Biofiltration of Isopentane in Peat and Compost Packed Beds

Zhao Wang and Rakesh Govind
Dept. of Chemical Engineering, University of Cincinnati, Cincinnati, OH 45221

Commercially available biofiltration systems have used natural bioactive materials in packed beds due to low media cost and easy availability. Detailed understanding and modeling of biofiltration systems are lacking in existing literature. Experimental studies on the isopentane treatment in air using peat- and compost-packed beds were conducted with inlet isopentane concentrations of 360 to 960 ppmv, and empty-bed gas-phase residence times of 2 to 10 min. High removal efficiencies (> 90%) were achieved at low contaminant concentrations (< 500 ppmv) and large empty-bed gas-phase residence times (> 8 min). For both peat and compost biofilters, there was an "optimal" water content that gave the highest removal efficiency. For higher water content, mass transfer of isopentane through the liquid phase controlled the biofiltration removal efficiency. At low water content, irreversible changes in the bioactivity of peat and compost occurred, resulting in an irrecoverable loss of removal efficiency. Increases in biofilter bed temperature from 25 to 40°C improved the removal efficiency. A mathematical model incorporating the effect of water content and temperature was developed to describe the packed-bed biofilter performance. Model predictions agreed closely with experimental data.

Introduction

In recent years, regulation of hazardous air pollutants under the Clean Air Act and its amendments has emerged as a major environmental issue. Major sources of volatile organic compounds (VOCs) in air are chemical production plants, manufacturing sites using common solvents, combustion sources, and waste treatment operations, such as wastewater treatment plants, vacuum extraction of contaminated soils, and groundwater stripping operations. Technologies for treatment of air contaminants can be classified into the following categories: (1) physical methods, such as adsorption on different sorbents, membrane separation, condensation, are capable of separating the contaminants from air, but most of them require subsequent treatment; (2) chemical methods, such as thermal destruction, catalytic conversion, chemical oxidation, may also require treatment of chemical by-products; (3) biological treatment, such as activated sludge process, bioscrubber, and biofilter.

In biological treatment, oxidation of contaminants is mediated by active microorganisms. Major advantages of biological treatment compared to physical and chemical methods include (1) minimal usage of chemicals; only low concentrations of mineral nutrients are needed for growth of microorganisms; (2) low energy consumption, since biological processes are usually operated at ambient conditions; and (3) no generation of secondary waste products that require further treatment or disposal.

Isopentane is used as a blowing agent in the manufacture of plastic foams, used mainly as packaging material and in disposable foam products, such as cups and plates. After the foam is manufactured, isopentane diffuses out of the foam material and contaminates the air during storage. Isopentane-contaminated air needs to be treated before being discharge into the environment. The concentration of isopentane in the contaminated air exiting the foam storage facility may be as high as 1,000 ppmv (Wu, 1992). The objective of this study was to investigate the microbial treatment of the exit air, containing a high concentration of isopentane (360 ppmv–960 ppmv), using packed-bed biofilters with peat and compost as support media.

Correspondence concerning this article should be addressed to R. Govind.

Table 1. Previous Studies on VOC Biofiltration Using Naturally Bioactive Materials

Name	Material	Target
Peters and Alleman (1982)	Wood chips, bark	BTEX compounds
Kardono and Allen (1995)	Compost	Benzene
Wang et al. (1996)	Peat, compost	Isopentane
Kampbell and Wilson (1987)	Soil	Butane
Togna and Singh (1994)	Soil, compost	Isopentane
Dawson (1993)	Soil	BTEX compounds
Benitez et al. (1995)	Compost	Benzene, ethylbenzene
Morgenroth et al. (1995)	Compost	Hexane
Hodge and Devinny (1995)	Compost, earth	Ethanol
Shareefdeen et al. (1993a,b)	Soil, peat, perlite	BTX compounds, methanol vapor

Background

A biofilter is usually a packed bed wherein contaminated air is contacted with active microorganisms. Early work on biofiltration was mainly concerned with odorous gases (Smith et al., 1973), sewage gas (Pomeroy, 1957, 1963, 1982; Leson and Winer, 1991), hydrogen sulfide (Carlson and Leiser, 1966; Smith et al., 1973; Don and Feenstra, 1984; Allen and Young, 1992; Ergas et al., 1995), and in treatment of odor from rendering plants (Bohn, 1975; Bohn and Bohn, 1986; Prokop and Bohn, 1985). Most of those applications used soil beds, wherein the odor-causing compounds were either adsorbed or converted to secondary products. Later, soil beds were also used for treatment of VOC emissions. Other naturally bioactive materials used in biofiltration include wood chips, composted bark, peat, and compost. A summary of the background literature on biofiltration of VOCs using naturally bioactive materials is given in Table 1. It was also found that control of bed moisture content and inlet air temperature were critical for effective biofilter operation (Hartenstein, 1987).

Other types of media used in biofilters are synthetic materials, such as activated carbon (Utgikar et al., 1991), ceramic pellets and extruded monoliths (Utgikar, 1994; Govind et al., 1993; Liu et al., 1994; Wang et al., 1996). These media serve as support for active immobilized biofilms. However, the major disadvantage of synthetic support media is the high cost compared to naturally bioactive media, such as peat, compost, and bark, or mixtures of these materials.

Previous mathematical models of biofilters assumed that a naturally bioactive medium, such as peat or compost, could be represented as an inert support medium, uniformly covered by an active biofilm of finite thickness. The transport of the contaminant occurred through an aqueous film outside the biofilm, followed by diffusion and biodegradation in the active biofilm (Ottengraf, 1984, 1986, 1990). However, naturally bioactive materials consist of porous particles that contain a distribution of active microorganisms inside the porous particle; thus diffusion-bioreaction is more likely to take place inside the particle rather than in a biofilm outside the particle. In this article, a shrinking-core model, commonly used for porous catalysts, is employed to describe this process. Also, though temperature and water content of the bed were critical in packed biofilter operation, they were never quantified in a mathematical model. It is important to incorporate these conditions in any mathematical description of the biofilter system.

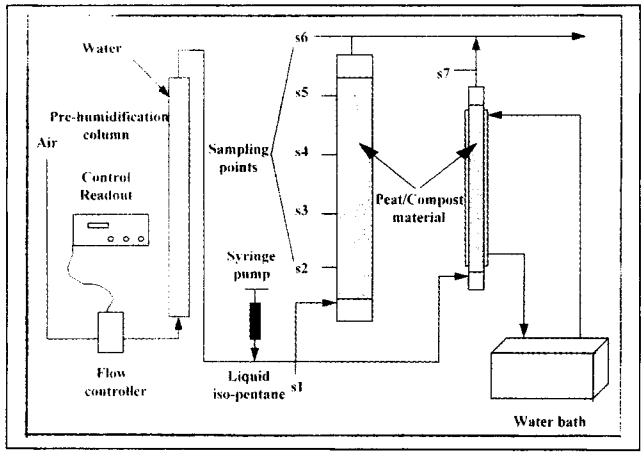

Figure 1. Experimental biofilter setup.

Experimental Methodology

Experimental setup

The experimental system is shown in Figure 1. Two glass biofilters were designed and assembled to test various types of support media. Each glass biofilter was made in two sections with a total height of 90 cm and diameter of 5 cm. It had provisions for six side ports for withdrawing gaseous samples. In addition, a glass microbiofilter (2.5 mm diameter, 100 mL empty volume) was designed and assembled to study the effect of temperature and water content. The microbiofilter is equipped with a jacket that is connected with a constant-temperature bath for controlling the reactor temperature. Incoming air was humidified by passing it through a column packed with 2 mm glass beads with a countercurrent flow of water. The air flow rate was controlled by a thermal mass-flow controller (MKS Industries, Type 1259, Control channel type 247). The desired concentration of isopentane in the air stream was obtained by injecting the isopentane into the air stream using a syringe pump (Harvard Apparatus, Model 11).

Peat and compost were tested as the natural bioactive media in the biofilter. The physical properties of the peak and compost media are listed in Table 2. Before operating the

Table 2. Physical Properties of the Media

Media	R (cm)	ϵ_b	ρ_b (g/mL)	W_O (g/g)
Peat	0.25	0.54	0.502	0.645
Compost	0.45	0.48	0.314	0.536

biofilters, the adsorption capacity of the peat and compost was measured using a smaller section of the biofilter with packing height of 25 cm. To eliminate the effect of biodegradation, both media were sprayed with 0.1 g/L $HgCl_2$ solution to sterilize the support media. Hence, physical adsorption of isopentane was the sole mechanism for its removal during the adsorption study.

The biofilters were operated continuously and the inlet and outlet isopentane concentration data were collected over a period of time. The concentration profiles of the isopentane in the biofilters were obtained by withdrawing samples from the inlet, outlet, and side ports along the height of the biofilter. Once the biofilter performance reached steady state, the concentration difference of carbon dioxide in the gas phase was also measured to assess the degree of mineralization of isopentane.

Experimental studies on the effect of water content

The water content of the support media was defined as

$$W = \frac{\text{g of water}}{\text{g of dry packing}}. \qquad (1)$$

The original water content (W_O) in the support medium (peat or compost) was measured by drying the medium at 100°C for 10 h, after which there was no change in weight. To achieve water contents higher than the original amount, water was added to the medium and the medium was mixed thoroughly. To obtain water contents lower than the original amount, the medium was dried at room temperature in a fume hood. Weight-loss measurements were made to determine the water content of the medium.

Studies on the effect of water content were conducted with saturated air using the microbiofilter. Various inlet isopentane concentrations were used in conjunction with media of different water contents to determine the effect of water content on the biofiltration removal efficiency.

Experimental studies on the effect of temperature

The effect of temperature was studied using the jacketed microbiofilter. For these experiments, the inlet air was preheated to the bed temperature by passing the gas through a coiled copper tube immersed in the constant temperature bath, used for circulating the water through the reactor jacket. The inlet and outlet isopentane concentrations were measured for different bed temperatures.

Analytical procedures

The concentration of isopentane in gas samples taken from the sampling ports were analyzed in a Hewlett-Packard 5710 gas chromatograph fitted with a Alltech C-5000 column [20 ft (6 m) long, 1/8 in. (3.2 mm) diameter] using a flame ionization detector. Nitrogen was used as carrier gas with a flow rate of 35 mL/min. The temperatures of the oven and the detector were maintained at 150 and 250°C, respectively. Carbon dioxide concentration in gas streams was determined using a Fisher 1200 gas partitioner provided with a conductivity detector and a Porapak 11-128-10 column [6 ft (2 m) long, 1/8 in. (3.2 mm) dia.] Helium was used as the carrier gas with a flow rate of 25 mL/min. Oven temperature was maintained at 50°C. All measurements were carried out in triplicate. The resulting inaccuracy of the gas chromatography (GC) analysis was generally less than 5% of the measured isopentane concentration.

Model Development

Mathematical modeling of a single particle requires consideration of simultaneous diffusion and degradation of isopentane within the particle. A spherical single particle of peat or compost, radius R, was assumed to have a uniform distribution of active microorganisms. At steady state, the growth rate of microorganisms, due to biodegradation, was balanced by its own decay, resulting in no net growth. The occurrence of this steady-state condition (growth is equal to decay), was verified by the carbon dioxide balance, as discussed later in this article. Differential mass balance of the contaminant inside the porous particle of the medium yielded the following equation (Bird et al., 1960):

$$\left(\frac{D_e}{r^2}\right)\frac{\partial}{\partial r}\left[r^2\frac{\partial C}{dr}\right] = J_i \qquad 0 \le r \le R, \qquad (2)$$

where D_e is the effective diffusivity of isopentane inside the porous particle, C is the concentration of isopentane, and J_i is the reaction rate.

Traditionally, when contaminant concentration is the only controlling factor, the Monod equation is used to express the biodegradation rate (Monod, 1949). However, in this study, the effect of water content on the rate of biodegradation has to be incorporated in the model equations.

In our tests on the effect of water content, three critical points were noted, as shown in Figure 2: (1) the point where irreversible decrease of removal efficiency occurred, W_i; (2) the point where removal efficiency was maximum, W_p; and (3) the maximum possible water content, W_{max}, when droplets of liquid water appeared in the medium. The removal efficiency increased when water content increased between W_i and W_p. The removal efficiency decreased when water content increased above W_p until the maximum water content W_{max} was attained.

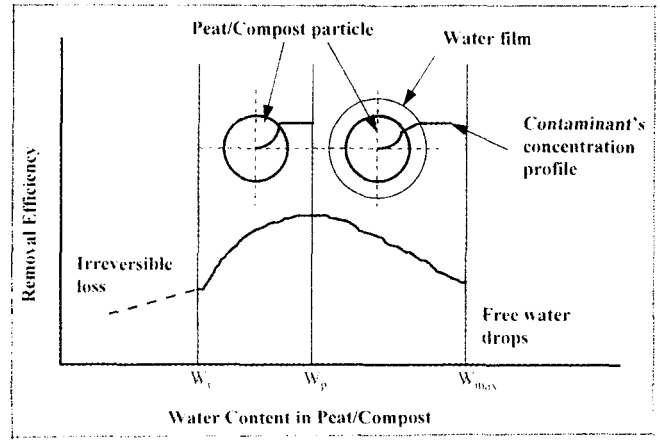

Figure 2. Effect of water content on biofilter removal efficiency.

It was assumed that when the water content was between W_i and W_p, water was mainly present with active cells inside the peat or compost particle. The particle was saturated with water at W_p. In this case, degradation was controlled by both the substrate concentration and the water content, and was mathematically expressed by a "double Monod" expression (McGee et al., 1972; Oh et al., 1994) as follows:

$$J_i = \frac{\mu_{\max} X}{Y} \frac{C}{K_s + C} \frac{(W - W_i)}{K_{sw} + (W - W_i)} = \frac{KC}{K_s + C} \cdot \frac{(W - W_i)}{K_{sw} + (W - W_i)} \qquad W_i < W < W_p, \quad (3)$$

where $\mu_{\max}$ is the specific growth constant; X is the biomass concentration; K_s is the half-velocity constant with respect to substrate; K_{sw} is the half-velocity with respect to water content; Y is the yield coefficient from isopentane to biomass; and K is overall maximum substrate conversion rate = $\mu_{\max} X/Y$.

Equations 2 and 3 yield the following overall equation:

$$\left(\frac{D_e}{r^2}\right) \frac{\partial}{\partial r}\left[r^2 \frac{\partial C}{dr}\right] = \frac{KC}{K_s + C} \cdot \frac{(W - W_i)}{K_{sw} + (W - W_i)} \qquad W_i < W < W_p. \quad (4)$$

The two boundary conditions for Eq. 4 were

$$r = 0 \qquad \frac{dC}{dr} = 0; \qquad r = R \qquad D_e \left|\frac{\partial C}{\partial r}\right|_{r=R} = k_g (C_b - C_f), \quad (5)$$

where k_g is the gas-phase mass-transfer coefficient; C_b is the isopentane concentration in the bulk gas stream; and C_f is the isopentane concentration at the particle surface with no external water film. The gas-phase mass-transfer coefficient, k_g, was calculated using the following equation for packed beds (Charpentier, 1976):

$$\frac{k_g P}{\rho_g u_b} = 2.3 \frac{(aR)^{-1.7}}{MW_s} \left(\frac{u_b \rho_g R}{\mu_g}\right)^{-0.3} \left(\frac{\mu_g}{\rho_g D_g}\right)^{-0.5}, \quad (6)$$

where P is the pressure in the biofilter; u_b is the air velocity; MW_s is the molecular weight of isopentane; a is the specific surface area of the peat/compost particle; ρ_g, μ_g, are the gas-phase density and viscosity, respectively; and D_g is the diffusivity of isopentane in the gas phase.

When the water content was between W_p and $W_{\max}$, water was present not only with the active cells inside the particle, but also as a liquid film outside the particle. When the water content increased above $W_{\max}$, free water droplets could be seen in the peat or compost media. The presence of a water film outside the particle resulted in mass-transfer limitations. This amount of water in the water film outside the particle was quantified as follows:

$$Q_w = \frac{\rho}{1 + W_O}(W - W_p) \qquad W_p < W < W_{\max}, \quad (7)$$

where Q_w is the amount of water in the water layer per unit volume of the bed, and ρ is the bulk density of the medium. The thickness of the liquid film was determined based on the assumption that the liquid film had uniform thickness, that is,

$$l = \frac{Q_w \cdot R}{3(1 - \epsilon_b)}, \quad (8)$$

where l is the liquid-film thickness, and ϵ_b is the void fraction of the bed. The mass transfer coefficient was calculated as follows:

$$k_w = \frac{D}{l}, \quad (9)$$

where k_w is the mass-transfer coefficient, and D is the diffusivity of isopentane in water.

The boundary conditions for Eq. 4 were modified as

$$r = 0 \qquad \frac{\partial C}{\partial r} = 0; \qquad r = R \qquad D_e \left|\frac{\partial C}{\partial r}\right|_{r=R} = K_g (C_b - C_f), \quad (10)$$

where K_g is the overall mass-transfer coefficient based on gas-phase concentrations. Combining gas-phase and liquid-phase mass-transfer coefficients, the overall mass-transfer coefficient was obtained:

$$\frac{1}{K_g} = \frac{1}{k_g} + \frac{1}{Hk_w}, \quad (11)$$

where H is the Henry's Law constant for isopentane.

The steady-state design equation for the biofilter was obtained by an overall mass balance (Bird et al., 1960), which was written as follows:

$$u_b \left(\frac{\partial C}{\partial Z}\right) + 3\left[(1 - \epsilon_b)\frac{D_e}{R}\right] \left|\left(\frac{\partial C}{\partial r}\right)\right|_{r=R} = 0 \quad (12)$$

where u_b is the gas velocity in the biofilter column, and Z is the height of the biofilter.

The additional boundary condition for Eq. 12 was

$$Z = 0 \qquad C = C_{in} \quad (13)$$

where C_{in} is the inlet concentration of isopentane.

The oxygen utilization for isopentane degradation was also described using mass balance within the particle:

$$\left(\frac{D_{eo}}{r^2}\right) \frac{\partial}{\partial r}\left[r^2 \frac{\partial C_0}{dr}\right] = J_o \qquad 0 \le r \le R, \quad (14)$$

where D_{eo} is the effective diffusivity of oxygen inside the porous particle; C_o is the concentration of oxygen; and J_o is the oxygen utilization rate, which could be related to isopentane degradation rate J_i:

$$J_o = \alpha J_i \tag{15}$$

where α is the stoichiometric coefficient of the reaction between oxygen and isopentane.

The preceding equations were used to model the biofilter system. Equations 4 and 12 were nonlinear second-order differential equations that had no general analytical solution, and hence only a numerical solution was obtained. The biokinetic parameters, K and K_s, and the effective diffusivity, D_e, were estimated from the experimental data using standard least-squares curve-fitting techniques.

Results and Discussion

Abiotic adsorption studies

Abiotic adsorption studies were conducted by spraying the peat or compost material with 0.1 g/L of mercuric chloride ($HgCl_2$) aqueous solution to prevent biological activity by the indigenous microorganisms. The air flow rate was maintained at 100 mL/min, and the inlet isopentane concentration was 350 ppmv. Figure 3 presents breakthrough data for compost, which shows that compost exhibited limited adsorption capacity for isopentane. Isopentane concentration in the exit air stream became equal to the inlet concentration (350 ppmv) in about 30 min, and the total equilibrium adsorbed concentration of isopentane was 0.0125 g isopentane/kg dry compost. Similar results were obtained on peat, with the total equilibrium adsorbed isopentane concentration of 0.0069 g isopentane/kg dry peat. The results also demonstrated that removal of isopentane in peat and compost biofilters for extended time periods (> 30 min) could not be explained by physical adsorption, and biodegradation of isopentane was the only logical explanation.

Steady-state biofilter operation

The bench-scale biofilter (5 cm diameter and 90 cm height of packed bed) was operated with prehumidified air at various inlet concentrations of isopentane and varying empty-bed gas-phase residence times. For both peat and compost materials, experimental data on isopentane removal efficiency were obtained at selected empty-bed gas-retention times (empty-bed volume of packed bed = 1.96 L) and various inlet isopentane concentrations. For both materials, the removal efficiency increased with decreasing inlet isopentane concentration and increasing gas-phase residence time. High removal efficiencies (> 85%) were attained with gas-phase retention times exceeding 8 min and when the inlet isopentane concentration was less than 500 ppmv.

Table 3. The Kinetic Constants of Isopentane Degradation

Support Media	K (ppmv)	K_s (ppmv)	$De \times 10^6$ (cm^2/s)	K_{sw} (g/g)
Peat	12.92 ± 0.25	5.0	1.8 ± 0.02	0.012
Compost	13.25 ± 0.28	8.0	2.1 ± 0.03	0.008

The isopentane elimination capacity (EC) of the biofilter bed was calculated using the following equation:

$$\mathrm{EC} = F_{\mathrm{air}} C_{in} \eta / V_{\mathrm{bed}}, \tag{16}$$

where F_{air} is the volumetric air flow rate (mL/min); C_{in} is the inlet isopentane concentration (ppmv); η is the fractional isopentane removal efficiency; and V_{bed} is the volume of the packed biofilter bed. Both peat and compost produced an almost constant elimination capacity of 0.25 g isopentane/L·day. Comparable elimination capacities for isopentane removal in biotrickling filters using synthetic support media has been reported by Togna and Singh (1994).

For air flow rate of 200 mL/min (empty-bed gas-phase retention time = 10 min), gas samples were taken from the inlet, outlet, and side ports to obtain the isopentane concentration profile along the height of the packed-bed biofilter. The experimental concentration profile data were used to fit the model equations (Eqs. 4 and 12), and the best-fit kinetic parameters (K, K_s, K_{sw}), given in Table 3, were obtained. Figure 4 shows the experimental data with model fit for compost beds. Examining the values of K_s, it is clear that K_s is much smaller than the inlet isopentane concentration, and hence the reaction rate is zeroth order in almost the entire biofilter bed.

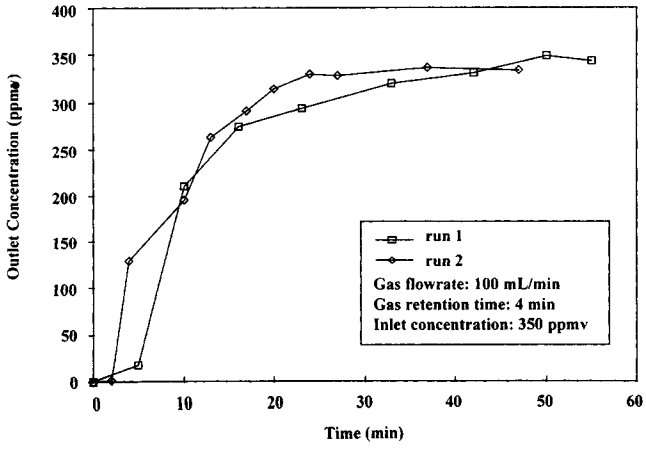

Figure 3. Breakthrough of isopentane in compost packed-bed biofilter.

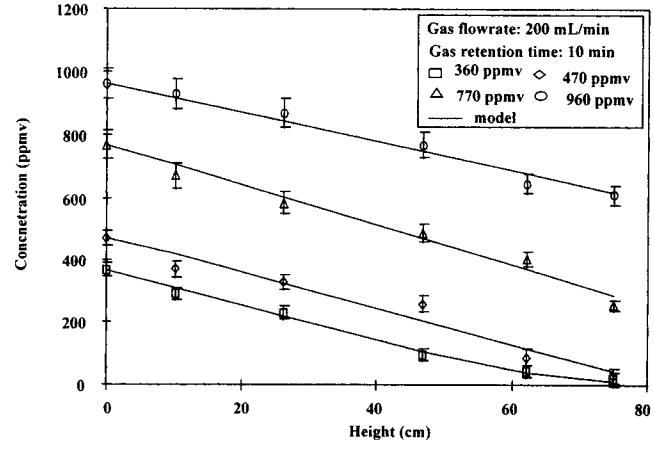

Figure 4. Comparison of model fit and experimental isopentane concentration profile in compost packed-bed biofilter.

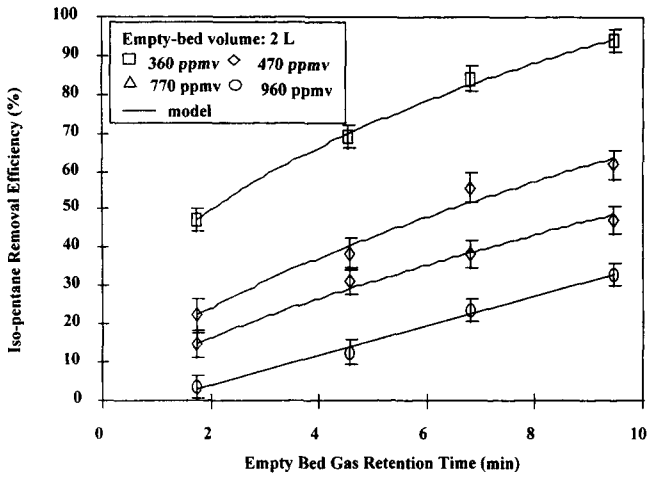

Figure 5. Effect of empty-bed gas retention time on removal of isopentane in compost biofilter; the continuous curves show model calculations.

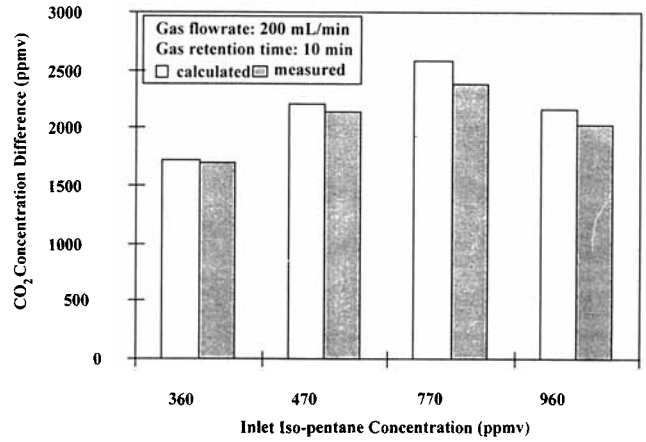

Figure 6. Comparison of experimental increase in carbon dioxide concentration and calculated values in compost packed-bed biofilter.

The best-fit kinetic parameters, determined from the concentration profile data, were used to calculate the isopentane removal efficiency for other empty-bed gas-phase retention times and inlet isopentane concentrations. Figure 5 shows the experimental isopentane removal efficiencies with the model predictions, illustrated by the continuous plots, for compost packed-bed. The model predictions are in close agreement with the experimentally measured isopentane removal efficiencies for different empty-bed gas-phase retention times and inlet isopentane concentrations.

The inlet and outlet concentrations of carbon dioxide were also measured, and the increase in carbon dioxide concentration was obtained at various inlet isopentane concentrations and gas retention time of 10 min (200 mL/min gas flow rate). Carbon dioxide is produced by the aerobic biodegradation of isopentane to carbon dioxide and water and due to decay of the biomass. The rate of biomass decay is proportional to the biomass concentration in the biofilter bed. As isopentane degrades in the biofilter bed, the biomass concentration increases due to partial conversion of isopentane to active cells. The remaining isopentane biodegrades to form carbon dioxide and water. The biomass yield determines the amount of isopentane that is converted to active cells. Eventually, biological equilibrium is achieved when the rate of biomass growth due to yield is equal to its decay rate. Biological equilibrium in biotrickling filters have been reported in the literature (Diks et al., 1994), although no mathematical analysis of this phenomenon was conducted. When biological equilibrium is attained in our biofilter, the amount of isopentane carbon that is converted to active cells becomes equal to the amount of carbon liberated as carbon dioxide due to biomass decay. Figure 6 compares the experimentally measured increase in carbon dioxide concentration for compost. These data are compared with calculated values based on total conversion of isopentane biodegraded to carbon dioxide. Within experimental error, the calculated increases in carbon dioxide concentration agree closely with the experimental values, indicating that biological equilibrium had been attained. This finding confirms our earlier model assumption that biomass concentration remains constant in the biofilter bed, and net biomass growth (actual growth minus biomass decay) was negligible.

Mathematically, biological equilibrium in biofilters can be written as follows:

$$bX = Y\frac{KC}{K_s + C}\cdot\frac{(W - W_i)}{K_{sw} + (W - W_i)}, \tag{17}$$

where b is the biomass decay coefficient and Y is the biomass yield.

The overall mass balance for isopentane in the biofilter bed is given by the following equation:

$$F_{\text{air}}C_{in}\eta = V_{\text{bed}}\frac{KC}{K_s + C}\cdot\frac{(W - W_i)}{K_{sw} + (W - W_i)}. \tag{18}$$

Since $K = \mu_{\max}X/Y$, combining Eqs. 17 and 18,

$$K = \frac{F_{\text{air}}C_{in}\eta\mu_{\max}}{bV_{\text{bed}}}. \tag{19}$$

The possibility of a potential oxygen limitation was investigated by model simulation using kinetic constants obtained in this study. At biological equilibrium, the overall isopentane degradation can be written as

$$C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O; \tag{20}$$

therefore, α equals 8 in this case. The maximum gas-phase isopentane concentration was 960 ppmv, and ambient oxygen concentration in air was used to calculate the isopentane and oxygen profiles inside the compost particle, as shown in Figure 7. Henry's law constants reported in previous studies on isopentane (Mackay and Shiu, 1981) and oxygen (Perry et al., 1984) are used to calculate concentrations of isopentane and oxygen at the surface of media, which are in equilibrium with gas-phase concentrations. Diffusivity of oxygen in water was used as the effective diffusivity in the medium particle, since retardation effects due to adsorption of oxygen are negligi-

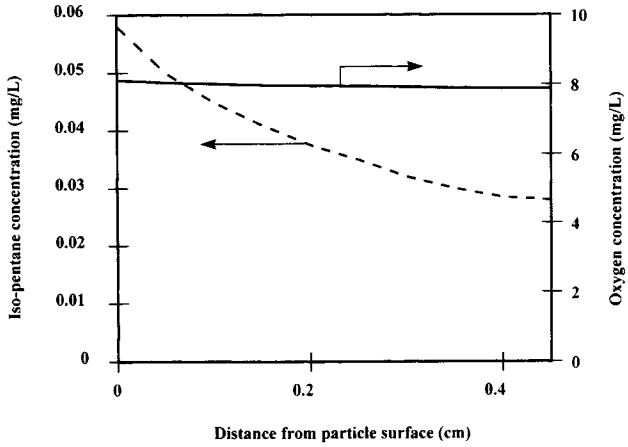

Figure 7. Simulation of isopentane and oxygen-concentration profile within compost particle.

ble. When the gas-phase isopentane concentration is the highest (960 ppmv), the oxygen profile inside the particle remains constant at its equilibrium concentration, indicating that there are no oxygen limitations in the biofilter. Hence, it was concluded that oxygen is not limiting at all experimental concentrations in the biofilter.

Effect of water content

Samples of media at different water content were tested in the small glass biofilter with an inlet isopentane concentration of 470 ppmv and gas flow rate at 20 mL/min. The steady-state removal efficiencies of isopentane under different water content were measured.

Figure 8 shows the effect of water content on the operating efficiency of peat and compost packed-bed biofilters. For peat, the original water content W_o was 0.645. The removal efficiency was maximized at a W_p of 0.66. When the peat water content was less than a W_i of 0.58, an irreversible loss in biofilter removal efficiency occurred, as shown by the dotted line. The removal efficiency increased when water content increased between W_i and W_p. The removal efficiency dropped when water content was increased above W_p until the maximum water content W_{max} was reached at 0.82.

Based on models developed in the previous section, the effect of water content was simulated. The kinetic constants estimated from steady-state operation were used in this simulation. The value of the parameter, K_{sw}, which best fitted the experimental data, is listed in Table 3. The goodness of model fit with the experimental values is shown in Figure 8.

For compost, the original water content W_o is 0.536, and irreversible loss of efficiency occurred at a W_i of 0.47. The removal efficiency was maximum at W_p of 0.56 and W_{max} was 0.71. The best-fit K_{sw} value is included in Table 3. Compared to peat, compost had a wider range of suitable water content for high-efficiency operation. The effect of water content on removal efficiency attained in peat and compost beds demonstrated the importance of maintaining water content in biofilters employing such naturally bioactive media.

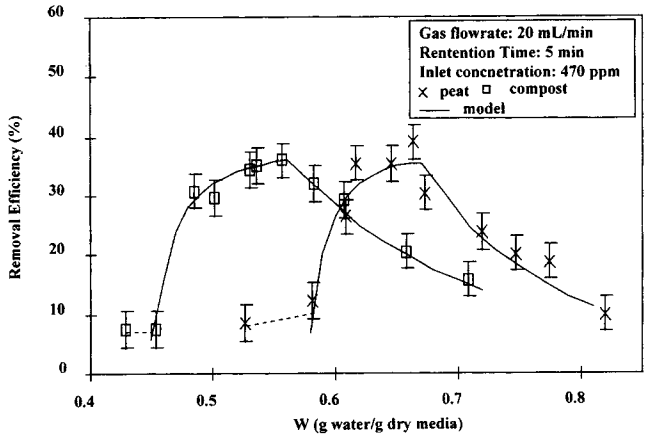

Figure 8. Effect of water content on removal efficiencies in peat and compost biofilter.

Temperature effect

Several tests were carried out at a column temperature between 25 and 40°C, and the results are shown in Figure 9. The degradation rates for both compost and peat were low at the lower temperature. The reaction rate increased rapidly from 25°C to 30°C, and the increase was less from 30 to 40°C. Further, the increase in biofilter removal efficiency with temperature exhibits a plateau, which indicated that both the isopentane biodegradation rate as well as the biomass decay rate increase with temperature.

The temperature dependence of the biokinetic parameters describing rates of growth and decay of biomass can be written using the Arhenius equation,

$$\mu_{max} = \mu_0 e^{-(E_1/RT)} \qquad b = b_0 e^{-(E_2/RT)}, \qquad (21)$$

where μ_0 is the intrinsic specific growth rate constant; E_1 is the activation energy of growth; b_0 is the intrinsic biomass decay coefficient; and E_2 is the activation energy of biomass decay.

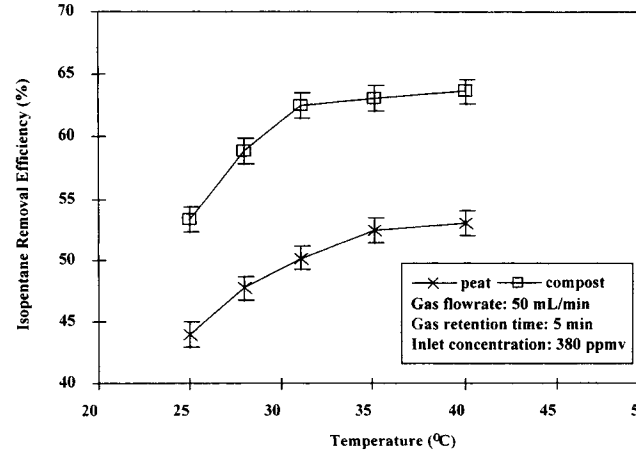

Figure 9. Effect of temperature on isopentane removal efficiencies in peat and compost packed-bed biofilters.

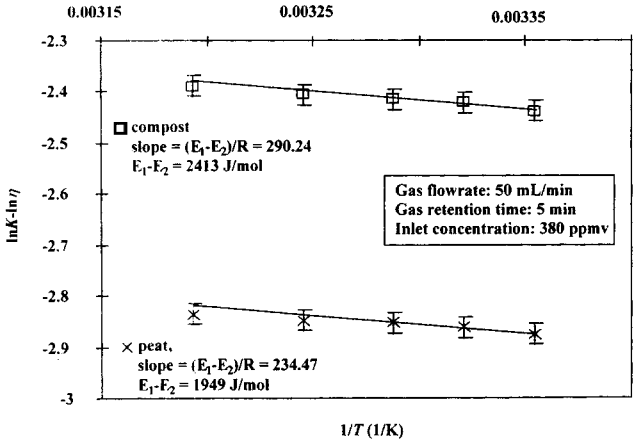

Figure 10. Determination of activation energies of net growth for peat and compost packed-bed biofilters.

Combining the preceding equations, we get

$$\frac{V_{\text{bed}}}{F_{\text{air}}C_{in}}\frac{K}{\eta}=\frac{\mu_0}{b_0}e^{-((E_1-E_2)/RT)}. \tag{22}$$

The term $(E_1 - E_2)$ was the activation energy for the net growth of biomass. Assuming that K_s was constant with temperature, and using the experimental data on fractional removal efficiencies at different temperatures, the best-fit values of the parameter, K, were obtained. A plot of $\{\ln(K) - \ln(\eta)\}$ vs. $(1/T)$, for both peat and compost media is shown in Figure 10. The activation energy for net growth of biomass was calculated as 1949.4 J/mol for peat and 2413.1 J/mol for compost material. The activation energy values were in the range for typical biological reactions.

Effect of gas-phase mass transfer

The overall mass-transfer coefficient was calculated, using Eq. 11 at the lowest gas flow rate of 200 mL/min. It was found that at this gas flow rate and bulk-gas isopentane concentration of 960 ppmv, the concentration drop of isopentane in the gas phase from the bulk to the particle surface was about 0.044 ppmv. This demonstrated that mass-transfer rates from the bulk gas phase to the particle surface did not control the overall isopentane degradation rate at all experimental gas flow rates.

Conclusions

Natural bioactive materials, such as peat or compost, are low cost and easily obtained for use in biofilters for treating air. Experimental studies described in this article have shown that peat and compost materials can be used to treat air contaminated with isopentane. The water content of the bed material and air temperature were found to dramatically affect the biofilter performance. Careful control of bed water content is essential for maintaining maximum removal efficiency. Peat and compost materials are effective at low contaminant concentrations, and high removal efficiency can be attained at reasonable gas-phase residence times. The range of operating temperature was found to be 25–40°C, and biotreatment effectiveness improved with temperature in this operating range. Hence, it may be cost effective to preheat the air, if the inlet air temperature is lower than 35°C. A mathematical model was developed to describe the biofilter with the consideration of the effects to water content and temperature. It was shown that at the highest isopentane concentration of 960 ppmv, there are no oxygen and gas-phase mass-transfer limitations in peat/compost biofilters. The calculated concentration profiles were found to agree closely with the experimental data. The model equations developed in this article can be used to design large-scale biofilters, if the biokinetic parameters are either known or determined in the laboratory.

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