

Improvement of biogas production in anaerobic digestion process through numerical model predictions

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The growth in population, urbanization, and industrialization has led to a substantial increase in both wastewater production and energy consumption, posing significant challenges related to their environmental impacts. The global demand for renewable energy sources and effective waste management strategies has intensified research into sustainable approaches that address both energy recovery and environmental protection, to contribute to circular economy.

Sewage sludge is a byproduct of wastewater treatment systems that can be used as feedstock for energy production by anaerobic digestion (AD) (Enebe et al., 2023). AD is a key process in wastewater treatment plant (WWTP) for the biological stabilization of sewage sludge, which can produce a fertilizer for agricultural applications and the simultaneous production of biogas fuel, which is composed mainly by methane (CH₄) and carbon dioxide (CO₂). Biogas is a renewable energy and environmentally friendly fuel, because methane can be utilized for electricity generation, heating, introduce in natural gas network and as a transportation fuel (Scarlat et al., 2018). AD offers a sustainable alternative by reducing sludge volume and producing biogas that at least can partially cover the energy requirements of WWTP. This dual benefit underscores the importance of optimizing the AD processes to maximize the biogas production and minimize sludge disposal costs (Li et al, 2024).

According to APA (2021), it is estimated that the 27 countries of the European Union produce annually approximately 10.14 million tonnes of dry matter of WWTP sludge. In Portugal, there has been a significant increase in the production of sewage sludge, from 2016 with around 429 thousand tons to 531 thousand tons in 2019. The biogas valorisation in WWTP was estimated in 2019, around 31 million of kWh.

Sewage sludge from WWTP is composed mainly of organic matter, including proteins, carbohydrates, lipids, and cellulose. It also contains inorganic components such as silica, aluminum, iron, calcium, and magnesium compounds. Essential nutrients like nitrogen and phosphorus are present in significant amounts. Additionally, the sludge includes trace elements such as copper, zinc, lead, and cadmium, as well as microbial biomass and residual polymers used during the treatment process (Stewart et al., 2022). The optimization of the anaerobic digestion process is essential for enhancing biogas yield, ensuring process stability, and achieving energy neutrality in WWTP operations. However, achieving these goals requires a precise control of operational parameters such as temperature, pH, alkalinity, inhibitor concentrations, flow, hydraulic retention time (HRT), organic loading rate (OLR), chemical oxygen demand (COD) and sludge composition. Understanding and simulating these parameters accurately is critical for improving process performance.

The present work aims to contribute for an improved understanding of the AD of mixed sludge (primary and secondary), seeking methane production. The study involves the numerical simulation of the AD system of a WWTP, analysing its susceptibility to disturbances in parameters such as: organic load, sludge age, temperature, etc. For each parameter evaluated, the effects on the biogas production and its methane content will be quantified, and appropriate actions to maximize methane production will be analysed. The numerical simulation will be performed using the GPS-X software developed by Hydromantis, which allows modelling wastewater treatment processes (Figure 1), based on ADM1: Anaerobic Digestion Model No 1 (Hydromantis, 2025). The methodology will involve simulating multiple scenarios to assess how oscillations in sludge characteristics and process parameters affect the biogas production. By optimizing these variables, the study seeks to enhance the biogas yield while maintaining process stability and efficiency. It is expected that results will provide insights into the interplay between sludge management and energy recovery, contributing to the development of sustainable and energy-efficient WWTP operations.

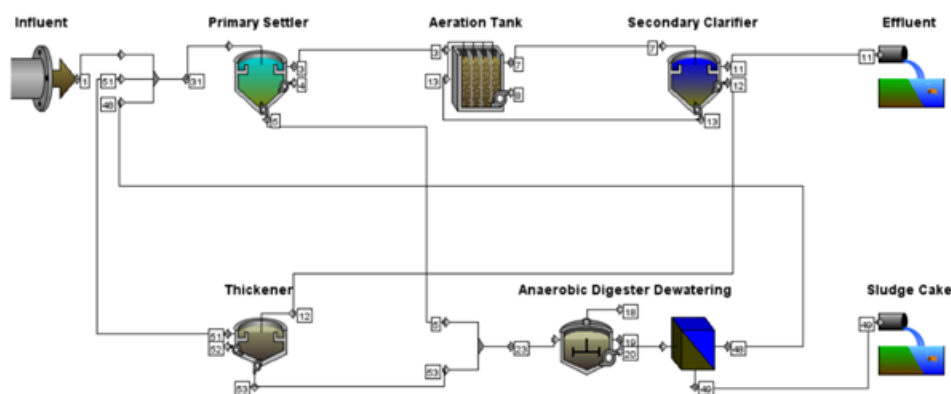


Figure 1. Scheme used by GPS-X for anaerobic digestion simulation (Hydromantis, 2025).

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