ELSEVIER

Chemical Engineering Science 63 (2008) 841–855

Chemical Engineering Science

www.elsevier.com/locate/ces

Determination of mass transfer coefficients for packing materials used in biofilters and biotrickling filters for air pollution control. 1. Experimental results

Seongyup Kim, Marc A. Deshusses*

Department of Chemical and Environmental Engineering, University of California, Riverside, CA 92521, USA

Received 20 March 2007; received in revised form 29 September 2007; accepted 12 October 2007
Available online 16 October 2007

Abstract

Gas film mass transfer coefficients ($k_G a_t$, $k_G a_w$) and liquid film mass transfer coefficients ($k_L a_w$) for packing materials used in biofilters and biotrickling filters for air pollution control were determined experimentally. Lava rock, polyurethane foam cube (PUF), Pall ring, porous ceramic beads, porous ceramic Raschig rings and compost–woodchips mixtures were investigated. The experiments were performed at gas velocities ranging from 100 to 8000 m h^{-1} and liquid velocities of 0.1–12 m h^{-1}, i.e., a wide range that covers most biofilters and biotrickling filters. $k_G a_t$ in biofilter packings ranged from about 500 to 2500 h^{-1}, while $k_G a_w$ and $k_L a_w$ in biotrickling filters ranged from 100 to 8000 h^{-1}, and 1 to 300 h^{-1}, respectively, depending on the packings and the conditions. This is markedly lower than mass transfer coefficients usually observed for conventional wet scrubbing. The gas film mass transfer coefficient ($k_G a_t$) of 50:50% vol compost–woodchips mixture, a common biofilter packing, was greater than this of a 20% vol compost and 80% woodchips mixture, though the mass transfer was not increased by increasing further the volume fraction of compost. All compost mixtures exhibited a greater gas film mass transfer coefficient than lava rock or other synthetic materials. The mass transfer coefficients of compost mixtures was also influenced by packing method and it was directly proportional to the surface area of the bulking agents added. The gas film mass transfer coefficient ($k_G a_w$) of five biotrickling filter packing materials increased linearly with gas velocity. The effect of liquid on the gas film mass transfer coefficient was not significant. Of all the biotrickling filter packings, the porous ceramic beads had the highest gas and liquid film mass transfer coefficients followed by lava rock, porous ceramic rings, 1 in Pall ring and PUF cubes. The liquid film mass transfer coefficient ($k_L a_w$) was directly proportional to liquid velocity and the effect of gas velocity was negligible. Several correlations allowing prediction of mass transfer coefficients are presented in Part 2 of this paper.

Keywords: Mass transfer; Absorption; Packed-column; Biotrickling filter; Biofilter; Environmental engineering

1. Introduction

Biological treatment is increasingly used to control air pollutants as it is cost-effective, especially for the treatment of low concentration of pollutant in large air streams. The most frequently used biotechnologies for air pollution control are biofiltration and biotrickling filtration (Devinny et al., 1999; Kennes and Veiga, 2001). Biofiltration refers to the treatment of gaseous pollutants or vapors in a packed bed of damp material (usually compost mixed with some bulking agent) on which pollutant-degrading microorganisms thrive. In biotrickling filters, a free aqueous phase is trickled over the packing (usually an inert material with a large surface area) to provide optimum conditions to a biofilm of pollutant-degrading bacteria (Cox and Deshusses, 1998). Thus, the pollutant undergoing treatment will be transferred directly to the biofilm in a biofilter, while it may be transferred first to the trickling liquid in a biotrickling filter.

External mass transfer, diffusion and biodegradation kinetics are the main factors affecting the performance of biofilters and biotrickling filters. A better understanding of these limitations is important in order to enhance the performance and design of these bioreactors (Kim and Deshusses, 2005).

* Corresponding author. Tel.: +1 951 827 2477; fax: +1 951 827 5696.
E-mail address: mdeshusses@engr.ucr.edu (M.A. Deshusses).

0009-2509/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ces.2007.10.011

These have been researched by several investigators. For example, Barton et al. (1999) discussed means to increase treatment in kinetically or mass transfer limited bioreactors for air pollution control and found out that the removal was substrate limited deep in the biofilm, but it was kinetically limited near the aqueous/biomass phase. Kirchner et al. (1992) concluded that a trickle-bed bioreactor was limited by oxygen diffusion in the biofilm, biological degradation reaction and external mass transfer. Picioreanu et al. (2000) developed a 2D model to explain the transport of substrate into biofilms and found that the substrate flux to the biofilm was greatly influenced by external mass transfer rate. Kim and Deshusses (2003) observed that the performance of biotrickling filters treating low concentrations of H_2S at very short gas contact times depended on the air velocity, indicating that external mass transfer was probably limiting. Kan and Deshusses (2006) developed foamed emulsion biofilter having high surface area for mass transfer ($2400\,m^2\,m^{-3}$) and its performance was 2–1000 times higher than other biotreatment.

In spite of the importance of mass transfer aspects in biofilters and biotrickling filters, no systematic study was ever conducted to determine mass transfer coefficients in these reactors. When mass transfer coefficients were needed e.g., for modeling purposes, investigators (Mpanias and Baltzis, 1998; Baltzis et al., 2001; Kim and Deshusses, 2003) have relied on the large body of information obtained for traditional packing materials used for gas absorption, stripping or distillation (Onda et al., 1968; Piche et al., 2001; Sherwood and Holloway, 1940, Shulman et al., 1955a,b). However, these mass transfer correlations cannot necessarily be applied to biofilters and biotrickling filters. This is because they were developed for different packing materials and may not apply to the very different operating conditions encountered in biofilters and biotrickling filters. Typical wet scrubber operating conditions are superficial gas velocities ranging from 1000 to $10,000\,m\,h^{-1}$ and trickling liquid velocities ranging from 10 to $150\,m\,h^{-1}$. On the other hand, gas superficial velocities in biofilters and biotrickling filters usually range from 60 to about $1000\,m\,h^{-1}$, and occasionally up to $6000\,m\,h^{-1}$ (Gabriel and Deshusses, 2003), while the liquid superficial velocity in biotrickling filters rarely exceeds $10\,m\,h^{-1}$.

Thus, the objectives of this study were to determine gas film mass transfer coefficients for various packings used on biofilters, and to determine both gas film and liquid film mass transfer coefficients for selected biotrickling filter packings. A wide range of gas and liquid trickling velocities was used to increase the applicability of the data.

2. Materials and methods

2.1. Experimental setup for gas film mass transfer coefficient ($k_G a_w$, $k_G a_t$)

For the determination of $k_G a_w$ (index w here denotes the wetted area), absorption of CO_2 in trickling caustic water was used because CO_2 reacts immediately in caustic water, hence the main resistance to mass transfer lies in the gas film (Linek et al., 1984). A schematic of the experimental setup is shown in Fig. 1. A bench-scale absorption column (PVC, 15 cm ID $\times$160 cm high, Harrington Plastics, Chino, CA) was filled with selected packing materials (see list in Table 1).The packing height was either 10 cm (for lava rocks, expanded clay, some compost beds) or 40 cm (Pall rings, polyurethane foam (PUF) and some compost–woodchips mixtures) depending on the pressure drop. A metered air stream resulting in air velocities ranging from 100 to $8000\,m\,h^{-1}$ was supplied by a centrifugal blower (Broan, Hartford, WI for high velocities, Roton,

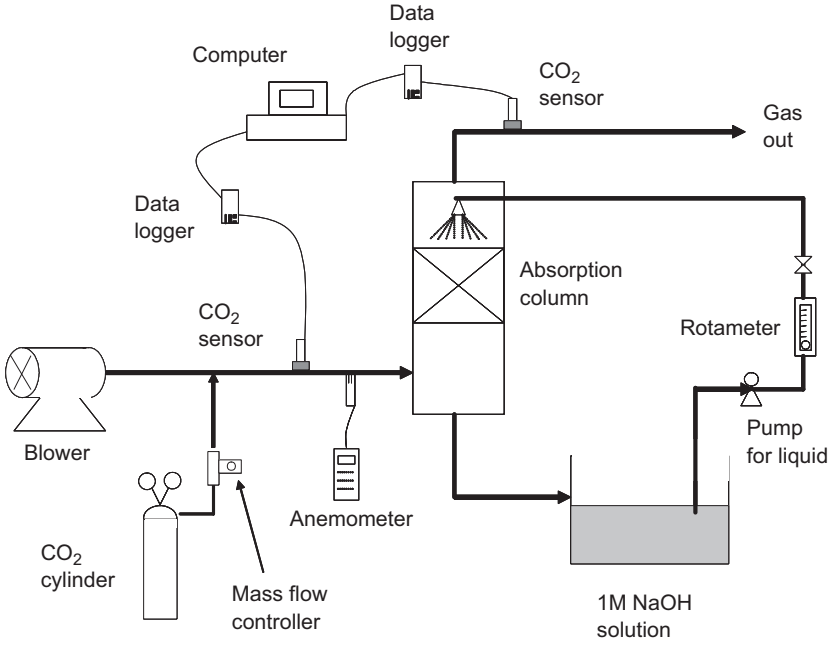

Fig. 1. Schematic of the experimental setup for $k_G a_w$.