LITERATURE REVIEW ON GREENHOUSE GAS EMESSION OF CONSTRUCTED WETLAND TREATMENT SYSTEMS

by

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Abstract

Constructed Wetland Treatment Systems (CWTS) are demonstrated to effectively trap carbon and methane emissions (Mitsch et. al, 2012). However, limited research has been conducted on the use of CWTS to remediate flue gas desulphurization (FGD) effluent. Based upon the high sulfur content of coal-fired powerplant effluent, it is likely that sulfate-reducing bacteria will be prevalent and reduce methanogenisis. In this project, six bioretention cells were built to model the CWTS at Jeffery Energy Center, and they will eventually be saturated with effluent so that the biological activity can be assessed by means of gas chromatography. Gas samples will be drawn through ports throughout the height of the cell to determine variability of greenhouse has production. Methane and carbon dioxide will be measured in initial trials to analyze the carbon sink potential of CWTS for FGD effluent.

Introduction

Constructed Wetland Treatment Systems (CWTS) have diverse functions including urban storm water storage, gray water treatment, and flue gas desulfurization (FGD) effluent treatment. Wetlands, both engineered and natural, are an overall carbon sink in the long-term (Mitsch et. al, 2012), despite often only being credited for emitting 20-25% of global methane emissions (Whalen, 2005). Urban bio retention cells effectively process stormwater from a catchment fifty or more times larger than the biofilter itself, however GHG emissions can vary drastically with saturation level (Grover et. al, 2013). According to EPA guidelines, Jokerst et al. demonstrated that CWTS for graywater recycling in a temperate climate met five day biochemical oxygen demand concentrations acceptable for unrestricted urban reuse in fall and summer, and effluent *E. coli* concentrations suitable for recreational swimming in all seasons except winter (2011).

A less utilized application of CWTS is for the treatment of flue gas desulfurization effluent from coal-fired electricity production. In the FGD process, a scrubber typically of lime or limestone removes many pollutants before releasing flue gas through smoke stacks. Waste from the scrubber including nitrogen and sulfate, as well as significant amounts of potentially toxic elements including selenium, mercury, and arsenic is transferred into water becoming FGD effluent (Talley, 2012). The full potential for CWTS for FGD treatment is yet to be realized, as most pilot studies operate at a small scale. However, the constructed wetland at Jeffery Energy Center near St. Mary's, Kansas, presents a unique opportunity as it is a full-scale treatment system for coal-fired FGD effluent. After a year and a half pilot study, a 24-acre system was designed by Burns & MacDonell with consultation with Kansas State University to treat 100% of the power plant's FGD effluent. Constructed wetlands have been extensively studied with regards to treatment of urban runoff and graywater reuse, but little research has been conducted on CWTS for FGD effluent. Many metrics involving water quality parameters were investigated in the pilot study, but much is left to be understood, especially with regards to greenhouse gas (GHG) sequestration as emissions were not measured. The pilot study showed high removal rates for mercury, selenium, and fluoride while yielding low a low removal rate for boron and negative removal for manganese, chloride, and sulfate (Talley, 2012).

The objective of this study is to quantify the potential for greenhouse gas sequestration by a CWTS treating FGD effluent. Bacteria and fungi within CWTS first use oxygen to decompose organic matter because it is the most energetically favorable. Aerobic decomposition yields 38 moles of ATP for every 1 mole of glucose metabolized, while anaerobic decomposition produces only 2 moles of ATP per mole of glucose (Atlas and Bartha, 1981). As anaerobic decomposition is less efficient, bacteria do not randomly oxidize trace elements and other nutrients to reduce carbon, but consume nutrients according to their redox potential as illustrated in **Figure 2**. Craft summarizes that "Once most of the O_2 is consumed, denitrifying bacteria use nitrate as an energy source, followed by Mn and Fe reducercers, $SO_4{}^{2-}$ reducers, and finally methanogens." (2001). Further investigation is necessary as the negative sulfate removal rate in the pilot study is contrary to multiple papers on the use of different nutrients in the place of oxygen in anaerobic environments according to decreasing redox potential. The high levels of sulfate in FGD effluent are expected to encourage decomposition by SRB and suppress methane generation as methanogenisis is less energetically favorable than sulfate reduction, ultimately sequestering greenhouse gases. The hypothesis to be tested is that in the presence of sulfate concentrations characteristic of FGD effluent, methane generation will be suppressed.

Study Approach

To investigate GHG emissions, six wetland columns have been designed in a similar fashion to the Jeffery energy center CWTS. The columns are multilayered (**Figure 1**), and three of the six are planted with switchgrass (*Panicum virgatum*). Columns were constructed such that they may be saturated with effluent from the bottom, similar to the full-scale FGD treatment wetland at Jeffry Energy Center. Columns are constructed with 4-ft lengths of 4-inch PVC pipe and 6 temperature probes are inserted throughout the length of each column through ½-inch vinyl tubing sealed with a septum. The top of the columns may be fitted with a PVC cap constructed to facilitate gas sampling. Gas samples will be drawn through a gas sampling port in this PVC cap and analyzed for carbon dioxide and methane concentrations using gas chromatography. In a similar manner to Kahmark and Millar (2008), samples will be drawn with a 10 mL syringe and inserted into a glass vial with a septum seal. The process will be immediately repeated to give the vial a gas overpressure. Grover et al. (2013) found methane emissions fluctuate with saturation, thus emissions will be measured with varying levels of saturation. GHG emissions, specifically methane and carbon dioxide, will also be measured with varying soil temperatures to investigate microbial activity, especially the possibility of sulfate-reducing bacteria (SRB). Under high concentrations of sulfate and with the exception of warmer temperatures, SRB use both hydrogen and acetate before methanogenisis occurs. Sulfate in the form of gypsum has been noted to reduce the methane emissions of rice paddies, and various forms of sulfur found in acid rain is estimated to suppress methane emissions globally by approximately 15 Tg currently and up to 26 Tg by 2030 (Gauci et al. 2004). Thus, in high sulfate conditions, natural wetlands and CWTS have great potential for GHG sequestration.

FGD scrubbers mitigate atmospheric pollution in terms of sulfur directly released, but the remediation of the wastewater effluent introduces new challenges. This study aims to quantify the environmental benefits or disparities introduced by the CWTS in terms of methane and carbon dioxide emissions. In future projects, we recommend measuring the hydrogen sulfide (H_2S) emissions, then totaling the carbon equivalent of all GHG compared to other FGD effluent reduction techniques.

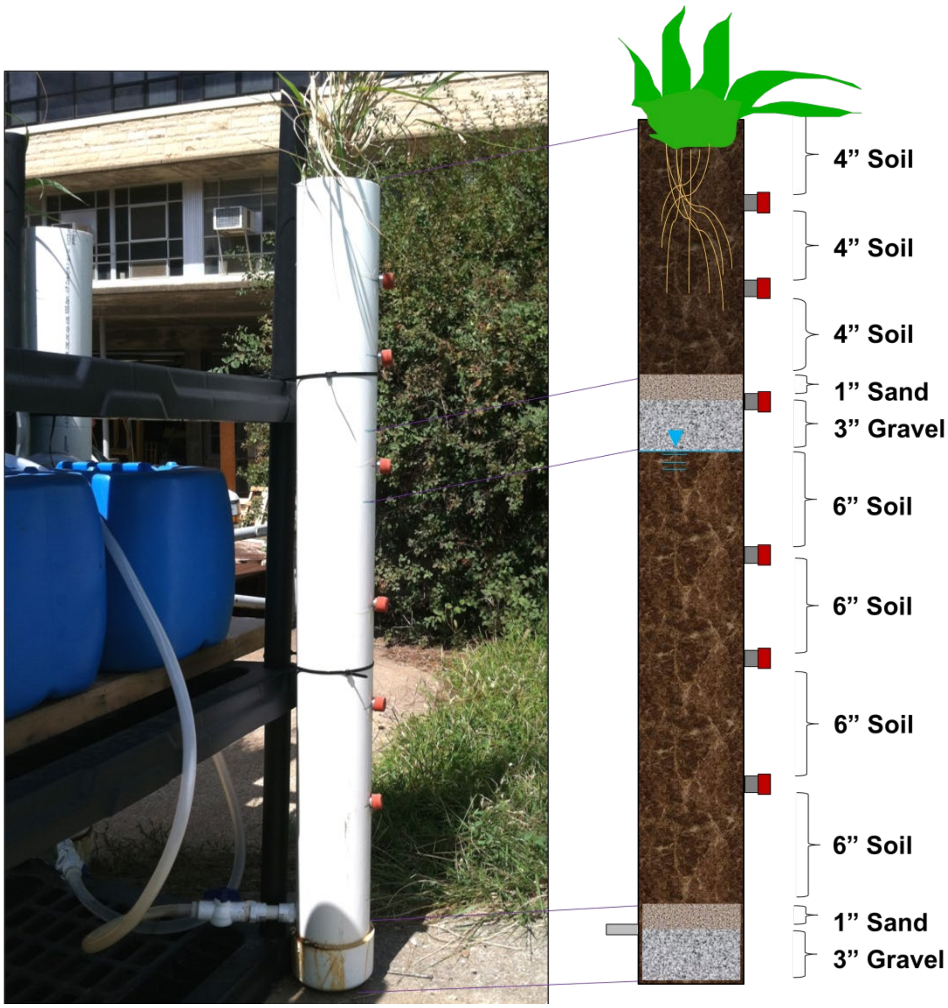

Figure 1. 1 of 6 columns representative of the Jeffery Energy Center CWTS.

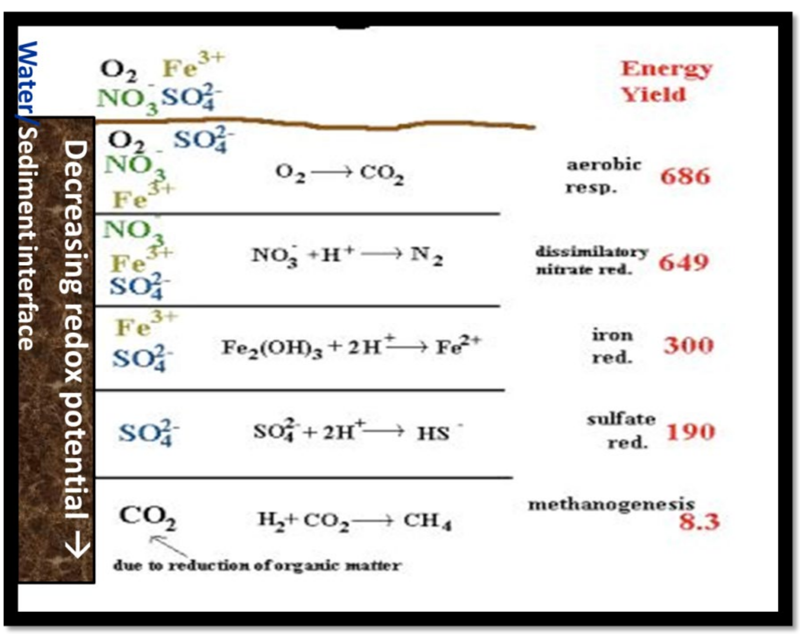

Figure 2. Energy yield associated with microbially-mediated oxidation-reduction reactions indicate the order of preference by which electron acceptors such as O2, SO4, and CO2 are utilized. The anaerobic conditions that persist in wetland sediments create an ideal environment for CO2 sequestration. However, these same conditions also create an ideal environment for methanogenesis, which can serve to partially offset the benefit of CO2 sequestration.

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