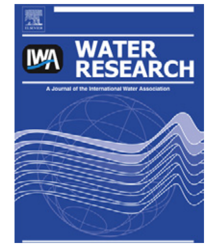
water research 44 (2010) 3924–3934

Available at www.sciencedirect.com

ScienceDirect

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



Effects of water vapor on activated carbon load equalization of gas phase toluene

Marilou M. Nabatilan, William M. Moe*

Department of Civil and Environmental Engineering, Louisiana State University, 3513B Patrick Taylor Hall, Baton Rouge, LA 70803, USA

ARTICLE INFO

Article history:
Received 4 October 2009
Received in revised form
19 April 2010
Accepted 23 April 2010
Available online 29 April 2010

Keywords:
Attenuation
Biofilter
Dampen
Load equalization
Humidity
Unsteady-state

ABSTRACT

Experimental testing and numerical simulations were conducted to assess the effects of elevated water vapor concentrations on the ability of granular activated carbon (GAC) to achieve load equalization of dynamically varying gas-phase toluene concentrations. Columns packed with Calgon BPL 4 × 6 mesh GAC were subjected to intermittent (8 h/day) toluene loading in air streams containing up to 90% relative humidity. Influent toluene concentrations ranged from 100 to 1000 ppm_v, and GAC column empty bed residence times ranged from 1.5 to 10 s. In comparison to load equalization performance achieved with dry air, high relative humidity improved load attenuation at high influent toluene concentration (e.g., 1000 ppm_v) but decreased the degree of load attenuation at low influent toluene concentration (e.g., 100 ppm_v). Model simulations conducted using a pore and surface diffusion model were in good general agreement with experimental observations. Collectively, results demonstrate that GAC columns can be of practical benefit as passively-operated load equalization devices even in the case of high relative humidity. Such systems may prove useful as a pre-treatment process for biofilters and other air pollution control devices that would otherwise be subjected to wide variation in contaminant loading.

1. Introduction

Aeration basins and other processes commonly employed in industrial wastewater treatment, manufacturing operations, and environmental remediation activities often emit gases containing appreciable quantities of volatile organic compounds (VOCs) in combination with high relative humidity (often at or near saturation levels) (Devinny et al., 1999; Converse et al., 2003; Iranpour et al., 2005). In response to regulatory pressure, controlling these gaseous VOC emissions has become a substantial concern for many industries and municipalities (Iranpour et al., 2005). Biofilters (fixed-film biological treatment processes) are an attractive technology for treatment of gas-phase pollutants in many of these applications due to their comparatively low cost, operational simplicity, and lack of secondary pollutant generation (Devinny et al., 1999).

Biofilters have been successfully applied for odor abatement and VOC removal at many wastewater treatment facilities, where gases may be collected for treatment at the headworks of a plant, from covered activated sludge aeration basins, or other processes (Devinny et al., 1999; Converse et al., 2003; Iranpour et al., 2005). Several challenges in design and operation, however, remain. In particular, intermittent industrial discharges, fluctuations in wastewater pollutant concentrations, and variation in wastewater flow rates result in fluctuating VOC concentrations in the associated off-gases (Melcer et al., 1994; Zhu et al., 1999; Escalas et al., 2003). This poses a challenge in design and operation of biofilters because transient periods of high and low influent pollutant loading can

* *Corresponding author*. Tel.: +1 225 578 9174; fax: +1 225 578 8652.
E-mail address: moemwil@lsu.edu (W.M. Moe).

0043-1354/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.watres.2010.04.028

adversely affect biofilter performance (Cox and Deshusses, 2002; Atoche and Moe, 2004; Li and Moe, 2005; Qi and Moe, 2006).

Research has demonstrated that columns packed with granular activated carbon (GAC) can serve as passively-operated load equalization devices as a pre-treatment step prior to biofiltration of gas-phase VOCs (Hori and Tanaka, 1992; Weber and Hartmans, 1995; Li and Moe, 2005; Moe and Li, 2005; Moe et al., 2007; Nabatilan et al., 2009, 2010). The rationale for such systems is that during periods of high contaminant loading, the GAC adsorbent can temporarily accumulate contaminants and then subsequently desorb them during intervals when concentration in the waste gas is low. This can serve several purposes including dampening fluctuations in organic loading to prevent shock loading of biofilters, and providing continuous feed to systems over periods when wastes are not being generated (Li and Moe, 2005). While use of GAC load equalization in conjunction with biofiltration has the potential to increase reliability and decrease costs, previous studies on such integrated systems have focused on treatment of dry gases having low or no relative humidity. Water vapor, however, is known to influence GAC adsorption capacity and mass transfer kinetics (Keener and Zhou, 1990; Cal et al., 1996; Russell and LeVan, 1997; Kim et al., 2004).

The overall objective of this research was to assess the effects of elevated relative humidity on load equalization by GAC columns subjected to dynamically varying loading of VOCs. Toluene served as a model VOC contaminant. Two sets of experiments were conducted. In the first, fixed-bed GAC columns receiving intermittent toluene loading (toluene present in the gas stream 8 h/day) were subjected to step increases in relative humidity to assess impacts of water vapor over a wide range of influent concentrations. In the second set of experiments, GAC columns of various packed bed depths were subjected to intermittent toluene loading in air having a relative humidity of 80% to determine effects of high water vapor concentration on load equalization as a function of empty bed residence time (EBRT). In addition to experimental testing, numerical simulations were conducted using a pore and surface diffusion model in an attempt to provide a mechanistic explanation for the experimental observations.

2. Materials and methods

2.1. Granular activated carbon and experimental apparatus

The adsorbent employed in this research was BPL 4 × 6 mesh GAC (Calgon Carbon Corp., Pittsburgh, PA), a microporous, bituminous coal-based activated carbon designed for use in vapor phase applications. This material has been extensively characterized previously in terms of pore size distribution and surface chemistry (El-Sayed and Bandosz, 2001) as well as water vapor adsorption capacity (Sullivan et al., 2007). This GAC has also been used in previous studies of toluene load equalization applied to dry gas streams (Li and Moe, 2005; Moe and Li, 2005; Moe et al., 2007; Nabatilan et al., 2009, 2010). GAC was rinsed with distilled water to remove fines, dried at 105 °C, and stored in desiccators prior to use.

The configuration of the experimental apparatus used in fixed-bed adsorption/desorption experiments is shown in Fig. 1. Packed columns were constructed of PVC (ID 7.62 cm) pipe. Each column contained a stainless steel support mesh at the bottom, 6-cm depth glass beads (5 mm diameter) to distribute air flow, a thin layer of glass wool, a layer of GAC, another thin layer of glass wool, and another 6-cm glass beads. As further described below, depth of the GAC layer varied between experiments. Some experiments employed columns comprised of a single section while others employed columns constructed with multiple sections in series to facilitate sampling at multiple bed depths.

Contaminant-free, dry compressed air (relative humidity ≤5%) flowed through an electronic mass flow controller (Aalborg Instruments, Orangeburg, NY) to regulate air flow through the system. For all experiments, the air flow rate was 22.8 L/min, corresponding to superficial gas velocity of 300 m/h in the packed columns. A portion of the air flow passed through an aeration stone submerged in a 20 L glass carboy filled with deionized water to provide the desired level of humidification. For dry air experiments, the carboy was bypassed and all air flow was directed to the packed column. Liquid toluene (ACS reagent grade, Sigma, St. Louis, MO) was delivered by syringe pumps (KD Scientific, Boston, MA) and evaporated into the air stream. A microprocessor-based controller (Chron-Trol, San Diego, CA) turned syringe pumps on and off as necessary. Gas sampling lines, located at the inlet and outlet of the GAC column, were comprised of Teflon tubing. Initial tests conducted prior to placement of activated carbon demonstrated that column components other than GAC had little or no adsorption capacity for toluene. All experiments were conducted at ambient laboratory temperature of 23 ± 2 °C.

2.2. Intermittent (8 h/day) toluene loading at various relative humidity levels

Initial experiments to assess the effects of various humidity levels on toluene load equalization were conducted using three separate columns, each containing 12.5 cm depth GAC, at a constant air flow rate (corresponding EBRT of 1.5 s). To simulate industrial treatment of off-gases with intermittent operation, toluene was supplied in the influent air stream for 8 h/day at a constant toluene concentration of either 100, 400,

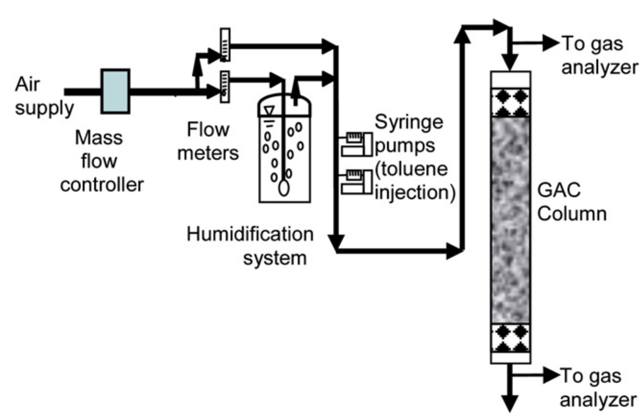


Fig. 1 – Experimental apparatus used in fixed-bed adsorption/desorption experiments.