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“Modelling and Technological Tools to Prevent Surface and Ground-Water Bodies from Agricultural Non-Point Source Pollution Under Mediterranean Conditions”

NPP-SOL

Report on Designing an Anaerobic Digestion System and Digestate Post-Treatment

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Non-Point Pollution SOLutions (NPP-SOL)

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Report on Designing an Anaerobic Digestion System and Digestate Post-Treatment

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1. Introduction

Anaerobic digestion (AD) is a sustainable technology for converting organic waste into biogas, a renewable energy source, and nutrient-rich digestate. Farm-style AD systems can offer decentralized waste management and energy production solutions, particularly in rural areas. The digestate produced can be a valuable resource but requires proper treatment to avoid environmental pollution. Constructed wetlands (CW) are a cost-effective and eco-friendly method for post-treating digestate to ensure safe disposal or reuse. Digestate from an AD system contains nutrients (N, P, K) and organic matter but may also have often contains salts, including sodium (Na^+), as well as other dissolved ions and minerals. Sodium concentration in digestate can vary widely, typically ranging between 0.5 to 5 g/L depending on the feedstock and operational conditions. It is generally higher in liquid digestate compared to the solid fraction because sodium is water-soluble. If digestate is used in agriculture without further treatment, high sodium levels can affect soil structure, reduce permeability, and impact crop growth if applied in large amounts over time (e.g., sodicity issues). Furthermore, excessive sodium in runoff from digestate application can contaminate surface and groundwater. If digestate is treated in CW, sodium may need to be monitored to avoid long-term impacts on plant and microbial health in the wetland. Combining AD with CW may offer circular economy integration as it recycles organic waste into energy and agricultural inputs. Additional environmental benefits of this process integration involve the reduction of methane emissions from unmanaged organic waste and prevention of groundwater contamination by treating digestate. In terms of cost-effectiveness, it involves low operational costs for farm-scale systems and minimal energy requirements.

2. Designing an Anaerobic Digestion System

The design of a farm-scale AD system requires careful consideration of feedstock, system components and operating parameters.

2.1. Feedstock

- Suitable organic waste materials available onsite: animal manure, crop residues, food waste.
- Characteristics: high moisture content, low contamination with non-biodegradable materials (straw, wood, plastic, glass) and balanced C:N ratio (20:1 to 30:1).

2.2. System Components

Digester Tank:

- Material: High-density polyethylene (HDPE).
- Capacity: Each one of the digesters contains 20 cubic meters and can be loaded with up to 200 kg of wet manure + 400L of water /day

Inlet:

- Designed to allow easy feeding of waste.
- Includes a mixer or a pre-treatment chamber for large organic particles.

Outlet for Digestate:

- Positioned at the base for continuous discharge.

Gas Storage Unit:

- Floating drum or fixed dome design.
- Capacity: 5 cubic meters to store biogas for farm use.

Gas Utilization:

- Biogas stove, generator, or heating device connected via gas piping with a pressure regulator.

Heating System (optional in the winter):

- To maintain optimal digester temperature (30–40°C for mesophilic conditions).

2.3. Operating Parameters

- Temperature: 30–40°C for mesophilic digestion.
- Retention Time: ~30 days.
- pH: 7–7.5 monitored regularly to prevent system failure.

3. Setup of the Anaerobic Digestion System

3.1. Site Selection

- Near the source of waste generation (farm).
- Away from residential areas to avoid odor issues.
- Accessible for maintenance and digestate transport.

3.2. Installation Steps

1. Level the site and construct a foundation for the digester tank.
2. Assemble the tank, inlet, and outlet pipes.

3. Connect the gas storage unit and gas piping to the utilization point.
4. Install safety features like a pressure release valve and flame arrester.
5. Fill the digester with inoculum (e.g., cow manure slurry) and water to start microbial activity.

3.3. Initial Operation

- Gradually introduce feedstock to avoid overloading.
- Monitor gas production and pH during the startup phase.

Figure 1. Farm farm-scale anaerobic digestion system in Newe-Ya'ar Research Center, Israel

4. Digestate Post-Treatment in Constructed Wetland

Digestate from an AD system contains nutrients (N, P, K) and organic matter but may also have often contains salts, including sodium (Na^{+}), as well as other dissolved ions and minerals.

4.1. Constructed Wetland Design

Wetland Type:

Horizontal flow constructed wetlands.

Dimensions: Length: 4–6 m; Width: 1.5–2 m; Depth: 1.4–1.8 m.

Filter-bed:

- Gravel and sand layers for filtration.
- Depth: 30–50 cm for substrate layers.

Vegetation:

- A variety of wetland plants acclimated to high organic loads and salt content of digestate from the AD system. Sodium-tolerant (halophytic) plants can be used in CW treating high salinity water, as they can thrive in high-sodium environments. Plants like Vetiver *(Chrysopogon zizanioides), Cyperus corymbosus, Cyperus articulated, Hydrocotyla vulgaris, Canna spp., Typha latifolia, Iris pseudacorus, Thalia dealbata, Eichornia crassipes, Bacopa monnieri*
- Root systems aid in nutrient uptake and oxygen transfer.

4.2. Operating Principles

- The digestate enters the inlet and flows through the filter-bed.
- Suspended solids are filtered out, and nutrients are absorbed by plants.
- Microbial activity in the filter-bed reduces organic matter.

4.3. The role of sodium in CW

The role of sodium in CW depends on its concentration and can influence water chemistry, soil properties, vegetation, and microbial activity. In moderate levels, sodium contributes to the overall salinity of the water, which can suppress certain pathogens, potentially aiding in the treatment of liquid manure. High sodium concentrations increase salinity, which can harm plants, inhibit microbial processes, and reduce the wetland's efficiency. Sodium can lead to dispersion, causing filter-bed particles to disaggregate. This reduces permeability and can lead to clogging, affecting water flow and treatment performance. Managing sodium adsorption ratio (SAR) is crucial to maintaining CW structure. High SAR values can destabilize the filter-bed, impairing the wetland's long-term functionality. High sodium levels affect microbial communities involved in critical processes like nitrification, denitrification, and phosphorus removal.

4.4. Maintenance

- Regular harvesting of plants.
- Periodic monitoring of influent and effluent quality (pH, EC, TOC, COD, SAR, Total N and Total P).
- Occasional removal of sludge buildup in the substrate.

Figure 2. Biomass sampling from the constructed wetland in Newe-Ya'ar Research Center, Israel

5. Conclusion

Integrating anaerobic digestion systems with constructed wetlands offers a sustainable solution for managing organic waste at the household level. This approach not only generates renewable energy but also ensures safe and efficient utilization of digestate, contributing to environmental conservation and resource recovery. Future research should focus on optimizing system performance and scaling up for broader community applications.