Anaerobic co-digestion of chicken litter and raw glycerol as a sustainable tool for the waste management of a Slovak poultry farm and to reduce its energy consumption

Juan José Chávez-Fuentes, Francisco Ruiz-Merino
Marianna Czölderová, Miroslav Hutňan
INTRODUCTION

• Worldwide: **21 billion** stocks of chicken
• **Industrial poultry farms** produces:
  – 74 % of raised chicken
  – 68 % egg production
• **Poultry manure**
  - **Solid waste**, traditionally used to enrich soils and as fertilizer
  - Carbon-rich waste, with significant content of N, P, S, K

• **Environmental concerns**
  - **Agricultural run-off**: Low N/P ratios leads to excessive application of P in the soil if application rates of manure are based on N requirement
  - **GHG emissions** from large manure pits: \( \text{CH}_4, \text{N}_2\text{O}, \text{CO}_2, \text{SO}_2 \)
  - **Traditional manure management** contributes to:
    Acidification of soils, eutrophication of waters, air pollution and global warming

---

Hong et al (2014)
INTRODUCTION

• **Anaerobic digestion**
  – **Sustainable tool to manage manure**, based on a natural decomposition process that happens in the absence of oxygen
  – **High biodegradability** of poultry manure
  – **Organic matter** contained in manure is transformed to biogas
  – Produces a **digestate** with improved characteristics
  – **Low C/N ratio** leads to ammonia accumulation: Toxicity and inhibition of the AD process (mostly methanogenesis)

  *Anaerobic co-digestion*
  – Feasible technique to mitigate ammonia accumulation and inhibition
  – **Crude glycerol** is a C-rich waste material that can be used as co-substrate
  – **Optimize C/N ratios** and improves process kinetics
  – **Co-digestion ratio** must be carefully managed to prevent overloading of reactors and to achieve the necessary degree of mineralization for stabilized sludge

Angelidaki et al., 1994
Borowski et al., 2013
Abouelenien et al., 2010
Jensen et al., 2014
Astals et al., 2012
CASE STUDY – The poultry farm

Major-size poultry farm located in Western Slovakia

- **158,000 chickens** in a growth cycle
  - Growth cycle: 42 days feeding of chicken + 18 days time gap
  - Weigh of chicken at the end of a cycle: **2700 g**

- **360 Mg of chicken litter** in a growth cycle
  - 184 Mg TS (Dry matter)
  - 158 Mg VS (Organic matter)

- **6 Mg (2.6 Mg VS)** Daily

0.054 kg hd⁻¹ d⁻¹
512 g TS kg⁻¹
438 g VS kg⁻¹
CASE STUDY – The poultry farm

Consumption of natural gas

- Heating of broiler sheds (13)
- Operational temperature 33 °C
- Operational days in a calendar year: 252 d

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Nm³ d⁻¹</th>
<th>GJ d⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>In summer days (84 d)</td>
<td>100</td>
<td>3.3</td>
</tr>
<tr>
<td>In winter days (84 d)</td>
<td>2,500</td>
<td>81.6</td>
</tr>
<tr>
<td>Transitional weather (84 d)</td>
<td>1,200</td>
<td>39.2</td>
</tr>
</tbody>
</table>

Consumption of electrical energy

- Mainly lights, feeding system, exhaust and ventilation fans, pumps

  2,000 kWh d⁻¹

ENERGY CONSUMPTION

- 320,000 Nm³ y⁻¹
- 10,500 GJ y⁻¹
- 630 MWh y⁻¹
Aim of this work

**KEY QUESTIONS**

1. Does anaerobic co-digestion help to prevent/mitigate ammonia inhibition?

2. Can the anaerobic process be stable in the long-term?

3. Can we take advantage of the chicken manure and cover the energy needs of the poultry farm?
MATERIALS AND METHODS

**Chicken litter**

- Fresh samples of chicken litter were collected directly from the poultry farm and stored in a laboratory freezer at **-18 °C**
- Besides excrements and urine, litter contains also straw (5-10 %w/w)
- Chicken litter was grinded and analysed; then, placed in individual bags and stored **at 4 °C** for immediate use

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C/N</td>
<td>15 ± 3</td>
</tr>
<tr>
<td>TS</td>
<td>512 ± 135 g TS kg⁻¹</td>
</tr>
<tr>
<td>VS</td>
<td>438 ± 131 g VS kg⁻¹</td>
</tr>
</tbody>
</table>
**MATERIALS AND METHODS**

- **Raw glycerol**
  - Samples of residual raw (crude) glycerol were collected from a biodiesel plant located 80 km away from the poultry farm

- **Inoculum**
  - Anaerobic sludge from another laboratory reactor with a previous experiment using poultry litter as main substrate

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C/N</td>
<td>&gt; 20</td>
</tr>
<tr>
<td>VS</td>
<td>814 ± 4 g TS kg⁻¹</td>
</tr>
<tr>
<td>COD</td>
<td>1,372 ± 28 g L⁻¹</td>
</tr>
<tr>
<td>COD</td>
<td>8.5 ± 0.5 g L⁻¹</td>
</tr>
<tr>
<td>TAN</td>
<td>1.7 ± 0.12 g L⁻¹</td>
</tr>
<tr>
<td>TS</td>
<td>37 ± 5 g L⁻¹</td>
</tr>
</tbody>
</table>
EXPERIMENTAL SET-UP
EXPERIMENTAL RESULTS

The graph shows the comparison between Mono-digestion and Co-digestion in terms of SRT and TAN over time (t). Key points include:

- **SRT (d)** and **TAN (mg L⁻¹)** are plotted along the y-axis.
- The x-axis represents time in days (**t (d)**).
- The graph displays two datasets:
  - SRT (dotted line)
  - TAN (solid line)

**Key Observations**:

- **Mono-digestion** is indicated by a solid line.
- **Co-digestion** is indicated by a dotted line.
- The C/N ratio is marked on the graph.
- SRT and TAN values are compared at different time points.
EXPERIMENTAL RESULTS

COD (g L\(^{-1}\))

VFA (g L\(^{-1}\))

TS, VS (g L\(^{-1}\))
EXPERIMENTAL RESULTS

Mono-digestion
Co-digestion

*Ratio 1.5:1

*Ratio 2:1

SBP (L kg⁻¹ VS)

OLR (g VS L⁻¹ d⁻¹)

t (d)
DISCUSSION: Technological design of the biogas plant

Based on experimental results

Chicken litter  6 Mg d\(^{-1}\)

**OPERATION**

- **OLR** = 2.5 g VS L\(^{-1}\)
- **SRT** = 51 d
- **AcoD ratio** = 1.5 : 1
- **\(\Theta\)** = 37 °C
- **pH** = 7.23

**SLUDGE**

- **COD\(_s\)** = 18.5 g L\(^{-1}\)
- **VFA** = 4.6 g L\(^{-1}\)
- **TAN** = 1.4 g L\(^{-1}\)
- **TS** = 5.8 %
- **VS** = 3.8 %

**BIOGAS**

- **SBP\(_v\)** = 1.15 L L\(^{-1}\)
- **SBP\(_{VS}\)** = 460 L kg\(^{-1}\) VS
- **CH\(_4\)** = 54 %
- **CO\(_2\)** = 43 %
- **H\(_2\)S** = 2520 ppm

**Scale-up**

- **Volume of sludge**  1,750 m\(^3\)
- **Volume of digester**  2,200 m\(^3\)

Technological parameters
DISCUSSION: Technological design of the biogas plant

**Feedstock parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeding rate</td>
<td>( M_{\text{total,in}} )</td>
<td>34.2</td>
<td>Mg d(^{-1})</td>
</tr>
<tr>
<td>Dry matter feeding rate</td>
<td>( T_{S_{\text{total,in}}} )</td>
<td>4.9</td>
<td>Mg TS d(^{-1})</td>
</tr>
<tr>
<td>Organic feeding rate</td>
<td>( V_{S_{\text{total,in}}} )</td>
<td>4.4</td>
<td>Mg VS d(^{-1})</td>
</tr>
<tr>
<td>Co-digestion ratio</td>
<td>( V_{S_{litter}} / V_{S_{\text{GLY}}} )</td>
<td>1.5</td>
<td>-</td>
</tr>
<tr>
<td>Chicken litter feeding rate</td>
<td>( M_{\text{litter}} )</td>
<td>6.0</td>
<td>Mg d(^{-1})</td>
</tr>
<tr>
<td>Daily chicken litter input (TS)</td>
<td>( T_{S_{\text{litter}}} )</td>
<td>3.1</td>
<td>Mg TS d(^{-1})</td>
</tr>
<tr>
<td>Daily chicken litter input (VS)</td>
<td>( V_{S_{\text{litter}}} )</td>
<td>2.6</td>
<td>Mg VS d(^{-1})</td>
</tr>
<tr>
<td>Raw glycerol feeding rate</td>
<td>( M_{\text{GLY}} )</td>
<td>2.1</td>
<td>Mg d(^{-1})</td>
</tr>
<tr>
<td>Daily raw glycerol input (VS)</td>
<td>( V_{S_{\text{GLY}}} )</td>
<td>1.7</td>
<td>Mg VS d(^{-1})</td>
</tr>
<tr>
<td>Fresh water input</td>
<td>( M_{\text{water}} )</td>
<td>26.1</td>
<td>Mg d(^{-1})</td>
</tr>
</tbody>
</table>

**OPERATIONAL PARAMETERS**

- OLR = 2.5 g VS L\(^{-1}\)
- SRT = 51 d
- AcoD ratio = 1.5 : 1
DISCUSSION: Technological design of the biogas plant

### Biogas production rate

<table>
<thead>
<tr>
<th></th>
<th>$Q_{\text{biogas}}$</th>
<th>2,005</th>
<th>Nm$^3$ d$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane production rate</td>
<td>$Q_{\text{CH}_4}$</td>
<td>1,085</td>
<td>Nm$^3$ d$^{-1}$</td>
</tr>
<tr>
<td>Engine power (CHP)</td>
<td>$P_{\text{CHP}}$</td>
<td>190 - 250</td>
<td>kW</td>
</tr>
</tbody>
</table>

| **Electrical energy**                      | $E_{\text{el}}$ | 4,560 | kWh d$^{-1}$   |
| **Thermal energy (heat)**                  | $E_{\text{th}}$ | 24,624 | MJ d$^{-1}$   |
| Income for electricity                     | $I_{\text{el}}$ | 502   | € d$^{-1}$     |
| Sulphur recovery potential                 | $S_{\text{out}}$ | 7.1   | kg S d$^{-1}$  |

**BIOGAS**

- $\text{SBP}_v = 1.15$ L L$^{-1}$
- $\text{SBP}_{\text{VS}} = 460$ L kg$^{-1}$ VS
- $\text{CH}_4 = 54\%$
- $\text{CO}_2 = 43\%$
- $\text{H}_2\text{S} = 2520$ ppm
DISCUSSION: Technological design of the biogas plant

Stabilized sludge

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digestate production rate</td>
<td>Mg_total,_out</td>
<td>29.8</td>
</tr>
<tr>
<td>Digestate (TS) production rate</td>
<td>Mg_total,_out (\text{TS})</td>
<td>1.7</td>
</tr>
<tr>
<td>Supernatant production rate</td>
<td>Mg_supernatant</td>
<td>22.9</td>
</tr>
<tr>
<td>Nitrogen recovery potential</td>
<td>kg N (\text{d}^{-1})</td>
<td>25.0</td>
</tr>
<tr>
<td>Phosphorus recovery potential</td>
<td>kg P (\text{d}^{-1})</td>
<td>1.5</td>
</tr>
</tbody>
</table>

SLUDGE

- TS = 5.8 %
- VS = 3.8 %
- COD\(_s\) = 18.5 g L\(^{-1}\)
- VFA = 4.6 g L\(^{-1}\)
- TAN = 1.4 g L\(^{-1}\)
- PO\(_4\)-P = 198 mg L\(^{-1}\)
DISCUSSION: Balance overview

Waste management

Energy

IN | OUT
---|---
Mg TS/d | Mg VS/d

Electrical energy
MWh/d

Biogas plant
Poultry farm

Thermal energy
GJ/d

Summer | Winter | Transitional
---|---|---
3,3 | 81,6 | 39,2
24,6 | Biogas plant

4,6

Poultry farm
Application of research outcomes

Socio-economic challenges

- Convincing farm authorities and decision-makers to move from traditional techniques to anaerobic digestion is mostly a hard job
- Getting financing from banks and investors or access to funds, loans, etc.
- Long payback of the biogas plant (BP)

  The fluctuation nature of the current global economy can cause the poultry farm to close or decrease its production, jeopardizing the operation of the BP

- Reaching a long-term compromise with the inhabitants of surroundings towns

Technical drawbacks

- High water consumption of the plant (Enable recirculation of supernatant?)
- Digestate quality parameters have to be improved (COD concentration stills to high)
- High content of hydrogen sulphide in biogas (H₂S removal in scrubbers?)
Application of research outcomes

Strengths

✔ AD process *contributes to mitigate the emission of greenhouse gases from manure* into the atmosphere, enhancing *CH₄-sequestration*

✔ *Manure management* of the poultry farm is solved in a more *sustainable way*

✔ *Biogas production rates can partially cover the energy needs of the poultry farm* (both thermal and electrical energy), reducing operational costs of the farm and generating a surplus that can be further commercialized

✔ *Digestate* possess attractive fertilizing properties
  - High content of N, P and K (and S in both digestate and ammonia); nutrients are easily assimilable for crop production
  - Nutrients recovery is possible

✔ The implementation of a BP *may generate more local jobs*
1. **Chicken litter** produced in the poultry farm is a **valuable substrate for biogas production**. AcoD of chicken litter and raw glycerol showed in general, a **positive impact on the anaerobic process** and helped to mitigate and prevent inhibition of the anaerobic process by ammonia.

2. A biogas plant of **V 2200 m³** is proposed based on operational parameters AcoD ratio **1.5** OLR **2.5 g VS L⁻¹ d⁻¹** and SRT **51 d**. Thus, it would be possible to transform **2150 Mg** of chicken litter produced in 6 cycles (annual production) into **722 000 m³** of biogas, yielding about **1660 MWh of electricity** and **8900 GJ of heat**.

3. Through anaerobic digestion, the **waste management** of the solid waste generated in a poultry farm is **improved** and the **energy needs** of the farm can be **partially covered**, bringing **substantial economic savings** to the farm.

4. **AD can help to mitigate environmental problems** related to animal manure, making animal farming more sustainable.
Ing. Juan José Chávez Fuentes, MSc.

Anaerobic Technology Group
Department of Environmental Engineering
Institute of Chemical and Environmental Engineering
Faculty of Chemical and Food Technology
Slovak University of Technology

Email: juan.fuentes@stuba.sk
www.fchpt.stuba.sk

Thank you for your attention!

This work was supported by the Slovak Grant Agency for Science VEGA (grant 1/0772/16) and the Mexican National Council of Science and Technology CONACYT.