# Assessment of greenhouse gas emissions during the anaerobic sludge mineralization process in vertical wetlands

Silva, D. A. P.*, Neves, T. A.*, Matos, M. P.**, Souza, C. L. *, Ferreira, D. B*.

*Department of Sanitary and Environmental Engineering, Federal University of Minas Gerais (Universidade Federal de Minas Gerais), Belo Horizonte, Minas Gerais, Brazil.

**Departament of Environmental Engineering, Federal University of Lavras, Lavras, Minas Gerais, Brasil.

**Highlights:**

The treatment of sludge from wastewater treatment plants in vertical wetlands is a low-cost technology.

· During the dewatering and stabilization of sludge in vertical wetlands, natural processes, and biochemical action lead to the production of gases with greenhouse effect potential.

· Adoption of technology that assumes local and economically viable conditions and that is in line with the principles of environmental sustainability.

**Keywords:** Greenhouse gases, anaerobic sludge, vertical wetlands

## INTRODUCTION

Sewage sludge (SE) poses a significant challenge in its proper disposal at sewage treatment plants (STPs). While sludge production typically accounts for less than 1% of the total wastewater treatment volume, the capital expenditure for its handling and management can reach 20-60% of the total operating costs of a wastewater treatment plant (WWTP) due to the necessary pre-treatment steps required before final disposal (Von Sperling and Andreoli, 2014). As a result, effective treatment is essential to ensure proper disposal, preventing environmental impacts and safeguarding the overall benefits of sewage collection and treatment systems (Silva et al., 2021). In Brazil, annual sludge production has reached more than 80 million tons (80% water content) and continues to increase. It is estimated that the sludge generated by 2025 will represent a total of 100 million tons. For correct final disposal, the ideal is to adopt treatment technologies that provide low operating costs, suitability to local conditions, and economic viability, while also complying with the principles of environmental sustainability (Tsutiya et al., 2001).

Typical sludge treatment processes involve solid-liquid separation, stabilization, and dewatering to reduce biodegradable organic matter and sludge volume (Nielsen and Larsen, 2016). A technology that has been widely used in sludge treatment is the use of wetlands, due to their lower energy demand, low operating costs, absence of chemical additives, and reduced environmental impact. Studies have shown that vertical flow wetlands for sludge treatment produce material rich in organic matter, with low moisture content. Additionally, the resulting biosolids can be safely applied to agricultural land.

The mineralization of organic material through biochemical processes leads to the production of gases with a potential greenhouse effect (GHG), primarily $CO_2$, $CH_4$, and $N_2O$. This presents an environmental concern that must be addressed before the widespread application of this technology. In this context, the objective of the present study is to evaluate $CO_2$ and $CH_4$ emissions from the mineralization of sludge accumulated in vertical wetlands, tested on a pilot scale over a 21-month period. The study aims to account for the effects of annual seasonality, including both dry and rainy periods.

## METHODOLOGY

This research was conducted in Belo Horizonte, MG, specifically at the Sanitation Research and Training Center (CEPTS) of UFMG/COPASA. It is situated within the Ribeirão Arrudas Sewage Treatment Plant (ETE-Arrudas), which is operated by the Minas Gerais Sanitation Company (COPASA) and primarily receives sanitary sewage. The plant is located at the geographic coordinates 19°53′42″ S and 43°52′42″ W.

At CEPTS, twelve pilot-scale vertical wetland units of uniform size were installed. Each unit has a volume of 0.9 $m^3$ (with a height of 0.9 m and an area of 1 $m^2$). These wetlands were filled with a support medium, which consisted of four layers arranged vertically: 10 cm of crushed sand (0.10 mm), 10 cm of gravel (5 to 25 mm), 15 cm of gravel (25 to 50 mm), and 15 cm of gravel (50 to 100 mm). Above the bed, a 40 cm space was designated for the storage of accumulated sludge. Drainage pipes (40 mm in diameter) made of PVC with 8 mm holes were installed at the bottom of each bed to collect leachate.

The units received a combination of sludge (0.02 $m^3$) and UASB reactor effluent (0.02 $m^3$) twice a week for the initial four months, serving as an acclimation period, followed by sludge-only loading every two weeks (15 days). To assess greenhouse gas emissions performance among the twelve units, they were divided into three configurations: four units planted with Tifton-85 grass (*Cynodon spp.*), four units planted with elephant grass (*Cenchrus purpureus*), and four control units without vegetation. Each configuration was subjected to two sludge loading rates: 75 kg of ST/$m^2$/year and 150 kg of ST/$m^2$/year.

The units were in operation with sludge following an acclimatization period from November 2022 to February 2024, resulting in the accumulation of a layer of sludge residue with varying thicknesses depending on the loading rate. Gas sampling was conducted using the static chamber method. Each sampling session comprised four gas collections over a fifteen-day period, spanning from the start of loading until the end of the resting period before the subsequent loading. The concentration of greenhouse gases in the chamber samples was determined by calculating the ratio between the peak areas of the samples obtained from the chromatograph and the areas of standard gas concentrations. Following this, the rate of gas increase over time was calculated based on the concentrations obtained from the chamber samples, utilizing a linear adjustment model. Once the best fit was determined, the flux can be calculated using the equation 1:

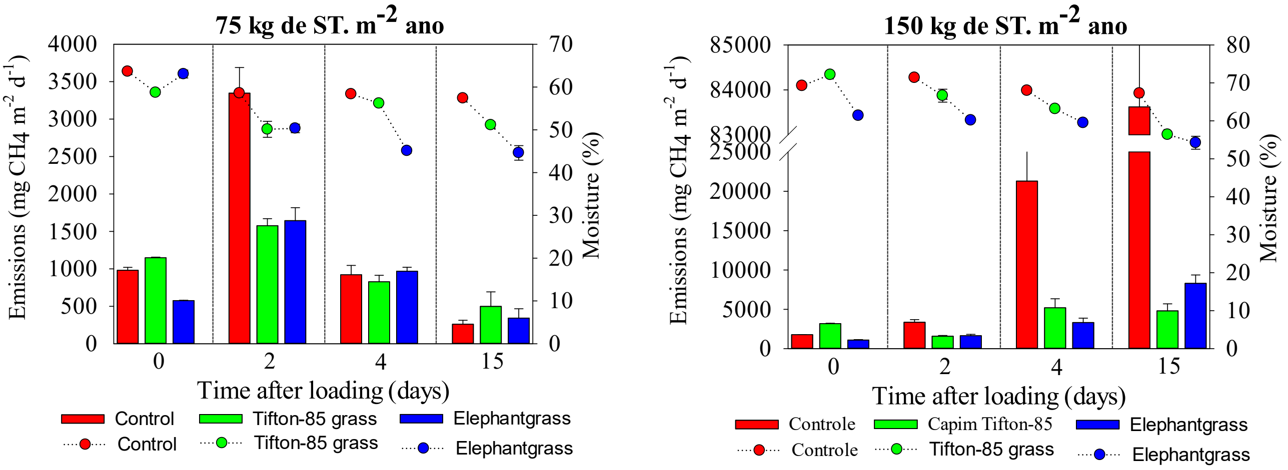
Equation 1: $\text{Flux}\ (\mu g\ CH_4\ m^{-2}\ h^{-1}) = \left(\frac{dC}{dt}\right) . \frac{V}{A} . \left(\frac{m}{Vm}\right)$

Where: dC/dt represents the rate of change of the gas inside the chamber per unit of time (ppm/hour); m is the molecular weight (g); V and A are the volume (L) and area of the chamber (m²), respectively; Vm is the molecular volume of the gas also in L, which needs to be corrected according to the temperature inside the chamber during sampling (1 mole of gas occupies 22.4 L under normal temperature and pressure conditions - CNTP), simply multiply 22.4 by (273 + T)/273, where T is the average temperature inside the chamber in degrees Celsius

## RESULTS AND CONCLUSIONS

The average daily $CH_4$ emission rates from the loading period to the end of the resting period are presented in Figure 1. Emission rates varied throughout the monitoring period, with the highest daily rates observed in control units and lower emissions in planted units. According to Ugget et al. (2012), greenhouse gas emissions are influenced by temperature and humidity conditions. Wang et al. (2019) also suggest that higher temperatures, combined with more anoxic conditions and the absence of oxygen, enhance the anaerobic microbial activities of methanogenic bacteria, leading to increased $CH_4$ emissions.

**Figure 1 –** Methane emissions in vertical flow wetlands during sludge treatment at loading rates of 75 and 150 kg TS m² year⁻¹.



For the loading of 150 kg TS m² year⁻¹, a different pattern was observed compared to the 75 kg TS m² year⁻¹ load, with emissions continuing to rise until the end of the resting period. These results align with findings from other studies, which reported increased $CH_4$ fluxes as a result of higher sludge loads. Greater sludge loads provide more fresh organic matter for anaerobic decomposition, with methanogenesis being the final stage of this process (Zhao et al., 2020). Based on the results, increasing the loading rate led to higher methane emissions. The presence of vegetation significantly reduced methane emissions, particularly during the resting period at a loading rate of 75 kg TS $m^2$ $year^{-1}$, due to enhanced aeration in the units.

## ACKNOWLEDGMENTS

The authors acknowledge the support received from the Fundação de Amparo à Pesquisa do Estado de Minas Gerais – FAPEMIG, the Instituto Nacional de Ciência e Tecnologia em Estações Sustentáveis de Tratamento de Esgoto – INCT ETEs Sustentáveis and the project Aliança Estratégica para Pesquisa, Desenvolvimento e Inovação PD&I entre COPASA, UFMG e CR-ETES.

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