COMPARISON OF ONE-STAGE AND TWO-STAGE FERMENTATION PROCESS OF FOOD WASTE

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OUTLINE

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   - Biohydrogen production from the fermentative stage
   - Anaerobic performances of **One** and **Two-stage** digestion processes?

2. MATERIALS AND METHODS
   - Substrate and initial inocula
   - Analytical parameters
   - Experimental set-up
   - Terms of comparison of the scenarios

3. RESULTS

4. CONCLUSIONS
INTRODUCTION

ANAEROBIC BIOREFINERY

Definition of Biorefinery (European Commission, 2017 - COMMISSION STAFF WORKING DOCUMENT on the review of the 2012 European Bioeconomy Strategy)

“Integrated biorefineries, which use processing technologies to fractionate biomass and biological waste streams, to produce food, feed, bio-based materials and fuel/energy in an integrated manner, are critical infrastructures for enabling the cascading use of biomass.”

Anaerobic biorefinery concept (Sawatdeenarunat et al., 2016)

“The anaerobic biorefinery is one of the biorefinery concepts, in which AD serves as a centerpiece to produce high-value, but low volume products (i.e., chemicals and drop-in biofuels to enhance economic viability of the system) and high-volume but low value products (i.e., heat, electricity, and conventional transportation biofuels) to achieve energy security.”
INTRODUCTION

BIOHYDROGEN PRODUCTION FROM THE FERMENTATIVE STAGE

Why Hydrogen production in anaerobic digestion?

H₂ is considered one of the cleanest energy sources and its energy density per mass (122 kJ g⁻¹) is 2.5 times compared to fossil fuels (Abdallah et al., 2016). It could be used to produce electricity through fuel cells.

What dark fermentation is?

DF is the first agidogenic step of AD where fermentative bacteria (e.g. Clostridium perfringens) break down organic matter into primarily H₂, CO₂ and soluble metabolic products (Ghimire et al., 2015).

The two-stage process:

DF can be implemented in a two-stage process where, in the second step, methanogenic bacteria convert the spent organic effluent from the first stage into CH₄ and CO₂ gas (Ariunbaatar et al., 2015). Enhancement of the total biogas production (Lee et al., 2010). The two gas flow could be used either by itself or mixed together in a mixture that simulates the composition of Hythane.
INTRODUCTION

RESEARCH QUESTION:
WHICH PROCESS BETTER VALORISE THE ANAEROBIC DIGESTION OF FOOD WASTE?

One-Stage Anaerobic Digestion

Two-Stage Anaerobic Digestion

Food Waste

Digestate

Food Waste

Digestate
MATERIALS AND METHODS

SUBSTRATE AND INITIAL INOCULA

Substrate:
Food waste (FW) is a highly desirable feedstock for anaerobic fermentation due to its high carbohydrate content, biodegradability and availability (Cavinato et al., 2012, De Gioannis et al., 2013).

Food waste was manually sorted from the organic fraction of municipal solid waste collected in a Tuscan municipality (Italy) by means of a kerbside collection system. In order to obtain a slurry with a total solid (TS) content suitable to wet fermentation, the sample was treated in a food processor, sifted with a strainer (3 mm diameter) and mixed with tap water.

Inoculum 1 to start-up – IN1:
Activated sludge collected from the aerobic unit of a municipal wastewater treatment plant was used as inoculum for the fermentative reactor. Activated sludge were heat treated at 80°C for 30 minutes prior to set-up with the aim of selecting only hydrogen producing bacteria while inhibiting hydrogenotrophic methanogens (Alibardi and Cossu, 2015). Tests were carried out when the inoculum temperature reached mesophilic conditions.

Inoculum 2 to start-up – IN2:
The seed sludge used in the methanogenic reactor was collected from an anaerobic reactor treating the organic fraction of municipal solid waste (OFMSW) and cattle manure.

<table>
<thead>
<tr>
<th></th>
<th>TS (% w/w)</th>
<th>TVS (% w/w)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN1</td>
<td>2.1 ± 0.2</td>
<td>1.5 ± 0.1</td>
<td>7.1 ± 0.0</td>
</tr>
<tr>
<td>IN2</td>
<td>2.9 ± 0.1</td>
<td>1.8 ± 0.1</td>
<td>8.2 ± 0.1</td>
</tr>
<tr>
<td>FW</td>
<td>5.7 ± 0.1</td>
<td>4.3 ± 0.1</td>
<td>3.8 ± 0.0</td>
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</table>
## MATERIALS AND METHODS

### ANALYTICAL PARAMETERS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Acquisition method</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>Metter Toledo probes (± 0.01)</td>
<td>Continuous</td>
</tr>
<tr>
<td>Temperature</td>
<td>Metter Toledo probes (± 0.1°C)</td>
<td>Continuous</td>
</tr>
<tr>
<td>Gas production</td>
<td>Volumetric counters (± 0.07 l)</td>
<td>Continuous</td>
</tr>
<tr>
<td>Gas storage</td>
<td>10 l Multilayer foil bags</td>
<td>Continuous</td>
</tr>
<tr>
<td>Gas quality (H₂, CH₄, N₂, O₂, H₂S, CO₂)</td>
<td>Gas-Chromatography, 3000 Micro GC INFICON</td>
<td>Daily</td>
</tr>
<tr>
<td>VFAs</td>
<td>Gas-Chromatography, 7890B Agilent</td>
<td>Daily</td>
</tr>
<tr>
<td>TS (substrate and digestates)</td>
<td>APHA, 2006</td>
<td>Daily</td>
</tr>
<tr>
<td>TVS (substrate and digestates)</td>
<td>APHA, 2006</td>
<td>Daily</td>
</tr>
<tr>
<td>Total Alkalinity</td>
<td>Titration, Martín-González et al., 2013</td>
<td>Daily</td>
</tr>
<tr>
<td>Partial Alkalinity (bicarbonate)</td>
<td>Titration, Martín-González et al., 2013</td>
<td>Daily</td>
</tr>
<tr>
<td>Intermediate Alkalinity (VFAs)</td>
<td>Titration, Martín-González et al., 2013</td>
<td>Daily</td>
</tr>
</tbody>
</table>
MATERIALS AND METHODS

EXPERIMENTAL SET-UP

Run 1 - One-Stage Anaerobic Digestion

- **Feeding:** daily
- **OLR R2:** 2.5 kgTVS/m³d
- **HRT R2:** 17 d
- **Volume R2:** 12 l (w.v.), 19 l (t.v.)
- **Temperature R2:** 37.0 ± 0.1 °C
- **Duration:** 42 d (25 d unsteady st., 17 d steady st.);

Run 2 - Two-Stage Anaerobic Digestion

- **Feeding:** daily
- **OLR R1:** 14.2 kgTVS/m³d
- **OLR R2:** 2.5 kgTVS/m³d
- **HRT R2:** 13 d
- **Volume R1:** 3 l (w.v.), 6 l (t.v.)
- **Volume R2:** 12 l (w.v.), 19 l (t.v.)
- **Temperature R1:** 37.0 ± 0.1 °C
- **Temperature R2:** 37.0 ± 0.1 °C
- **Duration:** 26 d (13 d unsteady st., 13 d steady st.);

Temperature was constantly kept at mesophilic conditions by a jacket where warm water heated up by thermostat was continuously recycled.

**pH in R1** was set at 5.5 and controlled through NaOH 2M solution addition. Previous studies found 5.5 to be the optimum pH for hydrogen production (Chinellato et al., 2013).

Steady state was performed for one whole HRT when AI/AP ratio was below 0.3 (Martín-González et al., 2013).
MATERIALS AND METHODS

TERMS OF COMPARISON OF THE TWO SCENARIOS

The two steady phases of the two runs were compared by means of:

- Volatile solids removal efficiency (%): \[ \eta_{TVS} = \frac{TVS_{IN} - TVS_{OUT}}{TVS_{IN}} \times 100 \]

- Specific Gas Production – SGP (Nl\textsubscript{biogas}/kg\textsubscript{TVS\textsubscript{IN}} d)

- Methane and Hydrogen content in biogas (%)
RESULTS

VOLATILE FATTY ACIDS AND ALKALINITY

- Linear relationship VFA - Total Alkalinity (TA) in the fermentative reactor (R1)
- Linear relationship VFA - Intermediate Alkalinity (IA) in the methanogenic reactor (R2)

![Graph showing the relationship between total VFA and total alkalinity across different scenarios.](image)
RESULTS

VOLATILE FATTY ACIDS

Comparison between VFA in R2 during Scenario 1 and 2:

- Total VFA concentration was almost steady during Scenario 1 and 2
- Decrease of propionic acid
- Increase of acetic and butyric acid

Comparison between VFA in R1 and R2 during Scenario 2:

- Butyric, valeric and hexanoic acid were degraded in R2;
- Acetic, propionic and isovaleric acids were almost stable
RESULTS

BIOGAS PRODUCTION AND QUALITY

![Graph showing biogas production over time for different scenarios.]

**Scenario 2:** increase in biogas production

- **SGP = +7.7%**

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>SGP [NL/kgTVS d]</th>
<th>GPR [NL/d]</th>
</tr>
</thead>
<tbody>
<tr>
<td>R2 – Scenario 1</td>
<td>694.4 ± 24.6</td>
<td>1.74 ± 0.06</td>
</tr>
<tr>
<td>R2 – Scenario 2</td>
<td>704.6 ± 28.5</td>
<td>1.77 ± 0.05</td>
</tr>
<tr>
<td>R1 – Scenario 2</td>
<td>43.1 ± 12.8</td>
<td>0.61 ± 0.18</td>
</tr>
<tr>
<td>R1 + R2 Scenario 2</td>
<td>747.7 ± 37.4</td>
<td>2.39 ± 0.21</td>
</tr>
</tbody>
</table>
RESULTS

BIOGAS PRODUCTION AND QUALITY

**Scenario 2:** increase in methane content
\[
\text{CH}_4 = + 3.2\%
\]

**Scenario 2:** hydrogen rich biogas in R1
\[
\text{H}_2 = 22.9\%
\]

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>H(_2) [%]</th>
<th>CH(_4) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>R2 – Scenario 1</td>
<td>-</td>
<td>65.2 ± 1.9</td>
</tr>
<tr>
<td>R2 – Scenario 2</td>
<td>-</td>
<td>68.4 ± 1.1</td>
</tr>
<tr>
<td>R1 – Scenario 2</td>
<td>22.9 ± 5.5</td>
<td>-</td>
</tr>
</tbody>
</table>
RESULTS

VOLATILE SOLIDS REMOVAL EFFICIENCY

Scenario 2: increase in volatile solids removal

\[ \eta_{TVS} = +6.8\% \]
CONCLUSIONS

COMPARISON BETWEEN ONE-STAGE AND TWO-STAGE ANAEROBIC PROCESSES

✓ Higher biogas production
✓ Higher methane content in the methanogenic reactor and a hydrogen rich biogas in the fermentative one
✓ Higher volatile solids degradation

RESEARCH QUESTION:
WHICH PROCESS BETTER VALORISE THE ANAEROBIC DIGESTION OF FOOD WASTE?

These first results allow to conclude that:

The Two-stage process is a valuable system to valorise food waste

Further analysis carried out with other OLR and HRT will be performed in order to confirm these preliminar findings and to evaluate better process conditions.
Thanks for your attention!
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