Comparative Analysis of Greenhouse Gas Emission from Three Types of Constructed Wetlands

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Wet wastewater treatment processes can produce anthropogenic greenhouse gases, including carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O). Wastewater treatment in the U.S. emitted 17.8 Tg CO₂ equivalent (CO₂-eq) in 2012, accounting for 0.27% of the U.S. total greenhouse gas emission and 14.3% of the total greenhouse gas emission from waste management and treatment activities (U.S. EPA, 2014). Constructed wetlands are green infrastructure for treatment of various types of wastewater. As ecologically engineered treatment systems, constructed wetlands mimic the appearance of natural wetlands (Figure 1). Constructed wetlands utilize natural processes involving macrophytes, soils or other porous media, and the associated microbial assemblages for water quality improvement. There are mainly three types of constructed wetlands [1]. Free water surface (FWS) wetlands typically consist of cells with aquatic plants, relatively impermeable rooting substrate, and shallow water. Treatment in FWS constructed wetlands occurs as water flows slowly above ground through the leaves and stems of aquatic plants. Horizontal subsurface flow (HSSF) wetlands contain beds of porous media that may have been planted with aquatic plants. Wastewater flows horizontally beneath the surface of the medium beds. Vertical flow (VF) wetlands contain beds of media that may have been planted with aquatic plants. Water is distributed over the ground surface or from the base, and flows downward or upward through the medium beds.

When designing a constructed wetland treatment system, wetland type is first selected in regards to several factors such as land availability, local climate, and wastewater characteristics. Sustainability has become an important consideration in wastewater treatment. Correspondingly, greenhouse gas emission from constructed wetlands has been measured in full-scale constructed wetlands in the last decade. Mander et al. [2] compared the three types of constructed wetlands in terms of CO₂-C, CH₄-C, and N₂O-N emission rates separately. Actually, the same mass emission rates of CO₂, CH₄, and N₂O contribute very differently to global warming. To compare the overall effect of greenhouse gas emissions amongst different types of constructed wetlands, it is necessary to calculate CO₂-eq emissions [3,4]. With inclusion of climate-carbon feedbacks in response to emissions of non-CO₂ gases, the 100-year global warming potential (GWP₁₀₀) is 1 for CO₂, 34 for CH₄, and 268 for N₂O (IPCC, 2013). CO₂-eq emission rate in the three types of constructed wetlands were then obtained by multiplying the emission rate of a greenhouse gas reviewed by (2) by its GWP as given in Equations 1-3:

\[
\begin{align*}
\text{CO}_2\text{-eq of CO}_2, \text{mg/m}^2/\text{h} &= (\text{CO}_2, \text{mg C/m}^2/\text{h}) \times (44/12) \times 1 \quad (1) \\
\text{CO}_2\text{-eq of CH}_4, \text{mg/m}^2/\text{h} &= (\text{CH}_4, \text{mg C/m}^2/\text{h}) \times (16/12) \times 34 \quad (2) \\
\text{CO}_2\text{-eq of N}_2\text{O}, \text{mg/m}^2/\text{h} &= (\text{N}_2\text{O}, \text{mg N/m}^2/\text{h}) \times (44/28) \times 268 \quad (3)
\end{align*}
\]

Based on emission rates of individual greenhouse gases, Mander et al. [2] concluded that CO₂ emission was significantly lower in FWS constructed wetlands than in HSSF and VF constructed wetlands, CH₄ emission was significantly lower in VF constructed wetlands than HSSF constructed wetlands, and that there were no significant differences in N₂O emission in various wetland types. Based on the CO₂-eq emission rates (Table 1), we found that:

1. CO₂-eq emission rate in constructed wetlands is in the order of HSSF>VF>FWS, either in terms of total or individual greenhouse gases except for CH₄ that FWS>VF;
2. CO₂-eq emitted from constructed wetlands is in the order of CO₂>CH₄>N₂O for all the three types of constructed wetlands.
3. CO₂ accounted for 76% of the total CO₂-eq emitted from VF constructed wetlands;
4. Both CO₂ and CH₄ are the primary greenhouse gases emitted from FWS constructed wetlands; and
5. CO₂ and CH₄ accounted for 51% and 41% of total CO₂-eq emitted, respectively, from HSSF constructed wetlands.

Table 1: Greenhouse gas emission in three types of constructed wetlands.

<table>
<thead>
<tr>
<th>Wetland Type</th>
<th>Average Range</th>
<th>Average Range</th>
<th>Average Range</th>
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</thead>
<tbody>
<tr>
<td>FWS wetland</td>
<td>BOD loading, mg/l</td>
<td>109</td>
<td>18.3-465</td>
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<td></td>
<td>TOC loading, mg/l</td>
<td>50.2</td>
<td>1.0-232</td>
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<tr>
<td></td>
<td>CO₂ emission, mg CO₂-eq/m²/h</td>
<td>338</td>
<td>108-645</td>
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<tr>
<td></td>
<td>CH₄ emission, mg CH₄-eq/m²/h</td>
<td>268</td>
<td>6.8-1224</td>
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<tr>
<td></td>
<td>N₂O emission, mg N₂O-eq/m²/h</td>
<td>55</td>
<td>0-274</td>
</tr>
<tr>
<td></td>
<td>Total emission, mg CO₂-eq/m²/h</td>
<td>661</td>
<td>1130</td>
</tr>
</tbody>
</table>

*Calculated with data reported by [2].

Figure 1: Appearance of full-scale constructed wetlands: a FWS wetland with well-established vegetation (left), a newly planted VF wetland with risers on concrete distribution pads (middle), and a HSSF wetland with planted and unplanted zones (right).
To reduce greenhouse gas emission from constructed wetlands, therefore, the efforts should be focused on CO₂ and CH₄ reduction rather than N₂O which is produced in biological nitrogen removal processes including nitrification and denitrification. Biological removal of oxygen-demanding substances releases CO₂ and CH₄, with more CH₄ produced under anaerobic conditions [4]. The larger CO₂ and CH₄ emission rates in HSSF than FWS constructed wetlands could be attributed to the higher biochemical oxygen demand (BOD) and total organic carbon (TOC) loading rates (Table 1). Although VF constructed wetlands have greater BOD and TOC loading rates than HSSF constructed wetlands, CH₄ emission rate is obviously lower than HSSF constructed wetlands because VF constructed wetlands are designed typically for aerobic removal of organic carbon and ammonium. The slightly lower CO₂ emission rate in VF than HSSF constructed wetlands could be attributed to the downward flow of effluent that absorbs and carries CO₂ out.

References