

Evaluation of Methane Production in an Artificial Wetland Used as a Wastewater Treatment

María Montes¹, Alejandra Vásquez¹, Melissa Cervantes², Pedro García¹ and Víctor Aguilar³

1. Department of Environmental Engineering, Institute for Engineering, University of Veracruz, Boca del Río, Ver. 94294, Mexico

2. Department Chemical Engineering, Faculty of Chemical Sciences, University of Veracruz, Boca del Río, Ver. 94294, Mexico

3. Department of Administration, Open Education System, University of Veracruz, Boca del Río, Ver. 94294, Mexico

Abstract: Currently, artificial wetlands have been promoted for wastewater treatment. These wetlands simulate the conversion of organic matter and nutrients, in which microorganisms attached to the support medium and plants act as active agents in the treatment. However, flooded soils have anaerobic conditions that favor the production of methane, a greenhouse gas with a global warming potential 21 times greater than that of CO₂. Therefore, a HSSFW (horizontal subsurface flow wetland) was installed to evaluate its efficiency by determining the COD (Chemical Oxygen Demand) and the CH₄ generated, using a gas chromatograph. The analysis revealed a maximum methane emission of 10.32% over a period of 79 days, or 23 hydraulic retention times, and a 72.52% organic matter removal rate, measured as COD, was achieved, concluding that it is an efficient system and that artificial wetlands are analyzed from the perspective of climate change mitigation and energy utilization.

Key words: Methane, mitigation, wetlands.

1. Introduction

Rapid population growth demands high consumption of natural resources, among which the high requirement for water stands out. Water is one of the resources in crisis because it is an essential element for life on the planet.

However, and much to our dismay, its use is determined by its availability in terms of quality and quantity, depending on its intended use. This generates wastewater that is discharged into receiving bodies of water and becomes a potential risk to human health, associated with diseases that are responsible for 80% of morbidity and mortality in developing countries. Furthermore, this wastewater contains a variety of organic substances and nutrients. When discharged into a body of water, these pollutants can degrade the quality of the aquatic environment and negatively impact ecosystem health [1, 2].

This is why sustainable technologies are emerging today; let's talk about the topic of "constructed wetlands".

Constructed wetlands are designed and built to effectively treat municipal wastewater, as well as rainwater runoff. They are also effective at removing water pollutants such as suspended solids, nitrogen, phosphorus, organic matter, and metals [3, 4].

Furthermore, they are natural purification systems where various decontamination processes are carried out simultaneously by physical, chemical, and biological components. It's worth noting that this system has low installation and maintenance costs, as well as being easy to operation [5-7].

Reducing nutrients and pollutant loads in wastewater can generate some byproducts such as methane, carbon dioxide, and nitrous oxide, called greenhouse gases, which in turn generate environmental problems by contributing to global warming.

Methane emissions into the atmosphere from wetlands depend not only on its production (methanogenesis) but also on its consumption or oxidation and its transport

from the sediment to the atmosphere.

However, not all the produced gas is emitted into the atmosphere, as some of it is oxidized by aerobic bacteria that inhabit the less reduced zones [8, 9].

Methane transport to the atmosphere occurs through three mechanisms: (a) passive diffusion through plants, known as ventilation; (b) diffusion through water; and (c) boiling or bubble formation (Fig. 1). Transport CH_4 by plants is through the aerenchyma, which are empty spaces that hydrophytes possess to transport oxygen from the leaves to the roots. The diffusion CH_4 through water is very slow due to its low solubility. Boiling refers to the passage of CH_4 bubbles through the water column without dissolving in it. This latter phenomenon has been observed to be an important mechanism for the transport of methane to the atmosphere [10, 11].

Therefore, it becomes necessary to quantify the contribution of these gas emissions. Similarly, it is necessary to know the methane concentration at different distances from the wetland to understand the factors that influence its production and thus be able to establish measures to mitigate the emission of this gas [12].

2. Materials and Methods

A horizontal flow subsurface constructed wetland with a working volume of 40 L and a flow rate of 0.19 L/min with a retention time of three days was constructed. The plant selected for water purification was the broadleaf cattail (*Typha latifolia*), as shown in Fig. 2. The filter used consisted of 10 cm (4-6 mm) sand, volcanic gravel with a particle size of approximately 6-12 mm, and mulch as fertilizer for the cattails, as shown in Fig. 3. The wetland was located in the backyard of the Institute of Engineering, and the wastewater was obtained from a discharge point located on the Mocambo Campus of the Veracruzana University.

2.1 Description of the Design and Construction of the Methane Collectors Produced in an HSSF

To quantify methane in the HSSF (Horizontal Subsurface Flow Constructed Wetland).

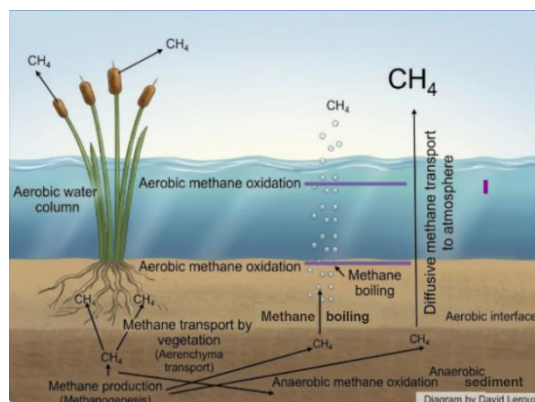


Fig. 1 Simplified scheme of the production, oxidation and transport to the atmosphere of CH_4 in wetlands.



Fig. 2 Constructed artificial wetland.

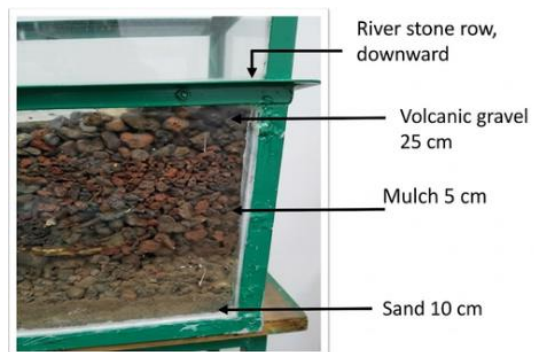


Fig. 3 Wetland filter layers.



Fig. 4 Collector pipe system.

six 60 cm long by 2 cm diameter PVC (Polyvinyl Chloride) pipes were placed, each with a valve that controlled the methane flow. A threaded connector was placed at one end of each pipe to attach a threaded cap, which has a piece of copper inserted to facilitate methane collection through a 0.5 cm diameter latex hose. The tubes were covered with silicone and Teflon tape to prevent gas leaks. A PVC cap was attached to the other end of the tube and fixed to the bottom of the constructed wetland (Fig. 4).

2.2 Methane Collection Tube System at the HSSF

In wetlands, redox gradients strongly influence the fate and transformations of organic matter. Aerobic conditions prevail in the water column, as well as in the first few millimeters of sediment. However, after approximately 15 cm of depth, root density decreases, and anaerobic conditions begin to prevail in the sediments. For this reason, perforations were made in the methane collection tubes, resulting in the following arrangement: two tubes at a depth of 3-4 cm, two others at 11-12 cm, and the last two at a depth of 23-24 cm, as shown in Fig. 5. They were placed in two rows of three tubes each, separated frontally by 45 cm and with a distance of 15 cm between each tube.

2.3 Placing the Sampling Bags in the Collection Tubes

For sampling, one end of the hose is required to be taken to the surface of the artificial wetland where a Tedla bag, which is used for methane collection, is connected.

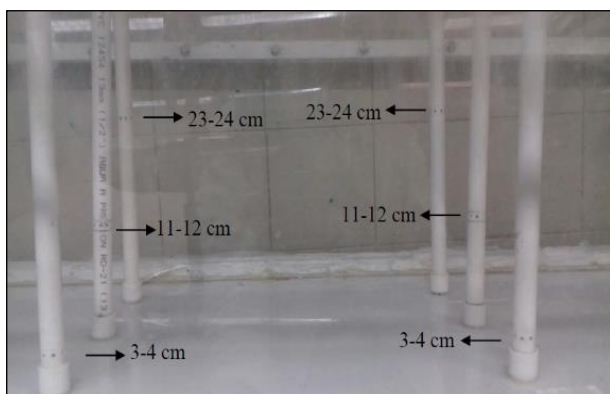


Fig. 5 Tubes with the screw cap and the piece of copper for later connection to the hose.

2.4 Determination of Methane by Gas Chromatography

For gas measurements, a PerkinElmer gas chromatograph was used with Turbochrom software. An Elite-Plot Q capillary column was selected, as it is excellent for separating gaseous compounds at room temperature. It was 30 meters long with a capillary diameter of 0.32 mm. According to the equipment's requirements, three gases were used for its operation: nitrogen, hydrogen, and compressed air. Hydrogen and compressed air are the inlet gases used to initiate the flame ignition process of the detector in a 1:10 ratio, while nitrogen serves as the carrier gas. The selected detector was a FID (Flame Ionization Detector), as it proved suitable for CH₄ detection.

2.4.1 Injection Volumes

Different volumes of 50-10 µl were injected to observe the variation in peaks between each volume and their retention times, as volume directly affects detection. An attempt was made to standardize the measurements for minimum methane volumes.

2.4.2 Retention Time

The retention time was established by performing tests with pure methane gas at a certain run time to have a reference time at which a peak appeared, in this way the reference time was decreased or increased to avoid losses of the gases.

2.5 Methane Measurement

It was verified in which area of the wetland the highest concentration of methane is found and how much the production kinetics are influenced by the availability of carbon.

2.6 Measuring the Efficiency of Artificial HSSF

The efficiency of the artificial horizontal flow subsurface wetland will be evaluated by the removal of organic matter measured as Chemical Oxygen Demand.

3. Results and Discussion

The artificial horizontal flow subsurface wetland was installed in the backyard of the Engineering

Institute. Fig. 6 shows the wetland as it turned out, and Fig. 7 shows the pipe system with the sampling bags.

The experiment lasted 169 days, during which the first 71 days were considered a system stabilization period; therefore, no methane sampling was performed during this time. Afterward, 98 days of sampling and 23 HRT (hydraulic retention times) were considered, with sampling every three days.

3.1 COD Elimination

The COD (Chemical Oxygen Demand) was determined according to the NMX-AA-030/2-SCFI-2011 technique. Closed reflux method, titrametric method. In Fig. 8, the development of the COD removal is observed, reaching a maximum value of 89.40%, a minimum of 33.96% and an average of 72.52%, showing that the efficiency of the wetland is good.

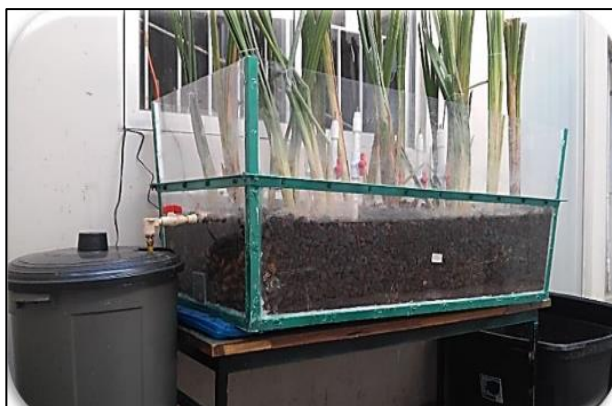


Fig. 6 Wetland with pipe assembly.



Fig. 7 Wetland with methane collection tube system and sampling bags.

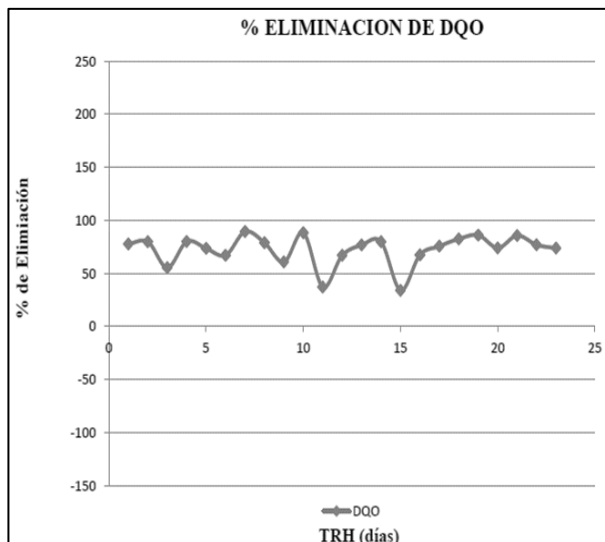


Fig. 8 COD removal percentage.

3.2 Methane Production in the Wetland

The sampling points were divided into two different zones separated frontally by 45 cm, A and B, and between each of the points, 15 cm, obtaining 6 sampling points, see Table 1, carrying out the measurement of CH₄.

Table 1 CH₄ values at sampling points.

Sampling point	Average in percentage of emissions
A1	9.77
A2	9.81
A3	9.84
B1	9.76
B2	9.85
B3	9.96

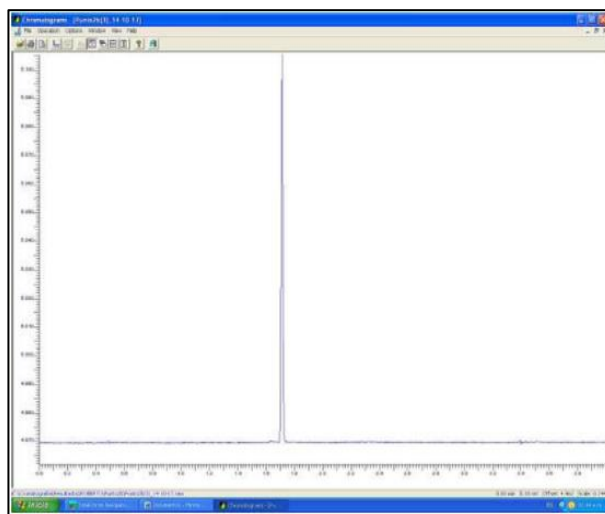


Fig. 9 Chromatogram of CH₄ generated in the HSSFW.

Table 1 shows that methane production did not vary significantly among the sampling points. The maximum emission percentages at two sampling points were 10.32% and 10.10%, corresponding to points B2 and B3. Furthermore, the volumes observed at these points were also higher. It was noted that the volume production was very small.

3.3 Chromatogram of Methane Emitted by the HSSFW

The collector gas was measured using the Tedlar bag at sampling point B to prepare the sample for injection into the gas chromatograph. Fig. 9 shows the output signal from the FID (Flame Ionization Detector).

4. Conclusion

The horizontal subsurface flow constructed wetland, built and implemented in the Environmental Engineering laboratory of the Engineering Institute, for the treatment of domestic wastewater generated from a dependency of the Mocambo campus, was analysis was conducted over 159 days, divided into two periods: a stabilization period of 87 days and an evaluation period of 72 days. The system operated with a HRT (Hydraulic Retention Time) of three days. The average pH was 8.18 and the average temperature was 27.2 °C.

The average organic matter removal rate, measured as COD (Chemical Oxygen Demand), was 75.52%, indicating good efficiency.

The broadleaf cattail (*Typha latifolia*), also known as bulrush, proved effective in creating a beneficial environment for the removal of contaminants present in domestic wastewater.

The greater the amount of organic matter in the domestic wastewater, the greater the methane production, especially at points B due to the 5% slope of the constructed wetland.

The maximum average value was 9.96%; therefore, it is concluded that point B3 had the highest methane production, and the volumetric production was even visible.

This phenomenon occurs due to the anaerobic decomposition of organic matter, a process of

methanogenesis carried out by microorganisms within the carbon cycle.

As a result, several solutions are proposed to mitigate methane emissions: recovering the generated CH₄ for use as bioenergy, reducing methane emissions by increasing substrate oxygenation, and using plants that promote oxygen transport to the rhizosphere. The wetland design can also be optimized by studying variables such as HRT (Hydraulic Retention Time), substrate type, temperature, and organic load.

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