*], *M. Hesham El. Naggar* [a], *Elsayed Elbeshbishy* [a], *Bita Baghchehsaraee* [b]

[a] *Department of Civil Engineering, The University of Western Ontario, London, Ontario N6A 5B9, Canada*
[b] *Department of Chemical and Biochemical Engineering, The University of Western Ontario, London, Ontario N6A 5B9, Canada*

ARTICLE INFO

Article history:
Received 6 September 2009
Received in revised form
16 October 2009
Accepted 18 October 2009
Available online 10 November 2009

Keywords:
Biological hydrogen production
Organic loading
Food-to-microorganisms ratio
PCR-DGGE

ABSTRACT

This study investigated the impact of six organic loading rates (OLR) ranging from 6.5 gCOD/L-d to 206 gCOD/L-d on the performance of a novel integrated biohydrogen reactor clarifier systems (IBRCSs) comprised a continuously stirred reactor (CSTR) for biological hydrogen production, followed by an uncovered gravity settler for decoupling of solids retention time (SRT) from hydraulic retention time (HRT). The system was able to maintain a high molar hydrogen yield of 2.8 mol H_2/mol glucose at OLR ranging from 6.5 to 103 gCOD/L-d, but dropped precipitously to approximately 1.2 and 1.1 mol H_2/mol glucose for the OLRs of 154 and 206 gCOD/L-d, respectively. The optimum OLR at HRT of 8 h for maximizing both hydrogen molar yield and volumetric hydrogen production was 103 gCOD/L-d. A positive statistical correlation was observed between the molar hydrogen production and the molar acetate-to-butyrate ratio. Biomass yield correlated negatively with hydrogen yield, although not linearly. Analyzing the food-to-microorganisms (F/M) data in this study and others revealed that, both molar hydrogen yields and biomass specific hydrogen rates peaked at 2.8 mol H_2/mol glucose and 2.3 L/gVSS-d at F/M ratios ranging from 4.4 to 6.4 gCOD/gVSS-d. Microbial community analysis for OLRs of 6.5 and 25.7 gCOD/L-d showed the predominance of hydrogen producers such as *Clostridium acetobutyricum, Klebsiella pneumonia, Clostridium butyricum, Clostridium pasteurianum*. While at extremely high OLRs of 154 and 206 gCOD/L-d, a microbial shift was clearly evident due to the coexistence of the non-hydrogen producers such as *Lactococcus sp.* and *Pseudomonas sp.*

1. Introduction

Hydrogen production from renewable substrates can reduce reliance on fossil fuels. It produces only water upon combustion, thus is considered as a clean energy source that can help mitigate pollution and global warming [1]. Biological hydrogen production is potentially regarded as one of the most promising alternatives for sustainable green energy production despite the feasibility of hydrogen production through water electrolysis and chemical cracking of hydrocarbons [2]. Among different biological processes for hydrogen production, dark fermentation is the most attractive one because of its potential of direct use of wastewater streams and organic wastes and its higher rate of hydrogen production in comparison with photo-fermentative processes [3].

Organic loading rate (OLR) is an important parameter in studying hydrogen bioreactors. In order to optimize a system for hydrogen production, it is essential to define either a range of the organic loading rates that the system can handle effectively, or an optimal organic loading rate for a maximum hydrogen yield. In the literature, there is no clear relationship between the hydrogen yield and the organic loading rate. In

* *Corresponding author at*: Department of Chemical and Biochemical Engineering, The University of Western Ontario, London, Ontario N6A 5B9, Canada. Tel.: +1 519 661 2111x85470; fax: +1 519 850 2129.
E-mail address: gnakhla@eng.uwo.ca (G. Nakhla).

0360-3199/$ – see front matter
doi:10.1016/j.ijhydene.2009.10.051

some cases higher OLRs decreased the hydrogen yield [4] whereas in some others higher OLRs increased the hydrogen yield [5]. For waste activated sludge as a seed material, it appears that increasing the OLR within the 40–160 gCOD/L-d increased hydrogen yield to an optimum of 1.6 mol H_2/mol glucose at an OLR of 120 gCOD/L-d [6], whereas hydrogen yield decreased with increasing OLR for both anaerobically digested sludge [7] and soil microorganisms [4]. Although lower molar H_2 yields at higher OLRs have been attributed to the inhibitory effect of higher H_2 partial pressures in the growth medium [4,8], variations in the composition of bacterial communities that become established at different OLRs [9] may be a major reason for lower yields. Hydrogen yield with digester sludge at an OLR of 45 gCOD/L-d was 1.3 mol H_2/mol glucose [7] as compared with 0.9 mol H_2/mol glucose with waste activated sludge [6]. Moreover, comparing the biomass concentration in two studies with continuously stirred tank reactors (CSTRs) utilizing agricultural soil as the seed and glucose as a substrate under approximately same OLRs, Van Ginkel and Logan [4] achieved much higher hydrogen yield (2.2 mol/mol) at a biomass concentration of 8 g/L compared to Zhang et al. [5] who reported 0.72 mol H_2/mol hexose with 0.9 g/L biomass. Oh et al. [10] achieved a hydrogen yield of 0.4 mol/mol at a biomass concentration of 2.2 g/L in a CSTR and Wu et al. [6] using a CSTR seeded with silicone-immobilized sludge realized a hydrogen yield of 1.6 mol/mol at 3.5 g/L of biomass compared to a hydrogen yield of 2.1 mol/mol achieved by Zhang et al. [5] at a similar OLR with a higher biomass concentration (4.6 g/L). It is thus clear that the higher biomass concentration in the reactors improved the hydrogen yield, which in essence shows that one of the key factors affecting the stability of hydrogen producing systems is maintaining higher biomass concentrations in the system. In addition, the low hydrogen yield and system failure was attributed to low concentrations of biomass due to washout [4].

This paper has two objectives; the first objective focuses primarily on the investigation of the effect of organic loading rate on the performance of a novel integrated biohydrogen reactor clarifier system (IBRCS) [11] and to specify an optimal range for organic loading rate that maximizes hydrogen yield. While the other objective of this paper is to assess the impact of organic loading rate on the physical and biochemical characteristics i.e. the various metabolic pathways and microbial shifts involved in biological hydrogen production, as well as particle size and settling properties. The premise of the IBRCS is decoupling of hydraulic retention time (HRT) from solids retention time (SRT), which has been demonstrated in a previous work [12].

2. Materials and methods

2.1. *Systems set up and operations*

Two lab-scale systems were operated at 37 °C for 220 days (Fig. 1), at six different organic loading rates ranging from 6.5 gCOD/L-d to 206 gCOD/L-d. Two integrated biohydrogen reactor clarifier systems (IBRCSs) comprised a continuously stirred reactor (CSTR) for biological hydrogen production (5 L working volume), followed by an uncovered gravity settler (volume 8 L) i.e. open to atmosphere for the decoupling of solids retention time (SRT) from the hydraulic retention time (HRT). Details of the operational conditions for the six runs are listed in Table 1. In order to enrich hydrogen producing bacteria, the sludges were heat treated at 70 °C for 30 min. Following the completion of each run and the attainment of steady-state conditions, the systems were cleaned and inoculated with pre-treated sludges. OLR-1 and 2 were run simultaneously, followed by OLR-3 and 4, and lastly OLR-5 and 6. The systems were monitored for total chemical oxygen demand (TCOD), soluble COD, volatile fatty acids (VFA), ethanol, lactate, glucose, volatile suspended solids (VSS), total suspended solids (TSS) and biogas composition including hydrogen, methane and nitrogen. The quantity of produced biogas was recorded daily using a wet-tip gas meter (Rebel wet-tip gas meter company, Nashville, TN, USA).

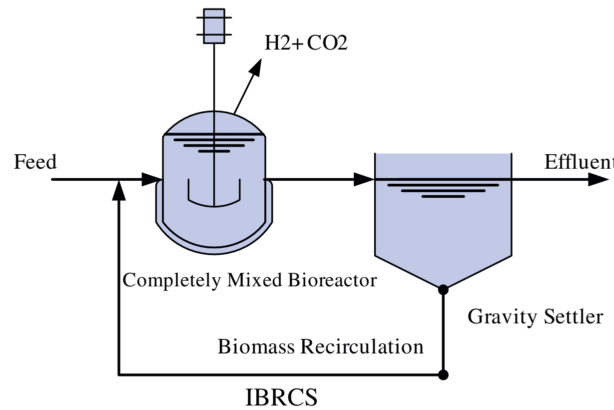

Fig. 1 – Experimental Setup for the integrated biohydrogen reactor clarifier system.

2.2. *Inocula and media compositions*

Anaerobically digested sludge from the St.Marys wastewater treatment plant (St.Marys, Ontario, Canada) was used as the seed. The two systems operated in parallel at the same time under two different OLRs for a total of six OLRs (three consecutive runs). The systems were seeded with 5 liters of sludge and started up in a continuous mode with the feed containing glucose at different concentrations as highlighted in Table 1. The same startup technique was repeated for the three runs. It must be emphasized that there was no sludge wastage from the clarifier throughout the operation, and the

Table 1 – Operational conditions.

	Glucose (g/L)	HRT (h)	SRT (h)	OLR (gCOD/L-d)	pH
OLR -1	2	8	50 ± 5	6.5	5.5–6.5
OLR -2	8	8	45 ± 4	25.7	5.5–6.5
OLR -3	16	8	45 ± 6	51.4	5.5–6.5
OLR -4	32	8	42 ± 6	103	5.5–6.5
OLR -5	48	8	27 ± 3	154	5.5–6.5
OLR -6	64	8	26 ± 2	206	5.5–6.5

Note. Values represent average ± standard deviation.