

1997 AIR BIOTREATMENT MEETING--US EPA_NC

a government/industry/academia parternship

EPA, ERC Auditorium

Research Triangle Park, North Carolina

ESD/OAQPS (MD-13), RTP, NC 27711

June 3, 1997

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Meeting Agenda

Preface

Introduction

PREFACE

This is the third annual bioreactor meeting hosted by the Emission Standards Division (ESD) of the Office of Air Quality Planning and Standards (OAQPS). The first two meetings involved mainly participation from the Wood Furniture and Cabinet Industry, state representatives, and EPA persons. The purpose of this meeting is to provide the EPA and other interested parties with a better understanding of the state of the technology. The meeting should also help industry/university participants understand the type of information EPA needs to consider such a technology, as a control option, in future regulatory development activities. As in the case of the prior annual meetings this meeting is not part of a formal regulatory activity. However, it provides EPA with the unique opportunity to work with the stakeholders in support of our regulatory efforts.

INTRODUCTION

Biodegradation can be an effective process for removal of relatively low concentrations in mg/m^3 of volatile organic compound (VOC) material and hazardous air pollutant (HAP) material from industrial waste air. This technology has potential application for e.g., in the paint, wood furniture, aerospace, and metal industries. There are numerous bioreactor system designs today. All use microorganisms to metabolize the pollutants and thus help in their biodegradation. Some biosystems are of the fixed-bed type, where the total air stream is directed into the bed carrying the microorganisms (Figure 1). In this case pollutants are removed from the air and are degraded in the same unit operation (UO). Other biosystem designs involve two distinct UOs. In the first the pollutants are separated and in the second they are biodegraded (Figure 2). The presentations today will include examples of both types of designs. A particle filter and a heater are shown in Figures 1 and 2. Presenters were not required to include such cost items.

Biological systems have several aspects in common: the air pollutants are first dissolved in a liquid phase, which determines the amount of pollutants that is separated from the air stream (captured). The pollutants are then degraded by the microorganisms, when the conditions are appropriate. Biosystems involving more than one UO may involve first dissolving pollutants in a hydrocarbon medium in the separation UO, and then transferring the pollutants to the second UO (or bioreactor) which contains the microorganisms in a water medium. The pollutants break down into CO_2 , water, and other by-products in the bioreactor unit. Both steps occur simultaneously in packed-bed biosystems such as that schematically shown in Figure 1.

The cells in the biomass need carbon (food) for growth and maintenance; otherwise the activity of the organism will be low. Therefore, a continuous supply of carbon is needed, otherwise a controlled operation will not be achieved. How this is achieved will vary with the design of the biosystem.

The solubility of the pollutant is in general important, as it determines the amount of available carbon. The ease of degradation of a pollutant is another important factor. In general aromatic compounds are easier to biodegrade than aliphatic compounds. The removal (i.e., utilization) of a pollutant (i.e., substrate) and the simultaneous growth of microorganisms are two

FIGURE 1

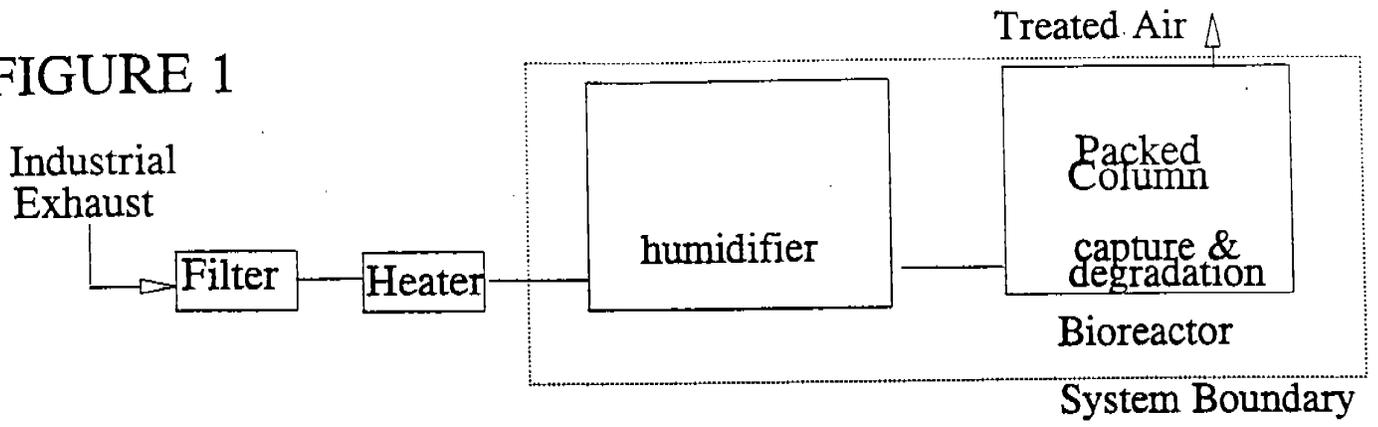
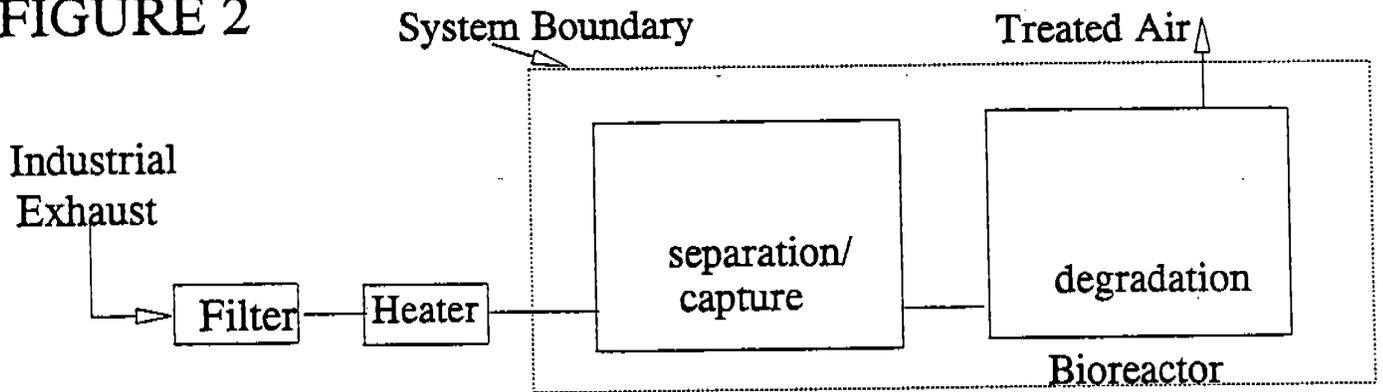


FIGURE 2



important events which occur simultaneously, and which affect the performance of a biosystem.

An external oxygen supply is required in aerobic systems, such as those that will be discussed today. The oxygen is needed for oxidative breakdown and for general use by the microorganisms. The activity of the microorganisms is increased by the presence of suitable nutrients which are compatible with the organism. Common nutrients include nitrogen, phosphorous, and potassium.

Many factors are involved in the operation of a bioreactor system. These include

- (1) pressure drop
- (2) humidity (or moisture content)
- (3) p-H value in the bio-layer
- (4) temperature
- (5) microorganism mix
- (6) max VOC/HAP concentration, and
- (7) composition of the polluted air stream

Therefore, before validating a biosystem for regulatory purposes operating data need to be developed to document the performance of such systems under various conditions. This data will need to be collected in some standardized format and will also need to satisfy EPA's quality assurance and quality control requirements. A list of US EPA quality system requirements for environmental programs is given in Appendix A.

A lack of a uniform procedure for reporting biodegradation rate, cost information, and compliance related information makes it difficult to compare the different designs on a uniform basis. To achieve this, we have provided specific guidance. Each presenter was required to size and cost a bioreactor system for a hypothetical mixture of pollutants in an air stream. Presenters were provided with the air flows, concentrations, and control efficiencies (Table 1). The presenters were required to use the EPA's cost procedure (Tables 2&3). A Lotus cost spreadsheet (mgcost.zip) was also provided for the convenience of the

presenters¹. The presenters were also asked to tabulate the cost data and to use the Metric units as the primary system of units (see Appendix A).

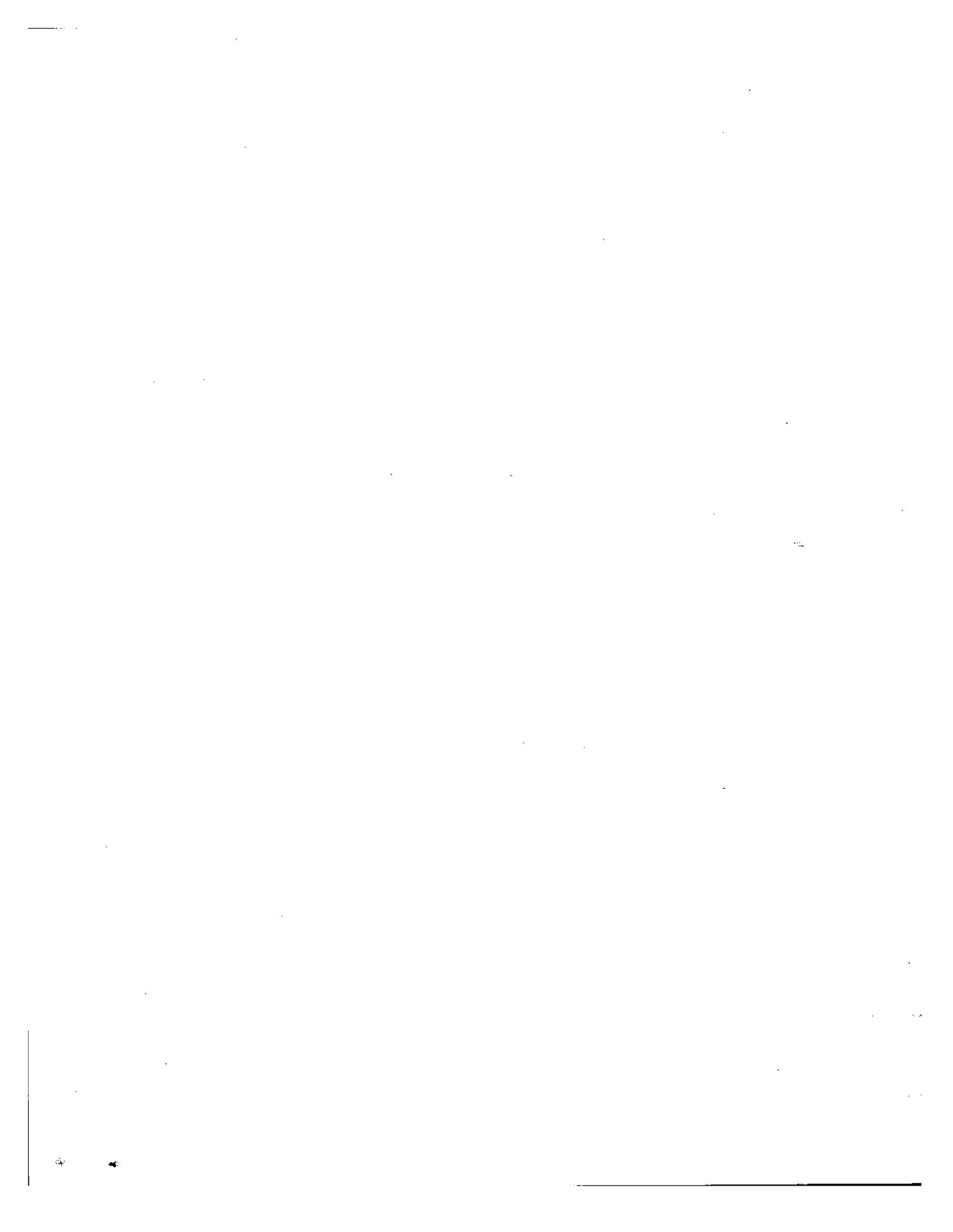
The last session on the Agenda today is the panel discussion.

Mohamed Serageldin, Ph.D.
US EPA (MD-13)

June 3, 1997

¹. The lotus cost spreadsheet is available on the OAQPS Technology Transfer Network (TTN): <http://ttnwww.rtpnc.epa.gov/index.htm>. Select TTN 2000 Master Search and Type "Bioreactor."

Presentation by EPA (Abstract)



Presentation by EPA (Abstract):

Linda Herring, Group Leader, Coatings and Consumer Products Group
Emission Standards Division/Office of Air Quality Planning and Standards

The use of bioreactor systems to reduce air pollutant emissions from industrial surface coating operations is of great interest to EPA, especially the Coatings and Consumer Products Group (CCPG). The CCPG is responsible for regulating categories of industrial surface coating operations that emit both hazardous air pollutants (HAP) and volatile organic compounds (VOC). In the last couple of years, we have issued regulations for wood furniture manufacturing, magnetic tape manufacturing, shipbuilding and ship repair, and printing and publishing. We have begun work on twelve additional categories and plan to publish proposed rules for them in late 1999 and final rules in late 2000 (paper and other webs, metal furniture, large appliances, metal cans, metal coil, miscellaneous metal parts, plastic parts, flatwood panelling, fabric, automobile and light duty trucks, reinforced plastic composites, and boat manufacturing). As we develop these regulations, we will be very interested in learning about cost-effective technologies for HAP and VOC control that can be used either as the basis for the regulations or as options for sources to use in complying with the regulatory requirements.

For bioreactor systems to be seriously considered by CCPG in regulatory development and by sources and enforcement offices as compliance options, certain information needs to be available. First, the effectiveness of the systems in reducing HAP and VOC emissions in an industrial setting needs to be demonstrated. Second, the capital and operating costs of the systems need to be determined. Third, testing and monitoring methods need to be identified to demonstrate both initial and continuous compliance with emission limits. If these things are known before the proposed rules are written, specific features can be included in the rules to facilitate the use of bioreactor systems for compliance. If they are not known before the rules are written, then sources would need to obtain approval from the agency implementing the rule (either EPA or the State) to use a bioreactor system for compliance. The rules would include criteria a source would have to meet to obtain approval. We are encouraged at the interest in biotreatment systems and look forward to further development and refinement of these systems for air pollution control.

Technical Presentations (Extended Abstracts)

- Paper No. 1**
 - Paper No. 2**
 - Paper No. 3**
 - Paper No. 4**
 - Paper No. 5**
-



EXTENDED ABSTRACT

1997 Air Biotreatment Meeting -- US EPA_NC
Research Triangle Park, NC 27711

BIOFILTRATION PILOT UNIT STUDY TO CONTROL FUGITIVE EMISSIONS
FROM A SOLVENT MIXING AREA AT
IMATION ENTERPRISE'S WHITE CITY, OREGON FACILITY

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White City, OR 97503

Introduction

PPC Biofilter, in conjunction with Imation Enterprises conducted a six month pilot study to determine if biofiltration was a viable option for controlling fugitive VOC emissions from a solvent mixing area. Imation Enterprises manufactures medical imaging film at their White City, Oregon facility. This process uses a variety of solvents including methyl ethyl ketone (MEK), acetone, methanol, ethanol, toluene, heptane, and ethyl acetate, with gas stream concentrations ranging from 0 to 100 ppm (as solvent).

PPC provided a commercial pilot unit containing two cubic meters of biofilter media, from which operating data and background information on biofiltration was gathered to evaluate the effectiveness of the technology for controlling VOC emissions from a highly variable source. Although the VOC concentrations were dilute, they represented a significant fraction of the uncontrolled emissions from the facility. This study indicates that biofiltration can be an effective and economical control option for dealing with highly variable VOC emissions sources.

Equipment

The pilot unit provided by PPC is a skid mounted unit, consisting of a pretreatment humidification chamber, followed by a totally enclosed insulated vessel containing two separate biofilter beds operating in series. Each bed contained one cubic meter of filter media. The pilot unit is fully instrumented and all pertinent operating parameters are logged and controlled via a computer control system. Air flows through the pilot unit are measured using orifice plates and differential pressure transmitters. The flows were set using manual gate valves. Differential pressure transmitters were also used to measure the pressure drop across the humidifier and both filter beds.

The moisture content of the filter media was maintained via the computer control system. To monitor the moisture content of the media, load cells are located in the reactor vessels to monitor the weight of the filter media. This weight is related directly to the moisture content of the filter bed. Initially, the control system was calibrated for the load cells to activate solenoid valves which control the addition of water to the filter media. During the course of the study, the

control logic was modified so that water was added to the media on a timed basis and the load cells were used to monitor the system.

Pilot Unit Operation

Gas Residence Time

During the course of the study, the pilot unit was operated at a number of different flow rates. Initially, the flow rate through the biofilter was set to provide an empty bed gas residence time (EBRT) of approximately one minute. Two months into the study the flow rate was adjusted to provide a 15-20 second EBRT. During the third phase of testing the flow rate was set for a 30-35 second EBRT. Figure 2 show the flow trends during the course of the pilot study.

Media Moisture Content

The performance of a biofilter is directly related to the moisture content in the filter media. Throughout the course of this study, the moisture content of the filter material was measured periodically, and the control system was adjusted to maintain a uniform moisture content. Initially the pilot unit was set to maintain and approximate moisture content in the filter media of 60-65%. During the course of the study, it became evident that the load cell control system was not capable of adequately responding to moisture needs of the filter material and a timer system was incorporated in the control system. The load cells were, however, reliable as monitoring tools for determining stable moisture contents and system operation. During the final phase of testing, the media moisture content was maintained at 65-70%.

Gas Temperature

The temperature of the gas stream entering the biofilter was monitored continuously and controlled as much as possible during the course of the pilot study. Inlet gas temperatures of 4.4°C (40°F), after the humidifier, were observed along with low removal efficiencies. Experience has shown biofilters to be much more effective at temperatures above 21°C (70°F). Attempts were made to control the inlet gas stream temperature using the humidifier sump heater. At the low flow rates (~60 second EBRT) the sump heater was able to maintain gas temperatures above 32°C (90°F). When the flow rate was increased to 460 m³/hr (15 second EBRT), the inlet temperature dropped to 21°C (70°F). At a 38 second EBRT, the inlet gas temperature fluctuated between 21°C (70°F) and 37°C (98°F), depending on ambient conditions.

VOC Monitoring

Throughout the pilot study, VOC concentrations were measured using both a flame ionization detector (FID) and by gas chromatography with a FID (GC/FID). The FID was used in an effort to obtain continuous inlet and outlet VOC concentration readings. The FID proved to be an unreliable measurement tool because moisture in the sample lines, with a high organic content, fouled the detectors. The FID results can only be used to note trends in the data, although the correlation between the FID and GC/FID data was fairly close.

Ambient temperature also affected sample delivery conditions to the FID. Thorough and rigorous design of the sample delivery system with an analyzer intended for continuous duty, could provide the destruction and process efficiency monitoring needed. However, once a stable ecosystem has

been established within the biofilter vessel, monitoring the process variables such as inlet temperature and media moisture content, provides reliable information regarding system performance, in much the same way that operating temperatures in a thermal oxidizer are related to system performance.

Waste water drainage from the biofilter had no detectable solvent content and required no pH adjustment before discharge. There was no blowdown of the recirculation water during this study, and at the end of the trial, solvent concentrations were below discharge limits.

System Performance and Results

The results of this pilot study indicate the biofiltration system works well in removing VOCs from the tested gas stream. The biofilter was able to handle the variability in the VOC concentration and composition and still provide consistent, reliable performance. The overall performance of the biofilter throughout the course of the study was 83% removal of the VOCs. During the final stage of the study, the biofilter consistently demonstrated removal efficiencies greater than 90%.

Of particular interest is the resiliency of the system. During the course of the study, the biofilter media dried out and this was reflected in the performance of the system. When the moisture content was brought back in line, the system performance rebounded, in a relatively short period of time, to previous performance levels.

Gas Residence Time

As previously mentioned the gas residence time in the bed was varied between 15 and 60 seconds. Good removal efficiencies occurred at all residence times, but the most consistent removal was obtained at 30-35 second EBRT.

VOC Loading

The wide variability in the concentration and composition of the VOCs in the process gas stream caused some initial concern regarding system performance. Due to this variability, removal efficiencies were not stable and did vary over time, however the system was able to respond to changes and maintain an average control efficiency of greater than 90%.

The availability of regular GC analysis allowed for the evaluation of the biofilter performance on specific compounds. As expected, low molecular weight, highly biodegradable compounds were removed most readily. Alcohols present in the gas stream were removed consistently, with average removal efficiencies of 97-98%. Average acetone removal efficiencies were 73% at a 15 second EBRT, 91% at a 30 second EBRT, and 93% at a 60 second EBRT. Average MEK removal efficiencies were 82% at a 15 second EBRT, 93% at a 30 second EBRT and 90% at a 60 second EBRT. It is interesting to note that the increase in EBRT from 30 to 60 seconds did not provide a significant improvement in VOC removal efficiency.

Of particular interest was the affect of alcohols in the gas stream on acetone removal. When alcohols were present in the gas stream, acetone removal was adversely impacted and removal efficiencies dropped by as much as 10%. Although there was a direct correlation between alcohol

concentration and acetone removal, there was not enough data to develop a relationship. Although the preferential degradation of compounds within a biofilter is accepted, more work needs to be done to explore the relationship between specific compounds in a particular gas stream and the removal efficiencies of the specific compounds.

Media Moisture Content

The media moisture content is the single most important variable affecting biofilter performance. During the most consistent period of operation, the moisture content of the filter media was maintained at 65-70%. Unfortunately, gas flow changed and temperature fluctuated during this period and it is difficult to attribute the excellent system performance to any single parameter. However, during the course of the study, there were a number of times the system performance dropped off significantly. During each of these periods of reduced removal efficiency, it was observed that the moisture content of the media had dropped significantly. When the moisture content of the media was returned to previous levels, high removal efficiencies returned.

Conclusions

The biofilter effectively dealt with the emissions from the solvent mixing room. It was able to adapt to the variable organic loading that was inherent in the system and provide consistent removal efficiencies of greater than 90%. Of particular importance, the biofilter was able to respond quickly and effectively to variations in gas stream composition and concentration. Based on the results of this study, the biofilter is a technically and economically viable alternative to more traditional VOC control technologies such as thermal oxidation.

This study also indicates the attention needs to be paid to the delivery of the treated gas stream to the biofilter. To provide the most stable operation, minimizing fluctuations in the inlet gas conditions at the biofilter may be necessary. Of primary importance is the temperature of the gas stream after humidification. To maintain a stable inlet temperature, the inlet duct work may have to be insulated to minimize the impact of ambient conditions. Additionally, if the process gas stream has an inlet temperature, after humidification, below 21°C (70°F) it will probably be necessary to increase the gas stream temperature prior to humidification.

Pilot studies such as this one give a clear indication of the applicability of biofiltration for controlling VOC emissions. Biofiltration will not meet all VOC control needs, but as more commercial installations come online, biofiltration will become an accepted alternative to more costly control technologies in situations where it does apply.

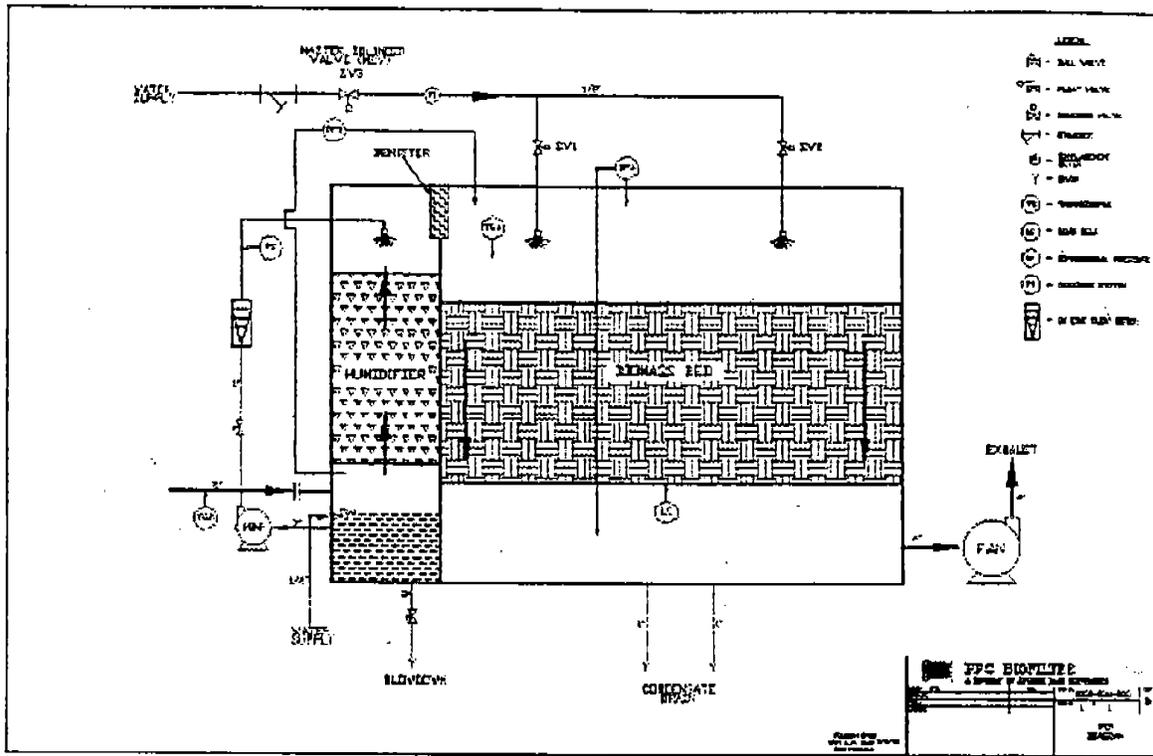


Figure 1

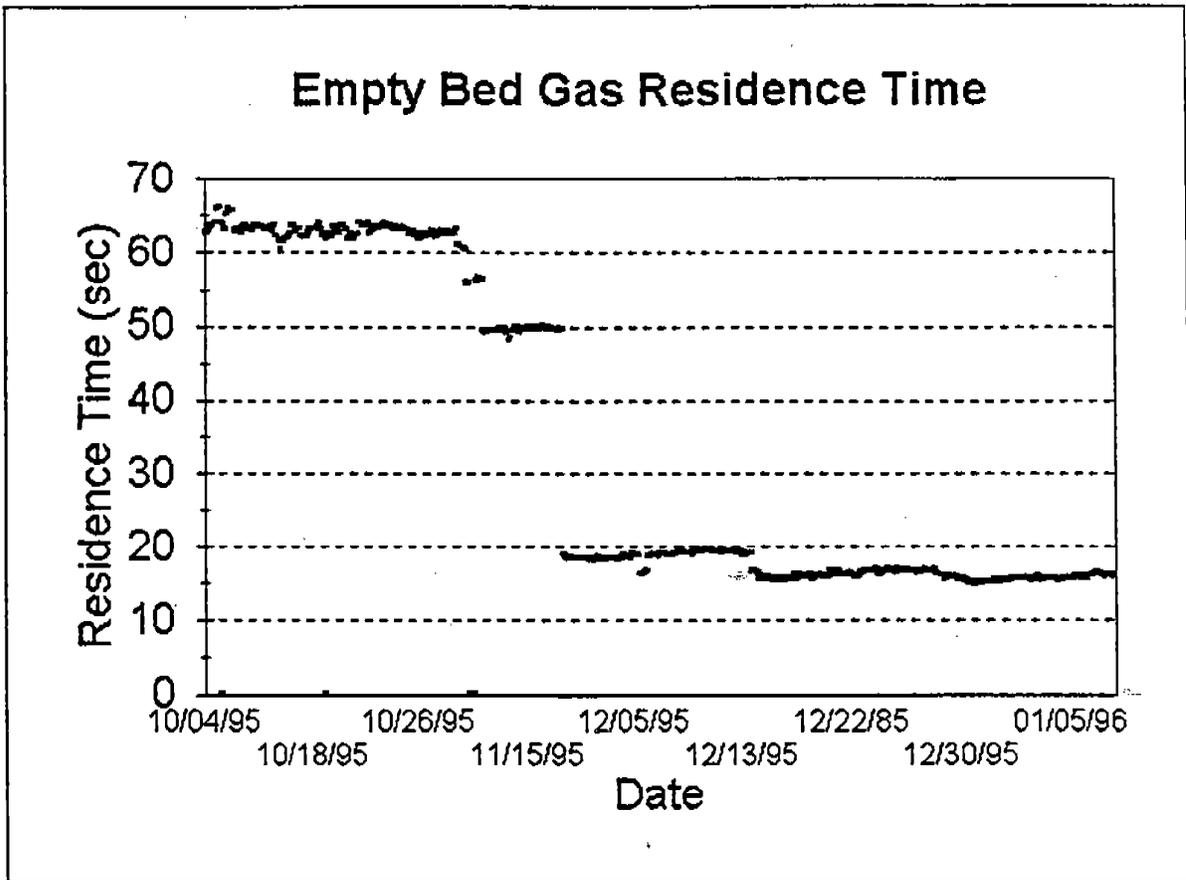


Figure 2

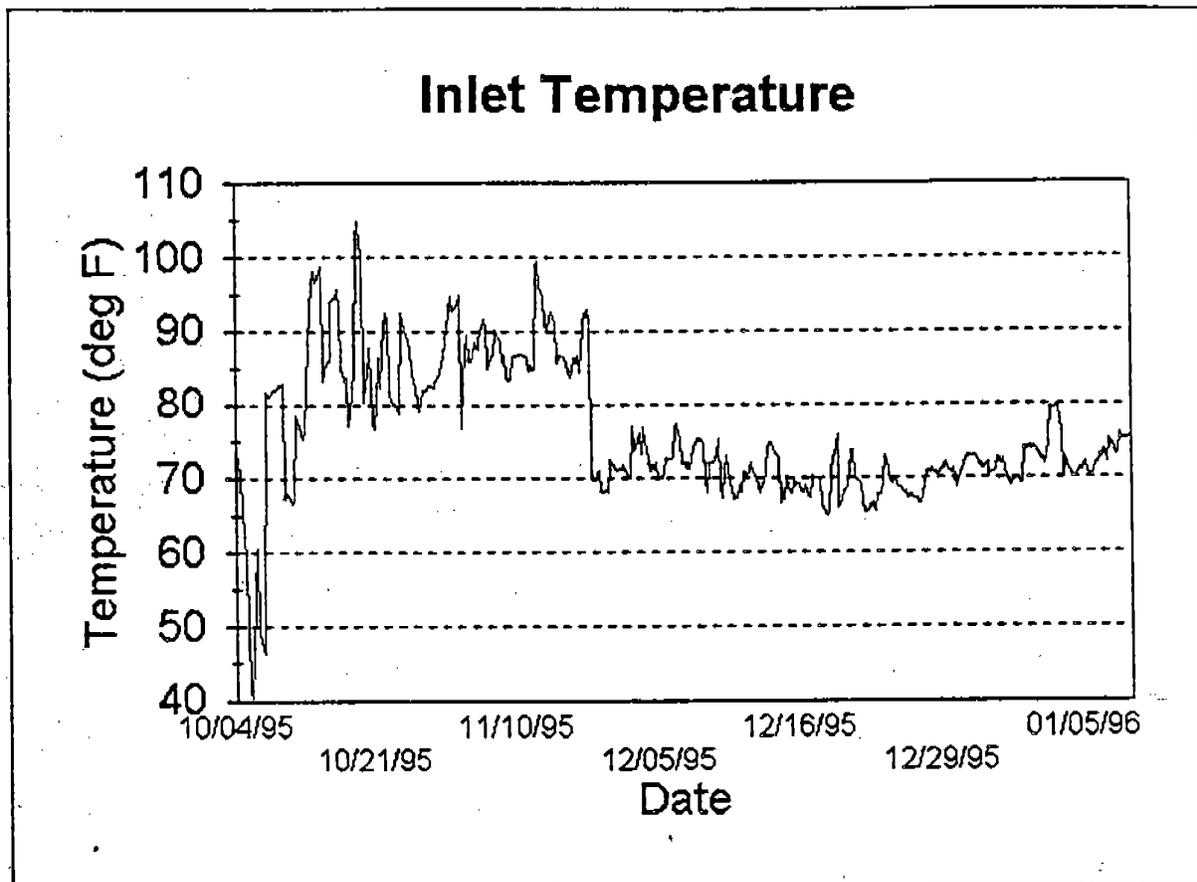


Figure 3

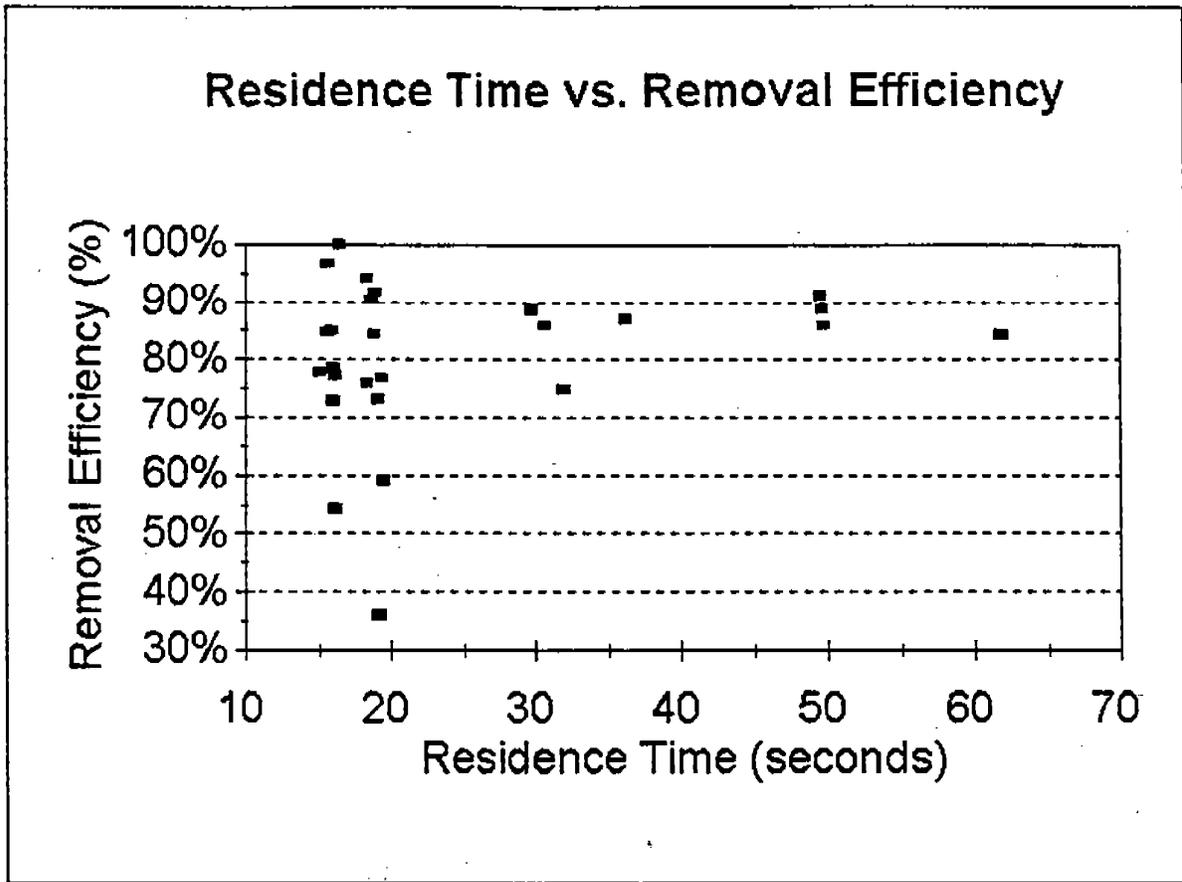


Figure 4

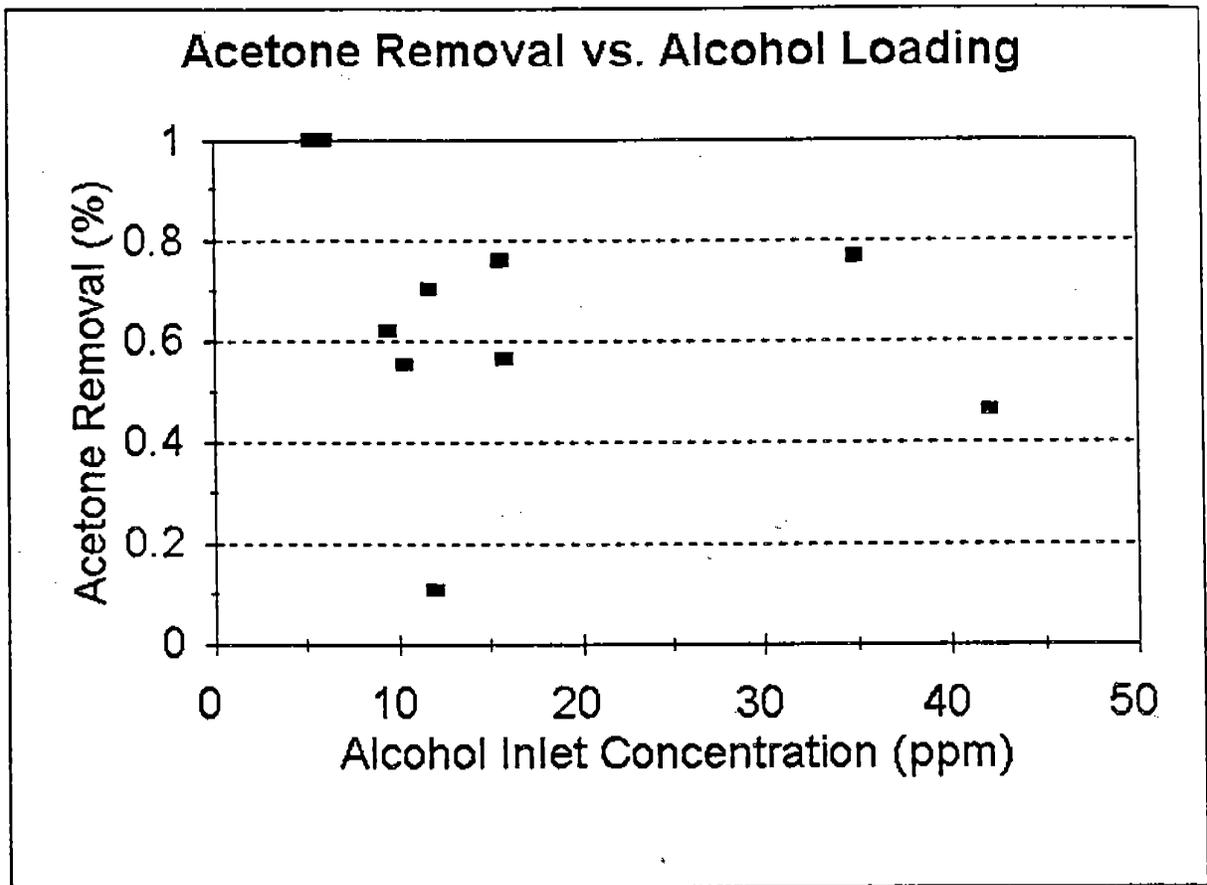
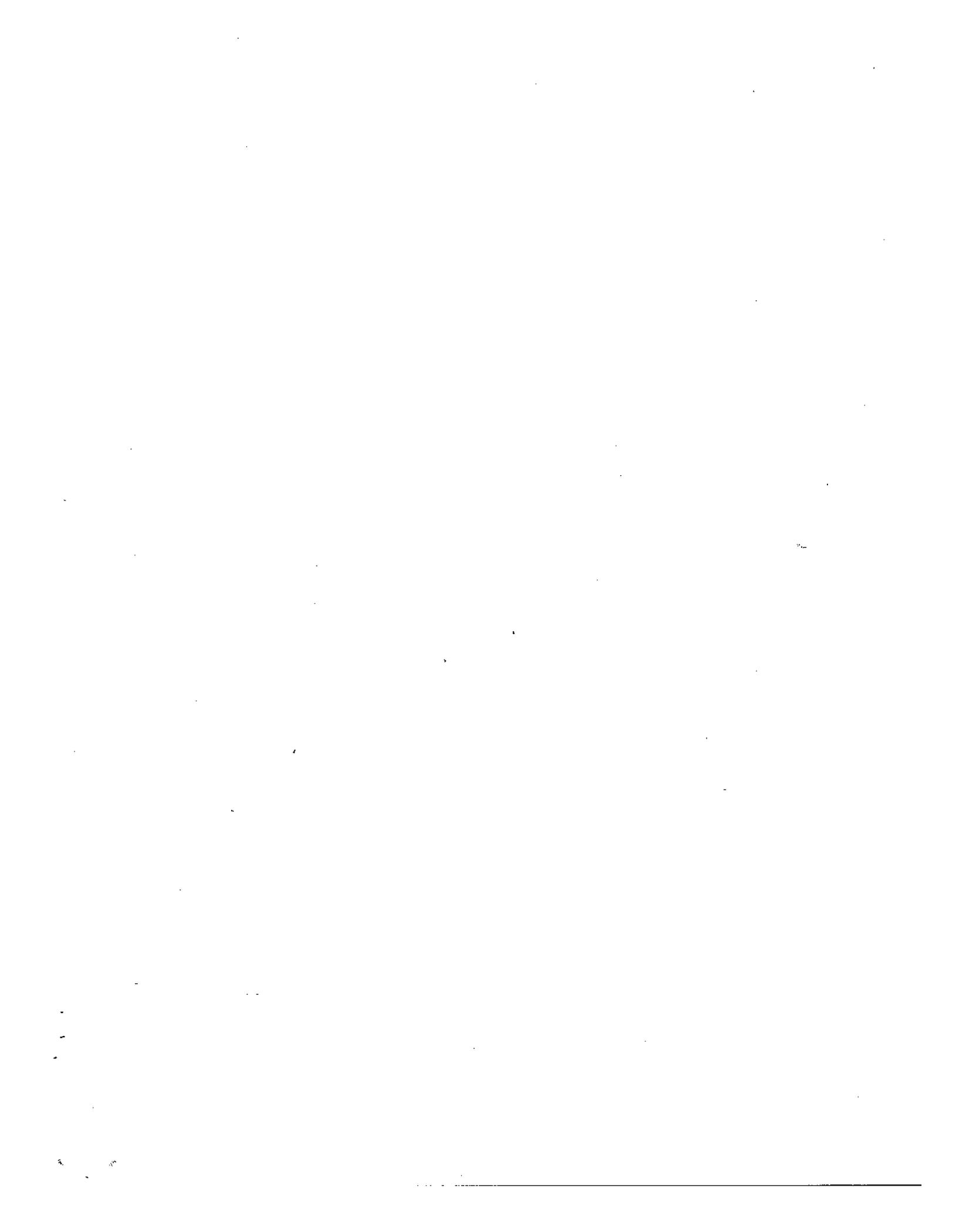


Figure 5



PREPRINTED EXTENDED ABSTRACTS

Presented at the 1997 Air Biotreatment Meeting -- US EPA
Research Triangle Park, NC 27711

BIOSCRUBBER TECHNOLOGY FOR THE CONTROL OF VOC AND/OR AMMONIA
LADEN PROCESS STREAMS

Timothy M. Owens, Ph.D. and Krishnamurthy Sridhar, P.E.
National Environmental Technologies, Inc. (and IsoTek, L.L.C.)

ISOTEK, LLC has developed a proprietary (patent applied for) technology for treating VOC and/or ammonia emissions in a gas stream. This technology combines wet scrubbing and biological treatment into a single-process.

The BIOVOC[®] scrubber technology, based on suspended growth biochemical oxidation, involves pumping a biomass slurry from a recycle/bioreactor tank through a non-clogging tray tower configuration. The VOC laden air stream is passed through the tower countercurrent to the slurry where the contaminant is absorbed and then metabolized by the biomass in the bioreactor. The treated air stream is then vented to the atmosphere. Coupling suspended growth process and tray tower scrubber design, the BIOVOC scrubber achieves high performance efficiencies at low capital and operating costs.

Case Study #1

A bioscrubber pilot test was conducted using a methanol-air gas mixture. The pilot system consisted of a 70 gallon bioreactor and a 12" diameter tray tower. The tray tower consisted of 10 counterflow sieve trays. A centrifugal pump recirculated biomass slurry through the tower and an ambient air blower aerated the contents in the bioreactor. The bioscrubber was operated at various gas flow rates and methanol concentrations in order to develop process design and scale-up parameters.

The performance of the bioscrubber is illustrated in Figure 1. A methanol saturated air stream containing 1.7 lb methanol/day was fed to the scrubber tower. Greater than 98% removal of methanol was achieved through the scrubber tower. The methanol absorbed into the recirculating biomass slurry was subsequently oxidized to CO₂ and H₂O in the bioreactor tank. The sludge blowdown from the reactor was approximately 7 gallons/day and contained <10 mg/L of unreacted methanol.

Relatively high methanol oxidation rates were observed in the bioreactor. Food / microorganism ratios up to 1.0 lb methanol/lb MLVSS/day were easily attained. As the F/M ratio varied from 0.5 to 1 lb methanol/lb VSS/day, the methanol concentration in the blowdown remained <10 mg/L and methanol in the exhaust was less than 5 ppm.

Case Study #2

Field trials using a pilot scale bioscrubber systems were conducted on a VOC and ammonia laden emission stream from a specialty chemicals manufacturing plant. The VOC constituents included methanol, formaldehyde and organic amines. The pilot system consisted of a water prescrubber, 600 gallon bioreactor and a 12" diameter tray tower. The tray tower consisted of 8 counterflow sieve trays. A centrifugal pump recirculated biomass slurry at a flow rate of 8 gpm through the tower and 53 scfm of ambient air was sparged to aerate the contents in the bioreactor.

The pre-scrubber consisted of a 70 gallon tank mounted with 3 sieve trays. Water adjusted to a pH 4 - 5 was recirculated at a flow rate of 9 gpm through the prescrubber. Inlet gas entered the prescrubber and exhausted into the bioscrubber tray tower. A metering pump transferred 25 gpd of liquid from the prescrubber tank to the bioscrubber reactor tank. The same volume of sludge from the bioscrubber reactor was discharged as blowdown. The prescrubber helped dampen wide fluctuations in the ammonia emissions in the inlet gas stream and provided a stable ammonia feed to the bioreactor. The prescrubber-bioscrubber system was operated at various gas flow rates in order to develop process design and scale-up parameters.

Greater than 98% of VOCs (including methanol and formaldehyde) were absorbed in the scrubber tower as indicated by EPA Method 25. The absorbed methanol and formaldehyde were subsequently oxidized in the bioreactor tank to CO_2 and H_2O . At steady state conditions the sludge blowdown contained negligible concentration of formaldehyde and <25 mg/L of unreacted methanol. The concentration of organic amine in the blowdown was directly related to the prescrubber operation. With precise pH control (4- 5), the organic amine in the inlet gas stream was absorbed into the prescrubbing liquid and decomposed to formaldehyde and ammonia. As discussed above, the prescrubber contents were metered to the bioreactor at a rate of 25 gpd. The organic amine concentration in the bioreactor blowdown was 0 mg/L.

Greater than 99.9% of ammonia was also removed from the gas stream. The absorbed ammonia was subsequently oxidized to nitrate and nitrite in the bioreactor. At steady state about 2.8 lb/day of ammonia was fed to the bioscrubber tower and was converted to nitrate and nitrite in the bioreactor. The nitrification of ammonia as a function of biomass loading rate is illustrated in **Figure 2**. Up to a loading rate of 0.1 lb $\text{NH}_3\text{-N}$ /lb VSS/day, >99.9% of the ammonia was converted to nitrate. At 0.2 lb $\text{NH}_3\text{-N}$ /lb VSS/day, ammonia began accumulating in the bioreactor liquid. The blowdown $\text{NH}_4\text{-N}$ varied from 0 - 10 mg/L and exhaust NH_3 concentration was <0.5 ppmv. Nitrate and nitrite that were formed as a result of ammonia oxidation were discharged along with the blowdown.

The steady state operating conditions are summarized in **Table 1**.

Biomass Ammonia Loading Rate

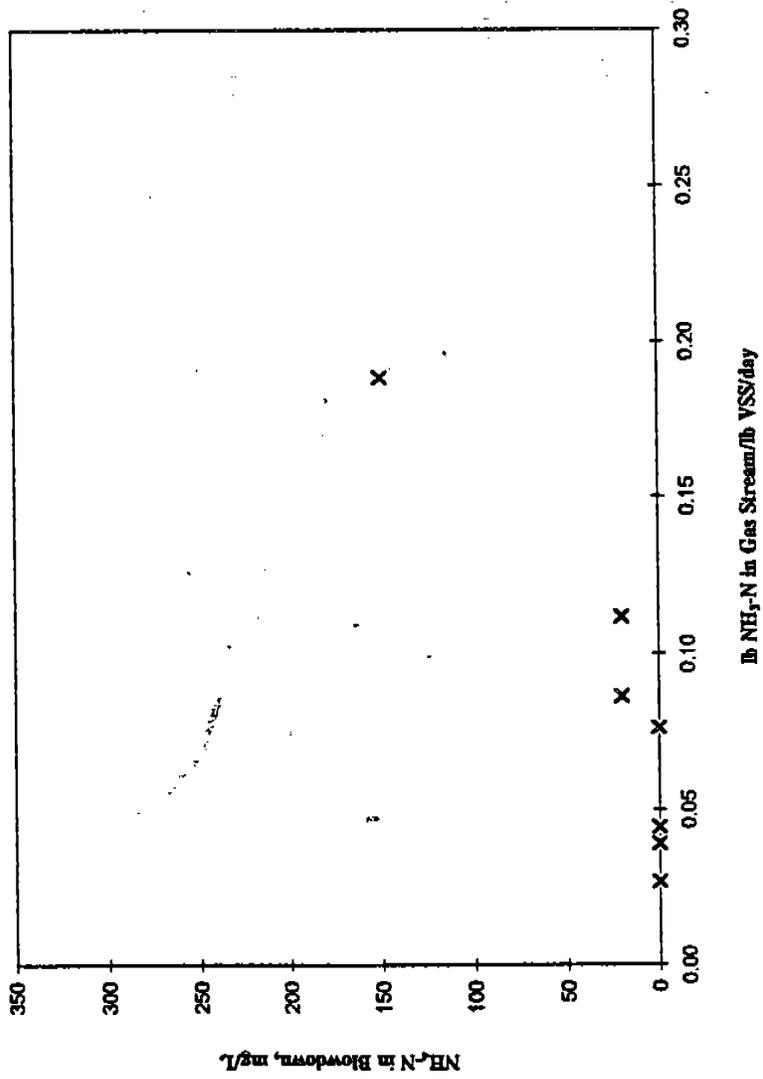


Figure 2

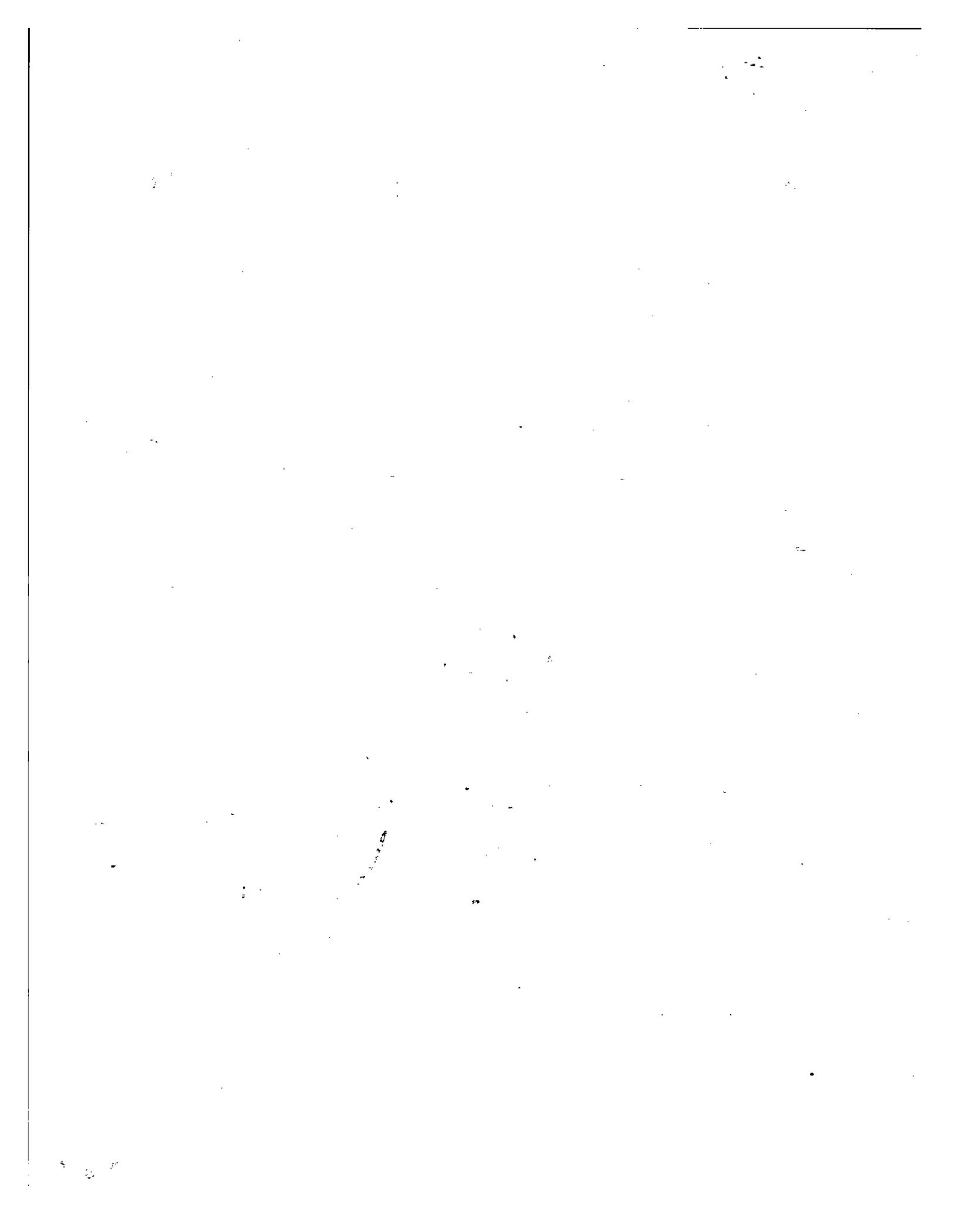
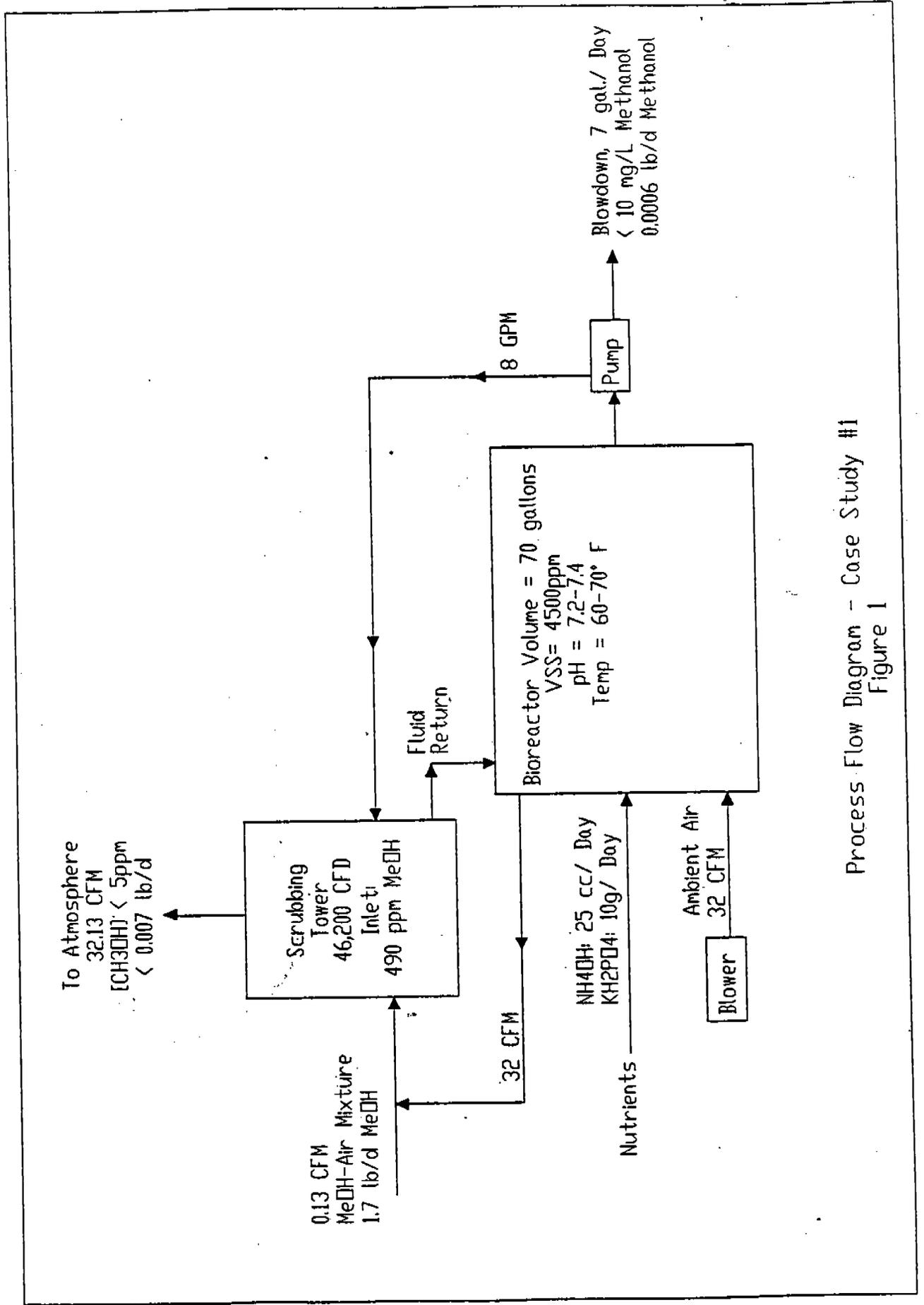


Table 1: Pilot System Steady State Conditions

Inlet Gas flowrate	15 acfm
Pressure Drop	2"- 3" W.C.
Ammonia Removal Eff.	>99.9%
VOC Removal Eff.	>98%
Blowdown	25 gpd (4% of reactor volume)
Blowdown Characteristics	<100 mg/L BOD ₅ 250 - 900 mg/L COD Formaldehyde = negligible Methanol <25 mg/L Organic amine = negligible NH ₄ -N <10 mg/L NO ₃ = ~20,000 mg/L NO ₂ <1,000 mg/L



Process Flow Diagram - Case Study #1
Figure 1

1997 Air Biotreatment Meeting
US EPA, Research Triangle Park, NC 27711
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SELF CLEANING GRANULAR ACTIVATED CARBON
HAPs/VOC REDUCTION FILTER
WITH CONTINUOUS BIOREGENERATION

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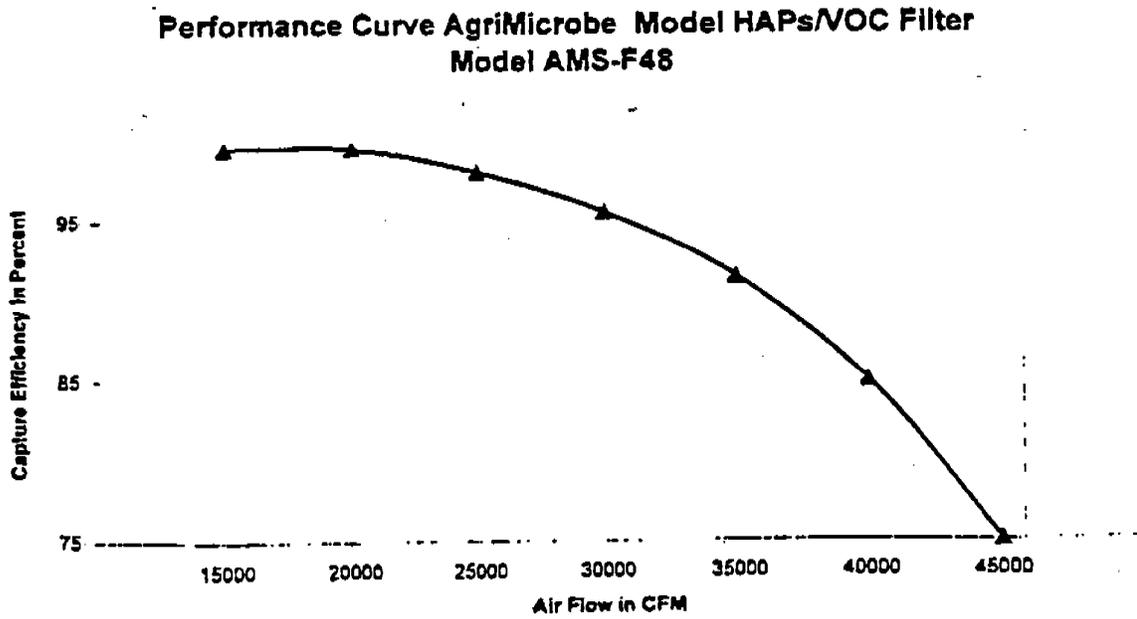
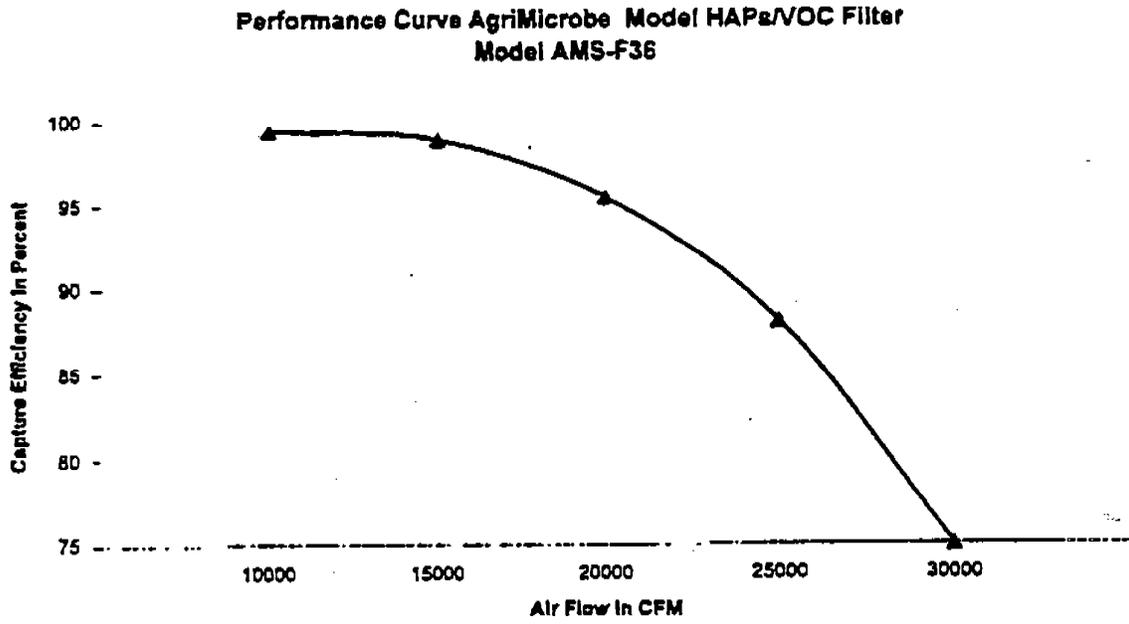
The AgriMicrobe Sales, L.C. HAPs/VOC Reduction filter is comprised of two(2) distinctive sections. The first section houses the granular activated carbon which is the capture media for the HAPs/VOC emissions from an exhaust air stack. The GAC used in the filter is designed for use in a wide variety of vapor phase treatment applications. It combines high surface area and fine pore structure in a product of exceptional hardness.

The GAC can remove as much as 99.99 percent of petroleum hydrocarbons and organic compounds from airborne emissions. The ability of a compound to be removed with GAC is a function of its solubility. Low solubility compounds adsorb better than high solubility compounds. This makes alcohols, ketones and ethers poor adsorbers, whereas most solvents and pesticides are excellent adsorbers. Also, GAC has a higher affinity for nonpolar compounds and branched molecular structures. Examples of nonpolar compounds are solvents, such as, toluene and xylene. Examples of branched compounds are pesticides.

Other factors affecting the adsorption ability of the GAC filter are relative humidity and approach velocity. The relative humidity needs to be near 50 percent and the approach velocity should be near 100 feet per minute.

The GAC can remove up to 0.3 pounds of HAPs/VOCs per pound of carbon without a breakthrough. Based on an AMF - 48 Filter containing 9440 pounds of carbon, the adsorption capacity is approximately 1880 pounds. This amount is based on the 66.67 percent of the filter which is not submerged into the water.

Because the contaminants are leached into the water section of the filter upon each revolution of the drum, the filter has the capacity to remove up to 1880 pounds of contaminants every ten(10) minutes. This factor makes the AgriMicrobe Sales, L.C. filter virtually unlimited in the concentration of the pollutants in the air stream.



The second section of the AgriMicrobe Sales, L.C. filter contains oxygenated water and AgriMicrobe Sales, L.C. Formula V® Microorganisms. As the drum containing the GAC rotates, the contaminants that are captured on the carbon are continually leached into the water. This provides a self-cleaning mechanism for the carbon and provides the food supply for the microorganisms. The water is oxygenated by means of a self-contained blower which blows air into the water through two(2) perforated pipes.

Based on test data, the AgriMicrobe Sales, L.C. Formula V® microorganisms can reduce the HAPs/VOCs to near drinking water quality in less than 24 hours. This suspended growth bioreactor, with limited food supply, results in no amount of sludge buildup so long as compounds are biodegradable. Almost all HAPs/VOCs in a gaseous state are biodegradable. The percentage of contaminants, i.e., aliphatic or aromatic, is not a controlling factor.

DATA SHEET FOR AGRI MICROBE SALES, L.C.
HAP/VOC REMOVAL FILTER
WITH CONTINUOUS BIOREGENERATION OF CARBON

Filters will be sized according to existing exhaust stack diameter, percentage of removal, and/or air flow. A AMS - F36 filter will handle one (1) stack or air flows up to 30,000 CFM with a control efficiency between 99.5% and 75.0%. One (1) AMS - F48 filter will handle flows up to 45,000 CFM with a control efficiency between 99.5% and 75.0%.

<u>Filter Model</u>	<u>Control Efficiency</u>	<u>Air Flow</u>
AMS - F36	99.5%	10,000 CFM
AMS - F36	99.0%	15,000 CFM
AMS - F36	98.0%	17,000 CFM
AMS - F36	95.5%	20,000 CFM
AMS - F36	88.0%	25,000 CFM
AMS - F36	75.0%	30,000 CFM
AMS - F48	99.5%	17,000 CFM
AMS - F48	99.5%	20,000 CFM
AMS - F48	98.0%	25,000 CFM
AMS - F48	95.5%	30,000 CFM
AMS - F48	91.5%	35,000 CFM
AMS - F48	85.0%	40,000 CFM
AMS - F48	75.0%	45,000 CFM

The following is a guide to use in sizing for the filters. Existing spray booths are sized for 100 feet per minute face velocity across the front of the booth. Therefore, the following booth sizes will have the CFM as shown.

<u>Booth Size</u>	<u>Air Flow</u>
8' x 12'	9,000 CFM
8' x 14'	11,200 CFM
8' x 16'	12,800 CFM
8' x 20'	16,000 CFM
8' x 24'	19,200 CFM
8' x 30'	24,000 CFM

COST ESTIMATE FOR
 AGRIMICROBE SALES, L.C. HAPs/VOC
 REDUCTION FILTER BASED ON
 FORMAT PROVIDED FROM DR. SERAGELDIN

Air Flow Rate	8,500 M ³ /min.
VOC emissions rate	327 MG/year
Portion of Emissions which are HAPs	48 %
Average Air Stream Concentration	330 mg/M ³
Equipment operating efficiency	95 % VOC Removal

Purchased (not installed) Equipment Cost (Cp) \$850,000

ITEM	COST
Direct Costs	
Purchased Equipment Costs:	
Equipment (EC)	\$ 850,000
Instrumentation	85,000
Sales Tax	25,500
Freight	42,500
Purchased Equipment Cost, PEC	
	\$1,003,100
Direct Installation Costs	
Foundations and supports	\$ 80,248
Handling and erection	140,434
Electrical	40,124
Piping	20,062
Insulation for piping and ductwork	10,031
Painting	10,031
Direct Installation Cost	\$ 300,930
TOTAL DIRECT COST, TDC	
	\$1,304,030
Indirect Costs (installation)	
Engineering	100,310
Construction and field expenses	50,155
Contractor fees	100,310
Start-up	20,062
Performance test	10,031
Contingencies	30,093
TOTAL INDIRECT COST, TIC	
	\$ 310,961
TOTAL CAPITAL INVESTMENT, TCI = TDC + TIC	
	\$1,614,991

ANNUAL COST DETERMINATION

Plant operation	1920 hr/yr
Equipment lifetime	10 yrs
Interest rate	7 %
Capital Recovery Factor	0.142
Replacement parts	\$85,000
Utility Requirements	
Electricity (Kw-Hr)	1.1

ITEM	COST FACTOR	COST(\$/HR)	TOTAL
Direct Costs			
Operating labor			
Operator	0.5 hr/shift	\$23.10	\$ 2,772
Supervisor	15 % of operator		416
Maintenance			
labor	0.5 hr/shift	\$23.1	2,772
supervisor	15 % of labor		416
materials	100 % of labor		2,772
replacement parts (10 % system/yr)			\$ 85,000
utilities (\$/Kw-hr)			87
Indirect Costs			
overhead	60 % of labor & materials		\$ 5,489
Administrative	2 % of TCI		32,300
property taxes	1 % of TCI		16,150
insurance	1 % of TCI		16,150
capital recovery	capital recovery factor x TCI		\$229,329
TOTAL ANNUAL COST			\$299,418
uncontrolled VOC emission rate (MG/yr)			327
VOC controlled (MG/yr)			310.65
controlled emission rate (MG/yr)			16.35
VOC cost effectiveness (\$/MG)			\$ 964
uncontrolled HAP emission rate (MG/yr)			157
HAP controlled (MG/yr)			149
controlled HAP emission rate (MG/yr)			8
HAP cost effectiveness (\$/MG)			\$ 2,018

PREPRINTED EXTENDED ABSTRACTS

Presented at the 1997 Air Biotreatment Meeting - US EPA NC
a government/industry/academia partnership: Research Triangle Park, NC 27711

MEMBRANE BIOTREATMENT OF VHAP/VOC EMISSIONS

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Department of Chemical Engineering
Box 7905, Raleigh, NC 27695

Volatile organic compounds (VOCs) and other hazardous air pollutants (HAPs) are present in currently used coatings in the furniture and other industries. Many of these compounds are either direct or indirect health threats: VOCs are ozone precursors and may be designated as toxic. Driven by the Clean Air Act Amendments of 1990, VOCs and HAPs in coatings are being reduced, thereby reducing emissions of ozone precursors and toxic compounds from painting operations. While solvent substitution has allowed compliance relative to HAP emissions, total VOC reduction through removal of organic solvents from coating has met with little success, so implementation of control technology appears to be the most promising long-term solution.

In the MBT system, VOCs are first separated from the air stream, concentrated, then completely metabolized by microorganisms. Selective removal and concentration of VOCs from the exhaust stream enables a tremendous reduction in volume directed to the final control device, dramatically reducing equipment costs. Furthermore, uncoupling of the process for VOC destruction from that for removal of VOCs from the air allows for independent optimization of each process. The system involves the use of microporous hollow fiber membrane contactors to mediate the extraction and concentration of VOCs from the air into an organic stripping fluid and to provide a physical support for degradative microorganisms. A schematic of the Membrane BioTreatment (MBT) System is given in Figure 1.

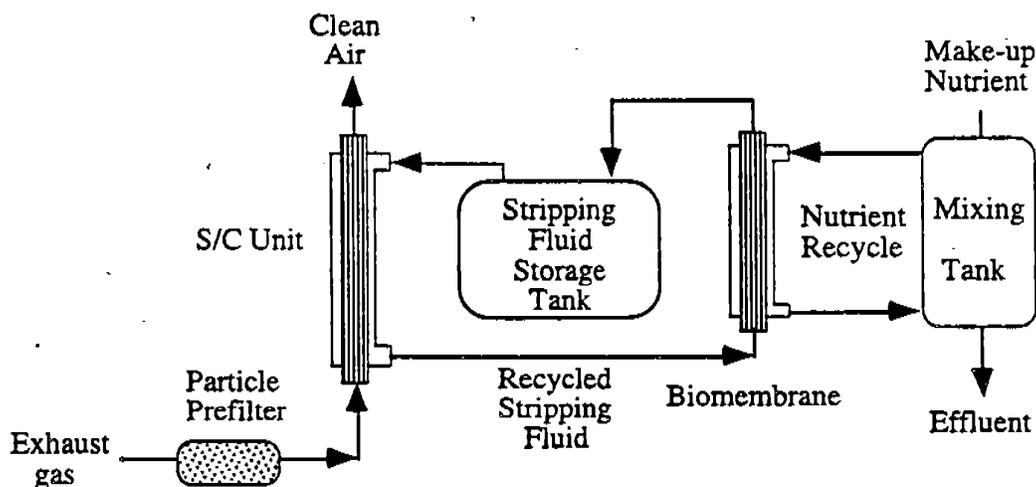


Figure 1: MBT Process Schematic

Exhaust gases laden with VOCs first pass through a particle filter which removes solid particles and residual atomized droplets of coatings or solvents. Next, the gases enter a membrane separation/concentration (S/C) unit. This unit employs bundles of microporous hydrophobic fibers, such as Hoechst Celanese's polypropylene Celgard membrane material. In the S/C unit,

vaporized hazardous air pollutants (HAPs) and VOCs are transferred from the exhaust gases into a stripping fluid medium (potentially octanol, mineral oil, sunflower seed oil, etc...) as shown in Figure 2 (dark particles are VOCs). The stripping fluid will be chosen to have low volatility, low water solubility, and high (fluid/air) partition coefficient for the VOCs. The medium serves as a pollutant sink and allows accumulation of significant HAP/VOC concentrations.

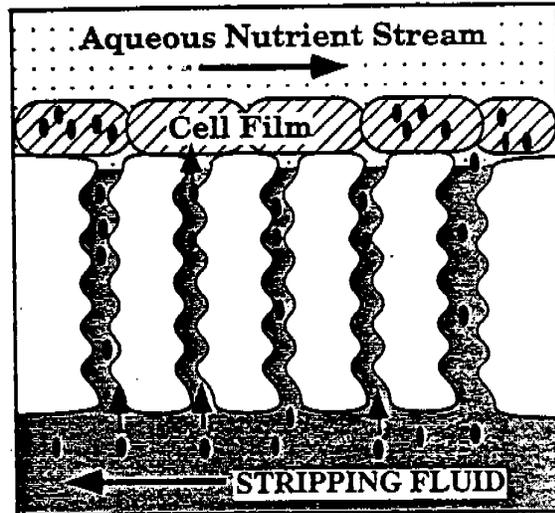
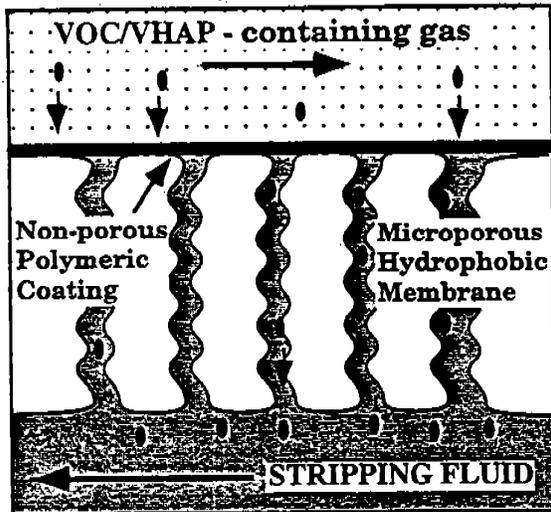


Figure 2: VOC extraction in the S/C Unit Figure 3: Bioextraction of VOCs

Upon exiting the S/C unit, the stripping fluid is delivered to a biomembrane unit. There, the stripping fluid will be circulated past one side of another microporous membrane with VOC-degrading bacteria in a film on the opposite side of the membrane. VOCs will diffuse through the membrane pores (filled with organic stripping fluid) and be selectively and completely metabolized by the bacteria, as shown in Figure 3. The solvent is then collected in a storage vessel, and ultimately recycled through the S/C unit. Outputs from the overall MBT System are clean air, carbon dioxide, and a mixture of water and non hazardous cell mass.

MBT offers unique advantages that are due to the nature of the control technology and the impact of implementation on coating operations. Advantages include the following:

- **High VOC destruction:** Naturally occurring bacteria consume pollutants as food for growth and energy.
- **Non-Pollutant Generating Process:** MBT generates no hazardous by-products.
- **Optimized Rates of Removal and Degradation:** Having separate processes for removal and destruction of pollutant compounds allows each to be designed and operated for maximum efficiency. Equipment size is also minimized under these conditions.
- **Adaptability:** MBT is fully adaptable to individual sites. S/C units are modular in nature which allows the pollutant removal process to be tailored to site-specific operating methods and regulatory permit requirements. Selection and optimization of suitable microorganisms ensures effective degradation of site-specific HAPs and VOCs.
- **Extended equipment life:** The operating life of the membrane units is estimated to be at least seven years. Each module of the S/C units may be changed on an individual basis. Also, extra modules may be built into the system and/or kept on-site to make replacement easier.
- **Operating flexibility:** Some coating operations are single shift, resulting in 8 hours of waste generation followed by 16 hours of down time. The storage tank uncouples waste

generation from biotreatment, allowing the biotreatment process to operate continuously, at optimal levels, independently of spray booth schedules.

- **Cost Effective Treatment:** Estimates indicate that this system will be significantly less expensive than other typical VOC control systems to install and operate.

MBT System Development

The MBT development project began December 15, 1995. Four furniture companies provided financial support for a feasibility study of the MBT process for treatment of VOC and HAP emissions from furniture finishing operations. For initial feasibility studies, experimental objectives were divided into two categories; mass transfer and biological degradation. Membrane mass transfer studies were conducted utilizing Hoechst Celanese Liqui-Cel[®] microporous hydrophobic hollow fiber modules and test apparatus. Biological degradation experiments were conducted with naturally occurring microorganisms isolated from soil samples removed from a site contaminated with gasoline.

a. Biological Experiments

Using a mixed consortium of organisms isolated in liquid culture from soil samples (removed from a site exposed to gasoline), model compounds from each of the represented species in furniture exhaust gases were examined for degradability. Compounds that have been successfully biodegraded are shown in Table 1. Following completion of these initial studies, organism subcultures were generated for specific compounds. By enrichment of the initial gasoline consortium with isobutyl acetate (IBA), methanol (MeOH), methyl ethyl ketone (MEK), methyl isobutyl ketone (MIBK), *meta*-xylene, and *para*-xylene in individual flasks, cultures capable of degrading each compound were developed.

Acetone	Benzene
n-Butyl alcohol	Diethylene glycol ethyl ether (DEGEE)
Ethanol	2-butoxyethanol (BOE)
Formaldehyde	Isobutyl isobutyrate (IBIB)
Isobutyl alcohol (IBA)	Methyl n-amyl ketone (MAK)
Methyl ethyl ketone (MEK)	Styrene
Methanol	Toluene
Methyl iso-butyl ketone (MIBK)	<i>m</i> -Xylene
<i>o</i> -Xylene	<i>p</i> -Xylene

Table 1: Compounds Successfully Biodegraded

Pure cultures were established on *meta*-xylene, designated mx-2, on *para*-xylene, designated px-2, and on DEGEE. Other consortia which grew on IBA, MEOH, MEK, MIBK, BOE, IBIB or MAK consisted of approximately three different strains each.

b. Partition Coefficient Experiments

The partition coefficient is defined as the ratio of concentrations of a given compounds in two phases at equilibrium. Before beginning work with Liqui-Cel[®] membrane modules, partition coefficient experiments were performed to investigate the equilibrium distribution of *m*-xylene, MEK, and MIBK between phases for stripping fluid/air and stripping fluid/aqueous systems. Octanol was chosen as the stripping fluid because data from previously conducted studies was readily available for comparison. Values of the partition coefficient at different temperatures are given in Table 2.

Temperature	Partition Coef.. [oct]/[air]			Partition Coef. [oct]/[water]		
	m-xylene	MEK	MIBK	m-xylene	MEK	MIBK
6 °C	9,865	2,181	∞	NA	NA	NA
22 °C	7,978	1,634	22,045	NA	NA	NA
31 °C	7,703	1,344	8,721	1,021	33	2.1

Table 2: Partition Coefficient Values

An additional set of experiments was run to evaluate stripping fluids other than octanol. This was due mainly to the relatively high cost of commercially available octanol. Partition coefficients were determined for m-xylene in several natural oils at 31°C. Those examined were corn oil, sunflower seed oil, and mineral oil, and partition coefficients were 8283, 8244, and 7284 respectively. These results were comparable to those for octanol. The purchase cost of these oils is roughly one quarter that of octanol.

c. Membrane Separation Experiments

A membrane separation system was constructed which allowed contacting of a m-xylene laden air stream with octanol inside a Liqui-Cel® hollow fiber module. Octanol was passed through the unit's shell space while air flowed through the fibers. The two phases were contacted in counter current cross flow. The octanol reservoir was run in recycle while air was allowed only a single pass through the system. Air flow rates were varied between 10 and 40 liters per minute, resulting in a minimum gas/membrane contact time of 0.004 seconds. The pressure drop across the membrane unit ranged from 0.5 to 2.0 psi, and the surface area available for mass transfer was 1.4 square meters.

Using the following equation, the membrane surface area, A_m , required to perform a defined separation, or the mass transfer coefficient, K_o , (for a known area) may be calculated. The subscripts A and O denote membrane unit air and solvent phases, the superscripts 1 and 2 represent inlet and outlet conditions, respectively. P is the air/octanol equilibrium partition coefficient of m-xylene, and Q is the volumetric flow of the respective phases.

$$A_m = \frac{\ln \left[\left(\frac{C_A^2}{P} - C_O^2 \right) + \left(\frac{C_A^1}{P} - C_O^1 \right) \right]}{K_o \left(\frac{1}{Q_o} - \frac{1}{Q_A P} \right)}$$

Using a conservative estimate for the m-xylene partition coefficient, $P_{air/oct} = 0.00014$, for the air/stripping fluid separation unit, it was determined that $K_o = 8.2 \times 10^{-6}$ cm/sec for fibers that were not coated with the polymeric film, and that values as high as $K_o = 2 \times 10^{-4}$ cm/sec could be attained with coated fibers. Similarly, for the biomembrane unit, it was determined that $K_w = 6.5 \times 10^{-3}$ cm/sec.

MBT System Configuration

MBT system implementation is anticipated to have the following basic configuration:

- One S/C unit, containing several membrane modules in an exhaust gas manifold, per booth. Each S/C unit would be serviced by one stripping fluid pump.

- Each S/C unit is operated independently. When a booth is inactive, the stripping fluid pump is off, isolating the particular S/C unit from the rest of the system.
- Stripping fluid is pumped to a central biotreatment unit, consisting of several membrane modules, in a temperature regulated enclosure with a footprint of approximately 250 - 500 square feet.
- Stripping fluid is then pumped to a storage tank, with tank volumes in the 50,000 to 250,000 gallon range.
- The system will be controlled automatically through an operator station. Data collection and bioprocess monitoring is performed continuously.
- Aqueous nutrient salt solutions are made up on site (in the biotreatment unit enclosure) from pre-mixed powders.

MBT System Field Trial

A preliminary field evaluation of the MBT system will take place at the Pulaski Furniture Plant in Pulaski, VA. The field evaluation is scheduled to begin in late fall, 1997. The unit will process 1,000 CFM of exhaust gas taken from the plant's central trunk line. The duration of the test will be six weeks. Following test completion, the unit will be relocated to the US EPA Coatings Laboratory at Research Triangle Park, NC for further pilot-scale evaluation.

MBT System Cost Analysis

Full scale MBT System costs were estimated utilizing a method developed by the US EPA's Office of Air Quality Planning and Standards and published in the *Cost Control Manual*. Because actual component costs necessary for full scale cost estimation under the EPA method are not available for the MBT System, these costs were estimated from two engineering economics textbooks: Ulrich, Gael. *A Guide to Chemical Engineering Process Design and Economics*, Wiley. New York, 1984. and Peters and Timmerhaus. *Plant Design and Economics for Chemical Engineers, 4th ed.*, McGraw Hill. New York, 1991. Costs obtained from these sources were inflated to December 1996 dollars using a ratio of CE indices prior to being imported into the OAQPS method spreadsheets. The spreadsheets calculated total capital investment and total annual costs for two plant air flow and VHAP/VOC loading conditions. A brief summary of the results for MBT Technology is presented below.

95% VHAP/VOC removal from exhaust air streams for both cases.

Case 1: 8,450 m³/min with a total VOC concentration of 330 mg/m³ at 25 C and 101.3 kPa. 327 MG/yr VOC.

Total capital investment:	\$2,880,000
Total annual cost:	\$691,350
VOC cost effectiveness	\$2,225/MG

Case 2: 5,700 m³/min with a total VOC concentration of 420 mg/m³ at 25 C and 101.3 kPa. 273 MG/year VOC.

Total capital investment:	\$1,806,700
Total annual cost:	\$440,000
VOC cost effectiveness:	\$1,700/MG

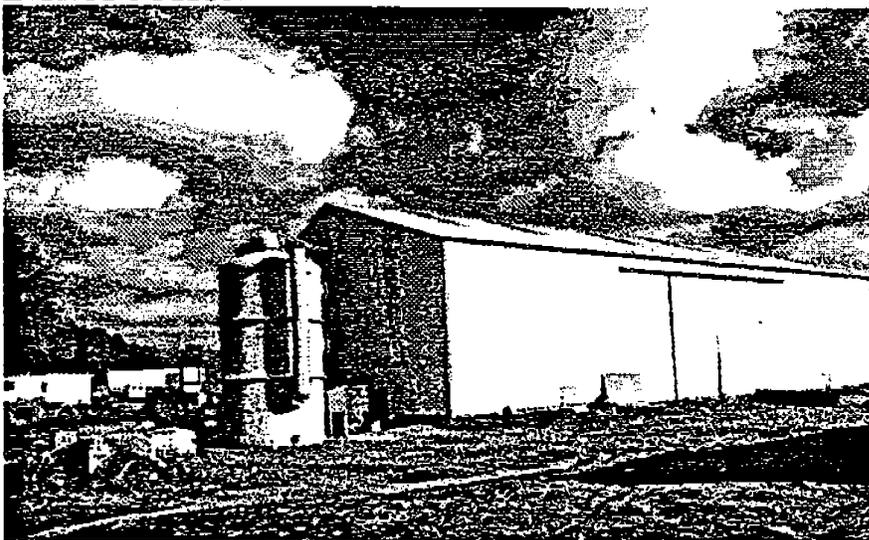
Presented at the 1997 Air Biotreatment Meeting--US EPA_NC
a government/industry/academia partnership: Research Triangle Park, NC 27711

PILOT BIOFILTER DEMONSTRATION FOR STYRENE AND METHYL ETHYL KETONE EMISSIONS

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501 Greene St. Suite 400 / Augusta / Ga / 30909

ABSTRACT: This project is a technology demonstration to establish the biofilter technique as a cost effective method of removing airborne volatile organic compounds (VOCs). The Biofilter was designed by Delphinus Engineering, Aiken, SC, and was installed and operated at Augusta Fiberglass Coatings in Blackville, SC. The primary VOC of concern at this facility is styrene, a toxic gas emitted by fiberglass reinforced plastic manufacturing. The system was designed to remove mainly styrene from the airstream from the Pipe Assembly Building. The biofilter has also proved capable of removing methyl ethyl ketone (MEK). Results from the demonstration have shown that the effluent generally remaining below 7 ppm of styrene. The average styrene influent is 200 ppm. The project has demonstrated a reliable and inexpensive method for removing low levels of VOCs.

INTRODUCTION



Several technologies are currently being used to reduce VOC emissions. These technologies include vapor scrubbing, thermal oxidation, catalytic oxidation, carbon adsorption, UV oxidation, corona destruction reactors, plasma technologies devices, and biofiltration. The first four are the mature technologies that have been proven effective at reducing VOC air emissions. The latter are newer technologies that are still being tested as to their effectiveness. The technique described and discussed here is a field-pilot biofiltration demonstration used to reduce styrene, methylene chloride and MEK air emissions.

Biofiltration can be widely applied to control

FIGURE 1: Biofilter at Augusta Fiberglass Coatings site.

VOC emissions from industrial and commercial sources, wastewater treatment plants and soil and groundwater remediation operations. Biofiltration is an air pollution control technology that cleans contaminated air as it passes through one or more beds of a selected media. VOCs are transported from the gas phase to the biofilm on the compost matrix and degraded to CO₂ and H₂O by the microorganisms in the biofilm. Cost analyses have shown that biotreatment of industrial waste gases containing VOCs is potentially 2 to 10 times less expensive than thermal oxidation or catalytic oxidation, 10 to 40 times less expensive than adsorption to activated carbon and 4 times less expensive than traditional scrubbing (Salemink, R., 1991 and Dharmovaram, S., 1991). Furthermore, vapor scrubbing and carbon adsorption techniques require further processing of volatile organic carbons to oxidize them to CO₂ and water.

Under a contract from Southeastern Technology Center (STC), Delphinus Engineering, Inc. is performing a technology demonstration for biofiltration of volatile organic compounds released from a production building at Augusta Fiberglass Company (AFC). STC promotes a technology transfer / deployment program funded by the Department of Energy (DOE).

The objectives of the pilot demonstration described here are:

- measure the biodegradation rate of compost microorganisms stimulated by styrene to determine the efficiency of the process,
- determine the major parameters that effect the biofiltration system and the consequences of long-term shut down of the fiberglass manufacturing process,
- determine the efficiency of the biofilter process when it is compared with other air emission reduction technologies, and

SITE DESCRIPTION

AFC is a commercial fiberglass production facility located in an industrial zone outside the city of Blackville, South Carolina. The site is comprised of approximately 168 acres of land and includes 15 production buildings, an administrative structure, and several storage buildings. The biofilter, Figure 1, has been constructed alongside the Pipe Assembling Building (PAB), a 60 ft. by 100 ft. (18m x 30m) building used to complete the construction of smaller specialty fiberglass items. AFC has complied with air emissions regulations, and mass balance calculations show styrene, methylene chloride and methyl ethyl ketone emissions at the PAB of 1.142 lb/hr (518 g/hr), 0.347 lb/hr (157 g/hr), and 0.095 lb/hr (43 g/hr), respectively.

TREATABILITY STUDY: SET-UP AND RESULTS

A treatability study was conducted to optimize biofilter media composition and styrene removal efficiency. Samples of the PAB exhaust were collected for VOC analyses using hand-held portable pumps and absorbent tubes; laboratory analyses of these samples show that styrene is the major VOC emission from the PAB. Based on these results, the biofilter treatability study was configured using only styrene as the VOC influent.

The dimensions of the treatability bioreactor were 6 inches (15.2 cm) diameter with a 4 foot (121.9 cm) bed height. The styrene inlet flow rate varied from 0.5 to 2 scfm. The selected media that presented best removal efficiency was chicken compost

and granular activated carbon (GAC) in a 2:1 ratio. Removal efficiencies using flow rate of 2 scfm are listed in Table 1. Different loading rules were used for each run in order to check percentage removal of varying influent styrene concentrations.

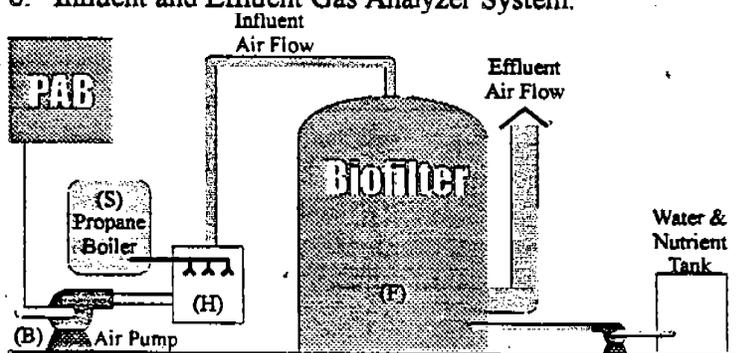
Table 1: Styrene Removal Pilot Experiment, 8/19/96 to 9/17/96

Influent (Relative ppb)	Effluent (Relative ppb)	% Removal
125200	4400	96.46
421250	1192	99.72
913520	50	99.99
203000	1700	99.16
130000	174	99.92
147700	0	100.00
2700	127	95.30
1141100	16840	98.52
354400	58870	83.39
410400	52240	87.27
877600	121800	86.12
1194000	214720	82.02

PROJECT DESIGN AND DESCRIPTION

The process flow diagram for the biofiltration system in operation at AFC is illustrated in Figure 2. The biofiltration system consists of the following major sub-systems / equipment and components:

1. Blower System (B);
2. Steam Generating Boiler (S) and Humidifier(H);
3. Bio-Filter Vessel (F);
4. Utility Supply System;
5. Instrumentation and Control System, and
6. Influent and Effluent Gas Analyzer System.

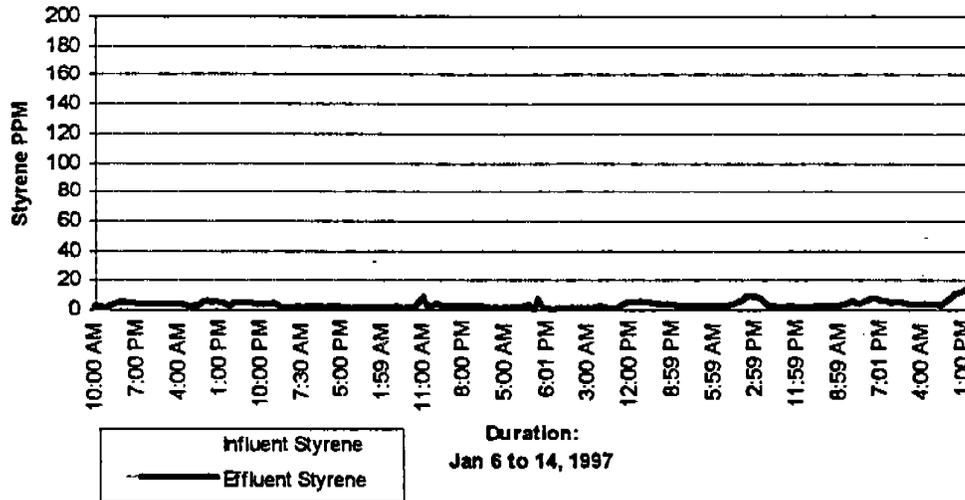


The biofilter system was placed on a reinforced concrete foundation and is connected to the PAB with Poly Vinyl Chloride (PVC) piping. The air pump (B) is a positive displacement blower that, with silencers, exhausts the building air stream through the biofilter tank. The blower system operates at approximately 1,000 scfm, resulting in a water column pressure drop across the biofilter bed in the range of 20" to 30". The biofilter system includes a propane fired boiler (S) providing steam to heat and humidify the influent air stream, and an automatic moisture system providing water and/or nutrients to the compost biofilter media via a series of spray nozzles in the tank. The average relative humidities (RH) of the air entering the biofilter bed is 38% and averages 85% leaving the biofilter.

The biofilter vessel is a fiberglass tank, 18 ft. high by 9 ft. diameter (5.5 m x 2.7 m), that was designed and manufactured by AFC. Analyses of the compost indicated a high percentage of nitrogen

FIGURE 2: Biofilter Process Flow Diagram

and phosphorus and a neutral pH. The selected GAC is a particle size of 5 to 10 mesh and, once mixed with the compost, is in two layers 4 feet (1.22 m) thick in the biofilter. The Instrumentation and Control System provides data on humidity and temperature, controls the steam and water injection to the biofilter, and the humidity and temperature of the influent and effluent biofilter flow.



A Bruel and Kjaer Model 1302 Infrared Photoacoustic Spectrometer (IRS) gas analyzer is used to analyze the influent and effluent concentrations of VOCs. The IRS is calibrated for styrene, methylene chloride, MEK, carbon dioxide, and water vapor, with a full set of measurements recorded every 30 minutes. Analyses of the effluent carbon dioxide concentrations will provide the aerobic respiration rate of the microbial population. The biofilter system has been automated to the point that trips to the site are made primarily to download data from the gas analyzer. The IRS has been used to gather data for the performance goals portion of the project, with the understanding that once the project is completed and the filter enters permanent operation, the IRS will be removed. The biofilter demonstration has shown that this technique requires lower maintenance cost than the other air emission control techniques.

RESULTS

Figure 3 is a chart of the IRS analyzer data showing styrene levels into and out of the biofilter for a normal week of operations at AFC. This chart shows styrene levels peaking at 200 ppm on the biofilter inlet and an outlet concentration that generally remains below 7 ppm. Styrene levels in the influent vary considerably due to the variations in the amount of work being performed in the building, but the effluent styrene levels remain consistently low.

The inlet concentrations of methylene chloride and MEK have been negligible and the performance of the biofilter has been addressed only in terms of styrene removal efficiency.

FIGURE 3: Styrene Levels Recorded over a Standard Week at AFC

FIGURE 4: Styrene Elimination Rates over the Sample Test Period

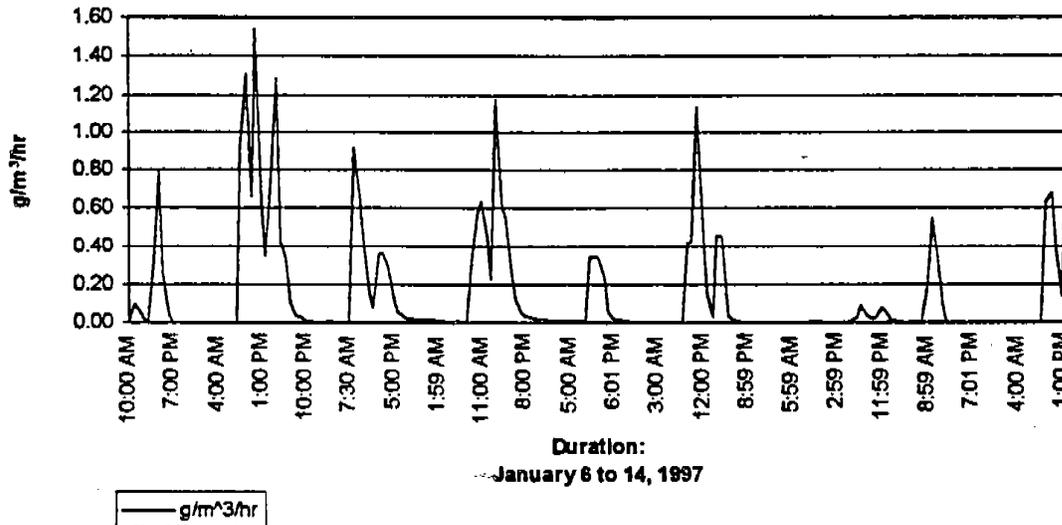


Figure 4 reflects the elimination rates of the biofilter bed for styrene using the data plotted in Figure 3. The elimination rates are calculated using the following equation:

$$E_R = (C_{in} - C_{out}) \cdot Q/V$$

Where E_R = elimination rate, g/m³/hr

Q = flow rate, m³/hr

C_{in} = influent gas phase pollutant concentration, g/m³

C_{out} = effluent gas phase pollutant concentration, g/m³

V = volume of the bed material, m³

CONCLUSIONS AND RECOMMENDATIONS

The results of this successful field-pilot biofilter demonstration provide strong support for the use of biofilters to treat plant styrene emissions. Because of the short duration of the project, some of the pilot demonstration goals could not be addressed at this time. The project commenced with contract award in June of 1996, construction was completed in August, and startup of operations in October of 1996. As of mid January, 1997, bed acclimation has been accomplished, and significant performance data have been acquired.

Data from the treatability study and the CO₂ effluent concentrations recorded by the IRS for the pilot technology demonstration support the biodegradability of styrene in this demonstration. The efficiency of the process in terms of a calculated biodegradation rate will be determined at the end of the demonstration. The biodegradability of styrene

has been well documented; intrinsic biodegradation rates from bench-scale biofilter for styrene has been in the range of 9 to 35 μg styrene per hour per mg dry weight (Togna, et al., 1992)

Figures 3 & 4 show that a steady-state effluent concentration was obtained and that acclimation of the bed was reached. It seems that the large fluctuations in the VOC mass loading due to changes in the manufacturing process is not adversely affecting the biofilter performance.

The efficiency of the biofilter process when compared with other air emission reduction technologies has been already demonstrated in this project. Traditional air pollution control technologies have been known to be too costly and, in some cases, not capable of treating low concentration VOCs. Conversely, biofiltration is both cost effective and provides treatment of low concentration VOCs.

The demonstration project has proven itself so well that AFC has requested that the biofilter remain in operation at the completion of the demonstration and become a permanent addition to their continuing program of environmental responsibility.

COST

Cost analyses for this system have not been finalized. The total estimated cost ranges from \$134,725.26 to \$250,000.00.

REFERENCES

Dharmavaram, S., 1991. "Biofiltration - A Lean Emissions Abatement Technology", 84th Annual Air & Waste Management Association Meeting and Exhibition, Vancouver, British Columbia

Salemink, R., 1991. "Technical and Economic Comparison of VOC Control Techniques" Vendor Literature - Clair Tech b. v., PO Box 8022, 3503 RA Utrecht, The Netherlands

Togna, A. P. & Folsom, B. R. 1992. "Removal of Styrene from Air Using Bench Scale Biofilter and Biotrickling Filter Reactors" 85th Annual Air & Waste Management Association Meeting and Exhibition, Kansas City, MO

APPENDICES

Table 1.

Table 2.

Table 3.

**US EPA Quality Systems Documents
Title 15: Metric Conversion
List of Registered Participants**

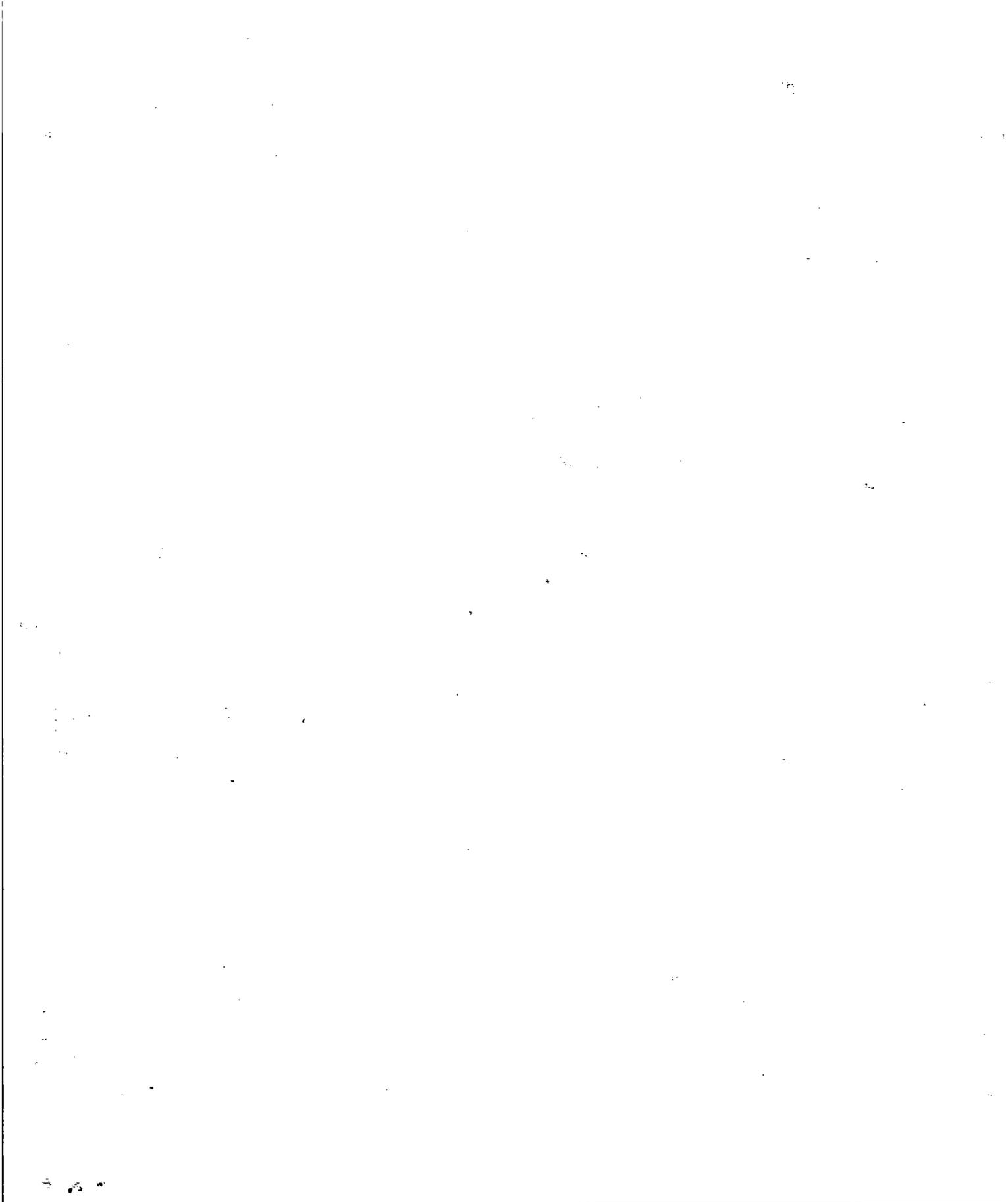


TABLE 1: CASE STUDIES, INFORMATION

The size and cost of a bioreactor system should be determined by utilizing a mixture of two aliphatic in *equal proportions* (isobutyl acetate and methyl ethyl ketone) and one aromatic (m-xylene) compound. The split should be 80% aliphatic to 20% aromatic by mass. These two groups of compounds are prevalent in wood furniture emissions and emissions from aerospace finishing.

Calculate the cost for the following air flows, concentrations, and control efficiencies.

-Condition No. 1:

8,450 m³/min (300,000 CFM) with a total VOC concentration of 330 mg/m³ at 25 C and 101.3 kPa.

-Condition No. 2:

5,700 m³/min (200,000 CFM) with a total VOC concentration of 420 mg/m³ at 25° C and 101.3 kPa.

-Control Efficiencies: 81% and 95%

(Control = Capture x Destruction)

For size and cost calculations, the pollutants should be in the proportions indicated above.

NOTE: Aliphatics generally present in wood furniture and aircraft emissions include, isobutyl acetate; alcohol (methanol, ethanol, isopropanol, butanol); ketones (methyl isobutyl ketone, methyl n-butyl ketone, methyl ethyl ketone, methyl isoamyl ketone); 2-butoxyethanol.

The OAQPS Method for calculating equipment cost and annual cost is outlined in *Attachments 4 and 5*. Additional information may be found in the OAQPS Control Cost Manual, Fourth Edition EPA 450/3-90-006; US EPA, OAQPS, RTP, NC 27711. January 1990. Contact person Bill Vataavuk (919) 541-5309.

Cost Index

The CE index for December 1996, 382.3, should be used to determine the purchased equipment cost.

Labor Cost: Use \$23.1/hr.

Bioreactor Lotus Cost Spreadsheet

For your convenience, a spreadsheet for performing the cost- calculations is included. The spreadsheet was prepared by Mr. Robert Shepherd of North Carolina State University. The file name is `mgcost.zip`. The appropriate values should be entered in the boxed area of the spreadsheet.

Cost Effectiveness Values

Provide in a table the VOC and HAP cost- effectiveness values and the purchased equipment

cost determined for the above conditions of control efficiency, flow rate, and mass concentration of pollutant.

Units

The Metric units are the *primary* units for the purpose of this meeting. A presenter may include English units in the tables or in the written text as follows: 10 cm (4 inches).

end of Table 1

TABLE 2. OAOPS Capital Cost Determination Method
(Cp = equipment cost)

Item	Cost
Direct Costs	
Purchased equipment costs:	
Equipment (EC) + auxiliary equipment	Cp
Instrumentation	0.10 x Cp
Sales taxes	0.03 x Cp
Freight	0.05 x Cp
Purchased equipment cost, PEC	PEC = 1.18 x Cp
Direct installation costs:	
Foundations and supports	0.08 x PEC
Handling and erection	0.14 x PEC
Electrical	0.04 x PEC
Piping	0.02 x PEC
Insulation for piping and duct work	0.01 x PEC
Painting	0.01 x PEC
Direct installation cost	0.30 x PEC
Total Direct Cost, TDC	1.30 x PEC
Indirect Costs (installation)	
Engineering	0.10 x PEC
Construction and field expenses	0.05 x PEC
Contractor fees	0.10 x PEC
Start-up	0.02 x PEC
Performance test	0.01 x PEC
Contingencies	0.03 x PEC
Total Indirect Cost, TIC	0.31 x PEC
Total Capital Investment, TCI = TDC + TIC	1.61 x PEC

end of table 2

TABLE 3 : OAOPS Annual Cost Determination Method

Item	Cost Factor	Cost(\$/hr)	Total
Plant Operation:			
Equipment Lifetime:	10		
Interest Rate:	7		
Capital Recovery Factor: (based on assumed 10 yr life)	?		
Replacement Parts:	10%/yr		
Utility Requirements:			
Natural Gas (m3/yr):	?		
Electricity (KW-Hr):	?		
Steam (kg/yr):	?		
Cooling Water (L/yr):	0		

Item	Cost Factor	Cost/Yr
Direct Costs		
Operating labor		
Operator	0.5 hr/shift x labor-\$ x shift/yr	
Supervisor	15% of Operator	
Maintenance		
Labor	0.5 hr/shift x labor x shift/yr	
Supervisor	15% of labor	
Materials	100% of labor	
Replacement Parts (% system replaced/yr)	10	
Utilities		
Natural Gas (\$/1000 m3)	99.6	
Electricity (\$/KW-Hr)	0.041	
Steam (\$/1000 kg)	9.24	
Cooling Water (\$/1000)	0.092	

end of table 3

**US EPA QUALITY SYSTEM
REQUIREMENTS DOCUMENTS**

STATUS REPORT - MAY 1997

EPA QA/R-1 EPA Quality Systems Requirements for Environmental Programs

QA/R-1 is the external policy document by which EPA will announce its implementation of the American National Standard ANSI/ASQC E4-1994, *Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs*. An internal preliminary draft has been completed and is awaiting formal adoption of the standard by EPA. The same information will be part of the EPA *Quality Manual for Environmental Programs*, an internal policy manual. When E4 has been formally adopted by EPA, the draft will be distributed for comment. Target Availability: External Draft, Summer 1997.

EPA QA/R-2 EPA Requirements for Quality Management Plans

QA/R-2 is the policy document containing the specifications and requirements for Quality Management Plans (QMPs) for organizations with which EPA has extramural agreements. An Interim Final version is awaiting Agency approval for release and is expected to be available for public comment and use shortly. QA/R-2 is the intended replacement for QAMS-004/80. The same information contained in this document is found in the EPA *Quality Manual for Environmental Programs*, an internal policy manual. Current Draft Version: August 1994. Target Availability: Final, Summer 1997.

EPA QA/R-2A EPA Requirements for Quality Management Plans for Analytical Laboratories and Facilities

QA/R-2A will provide detailed requirements for environmental analytical labs. Since there may be a national consensus standard for labs, the content of this document is unclear at present. This is still a planning item. Target Availability: Undetermined

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