Sustainable biogas purification system in landfills and municipal solid waste treatment plants: The Greek case study

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Introduction

The use of biogas for energy production is rapidly increasing across the European Union, driven by its lower cost and significant reduction in greenhouse gas (GHG) emissions compared to fossil fuels. However, conventional physical-chemical desulfurization techniques, while effective at reducing H_2S concentrations in biogas, pose substantial environmental challenges. These methods often require large quantities of chemical reagents, generate secondary waste, and incur high energy costs, which limit the widespread adoption of biogas as a viable fuel option. The BiogasNet technology offers an innovative solution by integrating biological processes to efficiently and sustainably desulfurize biogas, making it more suitable for energy production.

Materials and Methods

The nitrification unit consists of a scrubber and a nitrification bioreactor. In the scrubber, the ammonia content of the emissions of the composting unit is transferred to the aqueous phase. The scrubber effluent is directed to the nitrification bioreactor for the biological conversion of ammonia to nitrate ions under aerobic conditions.

The desulphurization unit includes an anoxic biofilter fed with the biogas produced from the landfill and the nitrate-rich solution from the first unit. The hydrogen sulfide (H_2S) in the biogas is bioconverted to sulfate ions (SO_4^{-2}). The sulfate ion stream is mixed with the ammonium ion solution of the first unit to produce a value-added product, $(NH_4)_2SO_4$, which can be used as a fertilizer.

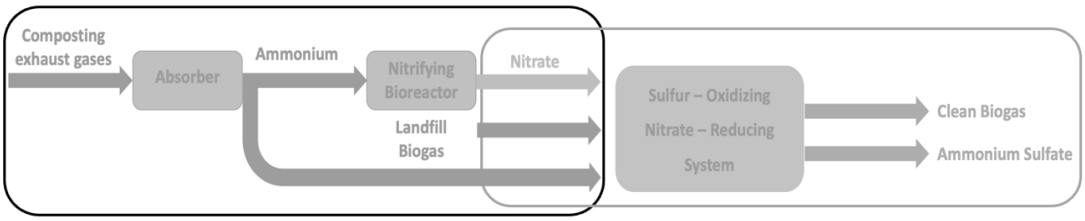
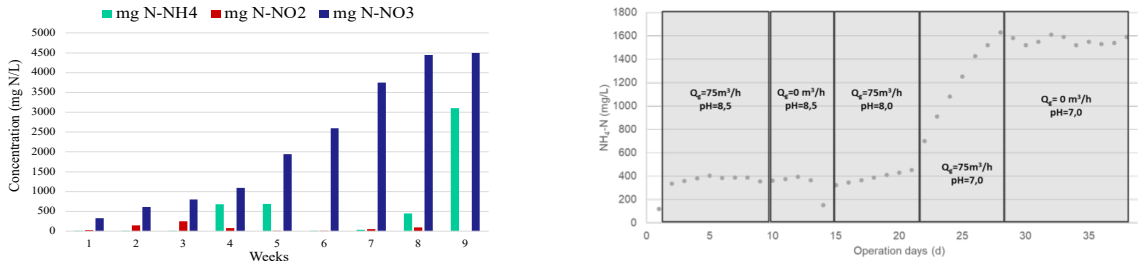


Figure 1. Diagram of the biogas purification system, where the nitrification and desulfuration stages are shown.

Results / Conclusions

The nitrification process was evaluated over a 9-week period within a 1000L bioreactor. The bioreactor initially operated in fed-batch mode for the first 5 weeks, treating up to 115 g NH_4-N/m³/day. During weeks 1 to 3, the system successfully achieved ammonium bioconversion with an inlet load (IL) of 50 g NH_4-N/m³/day. Increasing the IL to 115 g NH_4-N/m³/day during weeks 4 and 5 resulted in higher ammonium concentrations. Feeding was paused in week 6 to allow for complete bioconversion of N-NO_3. After transitioning to continuous mode operation with a nitrogen load of 160 g NH_4-N/m³/day during weeks 7 to 9, the system experienced lower nitrification yields and nitrate accumulation. The average ammonia gas inlet was maintained at 70-110 ppm in a controlled 65L working volume. After 40 days, steady-state conditions were achieved, characterized by a composting gas flow rate of 75 m³/h, pH 7.0, and daily liquid transfer of 40L to the bioreactor.



(a) (b)

Figure 2. (a) Nitrogen concentrations in different forms in the nitrification bioreactor during synthetic medium feeding period and (b) Ammonia nitrogen concentration in the scrubber.

During the fed batch operation, the liquid from the scrubber was used as the nitrogen source. For the first 18 days, the nitrification rates were low, although ammonia nitrogen was converted to nitrate nitrogen. However,

after additional inoculation on Day 19, nitrification yields improved significantly. The lag phase was very short, and most of the available ammoniacal nitrogen was consumed by Day 49. Notably, a temperature drop below 10°C due to heating failure on Day 50 did not significantly affect nitrification efficiency. Data from Days 68 to 115 are not depicted due to low nitrification rates during low temperature operation, although nitrification efficiency during this phase was very low, it was not zero.

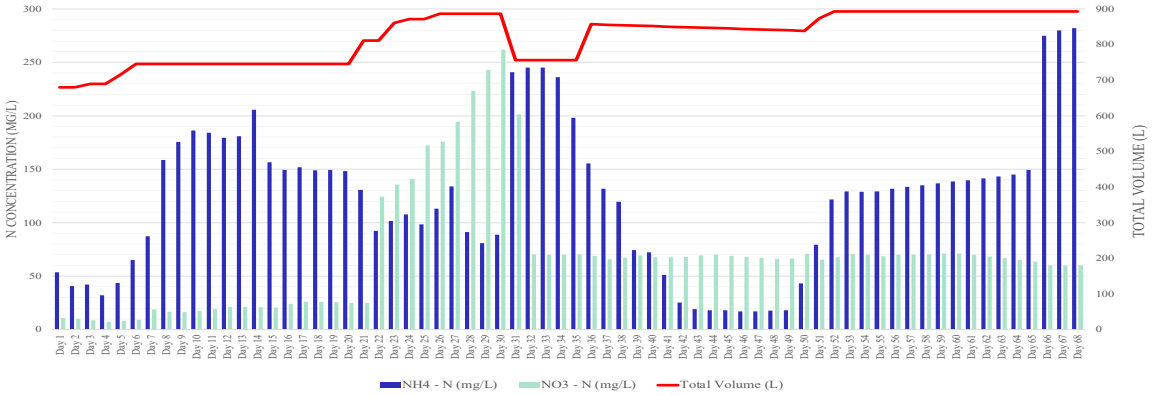
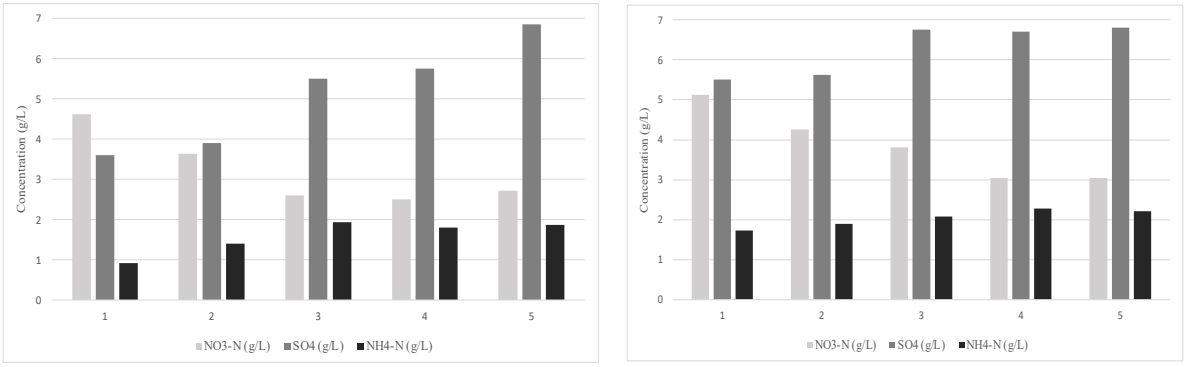


Figure 3. Nitrification bioreactor operation with ammonium scrubber feeding.

The desulfurization process involved the operation of the unit with biogas stream and two trial experiments in a 200L system using 50L anaerobic sludge as inoculum, 20L of mineral medium containing Na_2CO_3 (40 g/L), $NaNO_3$ (68 g/L), NH_4Cl (27 g/L), and NPK (3L), and a synthetic medium of sulfide (H_2S), more specifically a solution of 109 g/L Na_2S, in the evaluation of microbial activity within the anoxic biogas desulfurization process. During the first trial, over six days, sulfate concentrations increased, peaking at 1422.81g on Day 5, indicating effective microbial reduction of sulfur compounds. Thus, the added H_2S from the Na_2S solution served as a substrate for sulfur-reducing microorganisms. In the second trial, sulfate levels mirrored the first trial, confirming the reliability and robustness of the process.



(a) (b)

Figure 4. (a) Measurements during the first evaluation of microbial activity and (b) Measurements during the second evaluation of microbial activity.

The comparative analysis between the two trials revealed a consistent and replicable pattern in microbial activity. Noteworthy trends in nitrate, sulfate, and ammonium concentrations, coupled with stable pH levels and system volume, underscore the reliability and robustness of the experimental setup, thus, encouraging the operation of the unit with H_2S bio-sourced from biogas stream.

The efficiency of the anoxic biogas desulfurization process can be assessed by comparing the estimated H_2S input with the observed SO_4 concentrations in the liquid phase. The initial H_2S input was estimated at approximately 3.1 moles, equivalent to 307 g of SO_4. By comparing this with the initial and final SO_4 concentrations from the data table, it is possible to evaluate the efficiency of the process. The observed SO_4 production of 472.54 g is approximately 1.54 times greater than the expected production based on the estimated H_2S input. This suggests that the anoxic biogas desulfurization process in the current trial has demonstrated a growth in efficiency beyond the initial estimations.

During the last operational phase of the desulphurization plant where biogas was continually fed, high conversion efficiencies (~75%) were observed given the sharp increase in the sulfates concentration in the bioscrubber. Daily an increase in sulfates concentration of almost 1.9 g/L was observed. These results highlight the effectiveness of the BiogasNet technology in utilizing biological processes for both nitrification and desulfurization, thus transforming biogas into a cleaner and more sustainable fuel source.

Conclusions

In light of these findings, it is crucial to continue vigilant monitoring and analysis in subsequent trials, ensuring ongoing validation and refinement of microbial dynamics understanding. Further optimization opportunities should be explored, leveraging observed patterns and the system's demonstrated consistency to enhance efficiency and foster long-term sustainability.

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