High-rate anaerobic digestion of microalgae using an upflow anaerobic sludge blanket (UASB) reactor system: validation at pilot scale

Salama, Philippe; Ngoundjo, Fred; Frédérique, Matteau Lebrun; Pilon, Guillaume; O'Leary, Stephen J. B.; Guiot, Serge R.

For the publisher’s version, please access the DOI link below./ Pour consulter la version de l’éditeur, utilisez le lien DOI ci-dessous.

https://doi.org/10.4224/23002443

High-rate anaerobic digestion of microalgae using an upflow anaerobic sludge blanket (UASB) reactor system – Validation at pilot scale

Philippe Salama[a], Fred Ngoundjo[a], Frédérique Matteau-Lebrun[a], Guillaume Pilon[a], Stephen J.B. O'Leary[b] and Serge R. Guiot[a]
[a] Anaerobic Technologies & Bioprocess Control Group, EME; [b] Algal Carbon Conversion Program, National Research Council Canada

NRC·CNRC

Algal Carbon Conversion Program

ABSTRACT

Pilot validation trials for the anaerobic digestion of microalgae (*Scenedesmus* sp) were carried out on a UASB reactor (500 L). The trials took place continuously over a period of 3.5 months (102 days). The obtained biomethane generation efficiency (defined as the volume of biomethane produced per theoretical methane that could be stoichiometrically produced) was found to be above 60% for a hydraulic residence time (HRT) of 3.8 days. Biochemical methane potential (BMP) analysis confirmed the biomethane generation efficiency (both at low and high HRT) obtained with the pilot UASB reactor.

INTRODUCTION

- Microalgae is recognized as a promising feedstock for the production of biofuels (high carbohydrate and lipid content, fast growth rate, high biomass yield; CO_2 fixation; no competition for arable land);
- The high cost of algal biomass production limits large scale deployment of biorefineries; valorizing algal biomass into fuels and chemicals can reduce those costs and accelerate biorefineries deployment;
- Anaerobic digestion of algal biomass residues remaining after chemicals and liquid fuels production can make the process more sustainable by increasing the energy efficiency and recycling the nutrients for algal cultivation.

MATERIALS AND METHODS

Algae

Frozen *Scenedesmus* paste (shown in Figure 1) obtained from AzCATI (Arizona Center for Algae Technology and Innovation) was used for all pilot trails. In all, 150 kg (dry basis) of microalgae was used for the trial experiments.

Biomass

Two different types of granular biomass composed of a mixed bacterial source were used for all trials to carry out anaerobic digestion which is the process of converting algal substrate to biogas (i.e. biomethane). Lassonde biomass (shown in Figure 1) was obtained from Lassonde Industries Inc. located in Rougemont, Québec and Agropur biomass (shown in Figure 1) was obtained from Agropur's cheese transformation facility located in Notre-Dame-du-Bon Conseil, Québec.

Pilot Plant

Initially, algal feed solutions were prepared by diluting a known mass of algae paste using a feedstock preparation reservoir shown in Figure 2. The solution was then transferred to a 4 m^3 refrigerated storage reservoir (also shown in Figure 2) where it was maintained at a temperature of 6-7°C using a closed loop refrigerated glycol water mixture. From the stock storage reservoir, the algal solution was continuously fed to the 500 L UASB reactor shown using a lobe type transfer pump.

Sample Analysis

Sample analysis included biogas flow rate and composition. The influent/effluent concentrations of total solids (TS), volatile solids (VS), suspended solids (SS), volatile suspended solids (VSS), and total/ soluble chemical oxygen demand (tCOD and sCOD) were also measured. In addition, the volatile fatty acids (VFA) concentrations as well as the NH_4^+ ion concentration were measured by HPLC analysis. Finally, the biological methane generation potential (BMP) of various reactor effluent samples was also measured.

Figure 1. Microalgae Paste and Granular Biomass

Microalgae Paste | Lassonde Biomass | Agropur Biomass

Figure 2. Feedstock Preparation and Pilot Plant

Feedstock Preparation Reservoir | Refrigerated Storage (4 m3) | UASB Reactor (500 L)

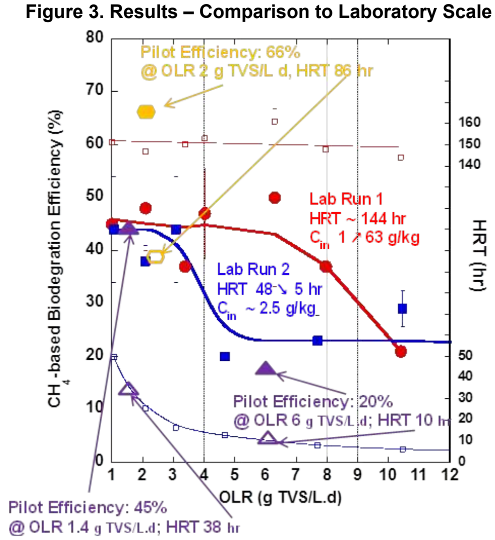
RESULTS

Table 1. Results – Operating and Performance Parameters

Parameters	Units	PVT-1	PVT-2	PVT-3	PVT-4	PVT-5	PVT-6	PVT-7	PVT-8
HRT	Days	1.6 ± 0.2	0.8 ± 0.1	0.69 ± 0.02	0.42 ± 0.01	0.45 ± 0.03	0.41 ± 0.02	**3.83 ± 0.75**	3.60 ± 0.45
OLR	gTVS/Lrxr.d	**1.4 ± 0.2**	**2.4 ± 0.5**	**3.77 ± 0.39**	**5.70 ± 0.59**	5.37 ± 0.74	6.38 ± 0.73	1.96 ± 0.47	**0.53 ± 0.11**
Upflow Velocity	m/hr	2	2	2	2	**4**	**2**	2	2
Biomass Source	-	Lassonde	Lassonde	Lassonde	Lassonde	**Lassonde/ Agropur**	**Lassonde/ Agropur**	Lassonde/ Agropur	Lassonde/ Agropur
TVSin	g/kg	2.18 ± 0.2	2.03 ± 0.4	2.58 ± 0.30	2.40 ± 0.3	2.42 ± 0.25	2.60 ± 0.29	**7.28 ± 0.35**	**1.90 ± 0.49**
sCOD	mg/L	140 ± 0.0	107 ± 13	158 ± 16	201 ± 9	164 ± 35	141 ± 12	252 ± 15	133 ± 10
VFA	mg COD-eq/L	20 ± 15	13 ± 10	19 ± 3	33 ± 13	24 ± 11	15 ± 3	28 ± 2	3 ± 1
NH_4^+	mg/L	60	48 ± 3	43 ± 7	39 ± 8	40 ± 3	37 ± 2	217 ± 25	178 ± 12
Flow Rate CH_4	L STP/Lrx d	0.24 ± 0.01	0.30 ± 0.02	044 ± 0.02	0.57 ± 0.08	0.59 ± 0.05	0.61 ± 0.03	0.62 ± 0.01	0.19 ± 0.02
Yield CH_4	mL STP/gTVSin	**223 ± 41**	**140 ± 23**	**117 ± 13**	**102 ± 21**	**113 ± 24**	**96 ± 13**	**328 ± 77**	**356 ± 43**
CH4 Prod./Theoritical CH4	%	**45 ± 8**	**28 ± 5**	**23 ± 3**	**20 ± 4**	**23 ± 5**	**19 ± 3**	**66 ± 16**	**71 ± 9**

All values in g/L. Total solids (TS); total volatile solids (TVS); soluble chemical oxygen demand (sCOD).

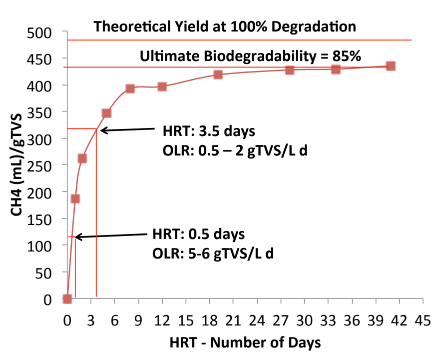
Figure 3. Results – Comparison to Laboratory Scale



UASB Reactor Operation Options

- Laboratory Option 1: High feed solids concentration (high TVS) at high HRT(e.g. ~ 6 d) ⇒ allows for OLR up to ~ **7** g TVS/L_{RXR}.d before degradation capacity exceeded (bioactivity limited).
- Laboratory Option 2: Low inlet solids concentration (low TVS) at low HRT (e.g. ~ 1 d) ⇒ degradation capacity exceeded at OLR as low as **3-4** g TVS/L_{RXR}.d (reaction time limited).
- Pilot Trials with Option 1: Degradation efficiency higher than laboratory trials ⇒ Higher microbial biomass content, hence higher bioactivity potential.
- Pilot Trials with Option 2: Similar efficiency than laboratory trials ⇒ same reaction time limitation.

Figure 4. - Biochemical Methane Potential (BMP)



Large Scale Potential Preliminary Analysis

Assumptions

Fictitious Case Study: Open pond algal production facility (80 tonnes dry basis/day).

Algae leftover for anaerobic digestion (AD) 25 tonnes (~30%) dry basis/day

- Inlet concentration at 8 g TVS/L & HRT 3.5 days
  - AD reactors volume: 11,000 m^3
- Methane production yield (0.3 LCH_4/g TVS, based on pilot trials)
- Cogeneration (CHP) efficiency[1]
  - Electricity generation: 40%
  - Heat Production: 50% (used for AD and other needs)

Energy and Economic Potential

- AD of algae could produce annually **9 GWh** i.e. power plant of 1 MW.
- Electricity revenue of **$0.6 MM/A** (at $0.07/kWh)
- Profitability to be determined from a more accurate technico-economic analysis.

References for Large Scale Potential Preliminary Analysis:

(1) Power N.M. and Murphy J.D., Which is the Preferable Transport Fuel on a Greenhouse Gas Basis; Biomethane or Ethanol. Biomass and Bioenergy 2009; 33; 1403-1412

CONCLUSIONS

- **Pilot plant continuously operated on algae feed for a period of 102 days.**
- **Pilot trials showed improved methane production efficiency with longer HRT (over 102 days), which is still low with respect to conventional CSTR approaches.**
- **For low HRT (10 hrs) and similar conditions, pilot trials showed similar efficiencies compared to laboratory scale runs.**
- **BMP analysis confirmed the results obtained from pilot trials.**
- **Basic preliminary scale–up analysis showed potential for energy production and revenue generation.**

ACKNOWLEDGMENTS

John McGowen (AzCATI), Arizona State University provided the algal biomass.

Alain Corriveau, Manon Sarrazin and Caroline Roy (NRC) for their excellent analytical assistance.

Claude Kirouac (Lassonde Industries Inc.) for supplying the Lassonde granular biomass.

Pierre Fillion (Agropur Dairy Cooperative) for supplying the Agropur granular biomass.

National Research Council Canada | Conseil national de recherches Canada

Canada