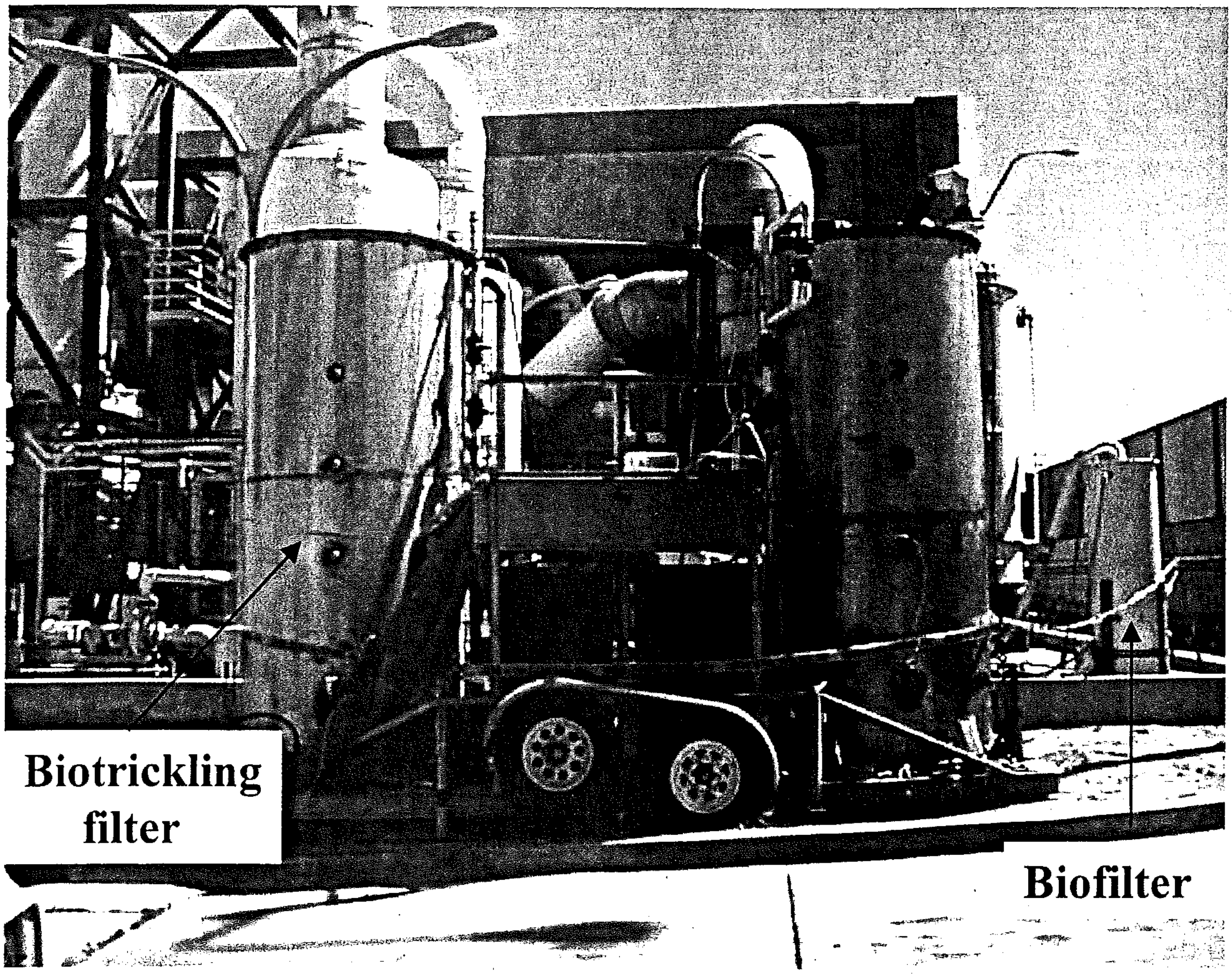
H_2S and VOC Removal at Headworks
Hyperion Treatment Plant



Draft Interim Report I

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Applied Research (WESD), Hyperion Treat. Plant
and EMD, Bureau of Sanitation, City of LA

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CITY OF LOS ANGELES

INTER-DEPARTMENT CORRESPONDENCE

DATE: December 26, 2000

TO: Distribution

FROM: Omar Moghaddam, Energy Management & Applied Research/WESD

SUBJECT: H2S and VOC Removal Pilot Project at HTP Headworks: Performance of Biofilter and Biotrickling Filter

This is the first interim report by the Applied Research Group/Wastewater Engineering Services Division (WESD) on the progress of subject matter. This project is funded by Water Environmental Research Foundation (WERF) and is prepared in collaboration with University of California, Riverside (UCR), University of California, Davis (UCD), Environmental Monitoring Division (EMD), and Hyperion Treatment Plant (HTP) staffs. The WERF subcommittee members' comments and reviews, the support from the Bureau of Sanitation Management and Environmental Engineering Division (EED) have been instrumental to the success of this project.

The project was performed in accordance with Research Permit No. 441 of SCAQMD Regulation issued for both biofilter and biotrickling filter with permits No. 364968, and No. 323294, respectively.

This document covers the work from March to September 2000 at Hyperion Treatment Plant. As noted in the Report the operations of biotrickling filter and biofilter have been successful. Other interim reports will follow to update the progress of the project, including cost studies and comparisons with chemical scrubbers, and possible applications to collection systems.

If you have any questions or comments, please feel free to contact Reza Iranpour at (310) 648-5280 or his staff Dariush Vosooghi/Dipak Patel at (310) 648-5127.

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EXECUTIVE SUMMARY

BACKGROUND

This is the first interim report on the biotrickling filter (BTF) and biofilter (BF) project at Hyperion Treatment Plant (HTP), covering experiments from March to September 2000. This project is funded by the Water Environment Research Foundation (WERF) and conducted by a team of personnel from the Applied Research Group (ARG) of WESD, the Environmental Monitoring Division (EMD), Hyperion Treatment Plant (HTP), and the Bureau of Sanitation management. The project is extensively benefited from the work by University of California, Riverside (UCR), University of California, Davis (UCD), and the WERF subcommittee.

The project was performed in accordance with Research Permit No. 441 of SCAQMD Regulation issued for both biofilter and biotrickling filter with permits No. 364968, and No. 323294, respectively.

Because of stricter federal and local air quality regulations, publicly owned treatment works (POTWs) have been focusing their attention on quantifying and controlling volatile organic compounds (VOCs) and toxic air pollutants emitted from wastewater and solids handling processes. The effort has been greatest in the Southern California Air Basin (SCAB), where New Source Review (NSR) regulations for toxics have been effective since 1990. The upcoming regulations include the establishment of Maximum Achievable Control Technology (MACT) standards for POTWs as mandated under the Federal Clean Air Act Amendments of 1990. In addition, new regulations proposed by the South Coast Air Quality Management District (SCAQMD) include the requirement for POTWs to meet facility-based standards for existing sources.

A POTW's waste air stream contains two groups of pollutants:

a) sulfur species, mainly hydrogen sulfide (H_2S), as the principle cause of odor nuisance.
b) a broad variety of speciated VOCs including non-halogenated VOCs (e.g., benzene, toluene, and xylenes) and halogenated VOCs (e.g., p-dichlorobenzene, methylene chloride, chloroform, and perchloroethylene).

The objectives of this project are:

a) to evaluate the applicability and effectiveness of BF and BTF in removing malodorous gases and VOCs at headworks facilities in HTP.
b) to compare the performance of BF and BTF in odor and VOC reduction.
c) to compare technical and economical feasibility of BF and BTF with the present chemical scrubber systems in the Bureau's wastewater treatment plants.
d) to investigate the applicability of BF and BTF to collection systems.

The project agreement was signed in late 1999, the setup was completed in early 2000 at HTP and the full-scale operation began in April 2000. An extensive field study program with protocols for sampling and analysis of H_2S and VOCs was developed. Testing has been done on a daily basis (long-term data), as well as more frequent hourly samples on selected days (short-term data). The analysis of VOC samples was performed by EMD. Specified VOCs were analyzed by Gas Chromatograph (GC) using Photoionization Detector (PID) / Electrolyte Conductivity Detector (ELCD). A portable Jerome meter was utilized to determine the concentration of H_2S up to 50 ppm. A Gas-Tech meter was used for measuring the H_2S concentration up to 100 ppm.

RESULTS / CONCLUSIONS

Tables 4 and 5 (Section 4 of the Report) summarize the average results for the BF and the BTF, respectively. These results are presented in much more detail in the Report (Section 4: Figures 5 through 12). The following summarize the results:

a) the biosystems are extremely easy to operate and maintain, and even to design and construct. However, the biofilter is even easier than the biotrickling filter.
b) nearly perfect removal of H_2S was obtained by both filters. The outlet concentration of H_2S is generally below 1-ppm level, which is in the range of the SCAQMD limit for wet scrubbers.
c) significant removal of non-halogenated VOCs was achieved by the biofilter, but not by the biotrickling filter. This was observed for natural VOC concentrations in the waste gas stream.
d) no significant removal of halogenated VOCs occurred for either filter. This was also observed for natural VOCs concentrations in the waste gas stream.

e) the removal of VOCs in these biosystems is a great advantage since VOC removal does not occur in chemical scrubbers.

Even though halogenated VOCs are not removed in these systems, the removal of nonhalogenated VOCs helps fulfill the regulations that aggregate all VOCs together. Several halogenated and non-halogenated VOC concentrations were below detection limit in the influent gas stream. The concentrations of these compounds are not reported.

RECOMMENDATIONS

The following items are recommended:

a) continue studies as outlined in Section 6.
b) investigate the application of these technologies for replacement of the present chemical scrubbers at the Bureau's facilities.
c) Investigate the application of these technologies in wastewater collection systems.

Based on several studies, wastewater collection systems have been identified as one of the main sources for VOC emissions. Therefore, further investigation of these technologies could create better and more economical methods to reduce odor and VOC emissions.

COMMENTS ON VOC REMOVALS

Although the detailed data show numerous instances in which the outlet concentration is greater than the inlet concentration for VOCs, it is not believed that these represent synthesis by the biomass. As the inlet concentration is seen in the data to be highly variable, and the filter medium has some capability for temporary adsorption of these compounds, the most likely explanation is that the higher outlet concentrations result from desorption of pollutants adsorbed minutes or hours earlier during unobserved periods when the inlet concentration was higher.

The difference in performance between the two types of filter for non-halogenated VOCs may in part result from their insolubility: the thin water layer in the BTF acts as a barrier between the gaseous VOCs and the biomass. As H_2S is much more soluble, the water would not be expected to interfere with the removal of this gas. On the other hand, the low pH in the water of the BTF probably contributed significantly to the poor performance of this unit, since VOCs degradation is most favored near neutral pH.

The results for VOC removal must be considered preliminary. There was no attempt to acclimatize the culture, and only short-term measurements were made. Using a culture that has not been exposed to high concentrations of VOCs provides a baseline for comparison with the behavior of cultures that have been so exposed, and long-term observations of the original culture allow assessment of the degree of acclimation that occurs under the VOCs concentrations prevailing in the headworks gas. We note that a culture that is acclimatized to a high concentration may not be stable at the low concentrations in the headworks gas, but may regress to a balance of organisms that is closer to what was originally present. On the other hand, temporary exposure to higher concentrations may trigger the synthesis of enzymes that allow these compounds to be metabolized at the ppb concentrations typical in these data. Plans and protocols for this prospective future work appear in Section 6.

The disappointing results for halogenated VOCs are consistent with decades of previous observations that very few microorganisms are able to decompose these compounds, and it is rare for a natural culture in this type of device to contain such organisms in large enough numbers to provide significant degradation.

Since the air stream from the headworks was divided to supply the two units, the excellent agreement between the H_2S inlet readings for the long-term studies of the two filters verifies the calibration and accuracy of the meters used for these measurements. As the short-term measurements of the two instruments were done on different days, the detailed plots cannot be directly compared.

Future study as outlined in Section 6 of this report would further improve the removal of VOCs especially halogenated VOCs by improving the acclimation of biomass in the media.

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ACRONYMS

BF	BIOFILTER
BTF	BIOTRICKLING FILTER
BTEX	BENZENE TOLUENE ETHYL XYLENE
CARB	CALIFORNIA AIR RESOURCE BOARD
EPA	ENVIRONMENT PROTECTION AGENCY
ELCD	ELECTROLYTE CONDUCTIVITY DETECTOR
GC	GAS CHROMATOGRAPHY
HTP	HYPERION TREATMENT PLANT
HP	HORSE POWER
HPE	HIGH PRESSURE EFFLUENT
MDL	METHOD DETECTION LIMIT
MGD	MILLION GALLON PER DAY
PID	PHOTO IONIZATION DETECTION
POTW	PUBLIC OWNED TREATMENT WORK
PVC	POLY VINYL CHLORIDE
PPM	PARTS PER MILLION
PPB	PARTS PER BILLION
SCAQMD	SOUTHERN CALIFORNIA AIR QUALITY MANAGEMENT DISTRICT
UCR	UNIVERSITY OF CALIFORNIA, RIVERSIDE
UCD	UNIVERSITY OF CALIFORNIA, DAVIS
VOCs	VOLATILE ORGANIC COMPOUNDS
WERF	WATER ENVIRONMENT RESEARCH FOUNDATION

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1. INTRODUCTION

This is the first interim report on the Biotrickling filter (BTF) and biofilter (BF) project at Hyperion Treatment Plant (HTP). This project is being conducted by a team composed of personnel from, the Applied Research Group (ARG) as WESD, the Environmental Monitoring Division (EMD), HTP, and Bureau of Sanitation management. There has also been extensive collaboration by University of California, Riverside (UCR), University of California, Davis (UCD), and Water Environment Research Foundation (WERF) Subcommittee.

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In light of stricter federal and local air quality regulations, Publicly Owned Treatment Works (POTWs) have been focusing their attention on quantifying and controlling volatile organic compounds (VOCs) and toxic air pollutants emitted from wastewater and solids handling processes. This attention has been most pronounced in the Southern California Air Basin (SCAB) where New Source Review (NSR) Regulations for toxics have been effective since 1990. The upcoming regulations include the establishment of Maximum Achievable Control Technology (MACT) standards for POTWs as mandated under the Federal Clean Air Act Amendments of 1990. In addition, new regulations proposed by the South Coast Air Quality Management District (SCAQMD) include the requirement for POTWs to meet facility-based standards for existing sources.

POTWs waste air stream contain two groups of pollutants:

- Sulfur species, mainly hydrogen sulfide (H_2S), as the principle cause of odor nuisance and
- Broad variety of speciated VOCs including non-halogenated VOCs (e.g., benzene, toluene, and xylenes) and halogenated VOCs (e.g., p-dichlorobenzene, methylene chloride, chloroform, perchloroethylene).

Treatment of either group in BF and BTF has been proven to be efficient and cost-effective.

The project agreement was signed in late 1999, the setup was completed in early 2000 at HTP and the full-scale operation began in April 2000. An extensive field study program with protocols for sampling and analysis of H_2S and VOCs was developed. Testing was done on a daily basis for a period of 6 months (long-term), as well as more frequent (hourly basis) on selected days (short-term). The analysis of VOC samples was performed by EMD. Specified VOCs were analyzed by using Photoionization Detector (PID) / Electrolyte Conductivity Detector (ELCD) detectors. A portable Jerome meter was utilized to determine the concentration of H_2S up to 50 ppm. The Gas-tech meter was used for measuring the H_2S concentration up to 100 ppm.

1.1 Objectives

The objectives of this study are:

- To evaluate the applicability and effectiveness of BF and BTF in removing malodorous gases and VOCs at Headworks facilities in HTP.
- To compare the performance of a BF and a BTF in odor and VOCs reduction.
- To compare technical and economical feasibility of BF and BTF with the present chemical scrubber systems in the Bureau's wastewater treatment plants.
- To investigate the applicability of BF and BTF to collection systems.

1.2 Current Status

The current achievements are:

- Preparation of a BF and BTF literature review report.
- Development and preparation of experimental protocols for use in pilot-scale experiments.
- Conducting sampling and analysis on H_2S and VOCs.
- Monitoring and record keeping of maintenance for both systems on a daily basis.

2. LITERATURE REVIEW

The following sections are devoted to a general literature review on off-gases biological treatment by BTF and BF in POTWs recently performed by ARG.

2.1 Biotrickling Filters at POTWs

Although BTF research in the US has trailed Europe over the past two decades, recently rapid progress is made especially in the area of odor treatment at wastewater treatment facilities. Waste gases at these facilities contain H_2S as the principle odor-causing agent in concentrations up to 100 ppm as well as lower concentrations (0-100 ppb) of various halogenated VOCs. Chemical scrubbers are currently employed to reduce the odor problem. Although they are effective in removing H_2S, high consumption of chemicals (e.g., caustic soda, bleach) and non-removal of VOCs are drawbacks of increasing concern.

In 1993, a BTF study was done at the Los Angeles County Sanitation Districts (Morton *et al.*, 1996). Greater than 98% and 99% removal of H_2S and odor, respectively, was demonstrated in a pilot unit with 0.3 m^3 of lava rock as the packing. The gas residence time was varied between 12 and 30 seconds. The pH control and nutrient feed were done by a continuous supply of secondary effluent water to maintain a pH in the range of 2.0 to 3.0. Due to concerns of clogging of the lava rock, a second experiment was set up using plastic packing. The H_2S removal efficiency was less, presumably because of mass transfer limitation due to a smaller specific surface area of the packing. It should be kept in mind that the high density of lava rock requires reinforced reactors. Lightweight packing with a high specific surface area such as polyurethane foam may be an attractive option for large-scale reactors.

Co-treatment of H_2S and VOCs has been studied in a number of projects. For optimization of both removals, there may be a conflict of optimal pH. H_2S is in general oxidized by *Thiobacillus* species with an optimum pH of about 2. VOCs are degraded by heterotrophs that in general prefer a neutral pH, although VOCs removal in low-pH, H_2S-oxidizing BF and BTF has been observed (Torres *et al.*, 1998; Chitwood *et al.*, 1999; Cox *et al.*, 2000). Chitwood *et al.* (1999) investigated a two-stage process at the Ojai Valley Sanitary District. This process contained an acid reactor with lava rocks for H_2S removal, followed by a neutral BF for VOCs removal.

Overall performance and removal efficiency of the two-stage process seemed slightly better than combined removal in a single stage BF (Chitwood *et al.*, 1999). Other studies focus on BTF, operated at a neutral pH by automated caustic addition, for simultaneous removal of H_2S and VOCs. A pilot-scale BTF at the County Sanitation Districts of Orange County removed greater than 87% of H_2S but removal of VOCs was disappointingly low at 11% (Torres *et al.*, 1998). Low VOCs loadings and frequent systems upsets were the presumed cause for poor VOCs removal.

2.2 Biofilters at POTWs

In the past two decades, many laboratory and field experiments have been performed using field, bench, and full-scale BF to remove odors and VOCs from gas streams POTWs. A summary of the selected works is presented as follows:

Finger *et al.* (1993) utilized a long-term pilot test of a four-module BF to assess reduction of odors and VOCs at East Division Reclamation Plant in Renton, Washington. Substantial reductions of H_2S (up to 99.8%), mercaptans (up to 84.7 %), odor units (up to 99.6 %) and amines were achieved. The average performances on selected VOCs revealed reductions ranging 25-55 percent. LeBeau *et al.* (1993) studied the control of H_2 S odors originating from wastewater lift stations. A full-scale BF was constructed at Appolo Beach Wastewater Lift Station at Hillsborough County, Florida. Two media of different composition were tested. After 14 days of operation, the BF began removing H_2S to below measurable levels and continued to do so throughout the next eleven months. Torres *et al.* (1994) conducted bench-scale experiments using eleven 7.5-cm internal diameters, 150 cm long BF columns to remove VOCs and odorous gases from headworks of Reclamation Plant No. 1 in Fountain Valley, CA. Four media, including two organic and two inorganic media (granulated activated carbon (GAC) and zeolite) were tested. Both the organic and inorganic media were effective in achieving high removal efficiencies for H_2S (up to 100%) and VOCs (50-95 %). Removal of halogenated VOCs was low (5-45%). However, tetrachloroethylene was efficiently removed in the GAC column (up to 95%), which was probably due to adsorption onto the carbon. Singleton *et al.* (1993) used a modular designed BF comprising of five trays in series in a pilot study. The BF inlet was fed by an air stream taken from a wet well in the primary sludge pumping station at the head of a wastewater treatment plant at Glen Falls, NY. A high H_2S removal (91-97%) was observed. A substantial reduction of benzene (22-90%), toluene (64-90%), ethylbenzene (70-90%), and xylene (33-70%) was achieved. In the experiment with VOCs, a three-week acclimation period was experienced. Giggey *et al.* (1993) used two BFs in enclosed composting facilities in Yarmouth, Massachusetts and Lewiston-Auburn, Maine. The BF at Yarmouth provided treatment for both the septage treatment facility and the composting facility. The BFs have demonstrated their ability to effectively treat odors in a cold climate with ambient temperature of below 0 °C. Removal efficiencies of odor and mercaptans were 24-93% and 99-100%, respectively. Wolstenholme *et al.* (1994) used a pilot test of bulk media BF to assess reduction of odors and VOCs from wastewater in foul streams in a reclamation plant in Renton, Washington. Four different modules were selected with various compositions of media. Substantial reduction of odorous compounds was achieved. The average reduction of odor units was 96 percent. Reduction of VOCs was variable. The average reductions were in 20 to 50 percent range. Singleton *et al.* (1993) performed a pilot study to remove H_2S, methyl mercaptan, dimethyl sulfide, and dimethyl disulfide from an air stream in Albany North Plant in Albany, NY. A modular BF was used for the first stage. To increase the organic sulfide removal, additional modules were used in series for the second stage. The removal efficiency of H_2S in the first stage was between 75 and 100. Average removal efficiencies for methyl mercaptan, dimethyl sulfide, and dimethyl disulfide in the first stage were 40.3 %, 22%, and -45% and in the second stage were 65.3%, 21.1 %, and -7%, respectively. Kartik Vaith and Jim Heydorn of CH2M Hill (1996) tested three BFs for three different applications of wastewater treatment plant and wastewater collection system. The media for these three BF were pine bark, peat/cypress wood chips/top soil and wood chips/compost/perlite/granular fill. There was very good removal efficiency for H_2S and for all other mercaptans. However, the larger BF showed signs of short-circuiting, which was not observed in smaller BF. Bonin *et al.* (1993) tested BFs at a wastewater treatment plant and wastewater collection system in Carry Sausset, France. The filter bed was a combination of peat and pine bark with a superficial gas load of 100 to $m^3/m^2/h$ and removal load of 10 $g/m^3/h$ with contact time of 30 sec. The filter bed area was 60-m^2 with an airflow of 5560 scfm. Using mineral media (schist with regular granulometry, 3-6 mm) would avoid formation of preferential channels and allow high gas velocity and high pollutants load. After nine months of operation, the operating cost was similar to that of peat BF but three times less than chemical scrubbers. The capital costs were about twice cheaper than the cost of peat BF because low gas contact times allowed for construction of relatively small units. Amirhor *et al.* (1993) performed a full-scale study at a biosolids composting facility in Darmouth, Massachusetts. The objective of this study was odor and odorous compound measurement. The BF bed area was about 5900 ft^2 and 3 feet deep with a contact time of 45 sec. The filter media had one part bark mulch, two parts wood chips, and one part leaf compost with retention time of 17 seconds for 24,000 SCFM at (4 SCFM/sq. ft). Monitoring was performed twice in May and December 1993. At the conclusion of this study, they found very good relation of odor reduction with the flow of air through different sites across the filter bed. This relationship was similar for very different odor concentration in the BF inlet. The results indicated significant odor removal efficiency at low airflow rates. There was a strong correlation between the air flow rates and the odor removal efficiency. The removal efficiencies measured for dimethyl sulfide also showed significant correlation with flow rates. However, there was an insignificant correlation between the flow rate and the removal efficiencies of dimethyl disulfide, methyl mercaptan, or NH_3.

Up to date, there are no direct comparisons available on the operation of BF and BTF at POTWs under the same conditions. This would require investigation of parallel operation of both systems, treating the same source of foul air (this is one of the unique objectives of the present project). Nevertheless, from the literature reviews as outlined above, a few general conclusions can be drawn with respect to POTWs.

I. BTF and BF versus chemical scrubbers/activated carbon units:

Advantages:

- Removal of VOCs, apart from effective H_2S and odor treatment.
- No generation of secondary waste streams.
- Substantial lower consumption of chemicals.
- Lower overall costs.
- Environmentally friendly technique, positively received by the public.

Disadvantages:

- BTF and BF are in general operated at longer gas residence times, hence larger reactors are required.
- Long term stability (years) of BTF and BF is still a subject of current research.

II. BF versus BTF

Advantages of BF (as compared to BTF):

- High removal efficiencies at low pollutant concentration (but low removal efficiency at high pollutant concentration over the long-term).
- Rapid start-up.
- Simple construction, maintenance, and operation.
- Low costs.

Disadvantages of BF (as compared to BTF):

- Large floor space is needed because the height of the BF packing is limited to maximally about 8 ft and because biological degradation rates in BF are lower than in BTF.
- Larger overall reactor volumes are required, as the volumetric elimination capacity is in general lower.
- Packing deterioration may cause poor performance after several months/years of operation, requiring periodical packing replacement.
- Poor control of biological reaction conditions due to the absence of recycling of liquid (no pH control, no discharge of metabolic products that may inhibit the microorganisms). This is why the removal efficiency is higher in BTF when high pollutant loads are supplied.

Generally speaking (many exceptions may exist depending on the application), BF would be the first option when the gas to be treated contains low concentrations of mainly easily biodegradable pollutants. With increasing pollutant concentration, and with pollutants requiring strict control of reaction conditions, BTF becomes the first choice. Other factors to be considered are the availability of floor space (BF -, BTF +) and overall costs (BF +, BTF -). The total cost of BTF construction and operation is in general between that of BF and chemical scrubbers. Also, BF shows a more rapid startup than BTF, but there is concern about maintaining constant BF performance over several years of operation. In general, BF performance will deteriorate more quickly with increasing pollutant concentration, most notably that of H_2S (sulfuric acid being the end product of the reaction, causing low pH). When treating high loads of H_2S and VOCs, long-term, constant performance is more likely to be obtained with BTF.

2.3 Theoretical Background

The principle of waste gas treatment in BTF and BF is biological degradation of the waste gas pollutants by microorganisms, predominantly bacteria but sometimes also yeasts or fungi. The end products of the bioreaction depend on the type of pollutant and the purpose of biodegradation by the microorganisms. Some typical examples are the following:

- VOCs such as toluene are a carbon and energy source for heterotrophic microorganisms. End products are in general CO_2, H_2O and microbial biomass.
- Inorganic sulfur compounds such as H_2S are an energy source, typically for species from the genus Thiobacillus. H_2S is oxidized to sulfuric acid (H_2SO_4) according to the following aerobic biological reaction.

$$H_2S + 2O_2 \xrightarrow{\text{Sulfur oxidizing bacteria (thiobacilli):}} H_2SO_4$$

- Halogenated VOCs such as dichloromethane are a carbon and energy source. End products are CO_2, H_2O, microbial biomass and hydrochloric acid (HCl).

In general, waste gas pollutants are degraded to products much less or not toxic at all. Discharge streams (gas, liquid, filter material) are in general of no concern with respect to state or federal regulations, provided that pollutant concentrations are reduced to required levels. This is an important advantage over chemical and physical techniques that often generate secondary waste streams.

In BTF, polluted air is blown through a reactor containing porous, synthetic packing with a high specific surface area. The packing is covered by a biofilm containing the microorganisms, and with a thickness anywhere in the 'µm to cm" range depending on the application. Liquid is sprayed over the top of the packing, and collected at the bottom for recirculation to the top. The liquid provides nutrients to the microorganisms in the biofilm. Its presence also allows regulation of the pH in the reactor by using a pH controller to regulate the addition of alkali to maintain a desired pH. This is especially important when treating sulfur and halogenated compounds that respectively release sulfuric acid, H_2SO_4 and hydrochloric acid, HCl when biodegraded. The airflow through the reactor may be either upward (countercurrent with the liquid) or downward (cocurrent operation). The theory predicts that countercurrent operation is less efficient because of stripping effects at the air outlet. However, experimental data show no major difference between cocurrent and countercurrent operation.

The principle of BF is comparable to that of BTF except for:

- The BF uses organic packings (such as compost and bark)
- In BF, there is no continuos recycling of a liquid over the packing.

The effectiveness of a BF is largely governed by the properties and characteristics of the support media, which includes porosity, degree of compaction, water retention capabilities, and the ability to host microbial populations. Critical BF operational and performance parameters include moisture content, media pH, media porosity and nutrient content. In general optimization of the process is more difficult to achieve in BF because of the lack of liquid recycling over the packing. Use of biosystem is restricted to waste gases containing pollutants that are biologically degradable. Microbial research over the past decades has progressed very fast, and many compounds formerly thought to be recalcitrant or not biodegradable can now be treated in these systems.

Biodegradation in BF and BTF are in general an aerobic process, basically because most waste gases are taken from sources containing ambient air. Hence, pollutants that require anaerobic conditions for biodegradation will not be removed, although a few exceptions exist. Biofiltration is a proven control technology for H_2S emissions. Low molecular weight and water-soluble compounds are easily biodegradable. Halogenated VOCs are degraded with more difficulty. Some pollutants require the presence of growth substrate for biodegradation (co-metabolism). For example, certain methanotropic bacteria degrade halogenated compounds in the presence of compounds such as methane or toluene.

Pollutant removal in BTF and BF is a two-step process as follows:

1. Diffusion or mass transfer of the pollutant from the waste gas into the biofilm.
2. Degradation of the pollutant by the microorganisms in the biofilm.

Either one of these two steps may be rate limiting, thus determining the overall performance. This depends on many parameters, of which the biodegradability and water solubility of the pollutants are the most important ones. Depending on the rate-limiting step, improvement of filter and BTF performance generally aims at improving the mass transfer rate or the biological degradation rate.

3. EXPERIMENTAL SETUP AND PROCEDURES

3.1 Facility Description

The HTP facility is approximately 15 miles southwest of downtown Los Angeles, California, along the coastline of Santa Monica Bay. HTP processes both liquid and solid wastes. HTP treats approximately 330 million gallons per day (mgd) of raw sewage collected from four major sewer interceptors. HTP also receives solids discharged to the wastewater collection system by upstream plants (primarily the Los Angeles-Glendale Reclamation Plant and the Donald C. Tillman Water Reclamation Plant).

Liquid processes consist of preliminary treatment, which includes flow control, screening as wastewater passes through the Headworks, and degritting by aerated grit tanks or nonaerated settling process. Primary treatment which removes floating and settleable material; secondary treatment, which by a process of aerobic biological activity, removes soluble and fine colloidal materials; and effluent pumping, which transports treated wastewater to an ocean 5-mile outfall for release after chlorination treatment. The plant is a full secondary facility, in which all effluent receive secondary treatment (high purity oxygen activated system, HPOAS).

The first process facility at HTP is the Headworks facility. The wastewater is screened through automatically raked bar screens approximately ¾-inch openings. The entire Headworks process air and building ventilation air is routed through single-stage packed tower scrubbers at a rate of 104,000 cfm. For this project, a small part of the Headworks air is routed to the BF and BTF. The exhausts from the BTF and BF are routed back to the inlet scrubbers. No blower is used, as the pressure differential available is about 5 inches head of water column, which is sufficient to ensure high airflow rates through the BTF and BF. Present airflow through the BTF is about 768 m^3/h (450 cfm) which corresponds to an empty bed residence time of about 18 seconds. The empty bed gas residence time in the BF is 20-25 seconds.

3.1.1 UC Riverside Biotrickling Filter Equipment

The pilot-scale reactor design was based on three successful years of operation of a bench-scale BTF at the Swiss Federal Institute of Technology (Zuber, 1995; Webster *et al.* 1999). The prototype system, designed and constructed by the University of California at Riverside and Environmental Biosystems (formerly located in Long Beach, CA), included two side-by-side tanks constructed of 304 stainless steel, each with an internal diameter of 1.52 m (5 ft) and height of 3.4 m (11 ft) (see Figures 1 and 2). For the present project, only one tank is being used. The tank has packed bed height of 2.1 m (7 ft), consisting of 7 layers of a COOLdek^{TM} PVC Munters 12060 structured packing with a specific surface area of 230 m^2 m^{-3} (68 ft ft^{-2}) and a void space about 90-95%. The bed volume of the tank is 3.9 m^3. A water knock out drum was installed after the BTF. It consisted of a simple 55-gallon drum.

The BTF includes one 0.75 HP water pump used to recycle the scrubbing solution over the packed bed. A portion of the total recirculating water is directed to the base of each tank to provide adequate mixing in the tank bottom. A volume of 0.6 m^3 (160 gallons) of recycled liquid is maintained in the base of the tank. Clear vinyl tubing is connected to two separate locations at the bottom of the tank to check the recycle water level. Hyperion secondary effluent that is called high-pressure effluent (HPE), filtered, and lightly halogenated serves as water and nutrient source. It is stored in a 0.8 m^3 (200 gallons) reservoir and is supplied continuously to the reactor via a peristaltic pump. A constant water level is ensured by an overflow connected to another peristaltic pump. The pH control is via a stand-alone Cole Parmer pH controller, which actuates the metering of 0.75-M (30-gallons/liter) sodium hydroxide (NaOH) solution to the base of the tank.

3.1.2 UC Davis BioFilter Equipment

The unit was constructed on the Davis campus and assembled at the wastewater treatment plant, between March 9, 2000 and March 30, 2000. Diameter and overall height of the unit are 0.61 (2-ft) meters and 2 meters (6 ft), respectively. Total packing medium depth is 1 meter (3 ft). The packing medium is a mixture of compost, oyster shells and perlite and is separated into two sections. The bottom (first) section is 0.25 meters (1 ft) deep and designed for H_2S removal while the top section is 0.75 meters (2.5 ft) and designed for VOCs removal (see Figures 3 and 4). Because of the production of sulfuric acid in the bottom section the unit is operated in upflow mode. Moisture control is always the most critical operating parameter in compost BF. In the UC Davis BF, moisture content is maintained by intermittent operation of a permeable soaker hose coiled inside the unit on top of each of the medium sections. The wetting schedule is controlled by standard battery operated garden sprinkler timers.

3.2 Procedures

3.2.1 Sampling Locations

Biotrickling Filter: Samples were collected from the BTF at five locations:

- P_{in} (inlet air duct)
- P_1, distance in packed bed (65 cm)
- P_2, distance in packed bed (115cm)
- P_3, distance in packed bed (165 cm)
- P_{out} (exhaust air duct)

Biofilter: Three sampling locations were considered for BF as follow.

- P_{in}
- P_1, distance in packed bed (40 cm) (e.g. between the first and second stage)
- P_{out}

Figures 2 & 4 shows the sampling locations as indicated for BTF and BF, respectively.

3.2.2 Sampling Procedures

Long-term sampling: Long-term sampling was performed on H_2S for both BF and BTF, on a daily basis at the inlet and outlet of BTF and BF and data are outlined on Tables 6 and 7 in Appendix II. The graphs are also shown in Figures 5 and 9.

Short-term sampling: The BTF and BF sampling schedules are shown in Tables 1 and 2. The graphs are shown in Figures 6 and 10.

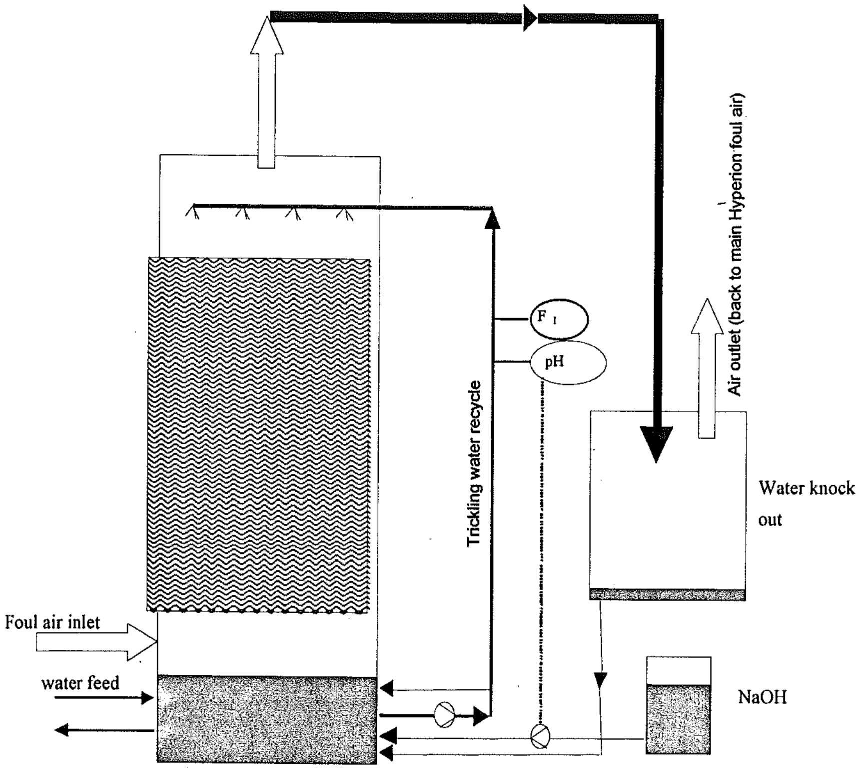


Figure 1. Schematic of the UC Riverside Biotrickling filter

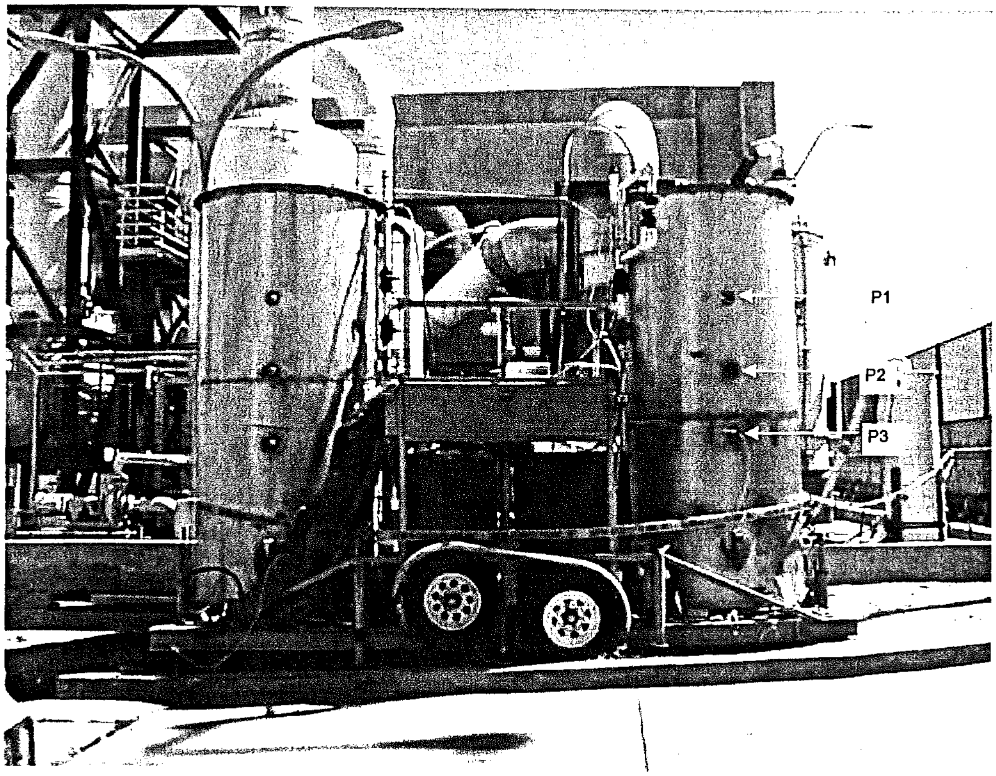


Figure 2. UC Riverside Biotrickling filter at Hyperion treatment plant

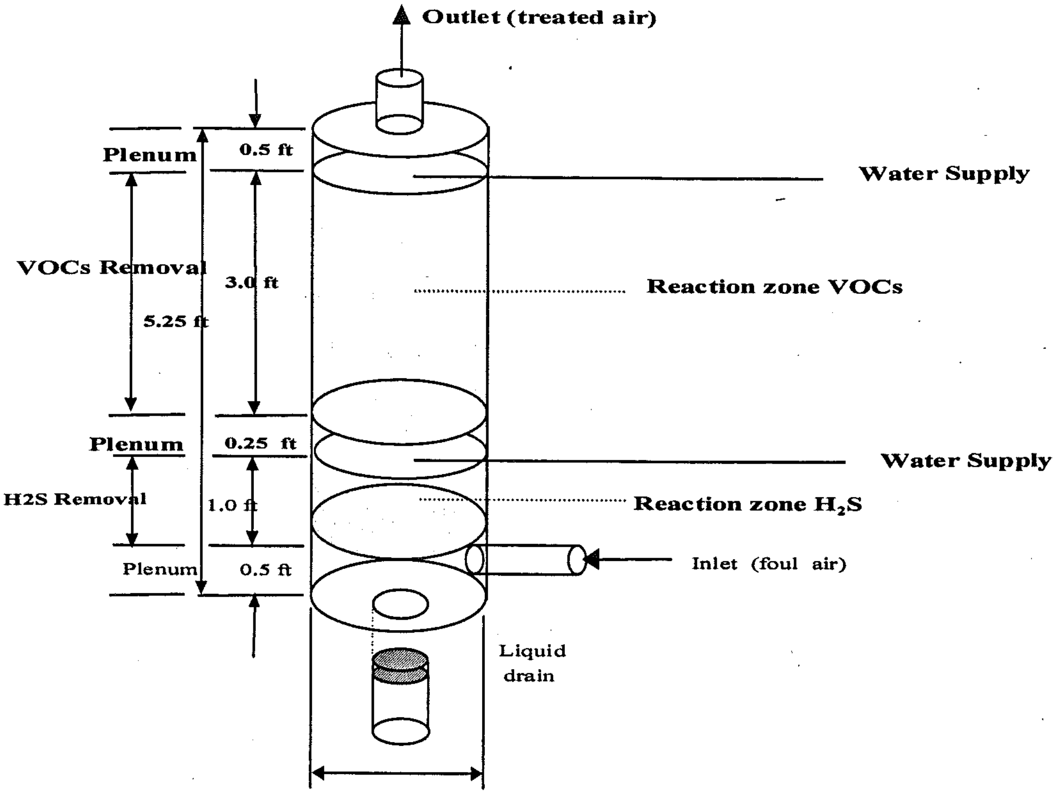


Figure 3. Schematic UC Davis Biofilter at Hyperion Treatment Plant

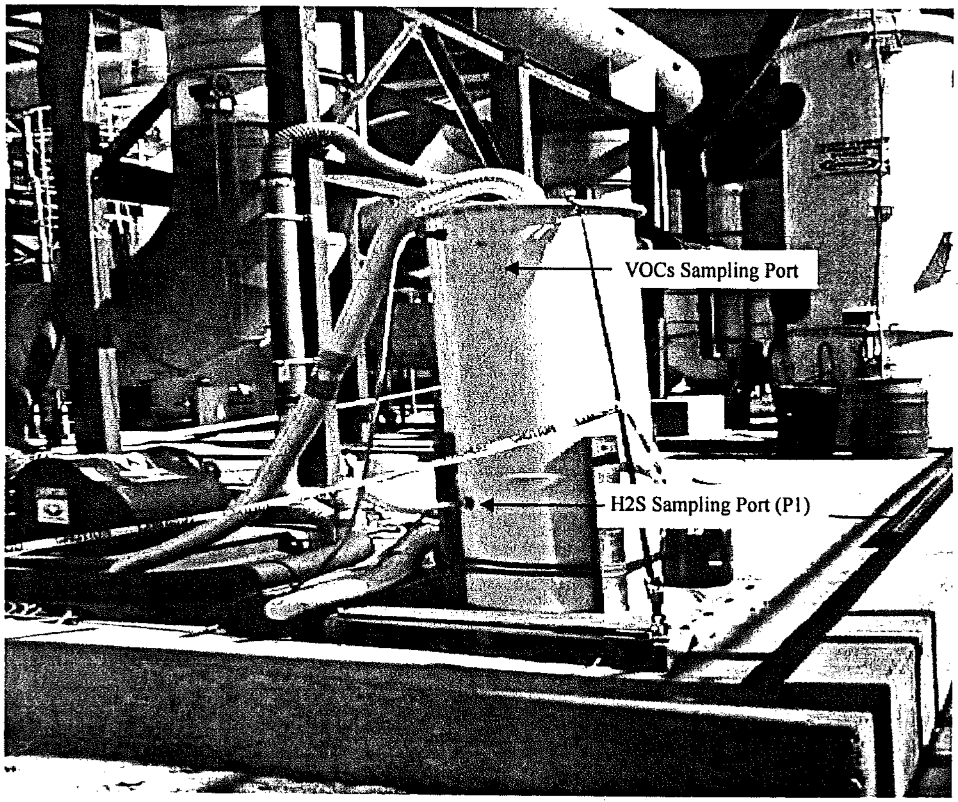


Figure 4. UC Davis Biofilter at Hyperion Treatment Plant

Table 1. Sampling schedule for BTF

Date	Time	H_2S (Pin & Pout)	VOCs (Pin & Pout)
5/1/00, 5/3/00,	7:00 am	2 Reading	X
5/8/00, 5/10/00,	10:00 am	2 Reading	X
5/30/00, 6/2/00	13:00 pm	2 Reading	X
	16:00 pm	2 Reading	X
	19:00 pm	2 Reading	X

Table 2. Sampling Schedule for Biofilter

Date	Time	H_2S (Pin & Pout)	VOCs (Pin & Pout)
5/2/00, 5/4/00,	7:00 am	2 Reading	X
5/9/00, 5/11/00,	10:00 am	2 Reading	X
5/31/00, 6/01/00	13:00 pm	2 Reading	X
	16:00 pm	2 Reading	X
	19:00 pm	2 Reading	X

Table 3. Parameters to be monitored

Compounds	Sampling Method	Analytical Method	Method Det. Limit (MDL)
Hydrogen Sulfide	Jerome Model 621-X	Jerome Model 621-X	3
Halogenated VOCs		EPA Method TO-14	
Methylene Chloride	CARB 422	PID/ELCD	0.5
Chloroform	CARB 422	PID/ELCD	0.5
Carbon Tetrachloride	CARB 422	PID/ELCD	0.5
Vinyl Chloride	CARB 422	PID/ELCD	2.0
1,1-Dichloroethene	CARB 422	PID/ELCD	0.5
Trichloroethene	CARB 422	PID/ELCD	0.5
Perchloroethene	CARB 422	PID/ELCD	0.5
1,2-Dichloroethane	CARB 422	PID/ELCD	0.5
p-Dichlorobenzene	CARB 422	PID/ELCD	0.5
Methyl Chloroform	CARB 422	PID/ELCD	0.5
Non-halogenated VOCs			
Benzene	CARB 422	PID/ELCD	0.5
Toluene	CARB 422	PID/ELCD	1.0
Total Xylenes	CARB 422	PID/ELCD	1.0

* PID –Photoionization Detector, ELCD --- (Electrolyte Conductivity Detector

Hydrogen Sulfide Measurements by Direct-Reading Instrumentation: A real-time ambient H_2S analyzer was used to determine the H_2S concentration in gas streams. A Jerome Instruments gold film analyzer or equivalent with a working range of 0.003 to 50 PPM was used in this evaluation. It is expected that the source concentrations at inlet and outlet of BF and BTF would be within the working range of this instrument. The instruments were calibrated with standard gases with known H_2S concentration.

Volatile Organic Compounds (VOCs) Sampling by CARB Method 422: Gas samples were collected in Tedlar bag in accordance with California Air Resources Board (CARB) Method 422 at each of the sampling points. The list of all VOCs and analytical procedures are shown in Table 3. This method applies to the sampling of gas for GC measurement of VOCs.

Quality Assurance/Quality Control: All applicable quality assurance procedures of the applicable sampling and analytical methods were followed. Approximately 10% of the samples were collected in duplicate. Only new Tedlar bags were used for this project.

4. RESULTS AND DISCUSSION

Data obtained from sampling VOCs and H_2S at both the BF and BTF are summarized in Tables 4 and 5. Both the BF and BTF show high removal efficiency for H_2S. The outlet concentration of H_2S is generally below 1 ppm level, which is in the range of SCAQMD limit for wet scrubbers.

4.1 Biotrickling filter

4.1.1 Hydrogen Sulfide Removal

The most successful aspect of this filter's operation is its removal of hydrogen sulfide. Removal efficiencies near 100% were observed on each day, despite substantial variations in the influent H_2S concentrations from day to day, and during periods of a few hours within the observation days.

4.1.1.1 Long-term Performance

Long-term sampling was done daily over a period of several months. The results are shown in Figure 5. As expected, the inlet concentration of H_2S increased, as the weather became warmer, varying from below 10 ppm near the start of the period to near 50 ppm near the end, with frequent substantial fluctuations from day to day. The average percent removal was around 99%.

4.1.1.2 Short-term Performance

The short-term performance is shown in Figure 6. During May 1, the concentration increased by a factor of around *7.5,* from about 6 ppm to about 45 ppm. Likewise, the lowest influent concentration observed on May 8 was slightly higher than the highest on May 3, the two being respectively slightly above and slightly below 25 ppm. The influent concentrations usually rose during the day, but this did not always happen, and there were many variations around the general pattern. Effluent concentrations were around 1 ppm or less in all measurements, so the removal factors were all at least 95%, and often around 99%.

4.1.2 VOCs Removal

These results were obtained with a culture that had received no treatment to acclimatize it to VOCs. It is possible that some degree of acclimation occurred during the period of the study, but the only hints of acclimation in these data occur for benzene and toluene, and the evidence is weak even for these compounds. Plans, protocols, and progress for additional work on this topic are in Section 6.

4.1.2.1 Short-term Non-halogenated VOCs Removal

As seen in Figures 7a, 7b, and 7c, significant removal efficiencies have been observed for benzene, toluene, and xylenes, but in contrast to the H_2S results this performance has not been consistently maintained. Only at 7 AM on May 30 was the removal efficiency above 90%. Since it was this high for all of these pollutants, the result appears to be real, but the other measurements on this day were below 40%, with a return to efficiencies above 40% on June 2 for benzene and toluene, but not xylenes. On May 1 and May 3, the filter was completely ineffective in removing all of these pollutants, with many measurements indicating slight emissions instead of removal. As seen for H_2S, the influent concentrations were highly variable, ranging from 3 or 4 ppbv to nearly 30 ppbv for benzene, and from around 10 or 15 ppbv up to more than 100 ppbv for toluene and xylenes.

4.1.2.2 Short-term Halogenated VOCs Removal

Figures 8a, 8b, 8c, and 8d show that the results for halogenated VOCs was even less satisfactory. Significant removal efficiencies were observed for dichlorobenzene on May 1 and 3, for tetrachloroethylene at 7 AM on June 2, and for all the halogenated VOCs at 7 AM on May 30. But otherwise the filter was ineffective on these substances, either achieving no detectable removal, or actually appearing to emit them. As seen for the other pollutants, the influent concentrations were highly variable, with methylene chloride, chloroform, and tetrachloroethylene showing intraday variations in which the maximum concentration was double or triple the minimum concentration, with observed values in a range from some tens of ppbv to 100 ppbv or more. Both the absolute quantities and the variation factors were smaller for dichlorobenzene, but it is not clear whether there is any connection with the slightly more favorable removal of this compound.

4.2 Biofilter

4.2.1 Hydrogen Sulfide Removal

The hydrogen sulfide results for this device were very similar to those for the BTF, and show that the BF also removed this pollutant more effectively than any other.

4.2.1.1 Long-term Performance

Long-term sampling was done daily. The results are shown in Figure 9. As for the BTF, the inlet concentration of H_2S was increased, as the weather became warmer, varying from below 10 ppm near the start of the period to near 50 ppm near the end, with frequent substantial fluctuations from day to day. The average percent removal was around 99%.

4.2.1.2 Short-term Performance

Figure 10 shows that, as for the BTF, removal efficiencies were between *95%* and 100% on each day of the short-term performance study, with all effluent concentrations around 1 ppm or less, and many close to 0. Influent concentrations for the days in this data set are similar to those seen for the BTF, ranging from around 10 ppm to around 50 ppm, including a monotonic rise on May 4 from 10 ppm to 50 ppm that is nearly identical to the rise on May 1 in Section 5.1.1.2, and a frequent but variable tendency to rise during the other days.

4.2.2 VOCs Removal

These results were obtained with a culture that had received no treatment to acclimatize it to VOCs. It is possible that some degree of acclimation occurred during the period of the study, but the data for the non-halogenated VOCs suggest a loss of removal effectiveness from early May to the end of the month. Plans, protocols, and progress for additional work on this topic are in Section 6.

4.2.2.1 Short-term Non-halogenated VOCs Removal

A significant difference from the BTF emerges from the measurements on non-halogenated VOCs, shown in Figures 11a. 11 b, and 11c. On May 2 and 4, the BF achieved removal efficiencies of *75%* or more for benzene and toluene, with many removals near 100%. For xylenes, the removals were lower but still significant on May 2, and the majority were close to 100% on May 4. The removals for all of these pollutants were much worse and more variable, on May 31 and June 2, all being below 75% and the worst for the xylenes being below 20%. The minimum removal for benzene and toluene were both around 35% or more, so that significant removals were still occurring, but the performance on these days was much less outstanding.

4.2.2.2 Short-term Halogenated VOCs Removal

Figures 12a, 12b, 12c, and 12d show that significant removal efficiencies were observed on some days for dichlorobenzene and methylene chloride, but no removal occurred on any day for tetrachloroethylene or chloroform. Furthermore, only for dichlorobenzene were the removal even moderately reliable, with removals of more than 20% observed on May 2 and 4 and June 1, but none on May 31. Significant removals of methylene chloride occurred only at 10 AM on May 2 and 1 PM on May 4. These observations confirm and extend the impression from the BTF in Section 4.1.2.2 that these types of devices, at least with their indigenous cultures, remove dichlorobenzene more effectively than other halogenated VOCs.

Table 4. Biotrickling Filter Performance

Hydrogen Sulfide (H_2S) (ppmv)				
	Date	Inlet (mean ± std. Dev.)	Outlet (mean ± std. dev.)	Removal Efficiency
	(4/00-9/00) (daily)	26 ± 7	0.56 ± 0.43	97 ± 3
	(1/5/00-2/6/00) (4 times/day)	25 ± 7	0.40 ± 0.30	98 ± 1
Volatile Organic Compounds (VOCs) (ppbv)				
Benzene	(1/5/00-2/6/00) (4 times/day)	10 ± 6	7 ± 4	19 ± 29
Toluene		65 ± 36	55 ± 42	20 ± 35
Xylenes		53 ± 33	53 ± 35	4 ± 27
p-Dichlorobenzene		10 ± 4	11 ± 4	19 ± 39
Meyhylene Chloride		33 ± 22	33 ± 23	2 ± 21
Chloroform		63 ± 17	61 ± 21	3 ± 20
Tetrachloroethylene		68 ± 35	67 ± 38	5 ± 21

Table 5. Biofilter Performance

Hydrogen Sulfide (H_2S) (ppmv)				
	Date	Inlet (mean ± std. dev.)	Outlet (mean ± std. dev.)	Removal Efficiency
	(4/00-9/4) (Daily)	22 ± 7	0.06 ± 0.09	100 ± 1
	(1/5/00-2/6/00) (4 times/day)	26 ± 8	0.37 ± 0.33	98 ± 1
Volatile Organic Compounds (VOCs) (ppbv)				
Benzene	(1/5/00-2/6/00) (4 times/day)	8 ± 3	2 ± 2	74 ± 23
Toluene		68 ± 18	12 ± 10	79 ± 20
Xylenes		69 ± 35	31 ± 21	56 ± 28
p-Dichlorobenzene		14 ± 4	11 ± 4	18 ± 17
Meyhylene Chloride		42 ± 27	38 ± 24	5 ± 21
Chloroform		74 ± 19	74 ± 19	0 ± 4
Tetrachloroethylene		79 ± 24	80 ± 24	2 ± 2

Figure 5. H_2S Removal, Long Term Performance, Biotrickling Filter (4-9/00)

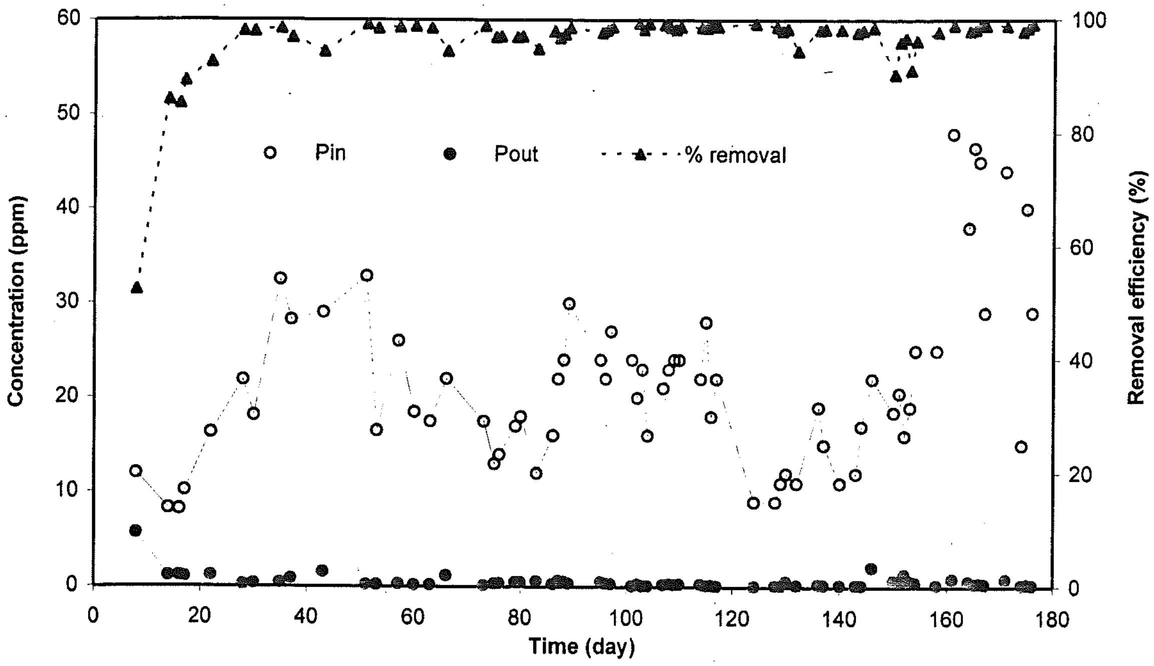


Figure 6. H_2S Removal, Short Term Performance, Biotrickling Filter

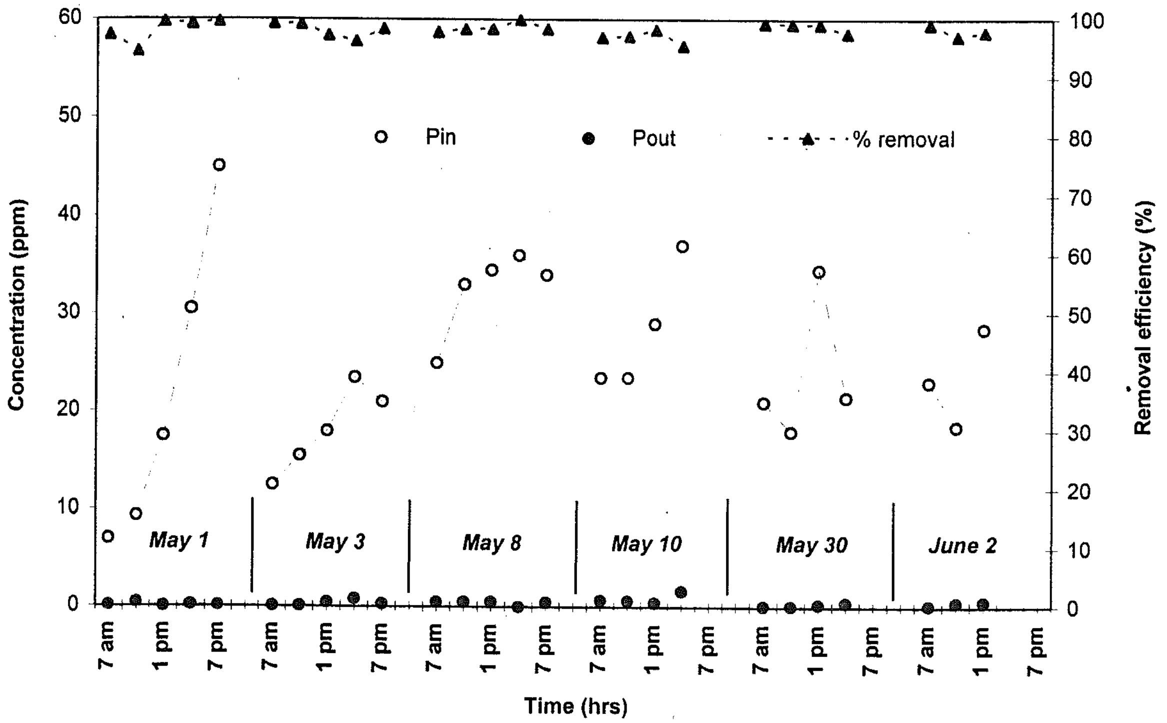


Figure 7a. VOC Removal (Benzene), Baseline, Biotrickling Filter

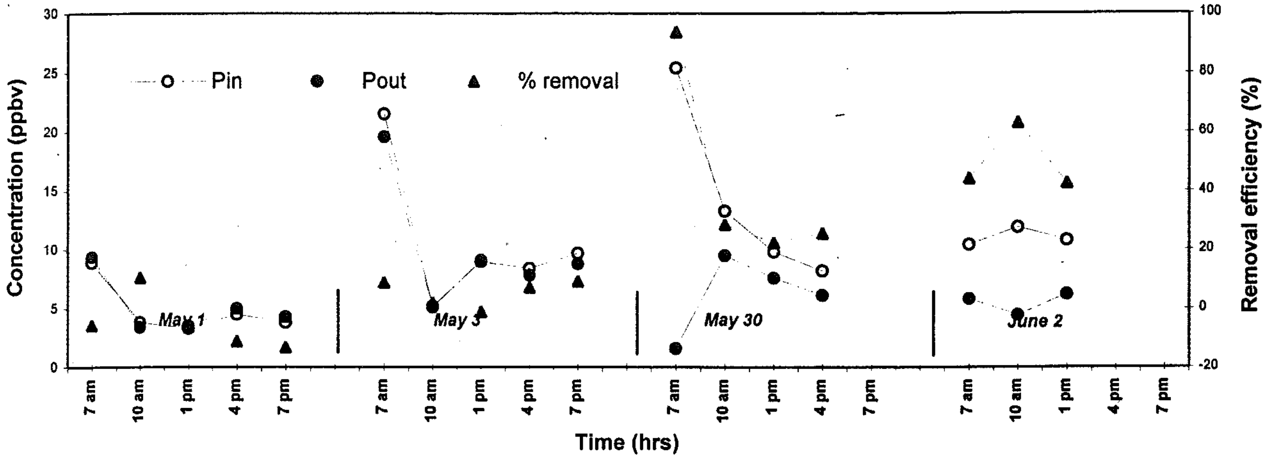


Figure 7b. VOC Removal (Toluene), Baseline, Biotrickling Filter

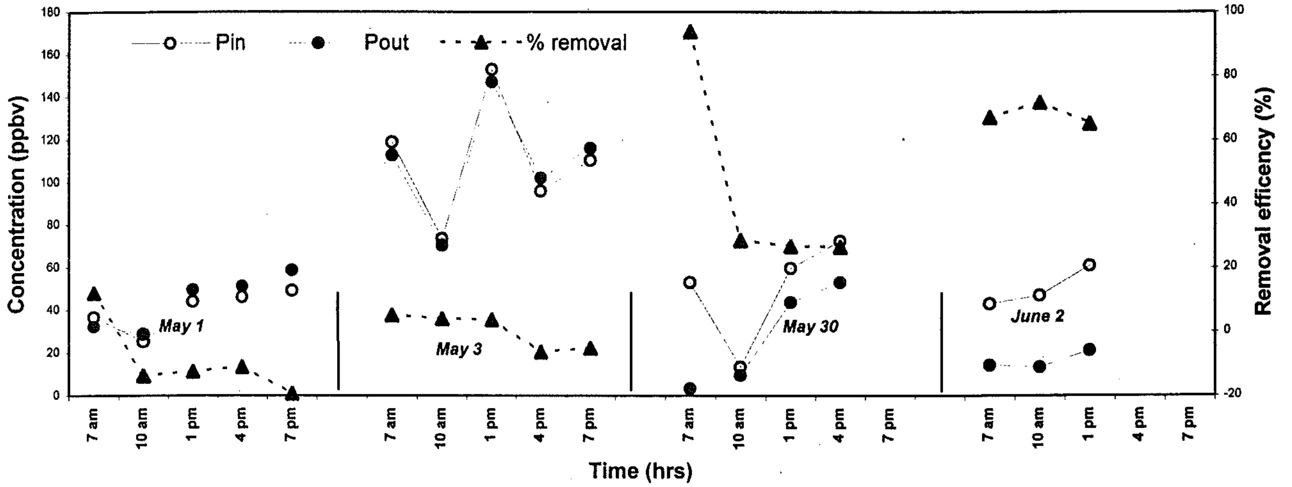


Figure 7c. VOC Removal (Total Xylenes), Baseline, Biotrickling Filter

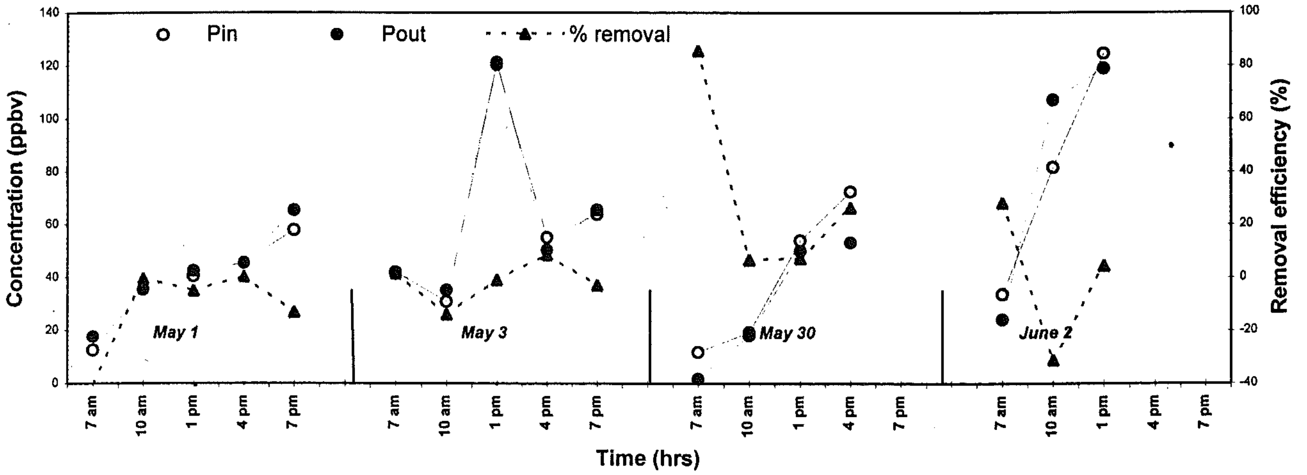


Figure 8a. VOC Removal (Dichlorobenzene), Baseline, Biotrickling Filter

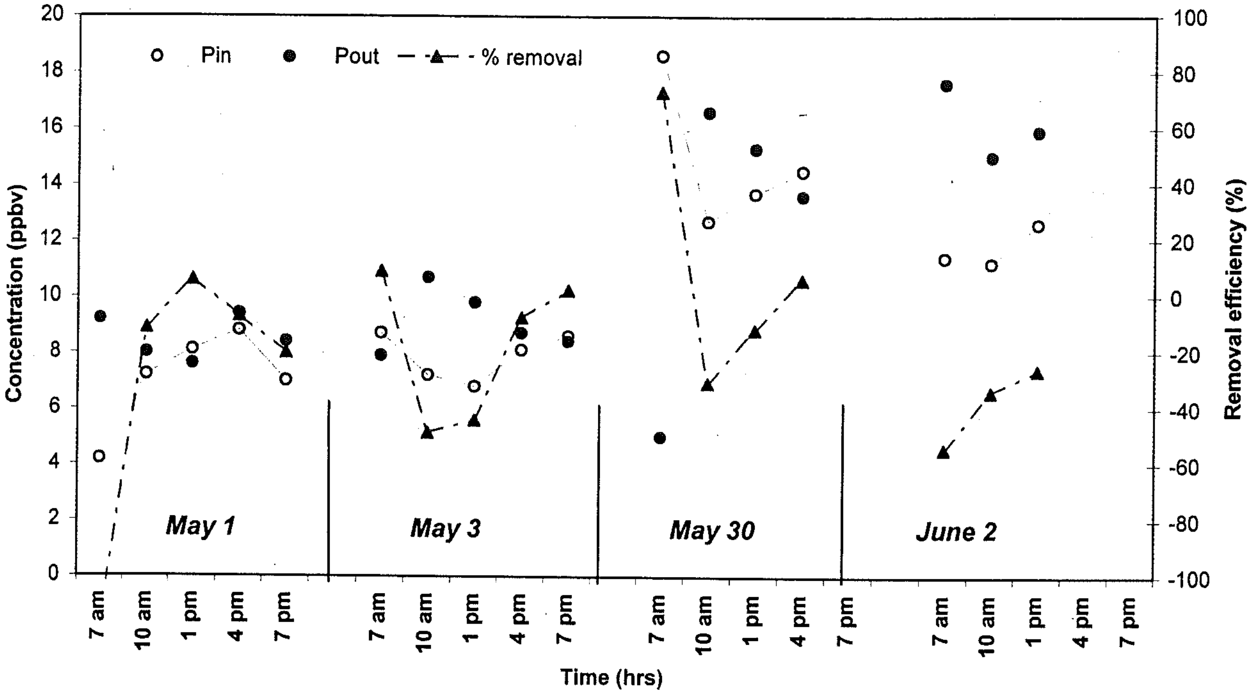


Figure 8b. VOC Removal (Methylene Chloride), Baseline, Biotrickling Filter

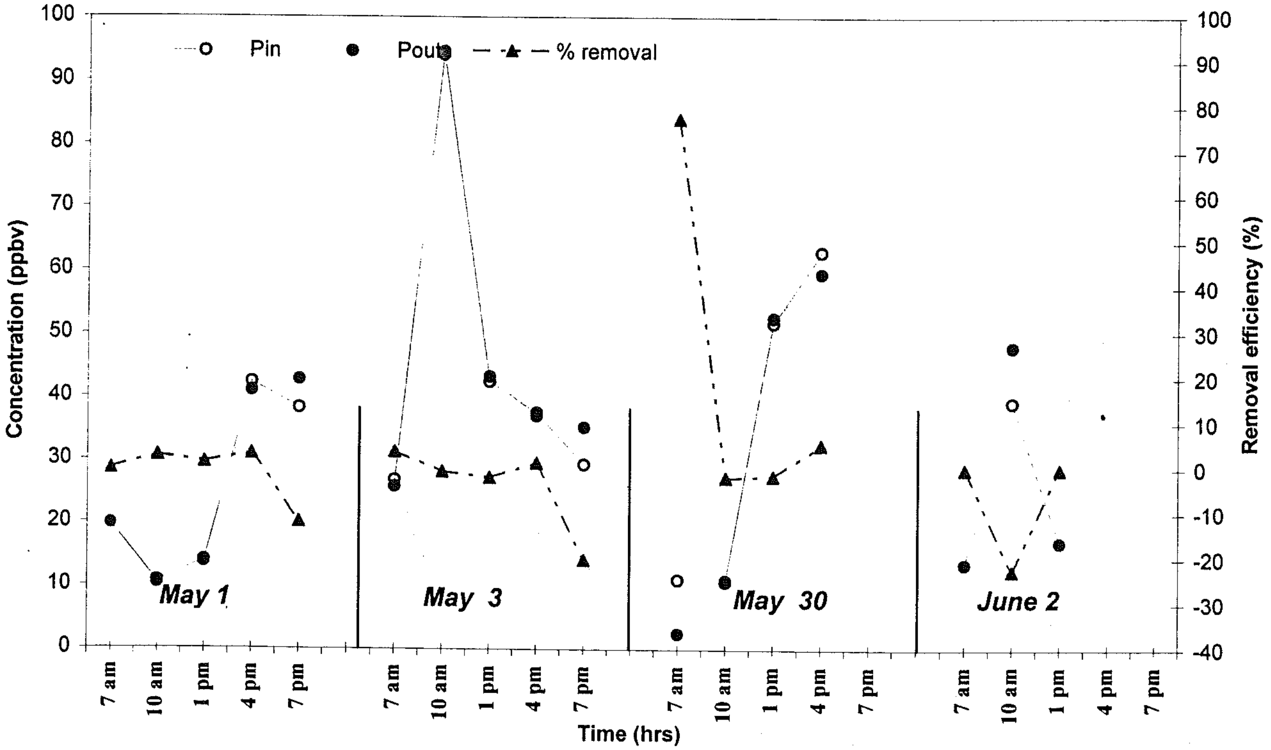


Figure 8c. VOC Removal (Chloroform), Baseline, Biotrickling Filter

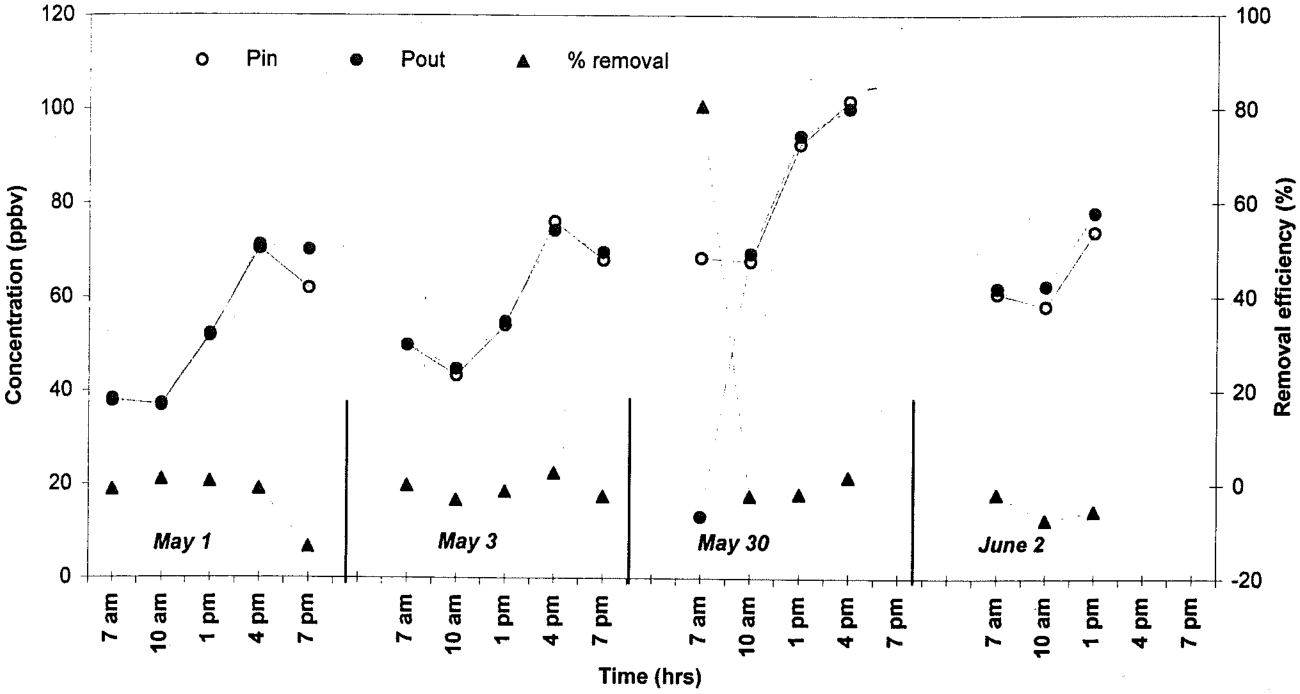


Figure 8d. VOC Removal (Tetrachloroethylene), Baseline, Biotrickling Filter

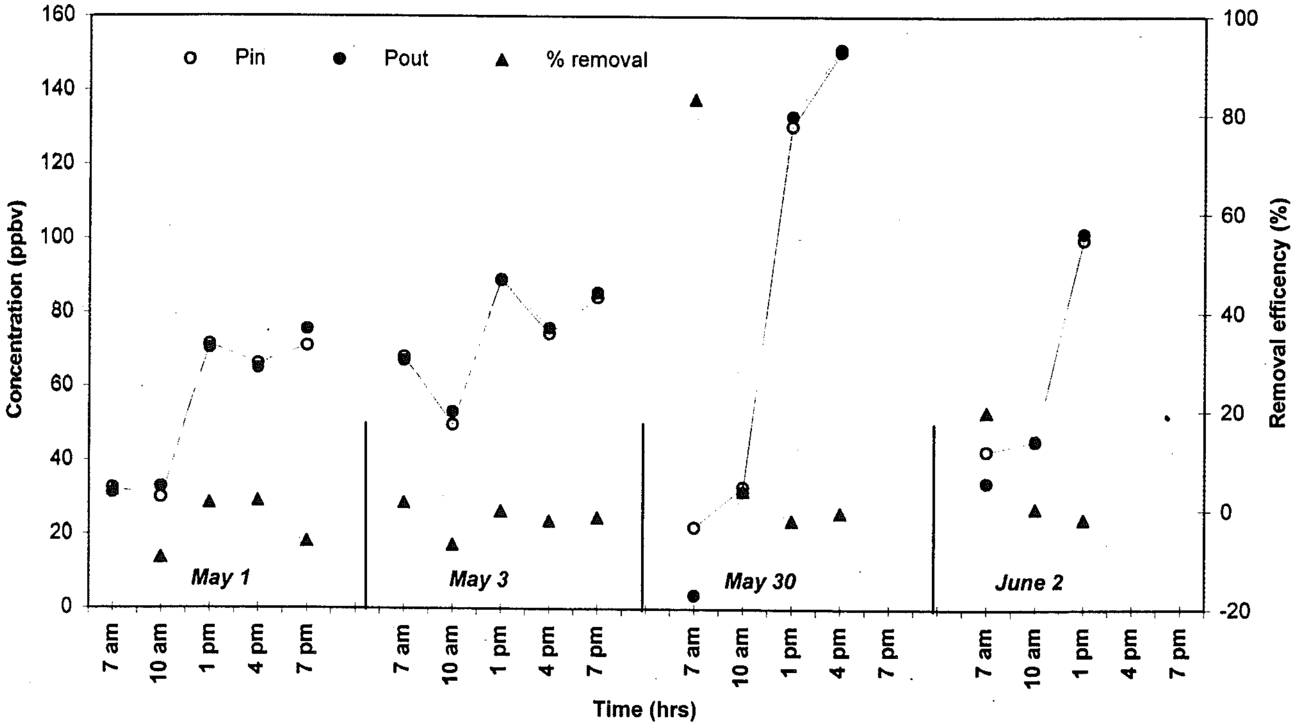


Figure 9. H_2S Removal, Long Term Performance, Biofilter (4-9/00)

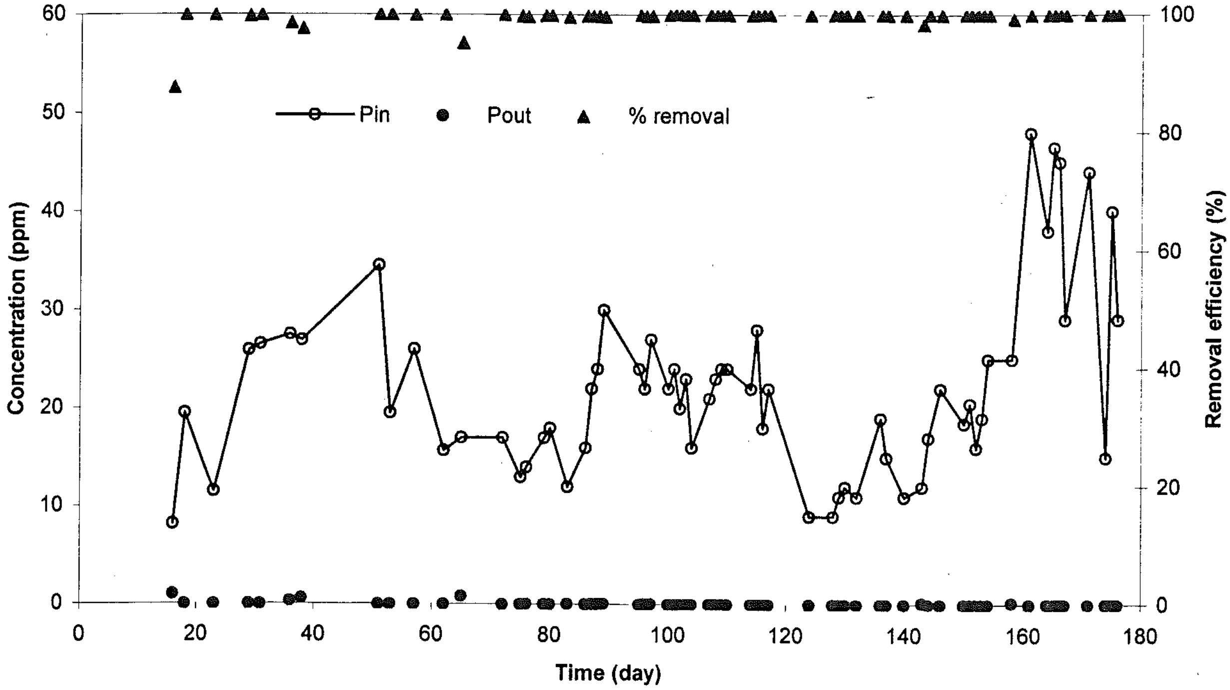


Figure 10. H_2S Removal, Short Term Performance, Biofilter

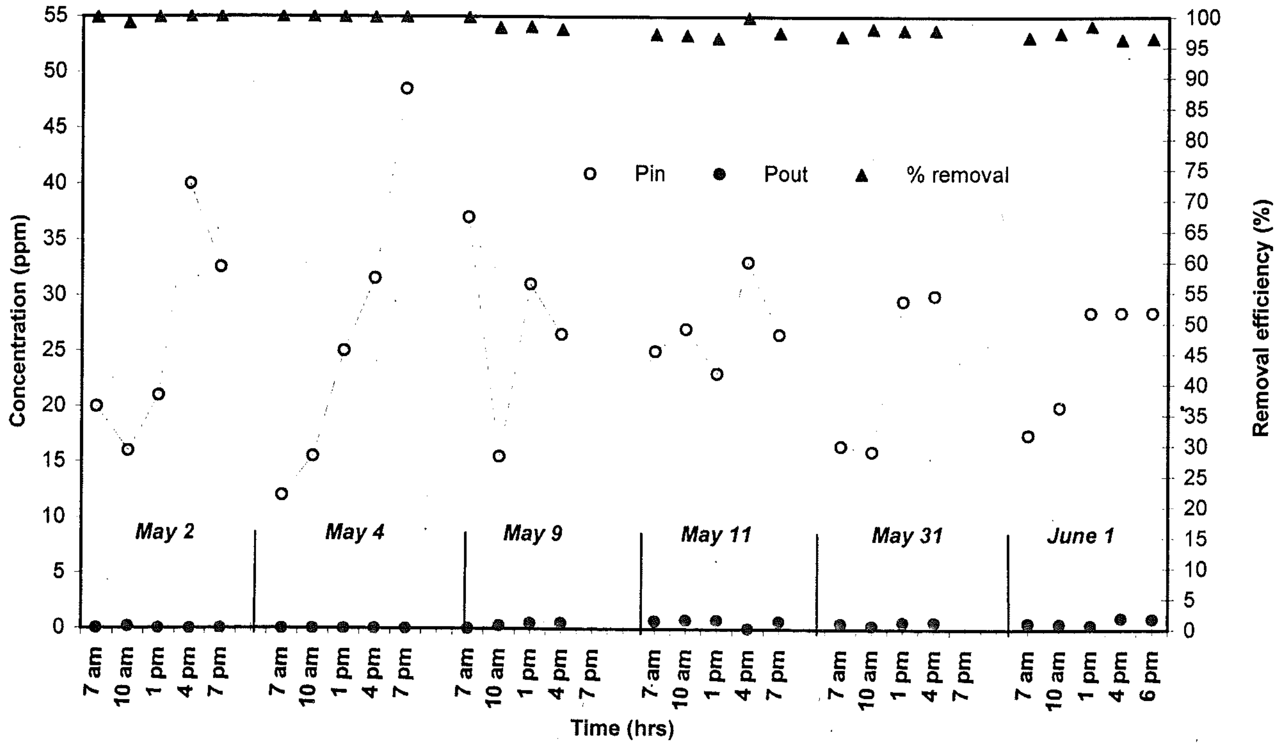


Figure 11a. VOC Removal (Benzene), Baseline, Biofilter

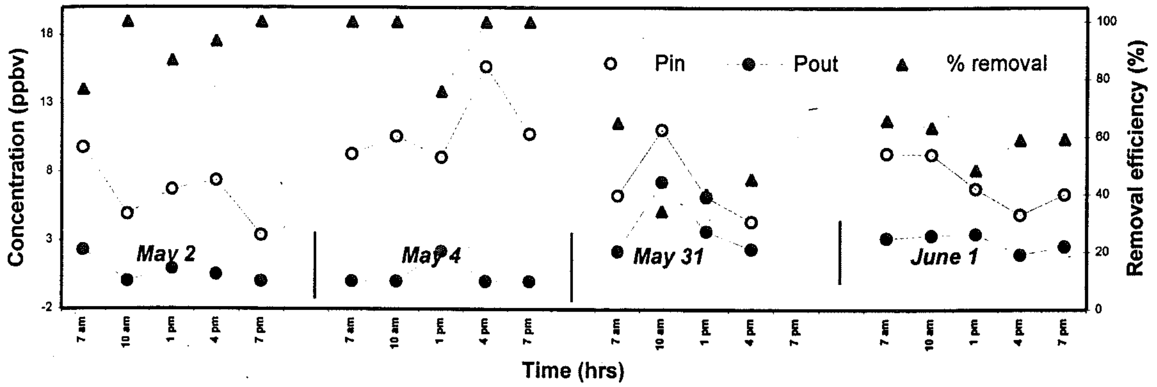


Figure 11b. VOC Removal (Toluene), Baseline, Biofilter

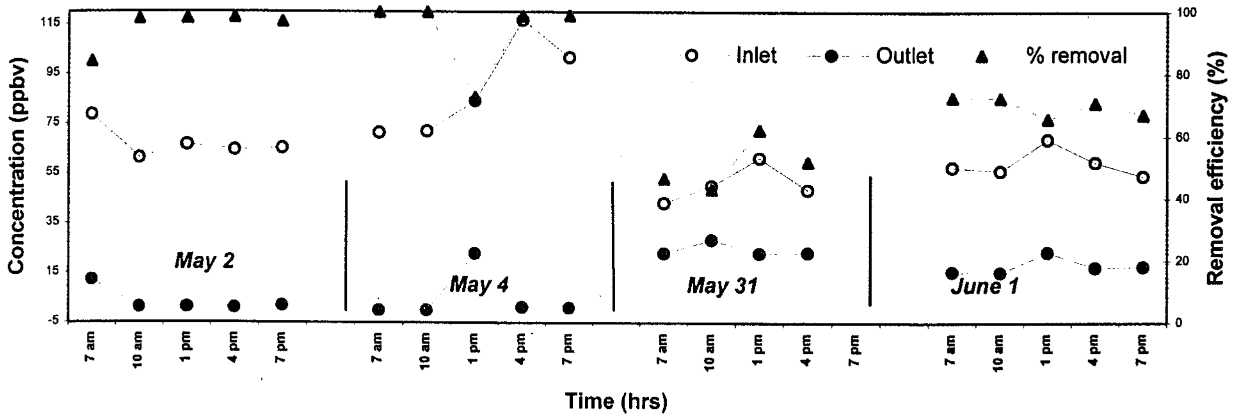


Figure 11c. VOC Removal (Total Xylenes), Baseline, Biofilter

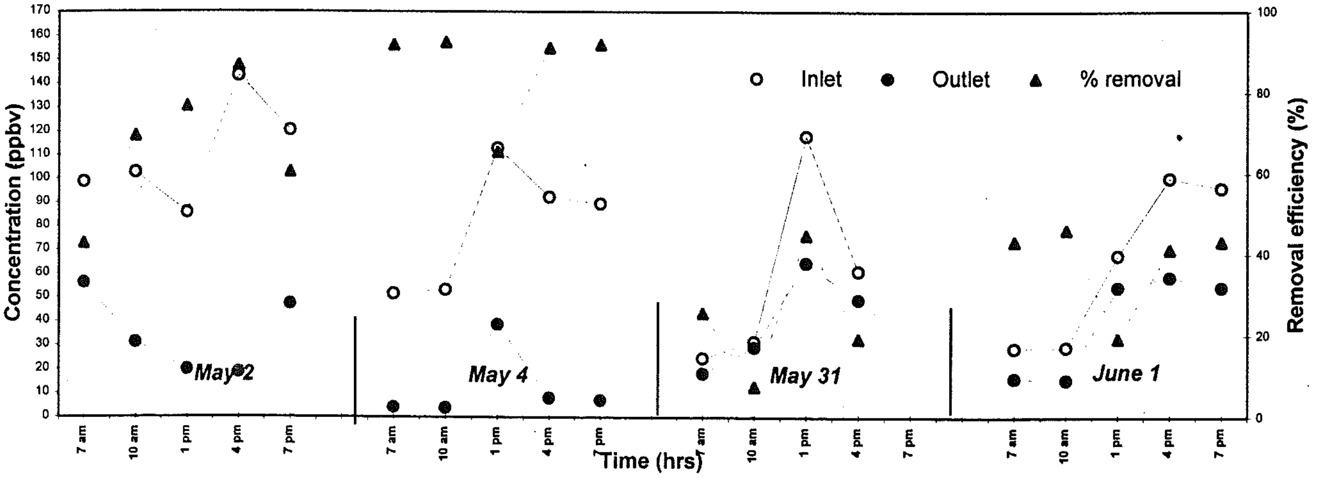


Figure 12a. VOC Removal (Dichlorobenzene), Baseline, Biofilter

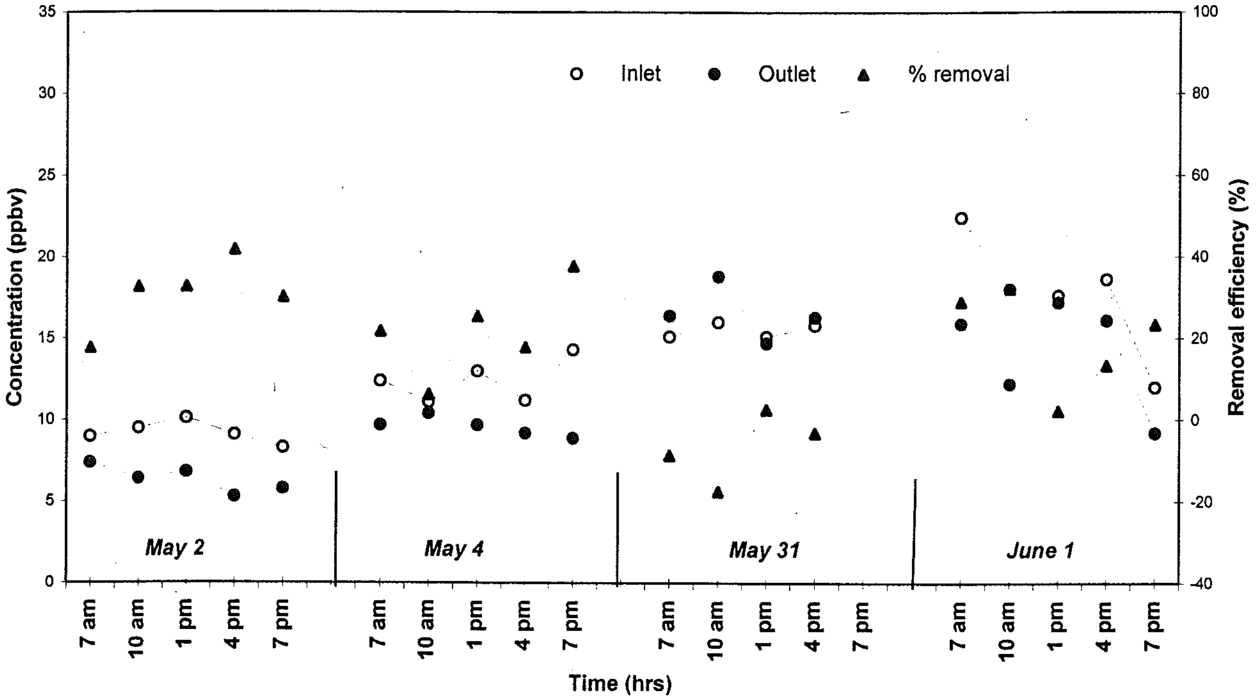


Figure 12b. VOC Removal (Methylene Chloride), Baseline, Biofilter

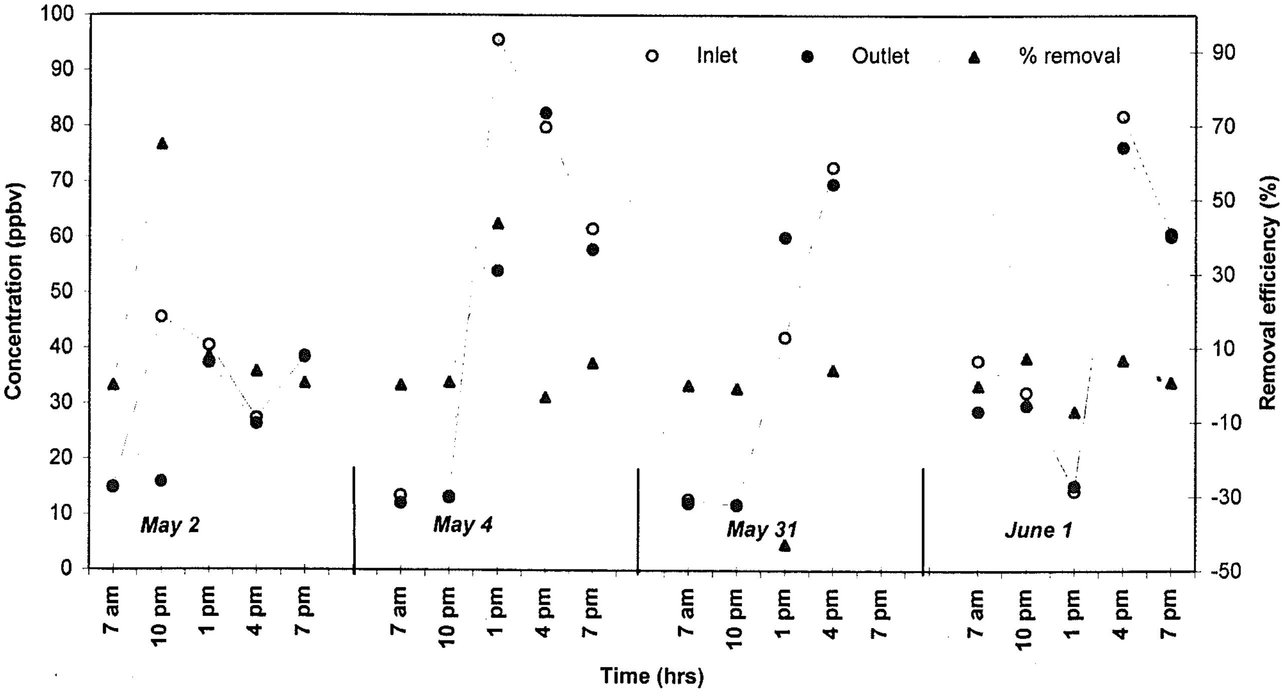


Figure 12c. VOC Removal (Chloroform), Baseline, Biofilter

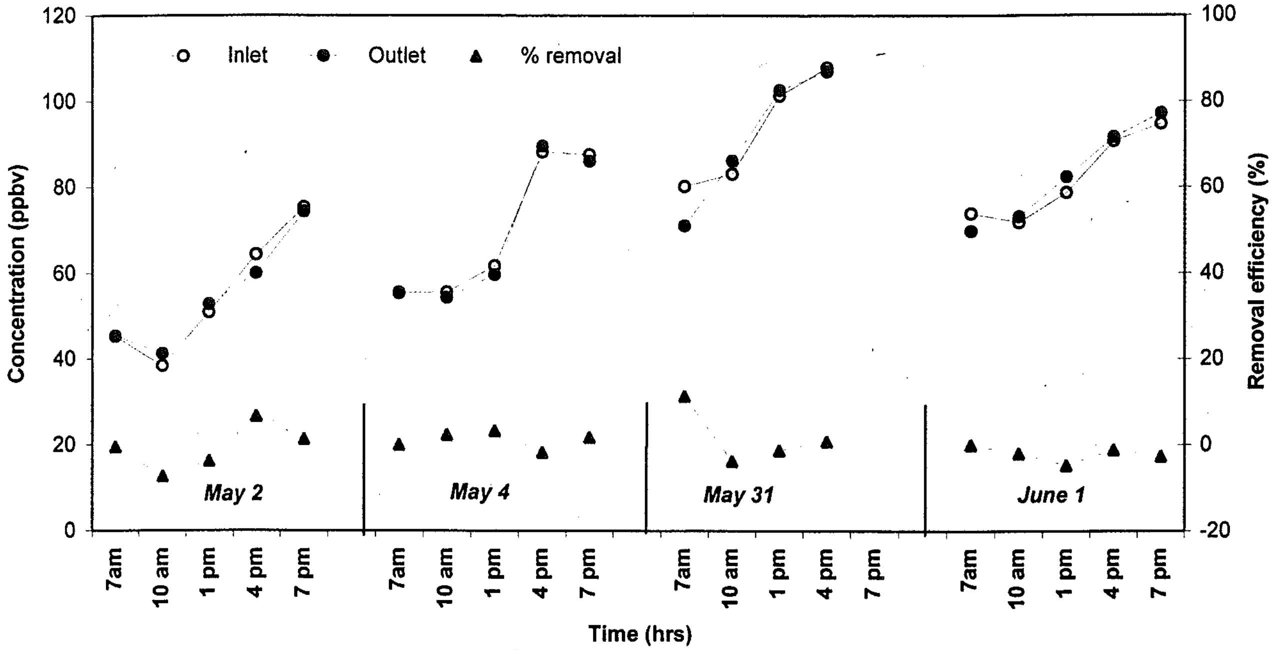
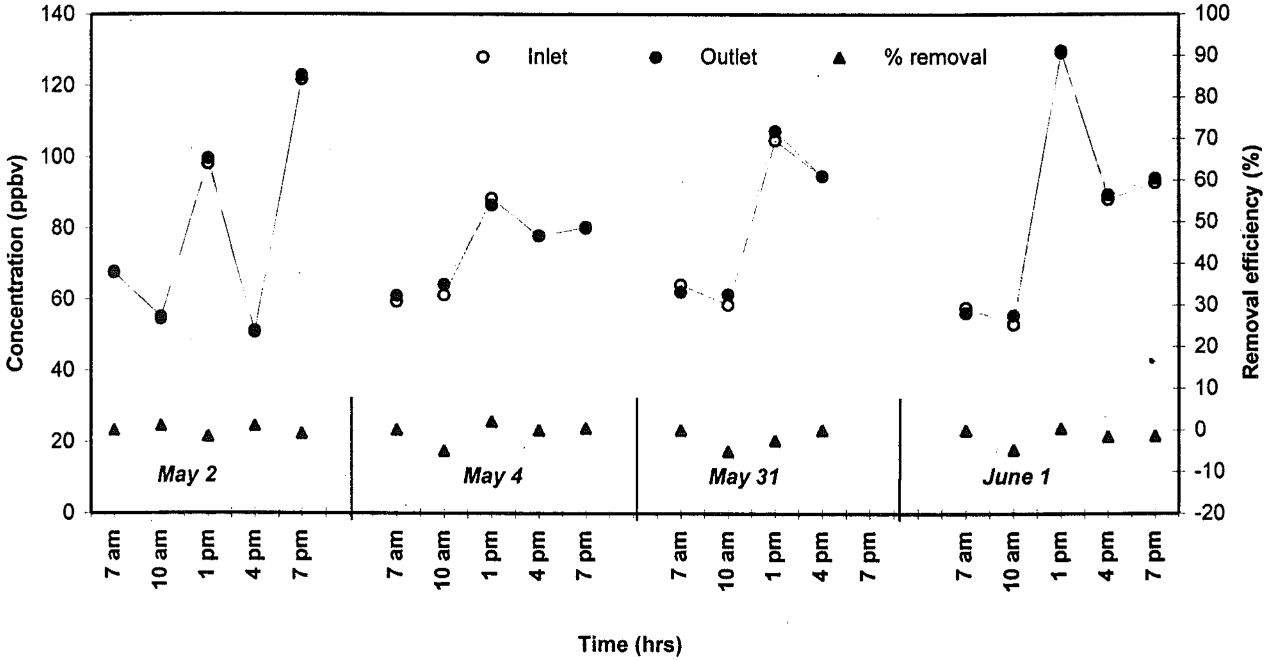


Figure 12d. VOC Removal (Tetrachloroethylene), Baseline, Biofilter



5. CONCLUSION

- After 6 months after start up the BF and BTF showed high percent removal of H_2S, 99 and 98 percent, respectively.
- The outlet concentration of H_2S is generally below 1-ppm level, which is in the range of SCAQMD limit for wet scrubbers.
- For the BF, the percent removal efficiency of non-halogenated VOCs is excellent with an average value of 88 percent.
- For the BTF, the percent removal efficiency for non-halogenated VOCs is poor due to low pH. The optimal pH of VOCs removal by heterotrophic microorganisms is, in general, near neutral.
- The percent removal for chlorinated hydrocarbons such as methylene chloride is very poor in both systems.
- Several halogenated and non-halogenated VOCs had very low or below detection limit concentrations in influent flow. The concentrations of these compounds are not reported.
- Removal of VOCs in BF takes place simultaneous with H_2S removal. VOC removal efficiencies probably depend on the biodegradability, concentration and water solubility of the VOC. In general, easily biodegradable, non-halogenated VOCs such as toluene and benzene are removed at efficiencies of 50-100%. Removal of halogenated VOCs (e.g., methylene chloride and trichloroethylene) is more difficult to achieve and removal efficiencies are in general between 0-50%. It should be noted that BF at POTWs are in general optimized for H_2S removal. VOC removal may be improved by increasing the gas residence and/or better control of pH.
- Various reports indicate that BTF and BF offer great savings compared to e.g. chemical scrubbers while showing comparable performance with respect to H_2S removal and better performance with respect to VOC removal. Reduction of overall costs of up to 50% is a general though realistic estimate, depending on the stability of the selected packing material and the required frequency of packing replacement.

6. FUTURE PLANS

The following outlined items will be investigated in the near future:

As shown and discussed in this report, the main focus of the research was on removal of H_2S from the Headworks' foul air (proof of concept). Both the BF and the BTF remove H_2S at near 100 percent efficiency at gas residence times of ~20 seconds. In the near future, experiments will be performed to optimize reactor operation and to stimulate the removal of halogenated and non-halogenated VOCs specifically for both systems.

1. Variation of the gas flow rate and H_2S concentration to determine the highest gas flow rate and the highest H_2S concentration at which the removal efficiency is still 100 %. These data are required for scale-up design to treat the total airflow from Headworks.
2. Stimulation of VOCs removal. To both systems specific bacteria will be added that are specialized in VOCs removal. Over a 3-week period, the concentration of 5 selected VOCs will artificially be increased to accelerate adaptation to and removal of VOCs. This experiment will demonstrate the feasibility of both systems for combined removal of H_2S and VOCs.
3. A detailed examination/analysis of the outlet air for removal of H_2S and selected VOCs as well as organic sulfur compounds and odor reduction (UCR). This experiment will relate H_2S and VOCs removal in the systems with overall odor reduction. Characterization of the odors may provide further information of the pollutants whose presence is the most critical for odor nuisance.
4. Optimization of the operation of both systems with respect to pH control, water flow, temperature, and nutrients. These data are required to determine the most cost-effective operation. Protocols for future study are attached in Appendix IV.

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APPENDIX I

ACRONYMS

Appendix I

ACRONYMS

BF	BIOFILTER
BTF	BIOTRICKLING FILTER
BTEX	BENZENE TOLUENE ETHYL XYLENE
CARB	CALIFORNIA AIR RESOURCE BOARD
DMS	DIMETHYL SULFIDE
DMDS	DIMETHYL DISULFIDE
EPA	ENVIRONMENT PROTECTION AGENCY
ELCD	ELECTROLYTE CONDUCTIVITY DETECTOR
FCAAA	FEDERAL CLEAN AIR ACT AMENDMENTS
GAC	GRANULATED ACTIVATED CARBON
GC	GAS CHROMATOGRAPHY
HTP	HYPERION TREATMENT PLANT
HP	HORSE POWER
HPE	HIGH PRESSURE EFFLUENT
HPOAS	HIGH PURITY OXYGEN ACTIVATED SYSTEM
MACT	MAXIMUM ACHIEVABLE CONTROL TECHNOLOGY
MDL	METHOD DETECTION LIMIT
MGD	MILLION GALLON PER DAY
MM	METHYL MERCAPTAN
NSR	NEW SOURCE REVIEW
PID	PHOTO IONIZATION DETECTION
POTWs	PUBLICLY OWNED TREATMENT WORKS
PVC	POLY VINYL CHLORIDE
PPM	PARTS PER MILLION
PPB	PARTS PER BILLION
SCAB	SOUTHERN CALIFORNIA AIR BASIN
SCAQMD	SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT
SCFM	STANDARD CUBIC FEET PER MINUTE
UCR	UNIVERSITY OF CALIFORNIA, RIVERSIDE
UCD	UNIVERSITY OF CALIFORNIA, DAVIS
VOCs	VOLATILE ORGANIC COMPOUNDS
WERF	WATER ENVIRONMENT RESEARCH FOUNDATION

APPENDIX II

MAINTENANCE DATA OF BIOTRICKLING FILTER & BIOFILTER

Appendix II

Table 6 Records of Biotrickling filter (UC Riverside)

Date	Time	BTF - HPE Tank		PH	H2S Concentration		Caustic tank (Gals.)	Comments
		Initial (Gals.)	Final (Gals.)		Inlet (ppm)	Outlet (ppm)		
6/6/00	7:30am	140	210	8.02	—	—	—	
6/7/00	7.30am	155	---	7.99	22	1.2	75	Fixed all inlet/outlet airhose
6/8/00	7:30am	105	220	8.96	21	1.4	210	Caustic tank fillup by Hub (UCR)
6/12/00	7:30am	25	200	7.14	18	0.6	200	Very hot day
6/13/00	7:30am	150	200	7.49	15	0.089	190	Very hot day - 90 to 99 deg. at beach
6/14/00	7:30am	160	---	7.19	18	0.83	185	Little claudy but hot afternoon
6/15/00	7:30am	115	215	7.62	13	0.39	181	Little cloudy but hot afternoon
6/16/00	7:30am	185	215	7.05	14	0.4	180	
6/19/00	7:30am	107	210	8.55	17	0.51	175	
6/20/00	7:30am	175	---	8.43	18	0.51	174	
6/23/00	7:30am	105	220	7.53	12	0.61	160	2 to 3 days no site inspection
6/26/00	7:30am	110	220	7.31	16	0.31	140	
6/27/00	7:30am	180	—	7.13	22	0.69	125	Slight Fog in morning, sunny Afternoon
6/28/00	8:30am	150	210	7.3	24	0.59	125	
6/29/00	7:30am	180	220	7.37	30	0.39	110	
7/5/00	7:30am	115	220	1.74	24	0.53	60	PH & Caustic tank level very low
7/6/00	6:50am	180	---	1.7	22	0.39	55	Dr Hub filled caustic tank
7/7/00	7:30am	125	220	8.63	27	0.33	175	Clean all small tubes/hose
7/10/00	11:30am	10	127	8.14	22	22	175	Water tank was empty
7/11/00	7:30am	100	220	7.7	24	0.13	174	Recycle water pump leaks into Caustic tank
7/12/00	7:30am	180	----	8.18	20	0.33	190	Caustic tank level high,
7/13/00	7:30am	135	220	8.14	23	0.13	220	Dr. Hub not able to fix water leaks.
7/14/00	7:30am	---	---	6.9	16	0.13		Drainage Analysis - pH 6.83, Sulfate 13900 mg/l
7/17/00	7:30am	5	220	6.7	21	0.26	200	Water tank completely empty, No leaks
7/18/00	7:30am	155	220	6.84	23	0.38	190	
7/19/00	7:30am	155	220	7.02	24	0.27	190	
7/20/00	7:30am	150	220	7.18	24	0.32	180	
7/24/00	7:30am	5	220	6.8	22	0.29	125	Water tank Completely empty
7/25/00	7:30am	155	---	6.78	28	0.17	120	
7/26/00	7:30am	95	220	6.74	18	0.19	55	Caustic tank level low
7/27/00	7:30am	150	220	7.05	22	0.12	20	
7/31/00	7:30am	50	220	8.68	10	*	215	Caustic tank filled by Dr Hub
8/1/00	7:30am	150	220	6.73	16	*	205	
8/2/00	8:30am	150	220	7.1	10	*	203	
8/3/00	9:45am	150	220	7.58	9	0.109	190	Use APC-HTP Gerome Meter
8/7/00	7:30am	45	220	6.64	9	0.17	175	
8/8/00	7:30am	155	220	6.69	11	0.16	165	
8/9/00	7:30am	150	220	6.99	12	0.65	155	
8/11/00	7:30am	87	220	6.92	11	0.19	137	
8/14/00	8:30am	50	220	7.04	19	0.29	100	
8/15/00	11:30am	150	220	6.98	15	0.25	85	
8/16/00	11:00am	150	220	6.9	15	*	70	
8/17/00	8:00am	175	220	2.31	23	*	50	
8/18/00	7:40am	150	220	2.11	11	0.24	30	
8/21/00	7:30am	30	220	2.1	12	0.21	200	Dr Hub fillup Caustic tank 8/18/00
8/22/00	7:45am	150	220	6.84	17	0.22	185	
8/24/00	7:15am	200	220	8.34	22	2.1	180	Power off for filter upon arrival
8/28/00	7:15am	25	220	8.18	18.5	0.71	170	
8/29/00	1:25pm	150	220		20.5	0.64	155	pH meter was off
8/30/00	7:45am	220	220	2.69	16	1.4	155	Power was off for BTF
8/31/00	7:30am	150	220	2.01	19	0.69	150	
9/1/00	8:15am	140	220	6.68	25	0.52	110	
9/5/00	7:30am	20	220	7.61	25	0.23	25	Caustic/Water tank were empty
9/8/00	7:30am	50	220	9.31	48	0.92	130	Inlet conc. Very high
9/11/00	7:30am	50	220	9.1	38	0.63	150	
9/12/00	7:10am	170	220	8.5	46.5	0.3	165	
9/13/00	8:00am	170	220	8	45	0.4	160	
9/14/00	7:30am	175	180	7.25	29	0.29	125	
9/18/00	7:30am	50	220	2.23	44	0.89	50	
9/21/00	7:30am	80	220	9.39	15	0.21	173	Dr Hub fillup caustic tank
9/22/00	7:30am	165	220	9.1	40	0.29	165	
9/26/00	7:30am	5	220	1.71	29	0.21	155	Water level & pH very low

* Influent data for these days were not included in graph

Appendix II

Table 7 Records of Biofilter (UC Davis)

Date	Time	H2S Concentration		Comments
		Inlet (ppm)	Outlet (ppm)	
6/6/00	7:30am	---	---	Spray system - Melnor (model 3025)
6/7/00	7.30am	22	0	Fixed all inlet/outlet airhose
6/8/00	7:30am	21	0	
6/12/00	7:30am	18	0.01	Very hot day
6/13/00	7:30am	15	0	Very hot day - 90 to 99 deg. at beach
6/14/00	7:30am	18	0.106	Little claudy but hot afternoon
6/15/00	7:30am	13	0.032	Little cloudy but hot afternoon
6/16/00	7:30am	14	0.05	
6/19/00	7:30am	17	0.03	
6/20/00	7:30am	18	0.025	
6/23/00	7:30am	12	0.055	2 to 3 days no site inspection
6/26/00	7:30am	16	0.036	
6/27/00	7:30am	22	0.06	Slight Fog in morning, sunny Afternoon
6/28/00	8:30am	24	0.05	Bret open BF for cleanup
6/29/00	7:30am	30	0.11	
7/5/00	7:30am	24	0.016	
7/6/00	6:50am	22	0.06	
7/7/00	7:30am	27	0.061	Clean all small tubes/hose
7/10/00	11:30am	22	0	
7/11/00	7:30am	24	0	
7/12/00	7:30am	20	0.002	Drainage Analysis - pH 2.19, Sulfate 4950 mg/l
7/13/00	7:30am	23	0	
7/14/00	7:30am	16	0.012	
7/17/00	7:30am	21	0.001	
7/18/00	7:30am	23	0	
7/19/00	7:30am	24	0	
7/20/00	7:30am	24	0.009	
7/24/00	7:30am	22	0.009	
7/25/00	7:30am	28	0.002	
7/26/00	7:30am	18	0.003	
7/27/00	7:30am	22	0	
7/31/00	7:30am	10	0	
8/1/00	7:30am	16	0	
8/2/00	8:30am	10	0	
8/3/00	9:45am	9	0	Use APC-HTP Gerome Meter
8/7/00	7:30am	9	0	
8/8/00	7:30am	11	0.002	
8/9/00	7:30am	12	0.002	
8/11/00	7:30am	11	0.001	
8/14/00	8:30am	19	0.002	
8/15/00	11:30am	15	0.009	
8/16/00	11:00am	29	0.003	UCD inject H2S inlet
8/17/00	8:00am	32	0	UCD inject H2S inlet, Velocity flow meter=0.67 m/s
8/18/00	7:40am	11	0.006	BF outlet 2 ft from bottom = 0.033
8/21/00	7:30am	12	0.2	
8/22/00	7:45am	17	0.004	
8/24/00	7:15am	22	0.015	Power off for filter upon arrival
8/28/00	7:15am	18.5	0.004	
8/29/00	1:25pm	20.5	0.004	
8/30/00	7:45am	16	0.006	Power off for filter upon arrival
8/31/00	7:30am	19	0.006	
9/1/00	8:15am	25	0.007	
9/5/00	7:30am	25	0.19	
9/8/00	7:30am	48	0.015	Inlet conc. Very high
9/11/00	7:30am	38	0.019	
9/12/00	7:10am	46.5	0.02	
9/13/00	8:00am	45	0.019	
9/14/00	7:30am	29	0.009	
9/18/00	7:30am	44	0.009	
9/21/00	7:30am	15	0.012	
9/22/00	7:30am	40	0.004	
9/26/00	7:30am	29	0.003	

APPENDIX III

PROTOCOLS FOR FUTURE STUDY (Distributed in September, 2000)

FORM GEN. 160 (Rev. 6-80)

REVISED

CITY OF LOS ANGELES

INTER-DEPARTMENTAL CORRESPONDENCE

DATE: September 19, 2000

TO: DISTRIBUTION

FROM: Rosann Paracuelles / Dariush Vosooghi / Reza Iranpour (WESD, Applied Research)

SUBJECT: **ADDITIONAL EXPERIMENTS WITH BIOTRICKLING FILTER AND BIOFILTER AT HTP: H_2S AND VOCs REMOVAL**

The Applied Research Group (ARG) in collaboration with UC Riverside and UC Davis has been doing testing on BTF and BF located at the Headworks of HTP since March 2000. In July 2000, results of the experiment have been discussed in the Plant Managers Meeting. As the Environmental Engineering Division (EED) has also been involved in a similar BTF Project at Hyperion, a two-hour meeting was held in July 2000 among all parties to discuss results and future plans. In this meeting, it was agreed that a protocol with more focus on VOCs measurements should be developed.

Accordingly, the enclosed is a protocol for future routine and challenge testing, in particular VOCs, with the BTF and the BF. It should be noted that spikes in the challenge testing should not affect the gas concentration in the headworks because a very small portion of the flow goes through the BF systems.

We are planning a meeting with EED and HTP staff for feedback on the protocols. We are planning to start the challenge testing in mid-October 2000. We would appreciate any comments on this matter on or before October 10, 2000.

These studies will lead to determining the BF' optimal design capacities. This information will in turn be used for evaluations of effectiveness of these systems for application to the total gas flow at Hyperion's headworks and various gas collection systems, for odor control and removal of VOCs.

If you have any questions regarding the above information, please feel free to contact Rosann Paracuelles at (310) 648-5763 or Dariush Vosooghi at (310) 648-5127.

Enclosures

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TABLE 1. REGULAR MONITORING (PERFORMANCE AND MAINTENANCE)

ITEM	PARAMETERS	FREQUENCY OF TESTING	
		BIOTRICKLING FILTER (BTF)	BIOFILTER (BF)
1	Caustic soda level	1x week	N/A
2	Gas moisture content (in moving samples)[1]	3 days/month	3 days/month
3	Gas velocity and flow rate (after the reactor)[2]	M, W	Tu, Th
4	H_2S levels (inlet, outlet, mid-height)[3]	M, W	Tu, Th
5a	HPE composition (P, N, K, pH, etc.)[4]	1 day/month	N/A
5b	Waste composition/by-products (SO_4^-, TOC, pH, BOD if sample is neutralized)	N/A	1 day/month
6a	HPE flow rate	N/A	UC Davis
6b	Liquid level (HPE), operation	M,W, F	N/A
7	Liquid Drainage Flow	M, W	Tu, Th
8	Moisture content of media	N/A	UC Davis
9	Operating temperatures (inlet and ambient)	M,W	Tu, Th
10	pH of media	M,W	UC Davis
11	Pressure drop	Weekly	Weekly
12	Air toxics monitoring for AQMD permit requirements [5,6]	One time – November	One time – October
	Ammonia		
	Benzyl Chloride ((chloromethyl)benzene)		
	Carbon sulfide		
	Carbonyl sulfide		
	Chlorobenzene (monochlorobenzene, benzene chloride)		
	Dimethyl disulfide		
	Dimethyl sulfide		
	Ethyl mercaptan		
	Ethylene dichloride		
	Hydrogen sulfide		
	Iso-propyl mercaptan		
	Methyl mercaptan		
	N-propyl mercaptan		
	1,1-Dichloroethene (vinylidene chloride)		
	1,2-Dichloroethane		
	1,2-Dichloroethylene (acetylene dichloride, 1,2-dichloroethene)		

TABLE 1. Continued

ITEM	PARAMETERS	FREQUENCY OF TESTING	
		BIOTRICKLING FILTER (BTF)	BIOFILTER (BF)
17	Benzene		
	Carbon tetrachloride (tetrachloromethane, perchloromethane)		
	Chloroform (trichloromethane)		
	Ethylidene chloride (1,1-dichloroethane)		
	Methylchloroform (1,1,1 trichloroethane)		
	Methylene chloride (dichloromethane)		
	p-Dichlorobenzene		
	Tetrachloroethylene (tetrachloroethene)		
	Toluene		
	Total Non-Methane Organics[7]		
	Total xylenes		
	Trichloroethene (trichloroethylene)		
	Vinyl chloride (chloroethylene)		
	Other VOCs in AQMD permit		
	Ethylene dibromide*[7]		
	Trichloroflouromethane*[7]		

* These are not present on AB2588 Reduced List of VOCs Compounds and are to be analyzed by Performance Analytical Laboratory.

Notes for Table 1:

[1] Moisture content is to be measured using SCAQMD Method 4.

[2] Gas velocity and flow rate are to be measured using SCAQMD Methods 1 & 2.

[3] H_2S levels are to be measured using Jerome Model 621-X or equivalent.

[4] Samples are to be stored at 0^0C until analysis is performed by ARG, UCR, UCD; Analysis of following is by HTP Laboratory. pH, conductivity, sulfate, elemental sulfur, chloride, total nitrogen, phosphorus, total organic carbon).

[5] Sampling is to be perfomed using CARB 422 Method; Analytical Method to be used is PID/ELCD.

[6] These compounds can be analyzed by EMD except for the following: methyl and n-propyl mercaptan and total non-methane organics.

[7] These compounds are to be analyzed by Performance Analytical Laboratory (PAL).

TABLE 2. VARIATION OF PARAMETERS

ITEM	PARAMETERS	FREQUENCY OF TESTING	
		BIOTRICKLING FILTER (BTF)	BIOFILTER (BF)
1	Decrease gas residence time	1 day/2 months	1 day/2 months
	H_2S Level (inlet, outlet, mid-height)		
	$Q_{(t=20\ sec)}$		
	$Q_{(t=10\ sec)}$		
	$Q_{(t=5\ sec)}$		
2	Spike H_2S concentration	1 day/2 months	1 day/2 months
	H_2S Level (inlet, outlet, mid-height)		
	10 ppm @ $Q_{(t=20\ sec)}$		
	25 ppm @ $Q_{(t=20\ sec)}$		
	50 ppm @ $Q_{(t=20\ sec)}$		
	75 ppm @ $Q_{(t=20\ sec)}$		
	100 ppm @ $Q_{(t=20\ sec)}$		
	125 ppm @ $Q_{(t=20\ sec)}$		
	150 ppm @ $Q_{(t=20\ sec)}$		
	175 ppm @ $Q_{(t=20\ sec)}$		
3	Spike VOCs concentration	1 day/2 months	1 day/2 months
	Benzene		
	Chloroform		
	p-Dichlorobenzene		
	Methylene chloride		
	Tetrachloroethylene		
	Toluene		
	Xylenes		

APPENDIX IV

SUPPORTING LITERATURE REVIEWS

(Summary of extensive literature reviews on bench, pilot and full-scale studies is available upon request.)

APPENDIX V

AQMD PERMITS

South Coast
Air Quality Management District
21865 E. Copley Drive, Diamond Bar, CA 91765-4182
(909) 396-2000 • http://www.aqmd.gov

March 17, 2000

Legal Owner or Operator:

Regents of The University of California
One Shield Avenue
Davis, California 95616

Equipment Location:

Hyperion Treatment Plant
12000 Vista Del Mar
Playa Del Rey, CA 90293

Application No: 364968

Permit to Construct and Operate
Experimental Research Operations

The system described below is granted a permit to Construct and Operate as allowed by and under the conditions set forth by Rule 441 of the Rules and Regulations of the South Coast Air Quality Management District subject to the following conditions:

Equipment Description:

INTRA-FACILITY PORTABLE BIOFILTER, 2 FEET IN DIAMETER AND 5.25 FEET HIGH, CONSISTING OF:

1. TWO ZONE COMPOST BIOREACTORS, ONE ZONE FOR SULFIDE REACTION AND ONE ZONE FOR VOC REACTION.
2. A BLOWER, 100 CFM MAXIMUM CAPACITY, AND AN AIR FLOW ORIFICE PLATE METER.

TO BE UTILIZED IN EXPERIMENTAL STUDY TO DETERMINE THE EFFECTIVENESS OF COMPOST BIOFILTER FOR BIOLOGICAL REMOVAL OF VAPOR PHASE CONTAMINANTS ASSOCIATED WITH VARIOUS MUNICIPAL WASTEWATER TREATMENT PROCESSES.

Conditions:

1. OPERATION OF THIS EQUIPMENT SHALL BE CONDUCTED IN COMPLIANCE WITH ALL DATA AND SPECIFICATION SUBMITTED WITH THE APPLICATION UNDER WHICH THIS PERMIT IS ISSUED UNLESS OTHERWISE NOTED BELOW.

2. THIS EQUIPMENT SHALL BE PROPERLY MAINTAINED AND KEPT IN GOOD OPERATING CONDITION AT ALL TIMES.

3. A SHUT-OFF VALVE SHALL BE INSTALLED AND MAINTAINED UPSTREAM TO THE BLOWER, SO THAT THE EQUIPMENT CAN BE COMPLETELY ISOLATED FROM THE MAIN AIR POLUTION CONTROL SYSTEM DUCTING.

4. WHENEVER BIOFILTER VENTS TO THE ATMOSPHERE, THE CONCENTRATION OF SULFUR COMPOUNDS, MEASURED AS HYDROGEN SULFIDE (H2S) AT THE OUTLET SHALL NOT EXCEED 1.0 PARTS PER MILLION.

5. THE OWNER OR OPERATOR OF THIS EQUIPMENT SHALL KEEP DAILY RECORDS OF OPERATING AND MONITORING DATA. THESE RECORDS SHALL BE MAINTAINED FOR A MINIMUM OF TWO YEARS AND MAID AVAILABLE TO THE AQMD PERSONNEL UPON REQUEST.

6. WITHIN 180 DAYS AFTER INITIAL STARTUP, THE OWNER OR OPERATOR OF THIS EQUIPMENT SHALL CONDUCT PERFORMANCE TESTS IN ACCORDANCE WITH APPROVED TEST PROCEDURES AND FURNISH THE AQMD WITH WRITTEN RESULTS OF SUCH PERFORMANCE TESTS WITHIN 60 DAYS AFTER TESTING. THE TESTS SHALL BE CONDUCTED IN DUPLICATE AT THE INLET AND OUTLET TO THE BIOFILTER, AND SHALL INCLUDE BUT MAY NOT BE LIMITED TO:

    1. BENZENE
    2. CARBON TETRA CHLORIDE
    3. CHLOROFORM
    4. DICHLORO BENZENE
    5. 1,4-DIOXANE
    6. ETHYLENE DIBROMIDE
    7. ETHYLENE DICHLORIDE
    8. METHYLENE CHLORIDE
    9. TETRA CHLORO ETHYLENE
    10. STYRENE
    11. 1,1,1-TRICHLORO ETHANE
    12. TRICHLORO ETHYLENE
    13. TRICHLORO FLUORO METHANE
    14. TOLUENE
    15. VINYL CHLORIDE
    16. XYLENES
    17. AMMONIA
    18 HYDROGEN SULFIDE
    19. CARBONYL SULFIDE
    20. CARBON DISULFIDE
    21. METHYL MERCAPTAN
    22. ETHYL MERCAPTAN
    23. DIMETHYL SULFIDE
    24. ISO-PROPYL MERCAPTAN
    25. N-PROPYL MERCAPTAN
    26. DIMETHYL DISULFIDE
    27. TOTAL NON-METHANE ORGANICS

    THE REPORT SHALL PRESENT THE EMISSIONS DATA IN PARTS PER MILLION VOLUME (PPMV)

7. THE AQMD SHALL BE NOTIFIED OF THE ACTUAL START-UP DATE OF THE EXPERIMENTAL RESEARCH PROGRAM WITHIN TEN DAYS OF THE START-UP DATE.

8. THE AQMD SHALL BE NOTIFIED OF THE COMPLETION OF THE EXPERIMENTAL RESEARCH PROGRAM NO LATER THAN TEN DAYS AFTER THE COMPLETION DATE.

9. WITHIN SIXTY DAYS AFTER THE COMPLETION OF THE EXPERIMENTAL RESEARCH PROGRAM, A COMPREHENSIVE REPORT OF THE TEST PROGRAM AND RESULTS SHALL BE SUBMITTED TO THE AQMD.

10. A WRITTEN REQUEST SHALL BE MADE AND APPROVED BY AQMD PRIOR TO MAKING ANY CHANGES TO THE PROPOSED EXPERIMENTAL RESEARCH OPERATIONS PERMIT.

11. THIS RESEARCH PERMIT SHALL EXPIRE ONE YEAR FROM THE DATE OF ISSUANCE. EXTENSION OF THIS PERMIT MAY BE GRANTED UPON WRITTEN REQUEST TO THE AQMD. THE REQUEST SHALL INCLUDE THE REASON FOR THE EXTENSION AND AN UPDATE OF THE PROGRESS IN THE RESEARCH PROGRAM.

It is the responsibility of the permitee to comply with all laws, ordinances, and regulations of other government agencies which are applicable to this operation.

This Rule 441 Research Permit shall expire on March 23, 2001. If you have any questions, please call Mr. Hassan Namaki at (909) 396-2699, or Mr. Charles Tupac at (909) 396-2684.

Sincerely,
L Bowen
Larry Bowen
Senior Engineering Manager
Toxic and Waste Management Unit

LB:CT:HN

CC: Omar Moghaddam, Hyperion
Sam Vergara, AQMD

SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT
21865 East Copley Drive, Diamond Bar, CA 91765

PERMIT TO CONSTRUCT

Application No.
323294
Page 1

Granted as of 1/21/1997

ID 110908

Legal Owner or Operator:

UNIVERSITY OF CALIFORNIA-RIVERSIDE
UNIVERSITY OF CALIFORNIA
RIVERSIDE, CA 92521

Equipment Location: VARIOUS LOCATIONS AQMD

Equipment Description:

BIOTRICKLING FILTER SYSTEM, TWO REACTORS, 11'-0" H. X 5'-0" DIA., 216 CU. FT. EACH, WITH TWO COLUMNS OF PACKAGING MATERIAL CONTAINING BIOMASS MICROORGANISMS, 5'-0" DIA. X 8'-0" H., 157 CU. FT. EACH.

Conditions:

1. OPERATION OF THIS EQUIPMENT SHALL BE CONDUCTED IN ACCORDANCE WITH ALL DATA AND SPECIFICATIONS SUBMITTED WITH THE APPLICATION UNDER WHICH THIS PERMIT IS ISSUED UNLESS OTHERWISE NOTED BELOW.

2. THIS EQUIPMENT SHALL BE PROPERLY MAINTAINED AND KEPT IN GOOD OPERATING CONDITION AT ALL TIMES.

3. THE OPERATION OF THIS EQUIPMENT SHALL COMPLY WITH THE DISTRICT RULE 402 (NUISANCE).

4. THE OPERATOR OF THIS EQUIPMENT SHALL NOTIFY THE DISTRICT AT LEAST 10 CALENDAR DAYS PRIOR TO THE START-UP OF THE RESEARCH OPERATION AT EACH SITE.

5. THE OPERATOR OF THE ABOVE EQUIPMENT SHALL SUBMIT TO THE DISTRICT A SUMMARY OF TEST RESULTS DATA FOR EACH TEST SITE.

6. THE ABOVE RESEARCH PROGRAM SHALL NOT EXCEED THE PERIOD OF NINE MONTHS AT EACH SITE.

PERMIT TO CONSTRUCT

Approval or denial of this application for permit to operate the above equipment will be made after an inspection to determine if the equipment has been constructed in accordance with the approved plans and specifications and if the equipment can be operated in compliance with all Rules of the South Coast Air Quality Management District.

Please notify ABDI MAJIDIFAR at (909) 396-2449 when construction of equipment is complete.

This Permit to Construct is based on the plans, specifications, and data submitted as it pertains to the release of air contaminants and control measures or reduce air contaminants. No approval or opinion concerning safety and other factors in design, construction or operation of the equipment is expressed or implied.

This Permit to Construct shall serve as a temporary Permit to Operate provided the Executive Officer is given prior notice of such intent to operate.

This Permit to Construct will become invalid if the Permit to Operate is denied or if the application is cancelled. THIS PERMIT TO CONSTRUCT SHALL EXPIRE ONE YEAR FROM THE DATE OF ISSUANCE unless an extension is granted by the Executive Officer.

By Dorris M. Bailey
DORRIS M. BAILEY
Principal Office Assistant

DMB/am