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Research review paper

Challenges and solut3ions for biofiltration of hydrophobic volatile organic compounds

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ABSTRACT

Volatile organic compounds (VOCs) emitted to the environment highly probably result in ecological and health risks. Many biotechnologies for waste gases containing hydrophobic VOCs have been developed in recent years. However, these biological processes usually exhibit poor removal performances for hydrophobic VOCs due to the low bioavailability. This review presents an overview of enhanced removal of hydrophobic VOCs in biofilters. Mechanisms and problems relevant to the biological removal of hydrophobic VOCs are reviewed, and then solutions including the addition of surfactants, application of fungal biocatalysts, biofiltration with pretreatment, innovative bioreactors and utilization of hydrophilic compounds are discussed in detail. Future research needs are also proposed. This review provides new insights into hydrophobic VOC removal by biofiltration.

Contents

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1. Introduction

Atmospheric pollutant emissions have increased over the past few decades due to the development of economy, and have become one of the most important problems that governments and the general public will have to face in the present century (Delhomenie and Heitz, 2005; Malhautier et al., 2005). Volatile Organic Compounds (VOCs) such as the low-boiling hydrocarbon, halogenated hydrocarbons, alcohols, aldehydes, ketones, ethers, acids, and volatile polycyclic aromatic hydrocarbons (PAHs) have been listed as prior substances by the European Water Framework Directive because of their risks to human health and hazard to the environment (An, 2004; Farhadian et al., 2008; Rene et al., 2010b; Hassan and Sorial, 2010). Emissions of these xenobiotic compounds mentioned above constitute about 7% of all atmospheric pollutants which have continuously increased since the beginning of last century (Delhomenie and Heitz, 2005). Moreover, some VOCs such as methane are greenhouse gases with a potential to cause global warming (Boucher et al., 2009), while others such as some hydrocarbons can lead to photochemical smog with other gases (NO_x) and produce ozone near the ground (Christensen et al., 1999; West and Fiore, 2005). Though the overall emission load of VOCs remains relatively low, VOCs emitted from industry and households are very likely to become ecological and health hazards, especially to humans, animals and the environment (Guieysse et al., 2008; Mudliar et al., 2010; Rene et al., 2010b; Rene et al., 2015).

Hydrophobic VOCs are released into the atmosphere from various industrial activities. The industrial use of the commercial hydrophobic compounds contributes significantly to the overall emission of these compounds. For instance, styrene is predominantly emitted from manufacturing of plastics, polymer industries, synthetic resins, and butadiene-styrene latex (Rene et al., 2010b; Jorio et al., 2000). Ethylbenzene is typically found in petroleum products such as diesel fuel and gasoline. It is commonly used as an intermediate or solvent in organic synthesis. In European Union, benzene and toluene are emitted at 79 and 976 kt per year into the air, respectively, constituting roughly 0.02% and 3% of the total non-methane VOC emission (Rene et al., 2015). *n*-Pentane, another hydrocarbon isolated from petrol, contributes 0.4% to the total non-methane VOC emission (EURAR, 2003). Although these VOCs constitute low percentage of the total non-methane VOC emission, they have an important impact on the air quality. This is especially true for those VOCs like benzene due to their potential health hazards including possible carcinogenic effect (Christensen et al., 1999). Therefore, more and more stringent laws and regulations for emission control of VOCs have been issued in response to the adverse health risks and potential environmental problems posed by these chemicals (Delhomenie and Heitz, 2005; Hernández et al., 2010; Muñoz et al., 2007; Liu et al., 2007). For instance, the enactment of the 1990 Amendments to the Clean Air Act (CAA) facilitates the development of more efficient biotechnologies for reducing air pollutant emissions (Zehraoui et al., 2012), and the market for biotechnologies begins to thrive with these increasingly rigorous regulations.

Though there are many processes for the control of VOC emission from waste gas streams, biological processes are based on the ability of microorganisms in biofilm form immobilized or attached on packing media such as peat, composts, polyurethane foams and other types of porous solid particles (Mallakin and Ward, 1996; Znad et al., 2007; Kim et al., 2007; Yang et al., 2011). When VOCs in waste gases flow through the support medium, these pollutants are absorbed by the biofilm and converted into innocuous products such as carbon dioxide (CO_2), water, and cell mass without generating undesirable by-products (Moe and Irvine, 2001). Therefore, biological processes when designed and operated properly exhibit advantages including cost-effectiveness, reliable robust performances and eco-friendliness over conventional methods such as physicochemical adsorption, condensation, incineration, and photolysis (Delhomenie and Heitz, 2005; Kumar et al., 2011; Malhautier et al., 2005; Mudliar et al., 2010). Recently, biological processes have become increasingly attractive and competitive, in which bioscrubbers, conventional biofilters, biotrickling filters, and novel biofilters have been used or developed (Devinny et al., 1999; Yang et al., 2003; Yang et al., 2010b; Hernández et al., 2010).

However, there still exist limitations to biological processes. One limitation involves the excess biomass accumulation, the uneven distribution of biomass and nutrient (Jorio et al., 2000; Yang et al., 2003). Many reviews on strategies of addressing this drawback are reported (Yang et al., 2010b). In addition, the low mass transfer of hydrophobic VOCs from the gas phase to the biofilm phase limits the supply of substrates to the microorganisms, resulting in a low bioavailability and a low rate of biodegradation of these compounds. Bioavailability represents the accessibility of a chemical for assimilation and possible toxicity (Alexander, 2000), and physical contact between microbes and organic compounds is an essential prerequisite for bioavailability and consequent biodegradation. To achieve contact, VOCs in gas phase usually need transfer from the gas phase to liquid phase and then to biofilm phase. Therefore, bioavailability is one of the key factors affecting VOC biodegradation in biofilters. In biofiltration system, the removal performance of hydrophobic VOCs is significantly affected not only by their physicochemical properties including the solubility in water, the Henry's law constant, the contaminant molecular structure and the gas flow, but also by microorganisms and moisture (Deshusses and Johnson, 2000; Kumar and Chandrajit, 2011; Zehraoui et al., 2012). For instance, hydrophobic VOCs such as hexane are more resilient to degradation than hydrophilic one like water soluble ketones in biological systems, as the removal efficiency of hydrophobic VOCs is limited by the low mass transfer rates from gas phase to biofilm phase (Zehraoui et al., 2012). Thus, an increase of the bioavailability of hydrophobic VOCs in the liquid or biofilm phase will be benefit for their degradation by microorganisms and improve the performance of biofilters (Arriaga et al., 2006; Laura et al., 2009; Hernández et al., 2011; Darracq et al., 2012; Ramirez et al., 2012a). However, if the mass transfer from liquid phase to biofilm phase is rate-limiting, further solubilization of VOCs may even result in an inhibition of VOC biodegradation in case of reaction limitation.

Many methods have been investigated for enhanced removal of hydrophobic VOCs in biofilters, including pretreatment, fungal biofilters, two-phase biofilters, surfactant addition, and low moisture operation, while little reviews are available in this field. This review focuses on bioavailability of hydrophobic VOCs in biofilters including factors both affecting bioavailability and biodegradation and strategies for improving bioavailability (see Fig. 1), and is supposed to help understand and design hydrophobic VOC biofiltration better.

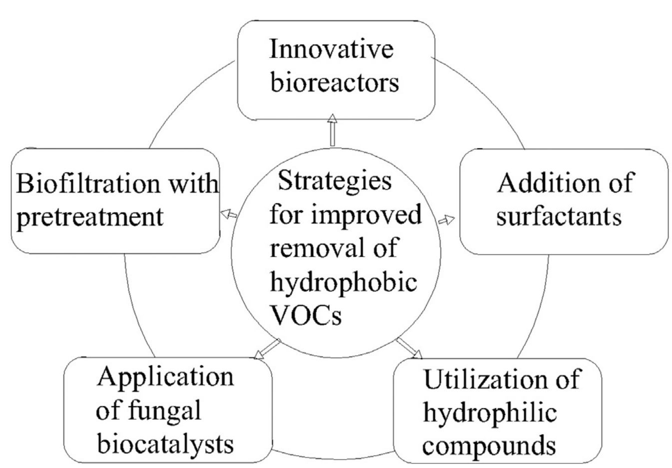

Fig. 1. Improving biodegradable approaches of hydrophobic VOCs.