AERATED WETLANDS

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5.7 AERATED WETLANDS

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5.7.1 Introduction

Aerated wetlands are saturated, HF or VF wetlands that rely on a mechanical system (an air pump connected to a subsurface network of air distribution pipes) to introduce air bubbles into the water being treated (Wallace, 2001). The use of an artificial aeration system dramatically increases the oxygen transfer rate compared to passive wetlands (Table 5.9), enabling improved performance for treatment reactions that require oxygen (such as nitrification) or occur more rapidly under aerobic conditions. The aeration system can also be operated intermittently to promote nitrification/denitrification (van Oirschot & Wallace 2014). A simple schematic and description of the process was covered recently by Dotro *et al.* (2017) and the improved treatment performance through aeration of pilot scale systems fitted to the first-order kinetic (*P*–*k*–*C**) model by Nivala *et al.* (2019b).

5.7.2 Design considerations

Standard HF and VF wetland systems rely on passive diffusion of oxygen into the water column. This is a very slow process in saturated-flow wetlands (HF and FWS) and passively improved upon in unsaturated-flow wetlands (VF and French VF wetlands). Mechanically aerating the system allows the amount of air introduced to be independent of the surface area of the wetland, allowing aerated systems to be loaded up to maximum clogging limits, which greatly reduces the area required and associated

Table 5.9 Estimated oxygen consumption in g $O_2/m^2/d$ for different TW types (adapted from Wallace, 2014)

TW Type	Estimated O_2 Consumption	Notes
HF wetland[1]	6.3	50th percentile values from Kadlec and Wallace (2009) assuming aerobic BOD removal and conventional nitrification.
FWS wetland[1]	1.47	
VF wetland (unsaturated)[1]	24.7	
French VF wetland (1st stage)[2]	40–60	Data from France indicates that the first stage of a French VF wetland can sustainable operate at roughly 1.5 m^2/PE
Aerated (HF and VF)	250	Mechanically aerated wetlands can achieve higher oxygen transfer rates, but 250 g/m^2-d is considered an upper $CBOD_5$ limit for clogging; most sustainable designs operate at $<$100 g/m^2-d (Wallace, 2014).

Notes:
[1]50th percentile values from *Treatment Wetlands, Second Edition* (Kadlec & Wallace, 2009); assuming aerobic BOD removal and conventional nitrification.
[2]Data from France indicates that the first stage "French VF" process can sustainably operate at roughly 1.5 m^2/PE (Molle *et al.*, 2005).

Table 5.10 Typical design parameters for aerated wetlands.

Design Parameter	Recommendation	References
Pre-treatment	Primary treatment common (CSO systems typically do not have pre-treatment)	DWA-A262E (2017)
Influent loading (inlet cross-sectional area)	$<$250 g $CBOD_5/m^2/d$ (maximum)* $\leq$100 g $CBOD_5/m^2/d$ (recommended)	Wallace (2014)
Specific area	$\geq$0.5 m^2/PE $\leq$80 $g/m^2/d$ $CBOD_5$	Stefanakis and Prigent (2018)
Influent distribution	$\leq$50 m^2 per feed point (unless bed is permanently flooded)	Dotro *et al.* (2017)
Air flow rate	$\geq$0.6 $m^3/m^2/h$	DWA-A262E (2017)
Air distribution	30 cm $\times$ 30 cm	DWA-A262E (2017)
Media size	8–16 mm	DWA-A262E (2017)
Treatment kinetics	pilot testing	Nivala *et al.* (2019b)

*Mechanically aerated wetlands can achieve higher oxygen transfer rates, but 250 g/m^2-d is considered an upper $CBOD_5$ limit for clogging (Wallace and Knight, 2006); most sustainable designs operate at $<$100 g/m^2-d (Wallace, 2014).

capital cost. Aerated wetlands are generally dimensioned based on clogging, hydraulics, uniform air distribution, and first-order kinetics (Table 5.10).

Aeration of wetlands follows standard wastewater aeration design practices in terms of calculating oxygen demands and air flows based on actual/standard oxygen transfer rates (AOTR/SOTR) protocols (Metcalf and Eddy Inc., 2003). However, the hydrodynamic mixing of the water column induced by aeration is greatly reduced in gravel-bed systems compared to ponds or tanks (Wallace, 2014). This requires that the air distribution in wetland beds be very uniform (Wallace, 2014). Most air diffusers in mechanical treatment systems are high-flow/small-area devices that are poorly suited to uniform distribution, and successful wetland aeration designs have been based on alternative pipes or tubing that can distribute air uniformly. This generally requires empirical testing to determine the air flow vs. air pressure relationship for the product(s) under consideration.

Gravel media used in the system must have pore spaces large enough to allow the passage of air bubbles. Sand is too fine for aerated systems as the air collects and "blows out" in just a few locations. Air bubbles moving through the gravel media can combine and coalesce into larger bubbles (reducing oxygen transfer), however air bubbles follow a tortuous path through the media, slowing their transit time (increasing oxygen transfer). As a result, wetland aeration systems typically demonstrate an oxygen transfer efficiency intermediate between fine-bubble and coarse-bubble diffusers (von Sperling & Chernicharo, 2005; Wallace *et al.*, 2007).

5.7.3 Potential design and operational issues

Since aerated wetlands are high-rate treatment processes, they are sometimes designed very close to clogging limits, especially for HF; if overloaded, they can clog and require resting or refurbishment like other types of treatment wetlands.

During construction, testing of the aeration system to verify proper air delivery is essential. Since the air distribution lines are buried at the bottom of the wetland bed, replacing/repairing air lines after construction is difficult.

Fouling of the air distribution lines has been reported in isolated cases due to iron precipitates forming at the air distribution orifices. Using acid (HCl) to clean fouled air lines has been reported to be a successful quick and low-cost method (van Oirschot & Wallace, 2014).

Although the selection of the appropriate blower for the air distribution network should be based on air requirements, they can sometimes be limited by the smallest available size that a client can accept (based on rigorous health and safety requirements). To illustrate, four systems in the UK used the same size of blower to provide aeration to different size tertiary and secondary systems, resulting in a specific power allocation ranging from 4 W/m^3 of wetland to 26 W/m^3 wetland (Butterworth *et al.,* 2016a). In systems that are over aerated, venting of the air has been necessary resulting in wasted energy and noise complaints from adjacent residents. To minimise this, the selection of the correct aeration equipment should be emphasized to the client.

Stress of plants in both passive and artificially aerated wetlands has been reported in the literature, with chlorosis (yellowing of the leaves) being most predominant (Weedon, 2014) and a downward gradient observed in plant height from inlet to outlet in highly aerobic systems. In an assessment of four full-scale systems, one of the systems struggled to establish the common reed (*Phragmites australis*) whilst its twin bed under equal conditions but without aeration thrived with the same plants (Butterworth *et al.,* 2016a). The other three artificially aerated systems reported normal plant growth. The difficulty experienced with plant establishment in some UK systems did not affect treatment performance. A side-by-side full-scale trial comparing reeds (*P. australis*) to reedmace (*Typha latifolia*) plantings showed both plant species exhibited signs of stress (chlorosis and stunted growth) when grown with artificial aeration. Further controlled trials proved reedmace is proportionally more affected by aeration than the common reed but its higher natural growth rate can offset the true impact of aeration on biomass production (Butterworth *et al.,* 2016b). Plant stress has been attributed to iron deficiency and/or toxicity in aerobic systems. The fact it happens on some systems but not all suggests complex interactions between the biogeochemical conditions in the wetland subsurface and the plants. To illustrate, from 27 aerated wetlands built with expanded clay aggregates as their main media (instead of gravel), there have been no reports of plant stress to date. Recent research suggests observed iron-induced stress in reeds could be related to the plant's genetic code, with an iron foliar spray currently being assessed as mitigation strategy (Ren *et al.,* 2018). In practice, plant species selection for artificially aerated wetlands is typically done by the designer based on previous experience, and a variety of native wetland plants have been used to date.