A sustainable solution for pig manure treatment: Environmental compliance with the Integrated Pollution Prevention and Control directive (PIGMAN)

Rena Angelidaki
List of partners with co-ordinator first

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<th>Partner</th>
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<td>11 Department of Biological Applications and Technologies, University of Ioannina</td>
<td>ABUOI</td>
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Main environmental problems caused by pig manure

- Contamination soil and ground water
- Contamination surface water
- Emission of green house gasses (carbon dioxide and methane)
- Emission of ammonia gas (acidification)
- Odour emission
Pig manure on Cyprus
Sludge cleaning (KIBUTZ LAHAV-Israel)

- Total swine manure 70,000 m³/year,
- 2 settling pond (4,000 m³)
- Sludge cleaning every year – 4,000 m³
Main objective

To develop and test a working prototype of a digester + water treatment plant:

• Removal of organic matter (anaerobic digestion)
• P precipitation as struvite and biofibers
• N removal by partial ammonia oxidation process and anammox process
Anaerobic digestion

Manure

Other

Digester

Biogas

Water

Solids

Compost

Water treatment
Flow sheet suggestion

Manure → Anaerobic dig. → Separation → Membrane Filtration → Anphos → ANAMMOX → Clean Waste Water

- CH4-prod., COD reduction
- COD reduction
- CH4-prod., COD reduct., Part. P removal
- P removal, partial N removal
- N removal
- COD reduction
- CH4-prod., COD reduct., Part. P removal
- P removal, partial N removal
- N removal

Filtrate (permeate) → Fibers

Membrane filtration tank → Decanter centrifuge

Pig manure → Storage tank → UASB → ANPHOS → OLAND

Biogas → UASB

UASB → Storage tank

Decanted effluent → Concentrate

Fibs → Membrane filtration tank

ANPHOS → OLAND

OLAND
DTU’s activities:

- Codigestion of manure together with animal byproducts
- Ultrafiltration of centrifugate
- P removal by struvite precipitation
- N removal by anammox process
Hegndal biogas plant

Reactor

Decanter Centrifuge

Ultra filter
Foaming 12 hours after initiation of the filtration, membrane clogging after 3 days of operation
Conclusions for the membrane filtration step

- Ultrafiltration not feasible
- Problem: We need to reduce the COD content of the effluent before it enters the ANAMMOX process.
- Solution: Post digestion in UASB reactor.
Revised process scheme

- **Anaerobic dig:** CH4-prod., COD reduction
- **Separation:** COD reduction
- **UASB reactor:** CH4-prodion, COD reduction, P removal, partial N removal
- **Anphos:** N removal
- **ANAMMOX:** Clean Waste Water
- **Biofibers**
Post digestion in UASB reactors

Reactor Volume: 350 ml
HRT: 96 hours
Temperature: 55oC
COD removal: UASB experiments

ANPHOS effluent from centrifuged digested manure was used as influent

Centrifuged digested manure was used as influent

Degradable COD removal efficiency (%)

Days

 reactor R1

 reactor R2

4x diluted
2x diluted
nondiluted
COD removal: conclusions

• 65-70 % of the organic matter in the centrifuged digested manure was anaerobically degradable.

• Degradable COD removal efficiency was around 70÷80 %.

• Almost no removal of ammonia and phosphates were noticed.
P removal as struvite (ANPHOS)

Anaerobic phosphorus removal

\[ \text{Mg}^{2+} + \text{NH}_4^+ + \text{HPO}_4^{2-} + 6\text{H}_2\text{O} \rightarrow \text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O} + \text{H}^+ \]

Operational Temp  
Optimal pH  
Mg+  
Reaction time  
30 oC  
8-10  
MgO  
1 hour
ANPHOS: conclusions

- High phosphate removal (95%)
- Ammonia removal (6 - 7 %) was both due to struvite formation, but also to ammonia stripping
ANAMMOX: Batch experiments

Substrate:
Synthetic wastewater containing NH$_4^+$, NO$_2^-$, NO$_3^-$, PO$_4^{3-}$, HCO$_3^-$

Inoculum: OLAND sludge (Ghent University)

114 mL serum vials
UASB reactor experiments

Start – up: synthetic wastewater containing NH$_4^+$, NO$_2^-$, NO$_3^-$, PO$_4^{3-}$, HCO$_3^-$

Total volume = 200 mL

HRT = 2.2 days

Anammox bacteria: granules: wastewater = 1:1:1
Partial aeration: an approach for improving Anammox process performance

Aeration of anaerobically digested pig manure in order to reduce as much as possible the residual biodegradable organic matter.

Set-up: A mixture of 20% of activated/nitrifying sludge and an 80% of digested pig manure, were aerated with an air pump during 24 hours.
Ammonia removal

Anammox reactor experiments are in progress
Removal of ammonia at different steps tested

<table>
<thead>
<tr>
<th>Step</th>
<th>NH$_4^+$ removal (%)</th>
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<tr>
<td>UASB</td>
<td>0 ÷ 4</td>
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<tr>
<td>ANPHOS</td>
<td>6 ÷ 7</td>
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<tr>
<td>ANAMMOX</td>
<td>Up to 100</td>
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ANAMMOX: conclusions

• Mass balance of the batch test showed that ANAMMOX plus nitrification and denitrification were taking place.

• Reactor experiments gave indication that the ANAMMOX bacteria were immobilised in the granules.

• 100% ammonia removal was achieved
Final process scheme suggestion

Manure → Anaerobic Digestion → Separation → UASB post digestion → Partial Aeration → Anammox process → Clean Waste Water

- CH4-prod., COD reduction
- COD reduction
- CH4-prod., COD reduct., Part. P removal
- Partial NH4+ conversion
- N removal
- Biofibers
- COD reduction
- Part. P removal
- N removal
- Manure
- Biofibers
- COD reduction
- Part. P removal
- N removal
Researchers involved in the present study

• Zhenwei Zhu
• Francesk Juan Roca
• Juan Carlos
• Dimitar Karakashev
• Jens Ejbye Schmidt
• Irini Angelidaki
Removal of COD, PO₄ and soluble N (NH₄, NO₂+NO₃)

- **Start**
  - Full-scale anaerobic digestion of pig manure
    - 19 g COD/L
    - 0.07 g PO₄/L
  - Pig manure: 70 COD/L, 6 g sol N/L, 0.09 g PO₄/L

- **Middle**
  - ANPHOS + UASB + aeration
    - 24 g COD/L
    - 0.003 g PO₄/L

- **Final**
  - ANAMMOX (assuming 100% addition of aerated manure)
    - 2.3 g COD/L
    - 0.3 g sol N/L
    - 0.003 g PO₄/L

**Analysis**

- **Full-scale anaerobic digestion of pig manure**
  - 70 % COD
  - 35 % sol N
  - 22 % PO₄

- **ANPHOS + UASB + aeration**
  - 26 % COD
  - 45 % sol N
  - 74 % PO₄

- **ANAMMOX (up to 30% addition of aerated manure)**
  - 1 % COD
  - 15 % sol N
  - 0 % PO₄