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Review

Integral approaches to wastewater treatment plant upgrading for odor prevention: Activated Sludge and Oxidized Ammonium Recycling

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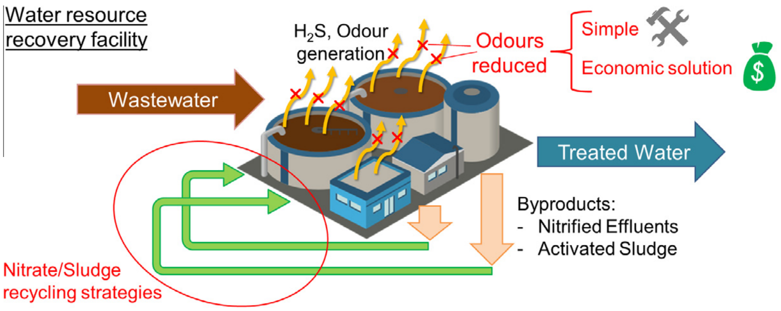
HIGHLIGHTS

- Activated Sludge Recycling and Oxidized Ammonium Recycling significantly reduce odors.
- Both alternatives can be easily implemented with minimum investment costs.
- Both strategies provide significant savings in further odor abatement.
- Activated Sludge Recycling can be expected to be electron acceptor-limited.
- Oxidized Ammonium Recycling is expected to be limited by biological activity.

GRAPHICAL ABSTRACT



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ABSTRACT

Traditional physical/chemical end-of-the-pipe technologies for odor abatement are relatively expensive and present high environmental impacts. On the other hand, biotechnologies have recently emerged as cost-effective and environmentally friendly alternatives but are still limited by their investment costs and land requirements. A more desirable approach to odor control is the prevention of odorant formation before being released to the atmosphere, but limited information is available beyond good design and operational practices of the wastewater treatment process. The present paper reviews two widely applicable and economic alternatives for odor control, Activated Sludge Recycling (ASR) and Oxidized Ammonium Recycling (OAR), by discussing their fundamentals, key operating parameters and experience from the available pilot and field studies. Both technologies present high application potential using readily available plant by-products with a minimum plant upgrading, and low investment and operating costs, contributing to the sustainability and economic efficiency of odor control at wastewater treatment facilities.

1. Introduction

Odor emissions are inherently associated to wastewater management. Over the past decades, the encroachment of new residential areas on water resource recovery facilities like wastewater treatment plants (WWTPs) has led to an increase in the number of administrative and legal complaints, which has forced governments to develop stricter regulations on odor emissions and exposure (Sironi et al., 2012; Stuetz et al., 2001). Odors can substantially reduce the perceived life quality and have been associated to a wide range of health-related symptoms such as nausea, headaches, insomnia, loss of appetite or respiratory problems (Naddeo et al., 2012; Sucker et al., 2008). In addition, some malodorous

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compounds such as H_2S entail severe occupational risks in confined spaces within WWTP (Vincent, 2001). H_2S and sulfur-containing compounds can account for up to 80–90% of malodorous compounds in WWTPs (Omri et al., 2011). Due to the enforcement of new environmental regulations and to the increasing awareness of companies operating WWTPs about their public image, odor management has become a priority in the design and operation of WWTPs (Easter et al., 2008; Estrada et al., 2011, 2012a).

The simplest strategies for odor control applied in WWTPs are based on impact minimization using passive barriers such as trees or buffer zones to promote the dilution of the odorants, but their effectiveness is limited and depends on wind conditions. The addition of masking and/or neutralizing chemical agents can also reduce the nuisance caused by malodorous emissions, however, little information is available on their effectiveness and the few published studies reported an increase in the odor concentration of the emissions after their application (Decottignies et al., 2007). Finally, end-of-pipe technologies are based on the collection and treatment of the odorous emissions generated in WWTPs, reducing the concentration of odorants before being discharged to the atmosphere. End-of-pipe technologies are usually classified into physical–chemical and biological techniques. The former group presents a high abatement efficiency and robustness when operated and maintained properly, but relatively high operating costs especially at medium and high odor concentration due to adsorption material and chemicals consumption, which also causes high environmental impacts (Alfonsín et al., 2015). Biological techniques constitute a more cost-effective and environmentally friendly alternative to their physical–chemical counterparts achieving high odorants removal efficiencies (Xie et al., 2009; Lebrero et al., 2012; Li et al., 2013), but still present significant investment costs and land requirements (Estrada et al., 2011, 2012b; Prado et al., 2009). Overall, the implementation of odor abatement technologies entails important costs and requires compelling operator efforts.

Both impact minimization (via passive barriers installation or chemical agents spraying) and end-of-pipe treatment address odor nuisance management once odorants have been produced and released from the wastewater. In this context, a more desirable approach would be the prevention of odorant formation and/or release from the wastewater. Limited options are available for the prevention of odorant release at WWTPs beyond proper design and good operating practices such as maintaining aerobic or anoxic conditions in the wastewater where possible, frequent cleaning of process units, minimization of the sludge retention time in thickeners and dewatering systems or the use of buildings and covers to confine the emission in key operation units (WEF, 2004; WERF, 2010). Unfortunately, many of these solutions require an expensive upgrading or re-design of the plant, increase process operating costs and have a limited potential to control the odor generation.

The present paper assesses two widely-applicable, emerging odor control technologies known as Activated Sludge Recycling (ASR) and Oxidized Ammonium Recycling (OAR), which possess a significant odor prevention potential for WWTPs at low investment and operating costs (Estrada et al., 2015; Husband et al., 2010; Kiesewetter et al., 2012). Despite these technologies have been discussed in technical forums and applied at few full scale in WWTPs with promising results over the past decade, their fundamentals, limitations and potential for odor prevention have not been explored using a systematic scientific approach (Constantine, 2006). The aim of this review is to present and critically discuss the fundamentals, potential and limitations of ASR and OAR for odor control based on all the technical information available to date (including typical operating parameters, process economics and experience from WWTP operators of field studies and applications) in order to provide a stepping stone for future research and widespread application of these promising strategies for odor prevention at WWTPs.

2. Activated Sludge Recycling

2.1. Fundamentals

In WWTPs based on activated sludge biological treatment, wastewater flows through an aerated biological reactor with dissolved oxygen concentrations and total suspended solids concentration of 2–3 mg L^{-1} and 1000–10,000 mg VSS L^{-1}, respectively. Microorganisms oxidize the organic matter and other pollutants under aerobic conditions. The biomass is afterwards separated from the treated water in secondary clarifiers. After clarification, the settled sludge usually presents 4000–12,000 mg L VSS L^{-1} and is recycled back to the anoxic or aerobic tanks (Metcalf and Eddy, 2003).

ASR is a strategy for odor control consisting of the recycling of waste or return settled activated sludge from secondary clarifiers or aerobic activated sludge from aerated biological reactors to the inlet of the WWTP headworks (Fig. 1). This promotes the consumption of odorous compounds before they volatilize from the liquid phase. Adsorption followed by oxidation of potential malodorous compounds is assumed to be the mechanism preventing their release from the subsequent wastewater treatment units (Kiesewetter et al., 2012). The recycled activated sludge from the aeration basin or the secondary settler contains significant concentration of oxygen (2–3 mg L^{-1}) and/or nitrate (6–10 mg L^{-1}) that will be used as electron acceptors for the oxidation of the odorants or the malodorous compound precursors (Kiesewetter et al., 2012). Biological odorant oxidation can thus take place by aerobic oxidation (Kelly, 1999) or anoxic oxidation coupled to denitrification (Soreanu et al., 2008). When oxygen or nitrate availability is limited, the production and precipitation of elemental sulfur is likely to occur. Under anoxic conditions, it is also possible to find incomplete denitrification with nitrate being reduced to nitrite instead of elemental N_2 (Krishnakumar and Manilal, 1999) (see Table 1).

Sulfide oxidation under aerobic conditions can be carried out by a wide range of well-known chemolithotrophic bacterial species belonging to the *Thiobacillus* genus among others. Some thiobacilli, such as *Thiobacillus denitrificans*, can also carry out the oxidation using nitrate or nitrite as an electron acceptor (Kelly, 1999; Soreanu et al., 2008). Activated sludge usually exhibits a high biological diversity holding the potential to adsorb and biologically oxidize most biogenic compounds responsible for odor nuisance (mainly reduced volatile organic or inorganic compounds such as H_2S, mercaptans, amines, indoles and fatty acids) (Table 2). In fact, the diffusion of malodorous emissions into aeration basins, known as activated sludge diffusion (ASD), has been employed as a method for odor control for more than 30 years, and activated sludge is commonly employed as inoculum for standard biological odor treatment systems such as biofilters and biotrickling filters (Barbosa and Stuetz, 2013; Shareefdeen and Singh, 2005).

The effect of iron salts, often added during wastewater treatment for phosphorus precipitation, present in the recycled sludge liquor can be also beneficial for odor prevention by promoting the precipitation of dissolved sulfide as ferrous sulfide (Ge et al., 2013; Zhang et al., 2011).

ASR can reduce the release of odorous compounds from the wastewater in the inlet works, pre-treatment, pumping stations and primary settlers, which are usually reported as the main responsible process units for malodorous emissions at WWTPs (Capelli et al., 2009; Frechen, 2004; Zarra et al., 2008).