Chemosphere 103 (2014) 92–98

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Fates of chlorinated volatile organic compounds in aerobic biological treatment processes: The effects of aeration and sludge addition

Wei-Hsiang Chen [a,*], Wen-Ben Yang [a], Chung-Shin Yuan [a,*], Jun-Chen Yang [b], Qing-Liang Zhao [b]

[a] Institute of Environmental Engineering, National Sun Yat-sen University, Kaohsiung 804, Taiwan, ROC
[b] State Key Laboratory of Urban Water Resources and Environments (SKLUWRE), Harbin Institute of Technology, Harbin 150090, China

HIGHLIGHTS

- The VOC distributions in aerobic biological treatment processes were investigated.
- The effects of aeration and sludge addition were studied.
- The concept of fugacity was used to predict the fates of the VOCs in the processes.
- The effect of aeration and sludge addition were limited.
- The physicochemical properties of the VOCs are important to determine their fates.

ARTICLE INFO

Article history:
Received 7 August 2013
Received in revised form 14 November 2013
Accepted 16 November 2013
Available online 8 December 2013

Keywords:
Volatile organic compound
Chlorinated hydrocarbon
Environmental fate
Wastewater treatment process
Aeration
Sludge

ABSTRACT

The emission of volatile organic compounds (VOCs) from wastewater treatment plants (WWTPs) is becoming an environmental issue of increasing concern. As biological treatment has been considered as one important approach for VOC removal, lab-scale batch experiments were conducted in this study to investigate the fates of four chlorinated hydrocarbons, including chloroform, carbon tetrachloride, trichloroethylene (TCE), and tetrachloroethylene (PERC), in the biological treatment processes with respect to the effects of aeration and sludge addition. The VOC concentrations in the phases of air, water, and sludge under four simulated treatment stages (the first sedimentation, the forepart and rear part of aerobic biological treatment, and the second sedimentation) were analyzed. The results were used to understand the three-phase partitioning of these compounds and to estimate their potentials for volatilization and biological sorption and degradation in these technologies with the concept of fugacity. It was observed that the VOCs were mainly present in the water phase through the experiments. The effects of aeration or sludge addition on the fates of these VOCs occurred but appeared to be relatively limited. The concentration distributions of the VOCs were well below the reported partitioning coefficients. It was suggested that these compounds were unsaturated in the air and sludge phases, enhancing their potentials for volatilization and biological sorption/degradation through the processes. However, the properties of these chlorinated VOCs such as the volatility, polarity, or even biodegradability caused by their structural characteristics (e.g., the number of chlorine, saturated or unsaturated) may represent more significant factors for their fates in the aerobic biological treatment processes. These findings prove the complication behind the current knowledge of VOC pollutions in WWTPs and are of help to manage the adverse impacts on the environment and public health by the VOCs from these particular sources.

1. Introduction

Volatile organic compounds (VOCs), defined by the U.S. Environmental Protection Agency (USEPA) and many preceding literatures, are composed mainly of carbon and hydrogen and can evaporate under the normal atmospheric conditions of temperature and pressure (Fenger, 1999; USEPA, 2012). Besides their detrimental effects on the environment by participating atmospheric photochemical reactions, a variety of VOCs have been of concern due to their different types of short- and long-term adverse health effects. Many VOCs have been proved to be carcinogenic, teratogenic, and mutagenic with chronic hazards to the skin, central nervous system, liver, and kidney, further raising the concerns about exposure to these volatile chemicals (Choosong et al., 2010; Yeh et al., 2011).

* Corresponding authors. Tel.: +886 7 5252000x4421 (W.H. Chen). Tel.: +886 7 5252000x4409; fax: +886 7 5254449 (C.S. Yuan).

E-mail addresses: whchen@mail.nsysu.eu.tw (W.-H. Chen), ycsngi@mail.nsysu.edu.tw (C.-S. Yuan).

0045-6535/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.chemosphere.2013.11.039

Emissions of VOCs from various anthropogenic sources into the atmosphere and their impacts on the environment and public health have been extensively investigated. The focuses of these studies included both stationary and vehicular emissions, such as industrial science parks (Na et al., 2001; Wu et al., 2006), petrochemical industries (Brock et al., 2003; Cetin et al., 2003), landfill sites (Pope and Disalvo, 1995; Zou et al., 2003), and vehicular activities (Majumdar et al., 2009). Of these sources, there is a growing concern regarding the emissions of VOCs from wastewater treatment plants (WWTPs). A great number of VOCs at appreciable levels contained in different types of municipal, residential, and industrial wastewater have the potentials to be released into the environment, mostly via volatilization, as the source waters undergo various treatment technologies in WWTPs (Fatone et al., 2011; Lehtinen and Veijanen, 2011). As a consequence, the emissions of VOCs from WWTPs have been under close scrutiny and investigation by public and local agencies worldwide (Hall, 1997; USEPA, 2012).

Currently, there is no single fully satisfactory method to remove VOCs from wastewater due to the difficulties linked to the diversity and concentration variability of VOCs typically found in wastewater (Wu et al., 2006; Fatone et al., 2011). Biological treatment has been considered as one important approach for VOC removal (Dos-santos, 1995; Moura et al., 2007). While biological reduction is the primary process for anaerobic treatment of VOCs, the activities of microorganisms in aerobic treatment are expected to be maintained or enhanced by aeration for effective VOC removal from wastewater. However, in the meantime, the effectiveness of aerobic treatment is likely to be negatively affected by volatilization of VOCs through the processes. With some VOCs being actually released into the environment, the treatment efficiencies of VOCs in conventional WWTPs are likely to be overestimated, as the results possibly vary among different VOC species (Chen et al., 2013).

The objective of this study was to characterize the fates of four chlorinated VOCs (chloroform, carbon tetrachloride, trichloroethylene (TCE), and tetrachloroethylene (PERC)) in four simulated treatment processes with respect to the effects of aeration and sludge addition, two important steps in WWTPs. The ubiquitous presences of these chlorinated VOCs have been reported in many preceding studies (Cooper et al., 1993; Burris et al., 1995; Feng and Lim, 2005), as their occurrences as the major chemical composition in the wastewater selected in this study have been demonstrated and reported in the preliminary investigation (Cheng et al., 2008; Yang et al., 2012). Lab-scale batch experiments were conducted under four different operational circumstances in consideration of different stages of wastewater treatment technologies (the first sedimentation, the forepart and rear part of aerobic biological treatment, and the second sedimentation). The wastewater and activated sludge used for the experiments were collected in a conventional WWTP receiving the combined flows of urban and industrial wastewater, rainfall runoff, and a number of additional flows. While controlling the VOC emissions from WWTPs is becoming an environmental issue of increasing concern, this study provides a better understanding regarding the fates of chlorinated VOCs in WWTPs with respect to the potential influences of aeration and sludge addition and are of help to manage the adverse impacts on the environment and public health by the VOCs from these particular sources.

2. Methodologies

2.1. Wastewater treatment plant and VOCs of interest

A municipal WWTP located within 10 km of the downtown of Harbin City in China was selected to provide the wastewater and activated sludge, with its operational parameters being considered to prepare the simulated wastewater treatment processes in the lab-scale batch experiments. The total daily design capacity of the plant is 325 thousand cubic meters per day. Approximately 95% and the remaining 5% of its influent are sourced from domestic sewage and local industrial discharges, respectively. The chemical oxygen demand (COD) ranged from 282 to 487 mg L^{-1} during the sampling period. The presence of a broad range of VOCs, including the four chlorinated hydrocarbons of interest in this study, in the wastewater of this study has been demonstrated in the preliminary investigation (Yang et al., 2012).

2.2. Lab-scale batch experiments

Lab-scale batch experiments were conducted by analyzing the concentrations of four chlorinated VOCs under four different operational circumstances. By using the wastewater from the primary effluent and sludge in aerobic biological treatment of the WWTP, a biological reactor with a capacity of 27 L (0.3 m (L) × 0.3 m (W) × 0.3 m (H) with a 9 L head space of air volume) and three aeration pipes connected at the bottom was used in the experiments (see Fig. 1). Given four major treatment technologies used in the WWTP, including the pre-sedimentation without aeration for the first 2 h, followed by the forepart (from the 3rd to 6th hour) and rear part (from the 7th to 10th hour) of aerobic biological treatment process, and post-sedimentation without aeration in the last 2 h, a bioreactor experiment continuously simulating the four stages (denoted below as the stage 1 through 4, respectively) was conducted. The sludge was added in the reactor prior to the experiments (from the 1st to 12th hour), and the reactor was aerated through the stage 2 and 3 (from the 3rd to 10th hour). In consideration of the operational parameters and characteristics of the real WWTP selected, the time periods for different stages of the experiment were determined, as the concentrations of mixed liquor suspended solid (MLSS) and dissolved oxygen were controlled at 3300 mg L^{-1} and 4 mg L^{-1}, respectively. Rather than providing a completely simulated treatment processes or directly collecting samples at different sections of the WWTP selected in this study, it is important to note that the purpose of this bioreactor experiment was to investigate and compare the single and combined effects of aeration and sludge addition on the phase distributions of VOCs through typical wastewater treatment processes, while these operational strategies (e.g., aerating or adding sludge) are not readily changed in real WWTPs. The concentrations of the VOCs in the air, water, and sludge phases were analyzed regularly, with the results being at least duplicated for quality assurance and control.

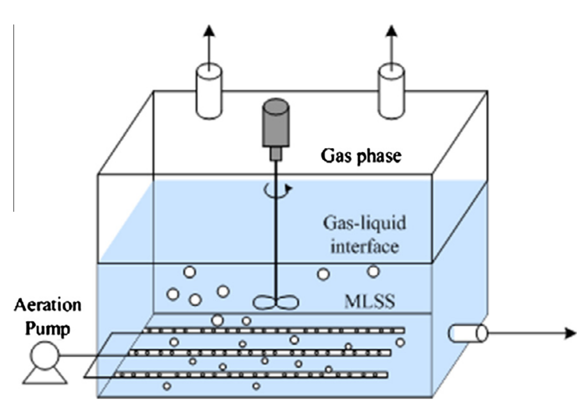

Fig. 1. The illustration depicting the bioreactor experiment used in this study.