

Operation of Biofilters with Different Packing Material - development of media and biological parameters for optimal odor treatment process in a biofilter

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담체변화에 따른 Labscale 바이오필터의 성능 실험

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요 약 산업체 발생 VOC를 효과적으로 처리하는 Biofilter 시스템을 고안하였다. 재질과 다공성이 다른 3기의 시스템으로부터 황화수소, 벤젠, 톨루엔, 크실렌의 단일성분과 복합성분계의 성능을 고찰하였다. 저 pH Biofilter(pH 2~3)의 장기운전이 가능하였고 벤젠의 경우 경쟁적 저해를 나타내었으나 일정기간의 운용 이후 혼합처리시 양호한 처리능력을 보여주었다.

Key Words : VOC, biofilter, low pH, packing material

1. Introduction

Biofilter systems harness the natural degrading abilities of microorganisms to oxidize organic contaminants biochemically into environmentally benign end-products such as carbon dioxide and water. The simplicity of the biofiltration process has resulted in its emergence as a practical, cost-effective technology for the treatment of large volumes of air contaminated with low concentrations as biologically degradable compounds, as compared with other traditional VOC and odor control technologies, such as incineration and carbon adsorption.

Publicly owned wastewater treatment works (POTWs) have always struggled with odor problems, caused chiefly hydrogen sulfide (H₂S). Recently there has been additional concern over release of hazardous air pollutants (HAPs). Regulators are concerned with acetone, benzene, carbon tetrachloride, chloroform, formaldehyde, methylene chloride, perchloroethylene, toluene, xylene, and others. These compounds enter wastewater collection systems through industrial dis-

charges, illegal dumping, or as disinfection byproducts [1]. While the concentrations are generally low, the large amounts of water handled by POTWs can make total emissions troublesome. Sulfide removal is commonly necessary for wastewater treatment plants and other industrial facilities, and it is the most economical to operate sulfide biofilters at low pH. However, the same waste air often contains VOCs that also should be removed. One approach is to use a second biofilter to remove these compounds, but this is inexpensive. Recently the studies of sulfide-removing, low pH biofilters for their ability to simultaneously treat volatile organics demonstrated effective performance.

Compost is the most widely used for the biofilter medium. It is inexpensive, nutrient rich, and has substantial adsorption capacity. The microorganisms remaining from the composting process constitute an excellent inoculum and the medium rapidly becomes effective at removing air pollutants. Compost has been used in biofilter treating VOCs and H₂S in many studies [2-4]. However, the life span of compost is limited to not more than 7 years [5] and is commonly much shorter. It decays over time, causing compaction, clogging, short circuiting and increased headloss across the bed.

Granular activated carbon, ceramic, and propri-

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etary materials have been used in biofilter [6, 7]. Inorganic media are not prone to compaction or shrinking and will last indefinitely. If they dry out rewetting is not difficult. However, some are much more expensive than compost and all required nutrient addition.

Cork is not prone to compaction or shrinking and will indefinitely. If they dry out, rewetting is not difficult. The life span of cork is commonly much longer than that of compost. Cork does not decay over time, not causing compaction, clogging and increased headloss across bed. It is inexpensive, and has high surface area and substantial capacity.

The objective of this research was to demonstrate the feasibility of using cork for the treatment of VOCs and H₂S at a single stage biofilter and to compare removal efficiency and bed life to conventional media biofilter.

2. Materials And Methods

2.1 Analysis

The concentrations of toluene, benzene, xylene were measured using gas chromatography (Hewlett Packard 6890) equipped with a flame ionization detector (FID). Response from the FID detector was immediate after sample injection, allowing for a large number of analyses in a short period of time. The carrier gas had a 10 : 1 ratio of air to hydrogen at flow rates ranging from 5 to 10 ml/min. For full-chromatographic analysis, a 60 m capillary column (0.53 mm I.D., 5 µm df, manufacture by Restek Corp.) separated gas constituents before detection by FID.

Carbon dioxide concentrations were also determined with the gas chromatograph. A capillary column separated carbon dioxide from other constituents in the gas sample. Because the FID cannot detect CO₂ directly, a methanizer was attached in-line after the capillary column and before FID. With hydrogen supplied as the carrier gas, CO₂ is catalytically reduced to methane by passage through the methanizer. The methanizer column consisted of a 7.5 cm long × 3.2 mm i.d. stainless steel tube filled with a special nickel powder that was heated to 375°C. The CO₂ is detectable by the FID to 1 ppm with this

system.

2.2 Continuous flow column studies

The bench scale column apparatus consisted of polyvinyl chloride (PVC) column with an inner diameter of 8 cm and height of 90.0 cm. Columns were sealed at each end with PVC caps fitted with hose drilled in the PVC and covered by rubber septa. Peristaltic pumps supplied air flow to the columns. One air stream passed through water to provide humidity while another passed through a liquid pollutant. Flow were independently measured by flowmeters. Backpressures were determined by a water manometer before the combined flow entered the column.

Air samples were taken with disposable syringes (5 cm³ in volume). Three 0.25 cm³ samples were taken per sampling port and injected into the GC. The average concentration of the three injections was used for data analysis.

2.3 Saturation studies

Start-up conditions were monitored by determining concentration profiles in the columns. Loading conditions were held constant. During this period, concentrations were primarily controlled by the adsorptive capacity of the biofilter material. Profile and effluent concentrations rose as column material was saturated. Also during this period, microbial populations and activity increased until a steady state condition was reached where contaminant loading equaled biological degradation plus discharge.

2.4 Water content measurement

The water content of the biofilter material was measured as weight loss on heating to 105°C for 24 hours and expressed as percent wet weight. Prior to sample collection, crucibles were ignited at 550°C to dry them and remove all volatile matter. The crucibles were weighted on analytical balance to an accuracy of 0.0001 g. Media samples were added and weighted. The material was then dried in an oven at 103°C for a minimum of 8 hours and a maximum of 30 hours. The sample was reweighted and the water content calculated. The pH values for samples were determined with the use of a pH meter

(Orion Research Inc.). Samples were saturated with distilled water, covered with parafilm paper to prevent equilibrium with ambient CO₂, allowed to stand for roughly one hour, and measured with the pH meter.

3. Results And Discussion

3.1 Bench-scale low-pH biofilters

Sludge from municipal wastewater treatment plants is used as inoculum. Because the organisms in the sludge have been exposed to the mixture of sulfide and organic gases, sludge is a logical choice as an inoculum. Sludge also is easily available source of dense biomass and diverse microbial populations. Thus, sludge is potential useful as an inoculum for virtually and biofilter application. Sewage sludge inoculum improved the performance of compost biofilters treating sulfide gases, presumably because it contained suitable sulfide oxidizing organisms.

3.2 Removal of hydrogen sulfide (phase 1)

Biofilter were operated with three different media (cork for column 1, zeolite for column 2, and granular activated carbon for column 3) for two month, treating an air stream containing hydrogen sulfide. The removal efficiencies of cork, zeolite, GAC biofilters were 99.2%, 98.3%, and 94.0% with average inlet sulfide concentration of 30 ppm, and an empty bed residence time of 30 sec. This initial two-month experiment for hydrogen sulfide treatment showed that biofilters were readily applicable to wastewater

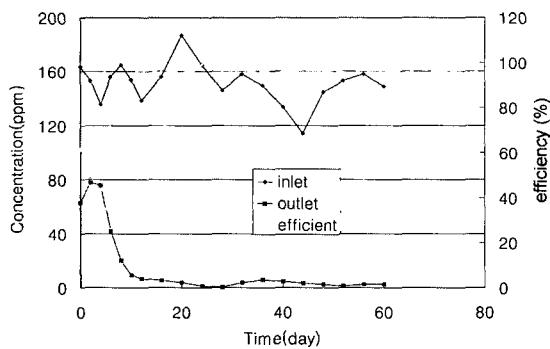


Figure 1. Gas concentrations (toluene) measured with operation time and the removal efficiency in a cork-packed biofilter

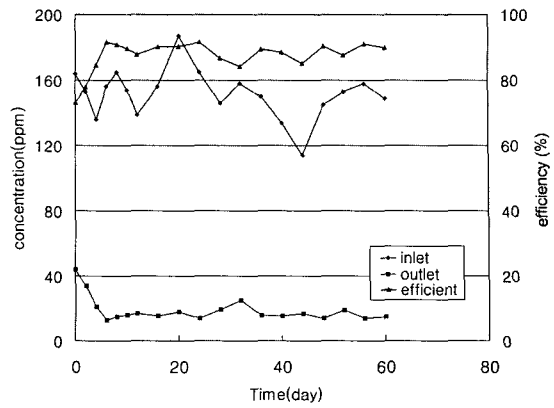


Figure 2. Gas concentrations (toluene) measured with operation time and the removal efficiency in a GAC-packed biofilter

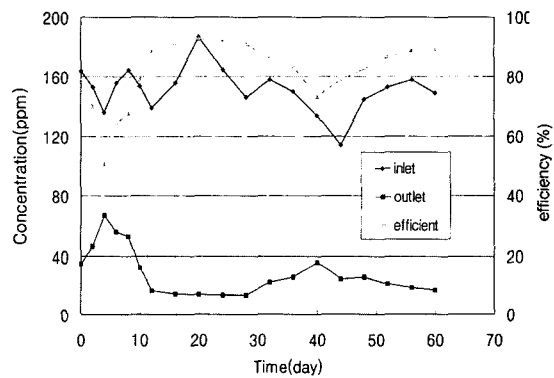


Figure 3. Gas concentrations (toluene) measured with operation time and the removal efficiency in a Zeolite-packed biofilter

plant (Figures not shown here).

3.3 Removal of toluene vapor (phase 2)

After two months of operation, biofilters were washed with nutrient minerals to lower the pH of filter media, and toluene vapor was added to the reactors in concentration up to 200 ppm, while the inlet sulfide concentration was maintained at 30 ppm (Figures 1 to 3). When toluene inlet concentration were less than 100 ppm, the removal efficiencies for cork, zeolite, and GAC biofilters were 81%, 92%, 65%.

Elimination capacity is the weight of the pollutant removed by the reactor per unit of the reactor per unit time. Typical units are g/m³/hr. Because biofilters often treat odorous emissions, elimination capac-

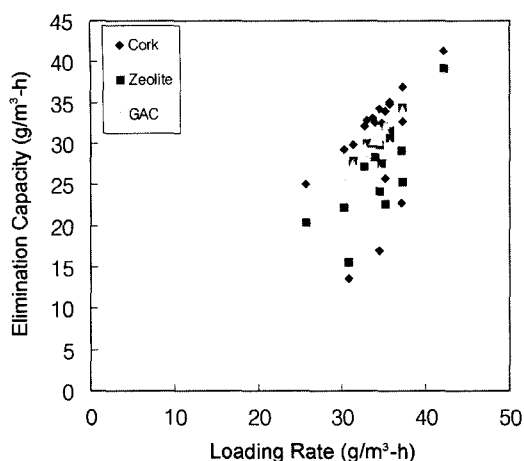


Figure 4. Toluene treatment performance summarized in a series of biofilters

ity may be expressed as odor/m³/hr. Elimination capacity is sometimes called degradation capacity may be misleading unless it is demonstrated that the removal is completely by biological degradation. Although there are many factors involved in reactor performance that are not considered in elimination capacity calculations, elimination capacity is the most informative single number for comparing performance of a biofilter to other biofilters and to other technologies. Typical elimination capacities for conventional biofilters treating common air pollutants range from 10 to 100 g/m³/hr [8]. The maximum elimination capacities of toluene for cork, zeolite, and toluene biofilters were 26 g/m³/h, 36 g/m³/h, and 28 g/m³/h, respectively when volumetric inlet loading rates were 54 g/m³/h (Figure 4).

During Phase 2, leachate pH values in cork, zeolite, and GAC biofilters declined to 2.1, 3.3 and 2.3. The variation in toluene concentrations along the biofilter packing height at different elapsed times was examined. The inlet concentrations at the elapsed times of 11 days, 24 days, 30 days, and 79 days were 8.7 ppm, 10.3 ppm, 12.8 ppm, and 2.9 ppm, respectively. The variation of dimensionless concentrations (ratio of outlet to inlet concentration, c/c_0) showed that the first 10 cm to 20 cm of the filter bed did not effectively treat toluene vapor. This was due to the low moisture content in filter media due to the bed drying. However, the performance of the biofilters improved with time.

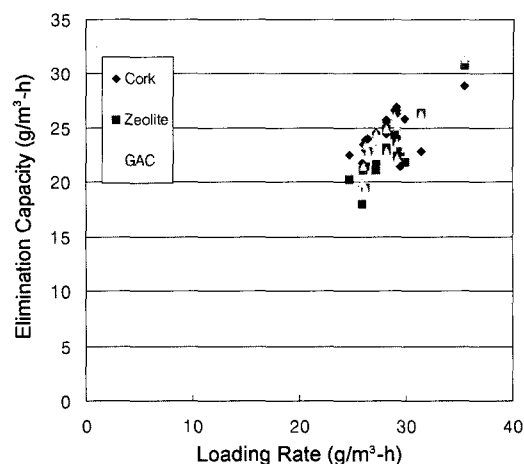


Figure 5. Benzene treatment performance summarized in a series of biofilters

3.4 Removal of benzene

Biofilters did not initially remove benzene effectively and the EBCT was increased from 30 sec to 1min. When the removal efficiency for benzene exceeded 70%, the EBCT was steadily decreased to 30 sec. The average, maximum, and minimum values of inlet benzene concentration were 132 ppm, 200 ppm, and 69 ppm with EBCT of 30 sec. The average removal efficiencies for cork, zeolite, and GAC biofilters were 80%, 70%, and 64%. The benzene removal in different filter media showed the same order of treatment effectiveness, with cork best and GAC worst. The removal efficiencies of benzene were much lower than those for toluene. Efficiencies greater than 80% were observed when volumetric loading rates were less than 3.7 g/m³/h for the three different biofilter media (Figure 5).

The maximum elimination capacities of benzene for cork, zeolite, and GAC were, 25.6 g/m³/h, 20.2 g/m³/h, and 24.2 g/m³/h. The removal efficiencies of benzene were significantly decreased when the volumetric loading rate was greater than 10 g/m³/h for all biofilters.

The biofiltration of benzene in the presence of sulfide at low pH required a longer acclimation period and lower inlet loading rates. However, the biofilters removed over 90% of benzene when inlet concentration was less than 40 ppm. Typical benzene concentrations observed in POTWs are much lower than these values.

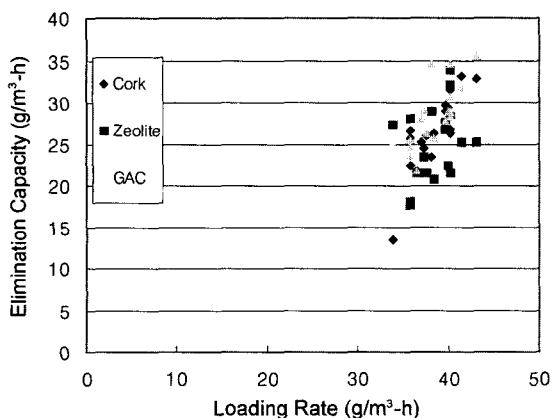
3.5 Removal of xylenes (phase 4)

Sulfide and xylene were used for two months after six months phase 1, 2, and 3 experiments. The values of average, maximum, and minimum inlet concentrations of xylenes were 200 ppm, 300 ppm, and 53 ppm, respectively, with an EBCT of 30s. The average removal efficiencies of xylenes for cork, zeolite, and GAC biofilters were 53%, 31%, and 54%.

The order of xylene removal in different filter media was cork > GAC > zeolite. The initial removal efficiencies of xylenes in phase 4 were 70.3% for cork, 85.3% for zeolite, and 85.3% for GAC when inlet concentration was 200 ppm. The effectiveness of biofilter performance decreased continuously with elapsed time even lower inlet concentrations. After the biofilters were washed with nutrient solution at pH 3, and acclimated biomass was removed with nutrient solution wash, the removal efficiencies improved to 79% for cork, 62.4% for zeolite, and 66% for GAC with inlet concentration 200 ppm. The zeolite biofilter showed the greatest performance improvement (see Figure 6). Adjusting of pH and nutrient addition resulted in fluctuating elimination capacities of biofilter operation.

3.6 pH variation

The pH of the medium has been found to decline in many biofilter applications. These declines are particularly severe for the treatment of hydrogen sul-



less effective.

Overall, the results indicate that low pH treatment does not have some limits, particularly that the elimination capacities for aromatic compounds are reduced. However, these limits are still high in comparison to concentrations seen in wastewater treatment plants and in many other facilities. Simultaneous low-pH treatment of sulfides and many hydrocarbons, on an inorganic medium at pH 2, is likely to be effective in many applications.

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References

- [1] J. R. Witherspoon, W.J. Bishop, and M.J. Wallis, "Emissions Control Options for POTWs", *Environmental Protection*, 4(5), pp. 59-66, 1993.
- [2] S. J. Ergas, E. D. Schroeder, D. P. Y. Chang, and R. L. Morton, "Control of Volatile Organic-Compound Emissions Using a Compost Biofilter", *Water Environment Research*, 67(5), pp. 816-821, 1995.
- [3] D. S. Hodge and J. S. Devinny, "Modeling Removal of Air Contaminants by Biofiltration", *J. Environmental Engineering-ASCE*, 121(1), pp. 21-32, 1995.
- [4] E. D. Schroeder, S. J. Ergas, D. P. Y. Chang, and R. L. Morton, "Control of VOC Emissions from a POTW using a Compost Biofilter", *Proceedings of the Water Environment Federation 65th Annual Conference & Exposition*, Sept. 20-24, New Orleans, LA, 1996.
- [5] C. Van Lith, "Evaluating Design Options for Biofilters", *J. Air. Waste. Manage. Assoc.*, 47(1), p. 37, 1997.
- [6] M. A. Deshusses *et al.*, "Behavior of Biofilters for Waste Air Biotreatment. 2. Experimental Evaluation of a Dynamic Model", *Environ. Sci. Technol.*, 29(4), p. 1059, 1995.
- [7] V. E. Medina, T. Webster, M. Ramaratnam, and J. S. Devinny, "Treatment of Gasoline Residuals by Granular Activated Carbon-Based Biological Filtration", *J. Environmental Science and Health Part A-Environmental Science and Engineering*, 30(2), pp. 407-422, 1995.
- [8] G. Lesson, M. Winer, and D. S. Hodge, "Application of Biofiltration to the Control of Toxics and Other VOC Emissions. Presented at the 84th Annual Meeting and Exhibition of the Air and Waste Management Association. June 16-21. Vancouver, BC, Canada, 1996.