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ORIGINAL PAPER

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Biofiltration eliminates nuisance chemical odors from industrial air streams

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Abstract This paper focuses on recent developments of biofiltration technology used in treating nuisance chemical odors from industrial and municipal air streams. In the biofiltration process, odorous chemical constituents in the air are first transported to biofilms by diffusion, solubilization and adsorption processes. Bacteria within the biofilms oxidize odor constituents into harmless and odorless products. Through successful laboratory and pilot research on biofiltration of odorous air-stream constituents, numerous commercial biofilters have been designed and installed across North America. In this paper, case studies related to biofiltration of air emissions from meat rendering plants, municipal wastewater treatment applications, and printed circuit board production are discussed to demonstrate the robustness of this technology in eliminating a wide variety of compounds.

Keywords Biofiltration · Biofilters · Odor contaminants · VOCs · Wood-based organic media · Manufactured inorganic media

Introduction

Industrial operations such as meat rendering, wastewater treatment, and printed circuit board manufacturing produce nuisance and, in some cases, toxic odor constituents. In meat rendering and wastewater treatment applications, odorous chemicals found are hydrogen sulfide (H_2S), methyl mercaptan, di-methyl sulfide (DMS), ammonia and ethylamine [9]. In addition to nuisance odor characteristics, there are several health effects including headaches, nausea, eye irritation, paralysis, and even death associated with these compounds when individuals are exposed to high concentrations. Similarly, printed circuit board manufacturing facilities emit odorous volatile organic compounds (VOCs) such as propylene glycol monomethyl ether acetate (PGMEA). Overexposure to glycol ethers can cause anemia, intoxication similar to the effects of alcohol, and irritation of the eyes, nose, and skin [10]. Thus, strict regulations are in effect for controlling emissions of these odorous and toxic chemicals.

Conventional treatment methods used to eliminate these contaminants from air are thermal oxidation, condensation, absorption, and adsorption. In thermal oxidation, the VOCs are completely eliminated; however, in all the other technologies odor contaminants and VOCs are simply transferred from one phase to another. To increase the efficiency of thermal oxidation and reduce fuel requirement for combustion, several forms of this technology (recuperative, regenerative and catalytic) are practiced [7]. Thermal oxidation produces the highest amount of greenhouse gases (CO_2), resulting largely from burning of fossil fuels. This technology is also expensive due to high temperature requirements, equipment costs, and the catalytic requirement. On the other hand, biofiltration is an economical and environmentally benign process. In this process, as the contaminated air is passed through a bed of media such as wood chips, peat, compost or inorganic media, contaminants and oxygen are first transferred to biofilms formed on the surface of the media particles and then metabolized by bacteria. Primarily, bacterial species are used, and to lesser extents molds and yeasts [6]. Naturally occurring packing materials such as peat and compost contain organisms capable of biodegrading some VOCs. Activated-sludge suspensions from sewage treatment plants can also serve as inoculum [6]. Required moisture for the media is provided by saturating the air before it enters

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the biofilter system, and also by occasional irrigation, as required.

Limiting constraints of biofilter applications in the past have been the absence of performance predictive tools, the large space requirements, and the frequent media replacements due to media decomposition and compaction. Significant work has been done in developing predictive mathematical models for biofiltration of VOCs [4]; however, removal data and important model parameters reported in the literature are specific to the media and the system used. Thus, more work is needed in developing predictive mathematical models for biofiltration of odorous compounds such as H_2S and DMS. Selection of biofilter media should be based on many factors including good adsorption property, buffering capacity, low pressure drop, good pore structure, very low compaction with time, and good biological properties [5]. Frequently, media with only good biodegradable properties (peat, compost, soil, chicken manure) are selected without giving consideration to structural, mass transfer characteristics or adsorption properties. Regrettably, poor performances are generally attributed to biofilter technology rather than media failure. Several biofilter companies and vendors have introduced manufactured media or media blends to address some of these issues [4]. The acceptance of this technology had been slow for several years but this trend is now rapidly changing.

The main objective of this work is to present recent developments in biofiltration technology through performance data, and to demonstrate the robustness of biofilter technology in eliminating a wide variety of compounds found in industrial and municipal air streams. Four different case studies dealing with different applications, biofilter configurations, media type, and airflow directions are presented.

Materials and methods

Application 1

The first application deals with a 15,000-cfm open-bed biofilter system (Fig. 1) that was installed at an animal rendering plant located at Hickson, Ontario, Canada. This biofilter system replaced a chemical scrubber that had failed to provide sufficient odor control. The biofilter was custom engineered and built at the plant facility. It consists of reinforced concrete and has a strong, slotted support floor that can handle the weight of a skid-loader. A gate entrance provides quick and easy access for media removal and replacement. In this design, a humidification manifold, located in the plenum, conditions and humidifies the air stream. Misting spray nozzles are configured and sized appropriately to ensure that relative humidity is greater than 98% at all times. In this case, the biofilter is filled with wood-based media (BIOMIX, BIOREM Technologies, Guelph, Ontario, Canada), which is produced as nuggets and screened to provide a consistently sized, coarse product with a surface coating of nutrient-enriched fines.

Materials and methods 1

The open-bed biofilter system was evaluated using a Fourier transform infrared (FTIR) mobile monitoring system (Lehder Environmental Services, Point Edward, Ontario, Canada). The FTIR unit can collect real-time data directly from point sources and measure VOC concentrations [9].

For odor analysis, air samples were collected in 30-l Tedlar bags (Valley Environmental Services, Mississauga, Ontario, Canada). Inlet air samples were diluted on-site 5-, 10-, 20-, and 30-fold with nitrogen gas. At the discharge of the open bed, nine locations (A–I) over a 48 × 48 square foot cross-section were selected for sampling. Gas phase samples were analyzed for odors and VOCs. Sulfur compounds and ammonia were analyzed by EPA method#15. In

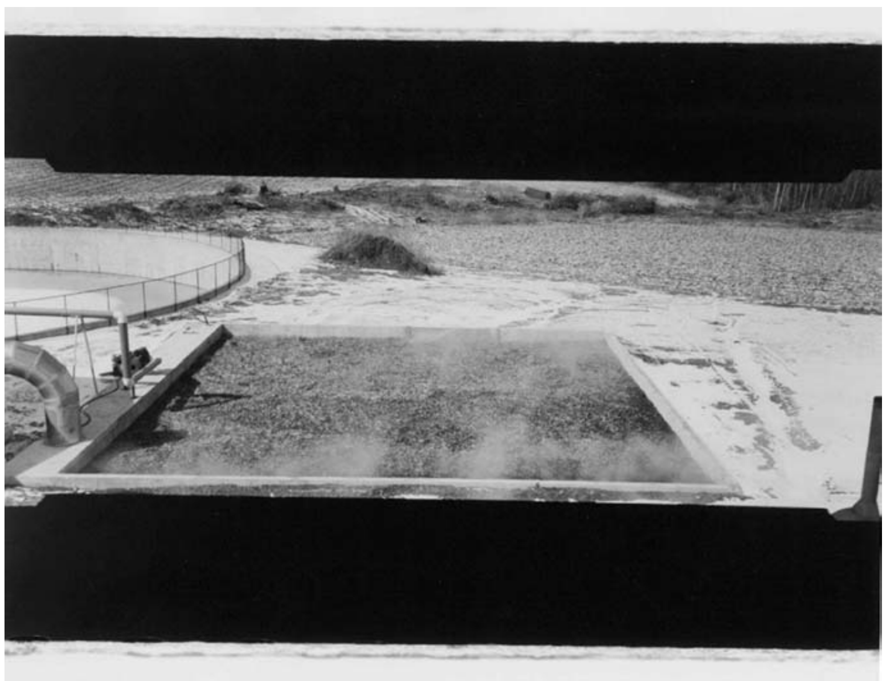

Fig. 1 A 15,000-cfm-capacity open-bed commercial biofilter system treats air emissions from a meat rendering plant. This biofilter is filled with a wood-based medium

determining odor units, a descending series of known dilutions are introduced simultaneously to all participants of the odor panel. The results for each sample are processed to determine the odor threshold value (OTV) for the sample. First, logarithmic values of dilution levels are plotted against panel responses. From the regression line between dilution levels and panel responses, OTV values can be determined. The point at which 50% of the panel can just detect the odor is recorded as the OTV or effective dilution to 50% response (ED_{50}). Since OTV is a dilution factor, it has no units but is often expressed in odor units (OU) [9].

Media samples were collected and analyzed for moisture content, pH and bacterial counts using standard procedures [4,9]. For total microbial count (TMC) measurements, 10 g of media particles collected from the biofilter were mixed in 100 ml of sterilized water. The TMC measures the total number of viable aerobic heterotrophs. In order to maintain consistency of the results, sample collection locations, sample size, suspension time, and mixing time were kept identical. TMCs were measured at different dilutions.

Application 2

The second application involves removal of H_2S in a laboratory pilot biofilter. H_2S is a highly odorous compound found in many applications including meat rendering and wastewater treatment processes. A maximum safe exposure limit of this compound is 10 ppm (NIOSH-REL) but it can be odorous even at a concentration of 0.1 ppm. Therefore, odor control systems must be designed to provide >99% removal in most cases. A number of research projects on biological removal of sulfur compounds have been carried out. Cadenhead and Sublette [1] reviewed microorganisms capable of degrading H_2S and found that *Thiobacillus thioparus, T. ferooxidans, Beggiatoa spp.,* and *Thiothrix spp.* are suitable bacteria for biodegradation of H_2S. Of the microbial cultures, they reported that inocula of *T. thioparus, T. versutus, T. thiooxidans* and *T. neapolitanus* were effective in removing H_2S for a wide range of potential applications with respect to pH (4.0–8.0). Cho et al. [2] showed that mixed cultures of *Hyphomicrobium, Thiobacillus* and *Xanthomonas* species were able to degrade efficiently the sulfur compounds methanethiol (MT), DMS and H_2S in a biofilter. In this study, no supplemental inocula were added and biofiltration was solely dependent on indigenous organisms applied in the synthetic media.

Materials and methods 2

Two identical laboratory pilot biofilters made of PVC columns were built and operated under different conditions. In a laboratory column study, it is common to run a control biofilter with sterilized media under identical conditions [8], but it is often impractical for pilot or larger systems. Each pilot biofilter has two stages with clear windows for visual inspections of the media. Biofilters were filled with synthetic medium (BIOSORBENS, BIOREM Technologies) consisting of hydrophilic mineral cores coated with sorption materials. The very high specific surface area of these materials allows for effective and efficient adsorption that compliments the biological oxidation process in removing odors and VOCs. In addition, the coatings include nutrient-rich organic material for microbe hosting and suitable binders to provide product stability. In order to provide moisture to the media, irrigation for a duration of 2 min twice per day was set. Pure H_2S gas was regulated and supplied via high-precision Teflon flow meters (Cole Parmer, Vernon Hills, Ill., USA) into the humidified air streams. No inoculum, other than indigenous organisms present in the media, were added to the biofilter. Concentrations were measured from the inlets and outlets of the biofilters using MSA Passport (MSA Instrument Division, Pittsburgh, Penn., USA), which has an accuracy of ±1.0 ppm. For measurements of air-flow rates, inline air-flow meters (RMC-121, ITM Instruments, Markham, Ontario, Canada) were used. Flow meters at the discharge lines allowed setting of the experiments at desired empty bed-residence time (EBRT), which is defined as the ratio of the medium volume to volumetric air-flow rate.

Application 3

The third case involves a full-scale biofilter treating air emissions from a wastewater pumping station where H_2S is the main odor-causing compound. This biofilter is a compact modular unit (Fig. 2) that was installed in the greater Toronto area. The modular design allows customers to add additional capacity by simply connecting another filter module to the system. System controls can be configured for a variety of user needs and range from low-cost manual controls to fully automated controls, which can include 24-h monitoring, alarms and continuous data collection. This modular biofilter system was packed with synthetic medium and operated under negative pressure.

Materials and methods 3

H_2S concentration data were collected by an ODALOG H_2S data logger (App-Tech, Brandale, Queensland, Australia) and compared with laboratory data (application 2). The ODALOG can record concentrations up to 200 ppm with accuracy of ±1.0 ppm. Two ODALOG H_2S data loggers were used for continuous measurements of inlet and outlet concentrations at 1-min intervals.

Application 4

The fourth case involves biofiltration of odorous VOC emissions from a printed circuit-board industry. This industry was the subjected of odor complaints from neighbors. A 7,500-cfm-capacity dual modular biofilter system (Fig. 3) combined with an impingement scrubber for aerosol removal was installed in the greater Toronto area in 2000. This system operates under negative pressure in the down-flow mode of operation. One biofilter unit was packed with wood-based and the other with inorganic synthetic media. The circuit board coating plant uses a formulated chemical mixture for surface coating. The VOCs contained in these emissions create an odor that migrates beyond the property boundaries of the plant. Due to the unique characteristics of the solder-masking formulation used in printed circuit board manufacturing, a laboratory pilot-scale biofiltration study was needed to obtain the required engineering data for full-scale design [10].

Materials and methods 4

The experimental pilot-scale biofilter unit used in the study consisted of four biofilters of 25-cm diameter and 65.0-cm media height. Biofilters were packed with wood-based and synthetic media. In order to create the contaminated air, the solvent (solder-masking agent) was placed in a tank. A portion of air stream was

Fig. 2 A 950-cfm-capacity modular biofilter system treats air emissions from a wastewater pumping station. The biofilter system is filled with a manufactured synthetic medium

Fig. 3 Commercial 7,500-cfm-capacity biofilter system at a printed circuit board manufacturing facility (Toronto, Canada). One unit is filled with the wood media and the other with a manufactured inorganic medium

bubbled through the solvent tank to generate desired VOC emissions. Adjusting the needle valve on the solvent line easily changed concentrations of VOCs in the air stream. The contaminated air was humidified and contaminated with the solvent vapor and then passed through the biofilter columns. Flow meters and valves allowed experiments to be carried out at various residence times.

Samples were taken from inlets and outlets of the biofilters using 5-l Tedlar bags. Samples were analyzed using a gas chromatograph (GC) equipped with a flame ionization detector (FID) and DB5 column (J and W Scientific, Brockville, Ontario, Canada). The conditions of the GC were as follows; 35m×0.25 mm, ID 0.25 μm; film DB 5 column; carrier gas, helium; injector temperature, 250 °C; detector temperature, 250 °C; oven initial temperature, 40 °C; oven final temperature, 160 °C; rate 5 °C/min. Samples from Tedlar bags were withdrawn by solid-phase micro-extraction (SPME) fiber (Supelco, Bellefonte, Penn.). A 30-s extraction/desorption time was set in using SPME, which gave more consistent readings than obtained by air sampling with gas-tight syringes. GC output showed several peaks corresponding to many VOCs present in the air streams. Since PGMEA is the most odorous compound, pure PGMEA solvent vapor was used for calibration and from this we determined its removal [10].

Due to the higher efficiency of the synthetic media as demonstrated from the pilot study (discussed below), air flow through the synthetic media commercial biofilter unit was set to handle twice the flow of the wood-based unit. In order to evaluate the performance of the commercial biofilter system, air samples were withdrawn from the inlet to the scrubber, from inlets to both biofilter units, at discharge points from two units, and from the discharge stack into 10-l Tedlar bags. Gas samples were analyzed using GC and SPME). The GC conditions were the same as described above.

Results and discussion

Application 1: biofiltration of gaseous odors from a meat rendering plant

Characterization of the air stream through FTIR measurements indicated that the common constituents were ammonia, methyl mercaptan, H_2S, ethylamine and DMS. The inlet concentration values and the average removal efficiencies of these compounds are summarized in Table 1. For all the compounds except methyl mercaptan, average removal efficiency exceeded 96%. The biofilter treated a contaminated air stream of 24,544 odor units with an average 96.6% removal efficiency in a 30-s EBRT. Odor removal efficiency over the range of media varied between 90 and 99%.

Moisture content, pH and total aerobic heterotrophic bacterial counts of the media were also analyzed. Media analysis showed that, except at locations B and C (see Table 2), percent moisture (standard deviation, SD = 1.5) and pH (SD = 0.7) were similar over the entire surface of the bed. Overall, the data indicate uniform distribution of air-flow, concentration, bacterial population, moisture content, and pH throughout the biofilter media. The open-bed biofilter with wood-based media successfully removed most odorous gaseous

Table 1 Data analysis (air stream characterization) of a 15,000-cfm biofilter installed at a meat rendering plant. OTV Odor threshold value, *OU* odor units

	Units	Inlet concentrations	Odor characteristics	Average removal (%)
Average OTV[a]	OU	24,544	–	96.6
Ammonia	mg/m^3	5.20	Pungent, sharp	99.9
Methyl mercaptan	mg/m^3	0.66	Sulfide, pungent	70.7
Hydrogen sulfide	mg/m^3	1.07	Rotten egg	96.6
Ethyl amine	mg/m^3	1.20	Fishy, pungent	>99.9
Dimethylsulfide[b]	mg/m^3	777.25[b]	Sulfide	>99.9

[a]Average outlet odor = 845 OU, standard deviation = 702 OU
[b]Higher than expected levels

Table 2 Data analysis (media) of a 15,000 cfm biofilter installed at a meat rendering plant. *CFU* Colony-forming unit, *A–I* Nine grid points selected over the entire 48 × 48 sq. ft biofilter for sampling. Average pH = 6.36, standard deviation = 0.7, average moisture = 61.2%, standard deviation = 1.5

Parameter	A	B	C	D	E	F	G	H	I	Average
pH	6.95	5.36	4.93	6.56	6.96	6.97	6.72	6.38	6.45	6.36
Moisture (wt%)	62.3	59.2	59.8	64.1	62.3	60.4	62.1	60.3	60.8	61.2
Total microbial count (CFU/g)	2.4×10^6	3.7×10^6	3.5×10^6	2.4×10^6	2.9×10^6	2.4×10^6	4.4×10^6	2.0×10^6	1.7×10^6	2.8×10^6

sulfur and ammonia compounds. Although, the inlet concentration of methyl mercaptan was the lowest (0.66 ppm), only 70.7% of this compound was removed (Table 1). Additional research is needed to investigate biofiltration of low-level odor constituents such as methyl mercaptan and other reduced sulfur compounds.

Application 2: biofiltration of H_2S using synthetic media in a laboratory biofilter

The concentrations of H_2S versus actual operational time (hours) was recorded continuously. The biofilter acclimation period was less than a day for both biofilter columns, which were operated at 20-s and 30-s EBRTs, respectively. Since the start-up, the biofilters worked effectively. The data show that low-level H_2S (˜12 ppm) can be removed completely with 20-s EBRT. Numerous sets of experiments were carried out to determine removal efficiencies at a variety of residence times, inlet H_2S concentrations and other operating conditions. Figure 4 shows >99% removal for an inlet H_2S concentration level of about 40 ppm at a 30-s EBRT.

In many waste treatment applications, the H_2S concentration in the process air fluctuates periodically. Experiments were done to verify the effectiveness of the synthetic media in response to spike concentrations or shock loading conditions. Figure 5 shows variations in inlet and outlet concentrations versus operational time. The results demonstrate that synthetic media can effectively handle fluctuations in inlet H_2S concentrations. At a 30-s EBRT, removal efficiency remained more than 99% regardless of the varying H_2S load. Based on these results, several commercial biofilters with synthetic media have been designed and installed for wastewater treatment facilities (Table 4).

Application 3: biofiltration of H_2S emissions from a wastewater pumping station

From the concentration measurements, removal efficiencies were determined. Figure 6 shows inlet concentrations and corresponding removal efficiencies versus operational time. As also observed in the experimental pilot biofilters, the full-scale system with synthetic media at a 30-s EBRT effectively eliminates varying H_2S loads (peak concentration of 80 ppm H_2S) with >99% removal efficiency. Figure 6 also shows the typical variation of concentrations expected from a pumping station facility. In Fig. 7, elimination capacity data, defined as g H_2S removed per cubic meter media per h, are compared. The graph shows there is a good agreement between pilot laboratory (refer to application 2) and field data, with the field data showing generally better performance. In general, full-scale field performance of synthetic media was superior to that obtained in the laboratory. This is most likely due to negligible wall effects in large systems and the beneficial presence of organic carbon and nitrogen sources in actual wastewater emissions.

Application 4: biofiltration of VOCs from a printed circuit board manufacturing facility

PGMEA elimination capacities obtained from the laboratory pilot biofilter units were plotted against loads to

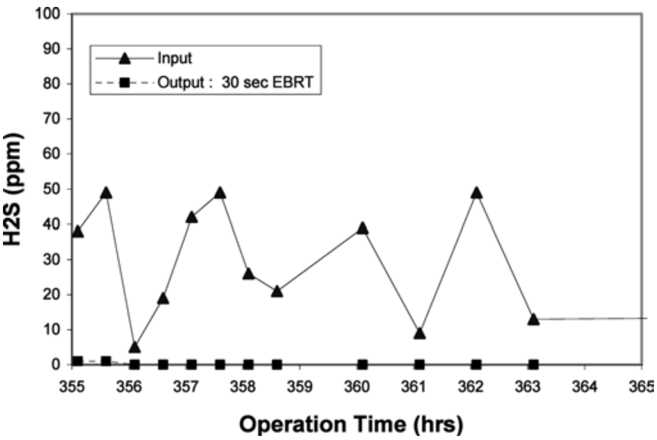

Fig. 5 Biofiltration of H_2S under concentration shock loading conditions

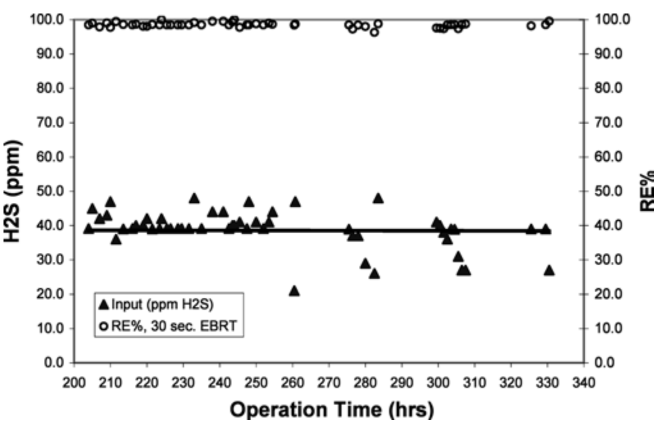

Fig. 4 Biofiltration of hydrogen sulfide (H_2S) using manufactured synthetic media in a laboratory biofilter

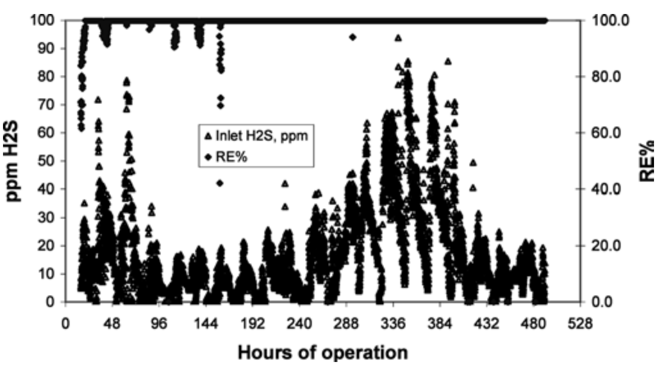

Fig. 6 H_2S removal data from a modular biofilter system (with synthetic media) installed at a municipal wastewater pumping station

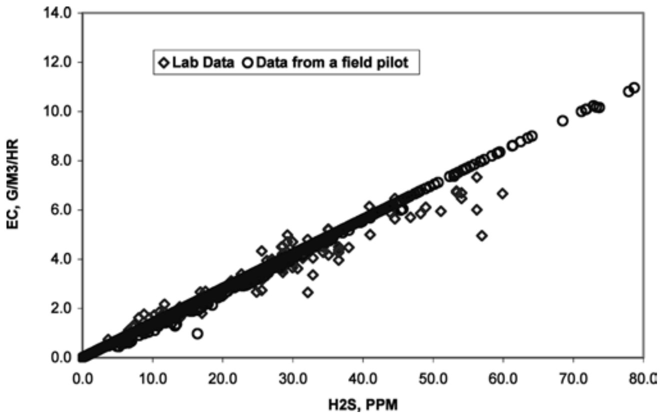

Fig. 7 Comparison of H_2S elimination capacity data of a laboratory and modular biofilter system installed at a municipal wastewater pumping station

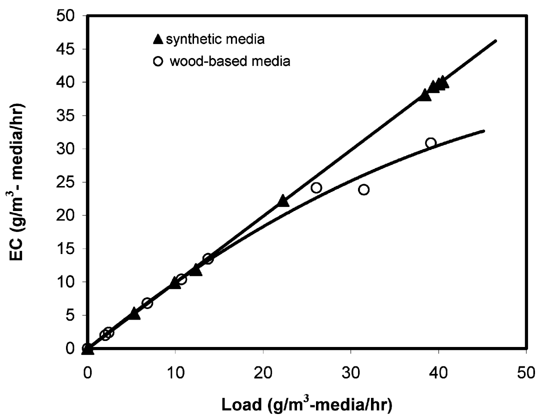

Fig. 8 Comparison of elimination capacities of propylene glycol monomethyl ether acetate (PGMEA) as a function of inlet loads to the laboratory pilot biofilters

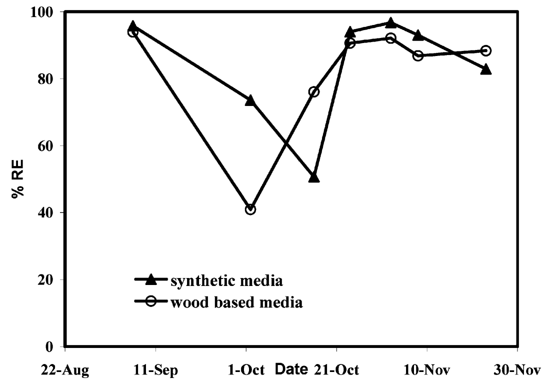

Fig. 9 Removal efficiency profiles of PGMEA from a commercial biofilter system. Note that flow through the synthetic medium unit is twice that of the wood media unit

Table 3 Media analysis from the biofilter at a printed circuit board facility. *CFU* Colony forming units

Media	pH	Total microbial count (CFU/g)	Percent moisture (dry basis)
October, 2000			
Wood-based media	7.59	6.8×10^7	121.7
Synthetic media	7.33	4.5×10^3	9.4
November, 2000			
Wood based media	6.90	2.3×10^7	150.4
Synthetic media	7.60	3.2×10^8	15.5

the laboratory-scale pilot biofilters. Figure 8 shows that, for greater than 20 g/m^3 of media/h of inlet load, elimination capacity drops for wood-based media. But for synthetic media, Fig. 8 shows load equal to the elimination capacity even for an inlet load of 40 g/m^3 of media/h (i.e. a removal efficiency of $>99.99\%$). Furthermore, for an average PGMEA concentration of 170 ppm, 99% removal efficiency was obtained for a synthetic media biofilter in less than 17 s EBRT. However, wood-based media under the same conditions showed a removal efficiency of 76%. Based on the engineering data collected from the pilot biofilter study, a 7,500-cfm-capacity biofilter system consisting of two units was designed and commissioned in August 2000. The units were initially packed with both types of media to obtain operational data. But in the future, wood media will be replaced with inorganic synthetic media.

Figure 9 shows the removal efficiency of PGMEA from the modular biofilter system. The average inlet concentration of PGMEA during the period of data collection was about 125 ppm. Initially, there was a drop in the removal efficiency due to media dry-out. Media samples also had very low moisture contents, which are reported on a dry-weight basis (Table 3). Table 3 shows media analysis data before and after media-dry-out. The table also shows that the bacteria counts ranged from low to high for synthetic media. The lower TMC level in October was due to a lower media moisture content of 9.4% measured on a dry weight basis. Wide swings in moisture content demonstrated problems with irrigation and media dry-out. The pH values of the media were in the acceptable range for bacterial growth (6.0–8.0). After adjusting the system for proper irrigation, biofilter units recovered biological activity with a removal efficiency of over 90%. In addition to PGMEA removal, the biofilter system also able removed non-targeted VOCs with $>80\%$ efficiency. The reason for a slight decrease in the removal efficiency during November (Fig. 9) was due to heat loss to the surroundings. A winterization program including the addition of steam to the inlet air has been designed to compensate for heat losses and to maintain year-round smooth operation of this biofilter system.

In order to evaluate, monitor and further improve design, biofilter data are being collected and analyzed from several systems. Other interesting applications include biofiltration of candle fragrances, glycerin manufacturing process emission, and waste oil recycling. Table 4 is a list of biofilter installations by BIOREM and some other companies. This table shows that biofilter vendors use different media, from sewage waste, pine bark, softwood chips, soil, compost, perlite, inert

Table 4 Full-scale biofilter installations by BIOREM and other companies. *WWTP* Wastewater treatment applications

Application	Owner/location	Air flow (cfm)	Builder	Media
WWTP	Mount Pleasant, S.C.	2,500	BIOREM, Guelph, Ontario.	Manufactured media (BIOSORBENS)
WWTP	Jefferson County, Ala.	30,000	BIOREM	Manufactured media (BIOSORBENS)
WWTP	City of Broomfield, Co.	40,000	BIOREM	Manufactured media (BIOSORBENS)
WWTP	City of Poughkeepsie, N.Y.	15,000	Webster, Ky.[a]	Softwood chips
Other applications				
Food and flavor	Allen, Ill.	13,000	PPC, Tex.[a]	Mixture of inert and organic materials
Rendering	Charny, Quebec	60,000	BIOREM, Ontario	Manufactured media (BIOSORBENS)
Candle wax	Brampton, Ontario	4,500	BIOREM	Manufactured media (BIOSORBENS)
Waste oil recovery	Kitchener, Ontario	1,000	BIOREM	Wood-based media (BIOMIX)
Soil vapor extraction	Exxon, Calif.	7–27	Resolution Inc., UC Davis, Calif.[a]	Sewage compost and perlite
Particle board dryer	Weyerhaeuser, Ga.	143,000	PPC, Tex.[a]	Inert and organic mixture
Foundry exhaust	Cast Alloy Inc., Calif.	10,000	BioFiltration Inc., Calif., USA[a]	Sewage sludge and pine bark

[a]See [4]

materials to synthetically manufactured media, in different applications. Problems associated with some of these media are reviewed and discussed in the literature [4, 5, 11]. This review is not comprehensive due to limited accessibility of performance data from other biofilter vendors. Based on our data, we have focused our discussions on four cases to demonstrate the robustness of this technology in treating a wide variety of compounds using different media and biofilter configurations.

Conclusions

This work demonstrated the effectiveness of advances in biofiltration technology in environmental management. An important advancement is the ability to use a manufactured inorganic media as an immobile support. The superior performance of these inorganic media over organic media was demonstrated through case studies describing the elimination of odorous air emissions from a meat rendering plant, a laboratory biofilter, municipal wastewater treatment application, and printed circuit board productions. Analysis of data from these biofilters confirms that biofilters can be successfully applied to a range of industries to eliminate odorous and VOC chemical constituents. In biofilter applications, intermediate product formation often causes media plugging and poor removal of contaminants. For example, Yang and Allen [11] reported that sulfate accumulation caused wood media to change from dark brown to yellowish white after a long-term operation during biofiltration of H_2S. Chung et. al [3] reported elemental sulfur deposits on peat media. Thus, research is needed in areas including bi-product identifications through biochemical pathways, microbial species identification, media development, microbial kinetic determination, predictive modeling and biofiltration studies of low-level odorous compounds. Industrial microbiologists can play a major role in advancing this technology.

References

1. Cadenhead PC, KL Sublette (1990) Oxidation of hydrogen sulfide by *Thiobacilli*. Biotechnol Bioeng 35:1150–1154
2. Cho KS, Hirai M, Shoda M (1991) Degradation characteristics of hydrogen sulfide, methanethiol, dimethyl sulfide, and dimethyl disulfide by *Thiobacillus thiorparus* DW44 isolated from peat biofilter. J Ferment Bioeng 71:384–389
3. Chung Y-C, Huang C, Pan JR, Tseng CP (1998) Comparison of autotrophic and mixtrophic biofilters for hydrogen sulfide removal. J Environ Eng
4. Devinny, JS, Deshusses MA, Webster TS (1999) Biofiltration for air pollution control. Lewis, New York
5. Leson G, Winer AM (1991) Biofiltration: an innovative air pollution control technology for VOC emissions J Air Waste Manag Assoc 41:1045–1054
6. Ottengraf SPP, Disks R (1990) Biological purification of waste gases. Chimicaoggi, May 41–45
7. Pefer Y (1996) VOC emission control strategies for the chemical industry. Can Chem News, November/December
8. Shareefdeen Z, Baltzis BC, Oh Y-S, Bartha R (1993) Biofiltration of methanol vapor. Biotechnol Bioeng 41:512–524
9. Shareefdeen, Z, Biran H, Wilson, S (2002) Biofiltration of nuisance sulfur gaseous odors from a meat rendering plant. J Chem Technol Biotechnol 77:1–4
10. Shareefdeen Z, Herner B, Webb D, Polenek S, Wilson S (2001) Biofiltration removes VOC Emissions from a printed circuit board manufacturing facility. AWMA 94th Annual Conference, Orlando, Florida, June 24–28
11. Yang Y, Allen E.R (1994) Part 1. Biofiltration control of hydrogen sulfide. 1. Design and operational parameters. J Air Waste Manag Assoc 44:863–868