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ENHANCED BIOFILTRATION OF TOXIC ORGANICS IN OFF-GAS STREAMS

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December 1995

Citation for this report should read as:

GASReP - Groundwater and Soil Remediation Program. Unpublished Report, No. 9284A. (1995). "Enhanced Biofiltration of Toxic Organics in Off-Gas Streams", 64p.

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ACKNOWLEDGEMENTS

The GASReP manager acted as scientific authority for the project entitled "Enhanced Biofiltration of Toxic Organics in Off-Gas Streams".

Environment Canada's Burlington Environmental Technology Office managed and co-funded the project. Other co-funders were:

Supply and Services Canada, Environmental Innovation Program (EIP)
Environment Canada, Industrial Programs Branch

December 1995

SOMMAIRE À L'INTENTION DE LA DIRECTION

Au cours des années passées, des pratiques inadéquates de manipulation de l'essence et des solvants ont entraîné la contamination des sols par des composés organiques volatils (COV). Laissés à eux-mêmes, ces COV peuvent éventuellement migrer et contaminer les approvisionnements en eaux souterraines. Il est donc très important d'assainir rapidement ces sols à l'aide de méthodes efficaces. Le présent rapport souligne l'utilité, à cette fin, de populations de microorganismes dégradant les COV, fixées dans un système de biofiltration. La biofiltration est une technique peu coûteuse dont on peut envisager l'utilisation pour remplacer ou compléter le traitement thermique ou l'adsorption sur charbon activé.

La biofiltration est une technologie de réduction de la pollution atmosphérique qui utilise des microorganismes immobilisés sur un milieu filtrant comme l'écorce, le compost, le sol ou la sphaigne pour dégrader les gaz polluants en eau, en dioxyde de carbone et en d'autres constituants inorganiques. Un courant gazeux contaminé passe à travers le biofiltre, ce qui permet aux contaminants de s'adsorber sur la pellicule liquide imbibant le milieu. Les microorganismes biodégradent ensuite les contaminants adsorbés, puis la biopellicule microbienne est ensuite régénérée. Les contaminants organiques peuvent aussi servir de source de carbone pour la croissance microbienne.

On a effectué plusieurs études en laboratoire pour étudier la biofiltration des COV. Dans la plupart des cas, on ne peut retracer facilement le plan d'ensemble et les conditions expérimentales de ces études. De plus, l'application à l'échelle réelle de résultats obtenus en laboratoire comporte une certaine incertitude. On a signalé des résultats à l'échelle réelle, mais ceux-ci ont généralement été obtenus avec des systèmes brevetés pour lesquels on ne dispose que d'une documentation limitée. De plus, les techniques de surveillance du rendement soutenu étaient souvent limitées. On a donc mis en évidence une carence en données de biofiltration bien étayées pouvant servir à l'étude de la capture des COV. La présente étude était destinée à documenter le rendement soutenu à l'échelle pilote et à repérer les difficultés présentées par le passage des études en laboratoire aux opérations à l'échelle réelle.

Le plan expérimental initial de conception et d'utilisation du biofiltre à l'échelle pilote employé pour cette étude a été basé sur un examen de la documentation publiée. Certains paramètres, notamment la quantité d'eau supplémentaire requise, ne sont pas bien définis dans la documentation. D'après certains ouvrages, l'humidification du seul courant d'air d'entrée suffisait et selon d'autres, il fallait rajouter de l'eau, mais les volumes variaient selon les auteurs.

Le biofiltre à l'échelle pilote a fonctionné d'octobre 1993 à janvier 1995. Les composés intéressants étaient le benzène, le toluène, l'éthylbenzène et les xylènes (BTEX). Le milieu utilisé comme biofiltre (0,9 m^3) était placé dans un contenant en fibres de verres de 1,4 m^3. Le milieu était constitué par un compost de feuilles et de déchets de jardin mélangés à de la perlite et à des copeaux d'écorce. Le courant d'air d'entrée était chauffé, humidifié et contaminé avant son injection dans le contenant rempli de milieu. Le taux de charge organique total était compris entre 16 et 22 g/(h·m^3) (calculé d'après le volume du lit vide) et les temps de rétention des gaz, entre 38 et 136 secondes (également calculés d'après le volume du lit vide). On a utilisé les canalisations servant au prélèvement des échantillons gazeux pour mesurer les concentrations de contaminants à l'entrée et à la sortie, ainsi qu'à trois profondeurs différentes dans le lit bactérien.

L'objectif global de l'étude était d'effectuer une analyse technique du procédé afin de définir les caractéristiques et les contraintes des techniques de biofiltration appliquées au traitement d'émanations gazeuses contenant des BTEX, libérées par des opérations d'évacuation des gaz du sol. Les objectifs spécifiques de l'étude étaient les suivants :

- documenter les taux de capture soutenue des BTEX, obtenus en milieu contrôlé et dans des conditions expérimentales bien définies;

- évaluer l'incidence des principaux paramètres de conception et de fonctionnement (par exemple, le taux de charge organique et le taux de charge volumétrique, ainsi que les vitesses d'addition des substances nutritives et de l'eau supplémentaire) sur les valeurs d'efficacité de la capture et

- déterminer les valeurs optimales de ces paramètres.

On a tiré les conclusions suivantes de l'étude :

- D'après le plan initial, on humidifiait le courant d'air d'entrée pour maintenir les conditions d'humidité requises dans le milieu (40 - 60 %) pour la biodégradation. Toutefois, la seule humidification du courant d'air était insuffisante pour maintenir les conditions d'humidité souhaitées à un taux de charge organique de 22 g/(m^3·h).

  Il était indispensable d'ajouter une quantité d'eau supplémentaire au biofiltre. Vers la fin de l'étude, on pouvait maintenir des valeurs d'efficacité de capture des contaminants dépassant les 80 % pendant des périodes de 26 et 42 jours en surveillant l'addition de substances nutritives et d'eau supplémentaire. Pendant ces périodes, les concentrations des émanations gazeuses étaient inférieures à 20 µg/L pour chaque composé.

- La régulation de l'humidité du milieu était le paramètre de fonctionnement critique influant sur l'efficacité de la capture des contaminants. La capture du xylène était très sensible à la réduction du taux d'humidité du milieu. Si on laissait le milieu devenir trop sec, il devenait hydrophobe et l'addition d'eau supplémentaire ne parvenait pas à lui redonner la plage d'humidité souhaitée. Il fallait alors broyer mécaniquement le milieu séché avant de le mouiller à nouveau. Un tensiomètre, installé alors que l'étude était déjà en cours, s'est avéré utile comme indicateur du taux d'humidité du milieu et des besoins en eau supplémentaire.

- On a observé que l'addition de substances nutritives augmentait l'efficacité de la capture des contaminants en présence de conditions appropriées d'humidité. L'addition de substances nutritives n'avait pas d'effet si le taux d'humidité du milieu était inadéquat.

- Le rendement du biofiltre n'était pas diminué par des périodes d'inactivité du milieu allant jusqu'à trois semaines.

- En utilisant les données recueillies pendant les périodes de pointe, on a étalonné un modèle cinétique d'ordre zéro et un autre d'ordre un pour la prévision des taux de capture soutenue des contaminants. On peut utiliser ces modèles ajustés pour prévoir l'efficacité potentielle de la capture des contaminants obtenue à l'aide d'un biofiltre à base de compost, en supposant que des conditions appropriées d'humidité et de teneur en substances nutritives puissent être maintenues. Toutefois, ce modèle ne devrait être appliqué qu'à des conditions de fonctionnement semblables à celles utilisées au cours de la présente étude.

Les résultats de l'étude permettent de faire les recommandations suivantes :

- Il est recommandé d'effectuer une étude pour vérifier si des ajustements réguliers apportés au taux d'humidité et à la vitesse d'addition des éléments nutritifs, basés sur des lectures au tensiomètre et des données sur l'efficacité de la capture des contaminants, permettent de maintenir un taux de capture élevé et constant pendant une longue période (p. ex. plus de 60 jours). Vers la fin de l'étude, des valeurs d'efficacité de capture des contaminants dépassant les 80 % étaient maintenues pendant des périodes de 26 et de 42 jours grâce à une stratégie de contrôle semblable. Il n'a pas été possible de poursuivre la démonstration de cette technique à cause de difficultés mécaniques et du manque de temps.

- Il est recommandé d'effectuer une étude d'optimisation après l'étude recommandée ci-dessus. À l'occasion, on a observé des valeurs d'efficacité de capture des contaminants dépassant les 90 %. Cette étude d'optimisation porterait sur les conditions de fonctionnement donnant des valeurs élevées d'efficacité de capture. On pourrait aussi mieux déterminer les incidences de la dose de substances nutritives à ajouter et celles de la composition du milieu. En outre, on a examiné une plage relativement étroite de taux de charge volumétriques et organiques au cours de cette étude. Il est recommandé d'en examiner une plus vaste plage afin ce déterminer les concentrations des effluents qui peuvent être obtenues.

- Il est recommandé d'élaborer, d'étalonner et de vérifier un modèle mécanique et dynamique pour la prévision du rendement d'un biofiltre à compost. Certains modèles existent déjà, mais ils ont généralement été étalonnés avec des données de fonctionnement supposées à l'équilibre.

- Il est recommandé d'effectuer une étude sur l'efficacité de la capture des contaminants avec un courant d'air d'entrée à composition complexe, et notamment renfermant des composés sulfureux. Ces derniers sont fréquemment associés aux courants d'air contaminés par les BTEX. Leur présence peut influer sur la capture des BTEX, surtout à cause de l'acide produit lors de leur oxydation.

- Il est recommandé d'étudier d'autres techniques biologiques de purification des gaz comme l'utilisation de lits bactériens. Dans certaines applications, ces lits présentent des avantages par rapport aux biofiltres. Parmi les avantages possibles, notons une régulation plus facile de l'humidité et une plus faible sensibilité à l'accumulation d'acide pendant le traitement de courants d'air contenant des composés sulfureux.

- On pourrait envisager la possibilité d'utiliser des dispositifs peu coûteux et peu encombrants comme des capteurs capacitifs pour la surveillance du taux d'humidité des milieux.

Enhanced Biofiltration of

Toxic Organics in Off-gas Streams

Prepared for:

Burlington Environmental Technology Office
Environment Canada

by:

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December, 1995

ENVIRΩMEGA

EXECUTIVE SUMMARY

Improper gasoline and solvent handling practices in the past have led to the contamination of soils with Volatile Organic Compounds (VOCs). If left untreated, these VOCs may eventually migrate and contaminate groundwater supplies. Therefore, timely and effective methods to remediate these soils are of great importance. This report focuses on the utility of using fixed populations of VOC-degrading microorganisms in a biofiltration system to destroy the VOCs. Biofiltration offers significant potential as a low cost alternative or supplement to thermal treatment or carbon adsorption.

Biofiltration is an air pollution control technology that utilizes microorganisms, immobilized on a filter medium such as bark, compost, soil or peat, to degrade gaseous pollutants into water, carbon dioxide and other inorganic constituents. A contaminated gas stream is passed through the biofilter allowing contaminants to adsorb to the liquid film on the media. Microorganisms then biodegrade the sorbed contaminants with subsequent regeneration of the microbial biofilm. Organic contaminants can serve as the carbon source for microbial growth.

Several bench scale studies have been conducted to investigate biofiltration of VOCs. In most cases, comprehensive design and operating conditions are not readily available for these studies. In addition, there is uncertainty associated with the application of bench scale results to full scale operation. Results from full scale applications have been reported, but generally proprietary systems were employed with limited design documentation. Sustained performance monitoring was also frequently limited. Thus, a lack of well documented biofiltration performance data for VOC removal has been identified. This study was intended to document sustained performance at pilot-scale and identify scale-up difficulties from bench-scale studies.

The original design and operation of the pilot-scale biofilter employed for this study were based on a review of published literature. Certain parameters, particularly the quantity of supplemental water required, were not well defined by the literature. Some work indicated that humidification of the influent airstream alone was adequate. Other works indicated that supplemental water was required, but differed on the volumes.

The pilot-scale biofilter was operated between October 1993 and January 1995. The compounds of interest were Benzene, Toluene, Ethylbenzene and Xylenes (BTEX). The biofilter media ($0.9 m^3$) was contained in a $1.4 m^3$ fibreglass vessel. The media consisted of a leaf and yard waste compost supplemented with perlite and bark chips. The influent airstream was heated, humidified and contaminated prior to entering the media containment vessel. The total organic loading rate ranged from 16 to 22 $g/(h \cdot m^3)$ (based on empty bed volume) and gas retention times ranged from 38 to 136 seconds (based on empty bed volume). Gas sample lines were used to measure the inlet and exhaust contaminant concentrations and concentrations at three depths within the bed.

The overall objective of the study was to conduct a process engineering analysis to define the attributes and constraints of biofiltration technology when applied to the treatment

of BTEX-laden exhaust gases from soil venting operations. Specific goals were to:

- document sustained BTEX removals achieved under controlled and well defined operating conditions;
- evaluate the impact of the important design and operating parameters (such as organic and volumetric loading rate, and nutrient and supplemental water addition rates) on removal efficiencies; and
- determine the optimal values for these parameters.

The following conclusions are made as a result of this study:

- The original design incorporated humidification of the influent airstream to maintain desired media moisture conditions (40% - 60%) for biodegradation. Humidification of the airstream alone was inadequate for maintaining the desired moisture conditions at an organic loading rate of 22 $g/(m^3 \cdot h)$.

  Supplemental water addition to the biofilter was critical. Near the end of the study, contaminant removal efficiencies exceeding 80% were maintained for periods of 26 and 42 days through control of supplemental water and nutrient addition. During these periods, off-gas concentrations were less than 20μg/L for each compound.

- Media moisture control was the critical operating parameter affecting contaminant removal efficiencies. Xylene removal was most sensitive to reduced media moisture content. Once the media had dried excessively, it became hydrophobic, and supplemental water addition was ineffective at regaining the desired moisture content range. Once dry, the media had to be mechanically broken before re-wetting. A tensiometer, installed part way through the study, was a useful indicator of media moisture content and supplemental water addition requirements.

- Nutrient addition was observed to increase contaminant removal efficiency if appropriate media moisture conditions were present. Nutrient addition had no effect if the media moisture content was inadequate.

- Biofilter performance was not adversely affected for media idle times of up to three weeks.

- A zero and first order model for predicting contaminant removal rates was calibrated to data collected during periods of sustained high contaminant removal. The fitted models can be used to predict potential contaminant removal efficiency from a compost based biofilter, assuming appropriate moisture and nutrient conditions can be maintained. The model should only be applied to operating conditions similar to those used in this study.

The following recommendations are made as a result of this study:

- It is recommended that a study be conducted to verify that regular adjustment of moisture and nutrient addition rates, based on tensiometer measurements and contaminant removal efficiency data, can sustain consistently high removal data for an extended period (i.e. > 60 days). Near the end of the study, contaminant removal efficiencies exceeding 80% were maintained for periods of 26 and 42 days, through such a control strategy. Further demonstration was not possible because of mechanical difficulties and time limitations.

- It is recommended that an optimization study be conducted following the study recommended above. Occasionally, contaminant removal efficiencies exceeding 90% were observed. It is recommended that an optimization study be conducted to investigate the operating conditions that result in these high removal efficiencies. The impact of nutrient dosage rate and media composition could be more firmly established. In addition, a relatively narrow range of volumetric and organic loading rate were examined in this study. It is recommended that a wider range be examined to determine the effluent concentrations that can be achieved.

- It is recommended that a mechanistic, dynamic model be developed, calibrated and verified to predict performance of a biofilter containing compost. There are existing models, but they have generally been calibrated with assumed steady state operating data.

- It is recommended that a study be conducted to investigate contaminant removal efficiency with a multiple compound influent air stream, particularly containing sulphurous compounds. These sulphurous compounds are frequently associated with BTEX contaminated air streams. Their presence may impact on BTEX removal, especially because of acid generated during oxidation of the sulphurous compounds.

- It is recommended to investigate other biological gas cleaning treatment technologies such as trickling filters. Trickling filters may have advantages over biofilters in some applications. These potential advantages include easier moisture control and reduced sensitivity to acid build-up during treatment of streams containing sulphurous compounds.

- Low cost and non-obtrusive devices such as capacitance probes should be investigated for monitoring media moisture content.

Acknowledgements

This study was made possible as a result of funding from:

Environmental Innovation Program (EIP), Supply and Services Canada
Industrial Programs Branch (IPB), Environment Canada
Burlington Environmental Technology Office (BETO), Environment Canada

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1.0 INTRODUCTION

Improper gasoline and solvent handling practices in the past have led to the contamination of soils with Volatile Organic Compounds (VOCs). If left untreated, these VOCs may eventually migrate and contaminate groundwater supplies. Therefore, timely and effective methods to remediate these soils are of great importance. Several treatment alternatives exist, including: soil excavation and subsequent disposal in a hazardous waste landfill, *in situ* volatilization, thermal stripping and vacuum extraction (Weston et al.(1991)). With volatilization, stripping and extraction, air emissions are controlled through the use of liquid/vapour condensers, incinerators, catalytic converters or gas phase granular activated carbon (GAC) (Hutzler et al.(1989)). Incineration is favoured when air emissions contain high concentrations of hydrocarbons. Gas-phase GAC may require heating of the extracted air to control the relative humidity so as to minimize the carbon usage rate. While these air emission controls are effective, they are expensive. This report focuses on the utility of using fixed populations of VOC-degrading microorganisms in a biofiltration system to destroy the VOCs. Biofiltration offers significant potential as a low cost alternative or supplement to thermal treatment or carbon adsorption.

Biofiltration is an air pollution control technology that utilizes microorganisms, immobilized on a filter medium such as bark, compost, soil or peat, to degrade gaseous pollutants into water, carbon dioxide and other inorganic constituents. A contaminated gas stream is passed through the biofilter allowing contaminants to adsorb to the liquid film on the media. Microorganisms then biodegrade the sorbed contaminants with subsequent regeneration of the microbial biofilm. Organic contaminants can serve as the carbon source for microbial growth.

Several bench scale studies have been conducted to investigate biofiltration of VOCs. In most cases, comprehensive design and operating conditions are not readily available for these studies. In addition, there is uncertainty associated with the application of bench scale results to full scale operation. Results from full scale applications have been reported, but generally proprietary systems were employed with limited design documentation. Sustained performance monitoring was also frequently limited. Thus, a lack of well documented biofiltration performance data for VOC removal has been identified. This study was intended to document sustained performance at pilot-scale and identify scale-up difficulties from bench-scale studies.

A pilot-scale biofilter was operated by Enviromega between October 1993 and January 1995. The compounds of interest were Benzene, Toluene, Ethylbenzene and Xylenes (BTEX). The overall objective of the study was to conduct a process engineering analysis to define the attributes and constraints of biofiltration technology when applied to the treatment of BTEX-laden exhaust gases from soil venting operations. Specific goals were to:

- document sustained BTEX removals achieved under controlled and well defined operating conditions;

- evaluate the impact of the important design and operating parameters (such as organic and volumetric loading rate, and nutrient and supplemental water addition rates) on removal efficiencies; and

- determine the optimal values for these parameters.

1.1 Basis for Biofilter Design and Operation

The initial pilot-plant biofilter design was based on readily available, published literature. Operating conditions were selected to reflect conditions that occur with soil vapour extraction systems and to reflect conditions that have been tested on biofilters at the bench scale. The primary design and operating parameters for the biofilter include:

i) candidate compounds
ii) biofilter media
iii) air flow rate and contaminant mass loading rate
iv) media moisture control.

These parameters are discussed in the following four sections.

1.1.1 Candidate Compound Selection

Full-scale biofiltration for odour control has been widely used in Europe, New Zealand and Japan since the 1950's. These applications have primarily focused on wastewater treatment plants where odorous emissions are generally characterized as having relatively low sulphurous contaminant concentrations (<3 ug/L for sum of dimethylsulfide, dimethyldisulfide, methylmercaptan: Amirhor (1995), <25 μg/L Lutz et al.(1994)). The list of compounds treated by biofiltration has, during the 1980s and 1990s, expanded to include BTEX. Bench-scale studies have confirmed the feasibility of treating contaminated air streams containing these compounds (Ottengraf et al.(1983), Ottengraf et al.(1986), Leson et al.(1991a), Ergas (1993)).

Sources of VOC contaminated air streams include volatilization during commercial processes and remediation of contaminated soils. Soil Vapour Extraction (SVE) is a widely accepted technique for the remediation of volatile contaminants from unsaturated ground formations (Frank (1994)). BTEX compounds in the off-gas during SVE remediation have widely recognized health risks associated with them, but are considered to be biodegradable.

Off-gas concentrations in SVE are characterized by initial high values followed by a rapid decline and a prolonged period of relatively low values. Initial concentrations and rates of decline are dependent on the nature of the compounds and the age of the site. The large variability of contaminant concentrations from SVE sites is indicated in Tables 1.1 and 1.2 as presented by Seed (1995). In Table 1.1, VOC concentrations ranged from 20 ppmv to 38,000 ppmv for the 30 systems tested. In Table 1.2, benzene, toluene and xylene concentrations ranged from greater than 1,800 ug/L during the first week to less than 100 ug/L after 56 weeks of soil vapour extraction at a contaminated gasoline station site.

In summary, the following factors were considered when selecting BTEX as the candidate compounds for this biofiltration study:

i) presence of BTEX in SVE off-gas stream
ii) accepted health risks associated with BTEX
iii) recognized biodegradability of BTEX

Table 1.1: Soil Vapour Extraction - VOC Off-Gas Concentrations

Number of Systems Surveyed	Flowrate (m^3/min, (cfm))		VOC Concentration (ppmv)	
	Range (per well)	Average (per well)	Range	Average
13	0.2 - 8.5 (5.3 - 300)	2.3 (80)	20 - 350	100
17	0.7 - 320 (25 - 11300)	62 (2200)	150 - 38000	4000

Source: Eklund et al.(1992)

Table 1.2: Soil Vapour Extraction - Benzene, Toluene, Xylene Off-Gas Concentrations

Week	Air Flow Rate (m^3/h)	Air Stream Concentration (ug/L)		
		Benzene	Toluene	Xylene
0	19.2	2,370	4,710	1,840
1	24.8	440	1,640	1,230
7	29.8	90	370	520
38	47.7	42	169	296
56	39.8	7	8	75

Source: van Eyk (1992) - Data from a contaminated retail gasoline station

1.1.2 Biofilter Media Selection

A large variety of media types has been used to support microbial growth including activated carbon (Hodge et al.(1991), Medina et al.l(1992), Severin et al.(1993)), peat (Rho et al.(1993)), compost (Seed (1995), Zurlinden et al.(1993)) and soil (Leson et al.(1991a)).

Compost media is often supplemented with inert materials such as perlite and bark to provide structural strength for the bed and/or reduce the operational pressure drop across the bed (Seed (1995), Zurlinden et al.(1993), Peters et al.(1993)).

Leaf and yard waste compost was selected as the media for this study because it satisfied the following criteria:

1) documented ability to biodegrade BTEX
2) low cost
3) readily available

The compost was obtained from All Treat Farms Limited located in Arthur, Ontario. Perlite was initially selected as an inert supplement although bark chips were also employed during the study.

1.1.3 Biofilter Influent Contaminant Mass Flow and Air Flow Rate Selection

The influent air stream to a biofilter can be described in terms of its contaminant mass flow [mass of contaminant/time] and its flow rate [volume of air / time]. These parameters have historically been modified and combined to include the biofilter bed volume and surface area. Common parameters used in literature to describe biofilter loading and operating conditions include:

1) Empty Bed Retention Time (EBRT) [(volume of bed)/(volume of influent air/time)]
2) Elimination Capacity (EC) [(mass of contaminant removed)/(volume of bed · time)]
3) Superficial Velocity [(volume of influent air)/(cross-sectional surface area · time)]
4) Removal Efficiency [(fraction of influent contaminant mass flow removed)].

Table 1.3 (taken in part from Seed (1995)) presents these parameters for many different systems that have used compost as biofilter media. Residence times in the biofilter range from 0.4 minutes to 6 minutes with 1 to 3 minutes being most common. Elimination capacities for BTEX compounds range from 0.8 to 75 $g/(m^3 \cdot h)$ with 20 to 30 being most common. Reported removal efficiencies range from 30% to greater than 97%. Biofilter bed depths were less than 1m, with the exception of Sabo et al.(1993) where it was 2.5m.

It has been common for authors to report elimination capacities and neglect to report the removal efficiencies that were achieved. However, in order to determine applications where biofiltration may be useful it is important to consider both removal capacity and efficiency. From Table 1.3, removal efficiencies of greater than 80% generally had elimination capacities of between 7 and 30 $g/(m^3 \cdot h)$. Therefore, this range of organic loading was targeted during the study.

Table 1.3: Historical Parameters for Compost Biofilters

Compound(s)	Media Type and Bed Volume	Loading Rate and/or Influent Concentration	Superficial Velocity and/or Residence Time	Removal Efficiency and/or Elimination Rate	Reference
Mixture: Ethylacetate Toluene Butylacetate Butanol	Compost and inert particles V = 53 L	Toluene: 5.06 - .308 g/m^3	Velocity[β]: 30 - 500 m/h EBRT[α]: 0.41 - 6.0 min	Toluene: 21 $g/(m^3 \cdot h)$ Mixture: 75 gCarbon/$(m^3 \cdot h)$	Ottengraf et al.(1983)
SVE off-gas	bark + peat + perlite + CSS[*] V = 1500 L	470 & 870 ppm THP[**]	not indicated	TPH[**]: 32 $g/(m^3 \cdot h)$ benzene: 0.8 $g/(m^3 \cdot h)$ toluene: 6.0 $g/(m^3 \cdot h)$	Zurlinden et al.(1993)
85% Kerosene 15% gasoline	CL[***] + CSS[*] + perlite + gypsum + activated sludge V = 16.7 L	25 - 1000 $[ppm \cdot m^3/(m^2 \cdot min)]$	EBRT[α]: 1 - 3 min	> 95% @ 152 $[ppm \cdot m^3/(m^2 \cdot min)]$	Peters et al.(1993)
BTEX	compost V = 8 L	300 ppm total BTEX	EBRT[α]: 1.2 min	70 - 90% BTEX 20 - 30 $g/(m^3 \cdot h)$	Kamarthi et al.(1994)
BTX	compost + perlite V = 16.3 L	2 - 110 $g/(m^3 \cdot h)$	EBRT[α]: 1.7 - 2 min	97% for ≤ 40 $g/(m^3 \cdot h)$	Seed (1995)
mixture: styrene methanol	bark + clay + coco fibre + chopped wood V = 400 L	2 - 60 gCarbon/$(m^3 \cdot h)$	Velocity[β]: 90 - 240 m/h EBRT[α]: 38 - 100 seconds	30 - 85% removal 15 - 7 gCarbon/$(m^3 \cdot h)$	Sabo et al.(1993)

Source: Seed (1995) with the exception of Sabo (1993) reference.
notes:
ß: Superficial Velocity = [(airflow rate)/(cross sectional area of biofilter)]
α: EBRT = Empty Bed Retention Time [(airflow rate)/(bed volume)]
*: CSS = Composted Sewage Sludge
**: TPH = Total Petroleum Hydrocarbon
***: CL = Composted Leaf and Yard Waste

1.1.4 Bed Moisture Control

The moisture content of the media has been identified by a number of researchers as a key variable which can greatly impact biofilter operation (Ottengraf et al.(1986), Kosky et al.(1988), van Lith et al.(1990), Leson et al.(1991b), Leson et al.(1991a)). The desired media moisture content (by mass) for optimal biofilter performance is generally considered to be 40 to 60% (Leson et al.(1991a), Ottengraf et al.(1983), Mueller et al.(1988), van Lith et al.(1990)). To maintain media moisture and prevent media drying, the influent air stream is generally humidified to near saturation levels. Sabo et al.(1993), Leson et al.(1991b) and Leson et al.(1991a) reported that humidification alone (i.e. no supplemental water addition required) was adequate to maintain the desired moisture levels while others have reported the need to supply supplemental water to the top of the media (van Lith et al.(1990), Leson et al.(1991b), Yavorsky et al.(1993), Rho et al.(1993), Zurlinden et al.(1993)).

Even when reporting that supplemental water addition was used, there is limited data available to indicate the quantity of water required. Van Lith et al.(1990) indicated that to prevent structure damage of the media (theoretical calculation), supplemental water droplet diameters should be less than 1 mm. In addition, tests as reported by van Lith et al.(1990) indicated that to prevent media structure damage, the rate of water addition should be less than 20 to 30 L of water/($d \cdot m^2$ of media). Yavorksy et al. (1993) did not report the rate of water addition but reported a total addition time of 1 to 2 hours per week. Leson et al.(1991a) reported water addition rate requirements of 7 to 14 mL of water per 1000 L of air treated. The reference for this last guideline was from personal communication and for a biofilter employing soil as a media. Therefore, it may not necessarily apply to compost biofilters.

A research team reported leachate collection at the bottom of the biofilter (Peters et al.(1993)) resulting from supplemental water addition. However, the volume of leachate collected was not reported.

Researchers (Yavorsky et al.(1993), Dharmavaram et al.(1993)) have used load cells to measure the mass of the media to monitor bed moisture content and hence the required rate of water addition. Water is added to maintain the total mass within a desired range. These systems can be quite complicated, as they must take into account the mass of the piping and vessel (depending on mass measurement location) and results also depend on the influent airstream flow rate and direction.

In summary, it is generally regarded that the range of desired bed moisture content is 40 to 60%. For this study, the influent air stream was continually humidified in the attempt to maintain this moisture range. Supplemental water addition was also employed, as deemed necessary. Initially, it was planned to base supplemental water addition on the volume of leachate collected. This proved inadequate and other control schemes were employed. As will be presented in Chapter 4, control of bed moisture content proved to be an operating problem throughout the study.

2.0 DESCRIPTION OF PILOT PLANT BIOFILTER SYSTEM

The principal components of the pilot-scale biofilter system were:

i) clean influent airstream
ii) humidification system
iii) airstream contamination dosing system
iv) biofilter media vessel
v) off-gas scrubber
vi) contaminant analysis system.

The influent airstream was heated, humidified and contaminated prior to entering the biofilter media containment vessel. Off-gas from the biofilter passed through a scrubber to minimize the contaminants remaining in the airstream following biofiltration. A schematic of the biofilter system is shown in Figure 2.1.

Each component is described in detail in the following sections.

2.1 Influent Airstream

Ambient air was forced through the process by a fixed speed 5 Hp Whispair Max model 2504 blower. The air flowrate to the system was manually controlled using a 5cm diaphragm valve and measured with a King Instruments K72 rotameter.

2.2 Humidification System

Following airflow measurement, the influent airstream passed through the humidification system. The purpose of this component was to provide a temperature controlled humidified airstream.

The humidification system consisted of the humidification column, influent airstream temperature control system and an entrained water separator. Each component is discussed separately.

2.2.1 Humidification Column

The humidification column was 2.43m high and 0.6m in diameter. Influent air entered the bottom of the column, travelled the height of the column to an effluent port near the top of the column. Water was sprayed from the top of the column, counter current to the air flow, by a pump drawing water from the column base. The water flow served two purposes:

i) heat transfer to warm the influent air
ii) humidification of the influent air.

To facilitate the heat transfer and humidification processes, a 1.2m portion of the column (0.6m up from the column base) was packed with 5cm diameter polypropylene Tri-Pack spheres.

The water level in the column was controlled by a float actuated valve. When the level was below a predetermined set-point as a result of influent air humidification, fresh tap water was allowed to enter the system.

2.2.2 Airstream Temperature Control System

As indicated in Section 2.2.1 the influent airstream was warmed by the counter current water flow. It was determined that the simplest method of controlling the influent air stream temperature was by controlling the temperature of the sprayed water which in turn was determined by the temperature of the water reservoir at the base of the humidification column.

A variable temperature set-point Honeywell model T675A controller was used to monitor the temperature of the humidifier effluent air stream. When the airstream temperature was below the set-point value, a pump was activated which circulated the water at the base of the humidifier through a 270L electric water heater. Heat transfer from the warmer water elevated the air temperature. The controller turned off the pump when the humidifier effluent air stream temperature reached the set-point value. The Honeywell system limited the air stream temperature fluctuations to within 1.5°C of set point.

2.2.3 Entrained Water Separator

Due to air stream's high velocity near the humidification column exit port, some carry-over of water droplets occurred. To allow the entrained water to settle out from the airstream, the humidified off-gas was directed to the entrained water separator. The separator was a closed fibreglass tank, 1.12m high and 0.6m in diameter. The influent port (top of vessel) transfer line from the humidification column was 7.6cm in diameter. The decreased air stream velocity in the separator separated the entrained water from the air and the water was collected at the bottom of the vessel. Accumulated water was removed daily from the separator.

2.3 Airstream Contamination Dosing System

Following the humidification system and prior to the biofilter vessel, the air stream was contaminated with the dosing compounds. A peristaltic pump (Cole Palmer with standard servodyne variable speed controller: pump head 7016) drew the candidate compound mixture from an external reservoir and pumped the solution through a fine orifice nozzle. The contaminants were discharged to the influent airstream near the centre of the pipe to promote complete volatilization of the compounds.

2.4 Biofilter Media Containment Vessel

The biofilter media was housed in a 1.4m^3 fibreglass vessel (1.22m high, 1.22m diameter). A conical steel lid was used for approximately half of the study and a flat steel lid was used for the remainder. The new lid was easier to remove and replace. The contaminated airstream entered the bottom of the vessel for part of the study (upflow mode) and entered the top of the vessel (downflow mode) during the remainder of the study. Upflow and downflow modes of operation were investigated to determine which mode provided better removal and operational characteristics. Upon vessel entry and before proceeding through the biofilter media, the air stream encountered a void space to encourage complete mixing and volatilization of the contaminants.

The biofilter media was supported on a steel framework that was located 11.5cm from the bottom of the media vessel. A steel mesh (0.6m square holes) and 5cm of gravel (1.5cm diameter) were laid on this framework to minimize biofilter solids loss from the system. The biofilter media was put on top of the gravel and occupied a volume of approximately 0.9m^3. Gas sample lines with purging valves (perforated steel) were located at three points in the media. These locations corresponded to media depths of 10%, 50% and 90% of the total media depth. Additional gas sample lines were located in the head space above and below the biofilter media.

A supplemental water supply system was located at the top of the biofilter vessel. The duration, frequency of application and water flowrate were controlled manually. Initially, two fine orifice sprinkler nozzles located approximately 20 cm above the surface of the biofilter were used. In an attempt to improve media watering capabilities and prevent plugging of the spray nozzles due to particulate matter, these sprinklers were replaced by a rotating arm mechanism. The arm had 0.15cm holes equally spaced 2.5cm apart along its length and was approximately 5cm above the surface of the media.

The biofilter media vessel contained a number of monitoring devices which included thermometers, a manometer and a tensiometer. A Trend Instruments bimetallic thermometer was located in the head space above the media. A second thermometer (Reotemp Instrument Corp) was located at the mid-depth point in the media near the centre of the media. A third thermometer (Trend Instruments) was located in the piping approximately 1m from the bottom of the biofilter vessel. A water manometer was used to measure the pressure drop across the biofilter media. A 0.6m long tensiometer, to indicate media moisture conditions and trends, was located at approximately the half media depth point and near the biofilter media centre. A complete description of tensiometer operation is presented later in Section 3.1.

A reservoir (approximately 2L) was located at the bottom of the biofilter containment vessel. It collected excess supplemental water that was not absorbed by the media (leachate). In addition, it collected any condensation that might occur in the biofilter or in the piping immediately after the biofilter. Since the reservoir contained both leachate and potentially condensate, the reservoir was referred to as the leachate/condensate reservoir and the liquid it contained is referred to as leachate/condensate through this report.

2.5 Off-gas Scrubber

The off-gas from the biofilter was directed through a scrubber to remove any trace contaminants remaining in the air stream following biofiltration. The scrubber consisted of a horizontally mounted drum (0.56m diameter, 0.81m length) which was filled with approximately 91kg of granular activated carbon. The biofilter vessel off-gas entered the scrubber through a 15cm port, passed through the activated carbon where contaminants were absorbed and clean air exited through a port at the other end. The scrubber was wrapped with heat tape to prevent condensation.

2.6 Contaminant Analysis System

Gas samples collected from the process were analyzed by direct injection to a Flame Ionization Detector Gas Chromatogragh (FID GC) coupled to an integrator. During the study two systems were used as a result of electrical failure in the first unit. The first was a Varian model 3700 with a Spectra-Physics SP4270 integrator and the second was a Hewlett Packard 5731A with a Hewlett Packard 3396A integrator.

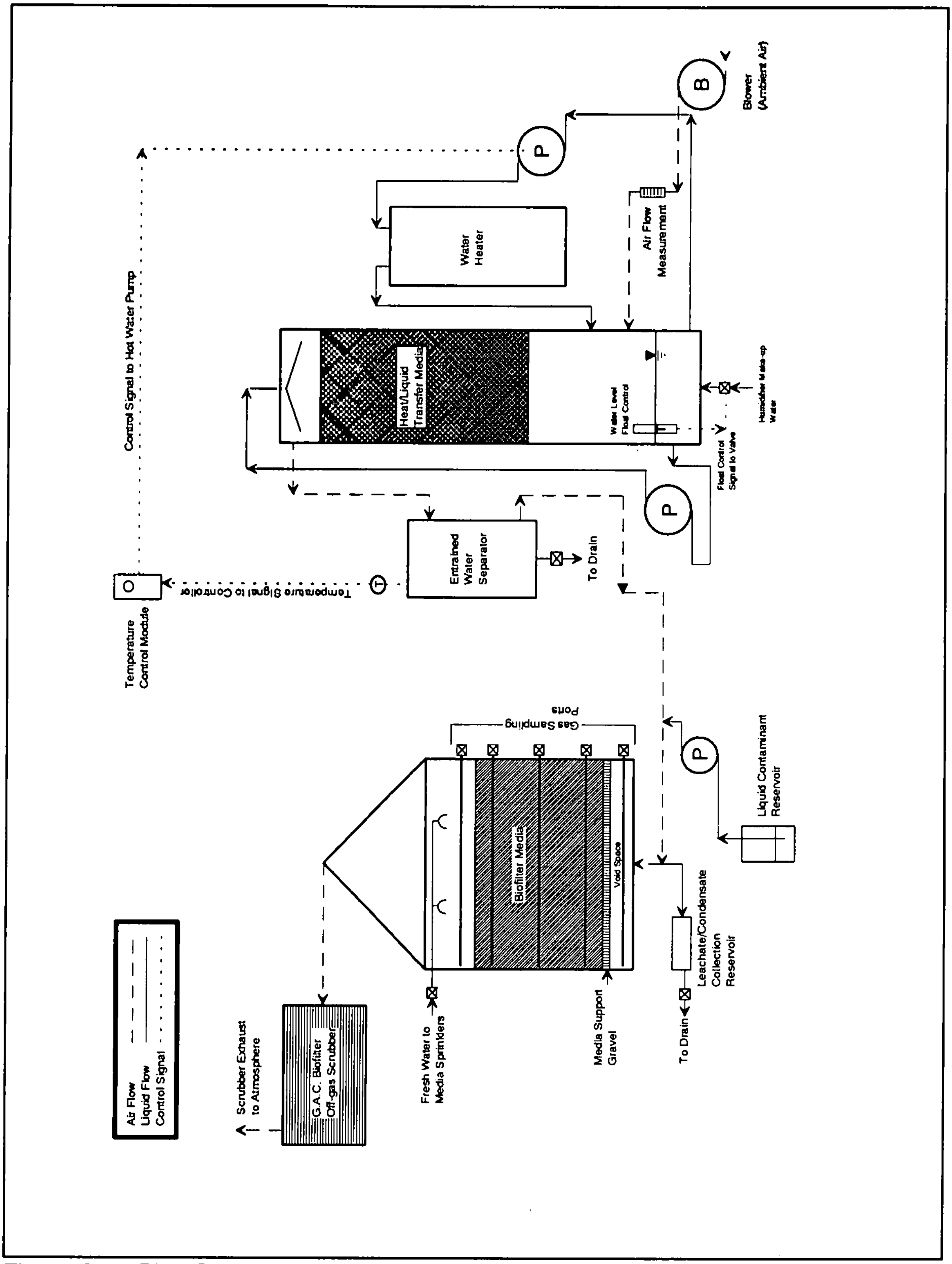

Figure 2.1: Pilot-Scale Biofilter Schematic (upflow mode)

3.0 BIOFILTER OPERATION

The pilot plant biofilter operation was initiated on October 7, 1993. Approximately one month of testing was employed prior to introducing candidate compounds. Dosing of the inlet air stream with the candidate compounds was initiated on November 8, 1993. This is referred to as Day 1 of the study.

The operation of the pilot plant biofilter is discussed in three sections. The first section presents design modifications following initial construction. The second section presents operating parameters during the study (e.g. influent flowrate and temperature). The third section presents specific tests that were conducted to elucidate biofilter performance.

3.1 Design Modifications

During the study, a number of physical modifications were made to the pilot plant biofilter system. These changes were implemented to improve biofilter performance and enhance operational control. Each modification is discussed separately. A summary of the physical modifications is presented in Table 3.1.

Table 3.1: Summary of Biofilter Physical Modifications		
Date	Modification	Reason for Modification
Oct 14 - 25, 1993	Add hot water loop to humidification system	Warm influent airstream
Oct 15 - Nov 7, 1993	Insulate pipes and processes	Reduce heat loss and condensation
Oct 27 - Nov 7, 1993	Enlarge media condensate collection reservoir	Monitor leachate collection volume and improve ease of leachate collection
Oct 14 - 25, 1993	Add entrained water separator	Remove entrained water in humidified effluent stream
Oct 29, 1993	Place heat tape around GAC bed	Prevent condensate build-up in GAC bed
Nov 11, 1993 (Day 4)	Modify VOC injection line	Reduce influent concentration variation
Feb 2, 1994 (Day 87)	Install rotameter online	Verify flow
Feb 11, 1994 (Day 96)	Install fertilizer injection port	Allow nutrients to be applied evenly to top of bed
Mar 11, 1994 (Day 124)	Separate humidification and heat transfer to influent air systems	Allow greater temperature control during large temperature swing periods
May 11-18/94 (Day 185-192)	Install media watering distributor arm to replace fine orifice sprayers at top of media	Reduce plugging of water distribution holes
May 25/94 (Day 199)	Install media thermometer	Determine degree of drying in biofilter media
May 27/94 (Day 201)	Install tensiometer	Indicate moisture trends and condition in biofilter media
Aug 8 - Aug 10, 1994 (Day 274-276)	Change airflow through biofilter from upflow to downflow	Determine operating performance in downflow mode (previously operated in upflow mode)

Hot Water System

It was initially anticipated that the blowers providing air to the biofilter system would warm the influent ambient air and that additional heating of the air stream would not be required. Upon start-up, it became apparent that little heat was being added to the air stream by the blowers (even under elevated blower backpressure) and that the temperature of the air stream entering the process was fluctuating with the ambient temperature. A residential hot water heater was installed to warm the water used in the humidification column and thus warm the influent air.

Insulation of Pipes and Processes

The air stream leaving the humidification column was generally hotter than room temperature and was assumed to be saturated with water. To minimize the potential for condensation, all process lines and vessels were insulated with 2.5cm thick Armaflex insulation.

Entrained Water Separator

Water droplets were entrained in the humidification column effluent air stream. This resulted in a lack of control in the amount of water that was added to the biofilter media. To minimize the amount of water droplets in the air stream, the velocity of the air was reduced by placing a large volume tank between the humidification column and the biofilter containment vessel. Water collected in this tank was drained daily.

Enlarged Media Leachate/Condensate Collection Reservoir

Despite attempts to minimize the production of condensate in process lines (e.g. by insulation of piping) and leachate from supplemental watering (e.g. by applying only the minimum required water), it became apparent that a certain level of leachate/condensate collection was inevitable. The leachate/condensate tended to collect in the air transfer line at the bottom of the biofilter media containment vessel. To prevent water accumulation from inhibiting process operation, an enlarged reservoir was installed to collect the condensate/leachate. The collected water was removed daily.

Heat Tape Around GAC Bed

Insulation of the GAC scrubber was found to be insufficient to arrest the production of condensate. Therefore, a heat tape was installed around the scrubber to counteract the loss of heat from the air stream.

Stack Condensate Collection

The effluent air stream from the scrubber was vented to the outside by a vertical stack. The rapid cooling of the off-gas resulted in approximately 4 L/d of water being produced in the stack. A collection trap was installed downstream of the scrubber to prevent water from proceeding down the piping and collecting in the scrubber.

Modified VOC Injection Line

The solution used to contaminate the influent air stream was injected at relatively low flow rates (0.2-0.4 mL/min). In the initial design, the candidate compound solution was delivered through a 3 mm diameter tubing. With the relatively low flow rates, large drops of the dosing solution tended to form at the end of the tubing, prior to dropping into the dosing pipe. This resulted in pulsed concentrations in the biofilter inlet air stream. Initial measurements of the inlet air stream indicated a high degree of concentration variability. To minimize this variability, the orifice at the end of the tubing which introduced the candidate compounds was reduced in size considerably. This resulted in the formation of very small droplets at the orifice which minimized contaminant concentration fluctuation of the inlet air stream.

Rotameter Installation

The shedding vortex air flow meter which was installed in the original design tended to provide unstable readings when low flow rates were employed. An in-line rotameter was installed that provided more stable and accurate measurement of flowrate.

Fertilizer Injection Point

In an experiment conducted at the University of Guelph, reduced removal efficiencies were believed to be the result of nutrient availability limitations within the media (Seed (1995)). To quantify nutrient requirements at the pilot scale, the pilot plant was modified to allow for dissolved fertilizer to be pumped through the originally installed fine misters located at the top of the media. Particulate matter in the solution obstructed the orifices and larger orifices were required to be made. In addition, the inability of the fertilizer dosing pump to produce high pressure flows resulted in uneven distribution of nutrients on the surface of the media.

The fine orifice misters were eventually replaced by a rotating arm mechanism which incorporated larger hole openings. These holes were not obstructed by particulate matter in the nutrient solution. In addition, the dosing pump could be avoided by introducing the solution into the main water line supplying the distributer.

Separate Humidification and Influent Air Heating Systems

Even with the addition of the water heater, the temperature of the influent air fluctuated (19 and 36°C) during the late winter and early spring when ambient temperature fluctuations were considerable. To improve influent air stream temperature control, the humidification and heating operations of the humidification column were separated. A dedicated pump was used to circulate hot water from the water heater into the humidification column. The on/off control of the pump was determined by a sensor measuring the humidification system's effluent temperature.

Media Watering Distributor Arm

When applying dissolved fertilizer to the media, particulate matter in the solution obstructed the orifices and lead to uneven fertilizer distribution. The fine orifice misters were replaced by a rotating arm mechanism which incorporated larger hole openings. These holes were not obstructed by particulate matter in the nutrient solution. The rotating arm mechanism provided greater uniformity of water or fertilizer addition.

Media Thermometer

A 0.6m thermometer was installed to determine the degree of heating within the media.

Media Tensiometer

A tensiometer is a sealed hollow tube with a porous ceramic tip and a vacuum gauge to measure the vacuum in the tube. It is commonly used to measure soil moisture content. Unless the tensiometer tip is immersed in water, there is a tendency for the water in the tensiometer to be drawn through the ceramic tip and into the media. This tendency creates a vacuum in the tensiometer. The dryer the media, the greater the tendency for the water to pass through the ceramic tip into the surroundings and therefore the greater the vacuum created in the tensiometer. The vacuum created is affected by both the surrounding moisture content and flow rate of air passing the tip.

A 0.6m long tensiometer was inserted into the core of the biofilter media to indicate media moisture content.

Downflow to Upflow System

The influent air to the biofilter vessel originally entered the bottom and exited the top of the vessel. This upflow operating condition was maintained until operating Day 274 (Aug 8, 1994). At this point, the influent and effluent air piping were reversed and a downflow operating mode was initiated. It was anticipated that excessive biofilter drying would be minimized with both the humidified airstream and the supplemental watering system entering the top of the media.

3.2 Biofilter Operating Conditions

This section presents the conditions under which the pilot scale biofilter was operated. The conditions discussed include:

i) media composition
ii) influent air flowrate
iii) influent air temperature
iv) contaminant loading rate
v) nutrient addition.

3.2.1 Media Composition

A summary of the media compositions used during the study is presented in Table 3.2. A leaf and yard waste compost, obtained from a commercial supplier, was used as the primary media for bacterial support throughout the study. Perlite was used to increase porosity and provide structure strength (media 1).

The composition was changed twice in attempts to improve performance. On day 131, 5cm of small 'pine bark nuggets' (2-4cm diameter) were placed on top of the perlite/compost mixture to improve water distribution over the media surface (media 2). On day 331, the layer of 'pine bark nuggets' was removed and the original perlite/compost media was mixed with oval bark pieces (5-15 cm long, 2-5 cm thick) in a 50%/50% volume ratio (media 3). It was anticipated that the addition of the large pieces would increase the effective void space of the media and therefore encourage moisture transfer throughout the bed.

Table 3.2: Media Composition During Study

Period	Media Identification Number	Media Composition*
Nov 9, 1993 - May 16, 1994 (Day 1 - 190)	1	mixture of: 60%: leaf and yard waste compost 40%: perlite (Volume basis)
May 17 - Oct 3, 1994 (Day 191 - 330)	2	fine pine bark nuggets on top of media #1
Oct 4, 1994 - Feb 15, 1995 (Day 331 - 465)	3	50%: media #1 50%: large decorative bark (Volume basis)

3.2.2 Influent Air Flowrate

The influent air stream flowrate ranged from 6.6 to 23.6L/s with corresponding nominal empty bed retention times ranging from 38 to 136 seconds. Influent air flow to the system was turned off for more than 7 days on three separate occasions. A summary of the influent air flowrates is presented in Table 3.3.

During the first three months of the study (days 1 to 70), flow rates were estimated from the measured influent concentrations and the contaminant dosing flow rate. This was required due to a malfunctioning vortex flow meter. During this period, three flow rates were maintained (23.6 L/s, 14.2 L/s and 9.4 L/s). The flow rates reported in Table 3.3 for these periods represent the average calculated value during each period.

An online rotameter was installed on day 87 immediately upstream of the humidification column. The flowrate indicated by the rotameter was checked daily. There was very little daily fluctuation. The flow rates reported in Table 3.3 following the installation of the rotameter represent target rotameter flowrates.

The variation in airflow rates was in part deliberate due to attempts to improve contaminant removal. However, flow variation during the first three months (days 1 to 70) was due to a malfunctioning vortex flow meter. During this period, air flow rates were estimated from the measured influent concentrations and the contaminant dosing flow rate. Following this period (days 87 to 465), flow measurements were indicated by online rotameter installed just prior to the humidification column.

Table 3.3: Influent Airstream Flowrates			
Date (Operating Day)*	Air Flowrate [L/s (cfm)]	Flow Direction	Empty Bed Residence Time** [s]
Nov 8 - Dec 14/93 (Day 1 - 37)	23.6 (50)$^{\alpha}$	upflow	38
Dec 15/93 - Jan 7/94 (Day 38 - 61)	14.2 (30)$^{\alpha}$	upflow	63
Jan 8 - Jan 16/94 (Day 62 - 70)	9.4 (20)$^{\alpha}$	upflow	96
Jan 17 - Feb 1/94 (Day 71 - 86)	---$^{\beta}$	---	
Feb 2 - Mar 14/94 (Day 87 - Day 128)	13.2 (28)	upflow	68
Mar 15 - May 10/94 (Day 129 - Day 184)	6.6 (14)	upflow	136
May 11 - May 18/94 (Day 185 - 192)	---$^{\Gamma}$	---	
May 19 - Jul 18/94 (Day 193 - 253)	13.2 (28)	upflow	68
Jul 19 - Aug 10/94 (Day 254 - 276)	---$^{\pi}$	---	
Aug 11 - Feb 15/95 (Day 277 - 465)	13.2 (28)	downflow	68

*: first day of VOC injection (Nov 8, 1993) corresponds with operating day 1
**: volume occupied by biofilter media (0.9 m^3) divided by air flow rate (m^3/s)
α: estimated flowrate based on measured influent concentration and VOC injection rate
ß: broken water supply lines
Γ: installation of rotating arm watering system for media moisture control
π: system changed from upflow to downflow system

3.2.3 Influent Air Temperature

The temperature of biolfilter influent air ranged from 19 to 36°C. The greatest variability occurred prior to the installation of the temperature controlled water pumping system (i.e. Day 125). Following this, the influent air temperature range was generally 30 - 34°C. However, because of difficulties heating the trailer between Day 412 and 465, the influent air temperature ranged from 26 - 33°C.

Table 3.4: Influent Airstream Temperatures	
Period	Temperature Range (°C)
Nov 8/93 - Mar 10/94 (Day 1 - 124)	19 - 36
Mar 11/94 - Dec 23/94 (Day 125 - 411)	30 - 34
Dec 23/94 - Feb 15/95 (Day 412 - 465)	26 - 33

3.2.4 Contaminant Loading Rate

A mixture of technical grade benzene, toluene, ethylbenzene and xylenes (25% each by volume) was used to contaminate the influent airstream. The injection rate was varied by changing the rotation speed of the peristaltic pump. At a 25 rpm rotation rate, contaminant injection rates ranged from 0.22 - 0.35 mL/min (0.28 mL/min midpoint). At 50 rpm, injection rates ranged from 0.34 -0.43 mL/min (0.38 mL/min midpoint).

The average contaminant loading rates are presented in Table 3.5. The total loading rates ranged from 16.2 to 22.0 g/(h·m^3), based on an empty bed volume.

Table 3.5: Organic Loading Rates to Biofilter					
Period	Average Loading Rate [g/(h·m^3)]				
	Benzene	Toluene	Ethylbenzene	Xylenes	Total
1 Nov 8/93-Dec 15/94 (day 1 - 403)	4.5	5.3	6.1	6.1	22.0
2 Dec 16/94-Jan30/95 (day 404-449)	3.3	3.9	4.5	4.5	16.2
3 Jan 31-Feb 15/94 (day 450 - 465)	4.5	5.3	6.1	6.1	22.0

3.2.5 Nutrient Addition

In order to examine the effect of nutrient requirements for biogrowth, a water soluble all purpose fertilizer (20-20-20: nitrogen, phosphorus, potash) was periodically added to the top of the biofilter media. Approximately 200 or 400 g of fertilizer were added on each occasion. The fertilizer was dissolved in water (varying amounts) and the solution then applied to the media through the supplemental water supply sprayers/distributor located at the top of the biofilter containment vessel. A summary of the nutrient addition schedule is presented in Table 3.6.

Table 3.6: Nutrient Addition Schedule

Date	Mass Injected [g]	Comments
Feb 4/94 (day 89)	410	
Feb 17/94 (day 102)	440	total water added much greater than typically used to wet media
Apr 5/94 (day 149)	400	total water added twice typically used to wet media
Jun 13/94 (day 218)	420	no excess water added
Jul 13/94 (day 248)	400	no excess water added
Aug 25/94 (day 291)	200	no excess water added
Oct 18/94 (day 345)	200	no excess water added

3.3 Tests Conducted

3.3.1 Smoke Tests

The purpose of the smoke tests was to estimate the residence time of the air in the biofilter media. This residence time estimate was then compared to the value based upon airflow rate and the empty bed biofilter media volume. An observed residence time considerably smaller than the ideal case would indicate channelling or short circuiting within the media.

A non-toxic white smoke was used as a tracer compound. With the biofilter containment vessel top removed and the system operating normally in the upflow mode, the smoke was injected into the influent airstream piping. The time and location at which the smoke first appeared were noted as well as when the bulk of the smoke appeared.

To conduct a smoke test and to make observations as to the degree of short circuiting, the off-gas end of the bed must be in full view. By removing the lid of the biofilter containment vessel, the top of the biofilter media can be seen. Therefore, a smoke test can be conducted when the biofilter is operated in an upflow mode. However, since the bottom of the bed can not be seen (view restricted by the biofilter containment vessel), no smoke tests can be conducted when the biofilter is operated in a downflow mode.

4.0 RESULTS: CONTAMINANT REMOVAL

This chapter presents contaminant removal results during the study. Daily operating parameters are presented in Appendix A1. Performance data, such as observed pressure drop, not directly related to contaminant removal, are presented in Appendix A2.

The removal rates across the biofilter for each compound (benzene, toluene, ethylbenzene, m/p-xylene and o-xylene) were calculated as:

$$\text{Removal Efficiency [\%]} = ((C_o - C_e)/C_o) \times 100$$

where: C_o = measured influent concentration
C_e = measured effluent concentration.

Sampling to determine removal efficiency was conducted on approximately 100 days during the study. Sampling was not conducted at a constant frequency during the study. Frequent sampling was often employed after changes to operating conditions. Less frequent sampling was employed after extended operation at given operating conditions.

Figures 4.1a to 4.1e summarize contaminant removal efficiency during the study for each compound. Analytical results are presented in Appendix B. In Figures 4.1a to 4.1e, the day of operation is presented on the x-axis and the contaminant removal efficiency is presented on the y-axis. The percentage removal for each day is indicated by the filled rectangles on the graphs. The figures also indicate the following operating data:

- airflow rate (vertical lines separate periods with different flow rates; number above each period indicates flow rate)
- direction of airflow (upflow changed to downflow on day 276)
- organic loading rate (reduced from 22 to 16.2 $g/(m^3 \cdot h)$ on day 402)
- nutrient addition (filled cross ["+"] indicates days when nutrients were added to biofilter)

Figures 4.1a to 4.1e indicate that contaminant removal efficiency was highly variable during the study. There were periods of low contaminant removal efficiency (i.e. < 50%) and periods of relatively high contaminant removal efficiency (i.e. > 80%). However, the periods of high contaminant removal were never sustained for longer than a four week period. Generally, removal efficiency trends were similar for all compounds (i.e. periods of low and high removal generally corresponded), although some differences were apparent as will be discussed in Section 4.1. Much of the study effort was allocated to identifying the operating conditions that led to low and high removal efficiency and attempts to maintain those conditions promoting high removal efficiency.

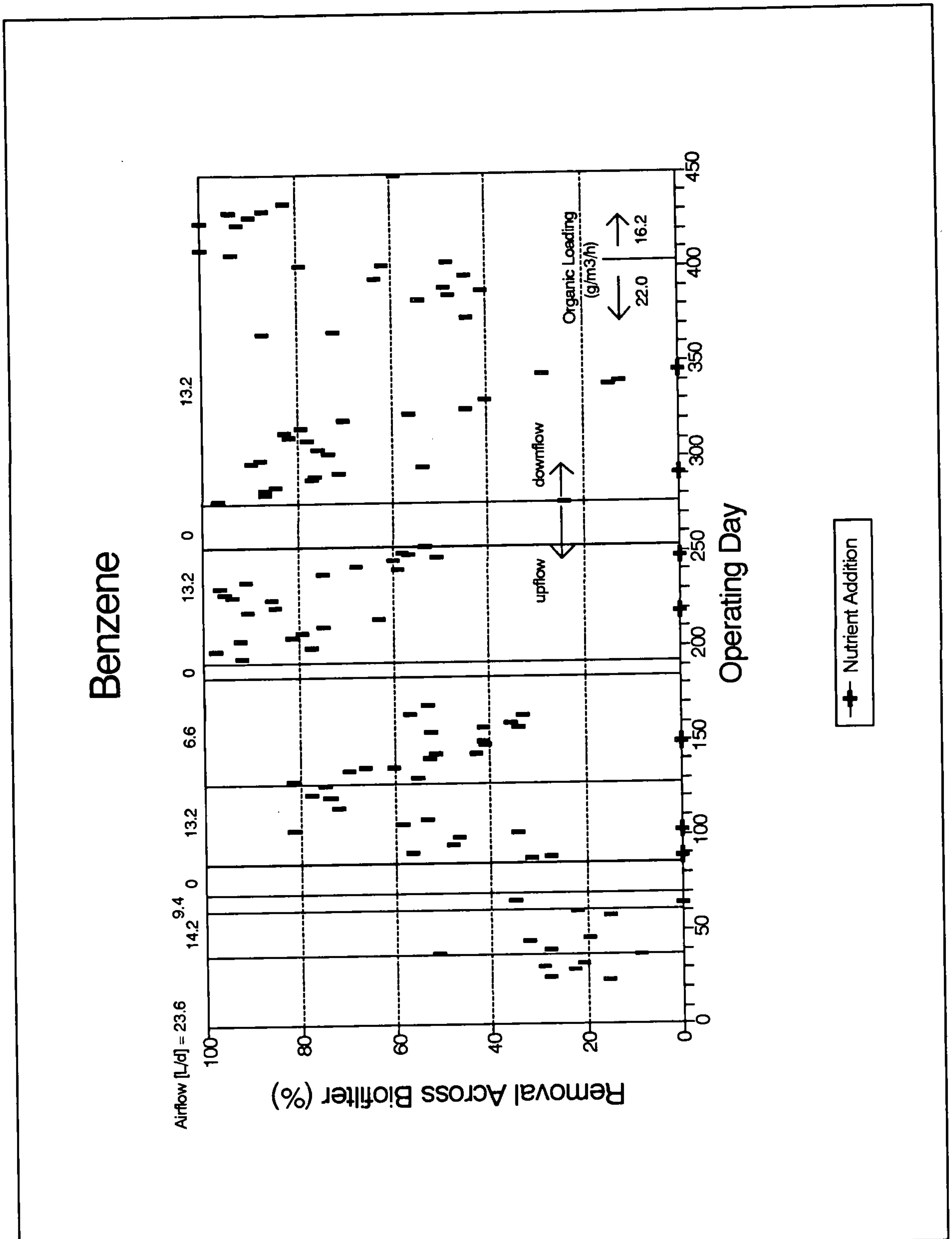

Figure 4.1a: Contaminant Removal During Study - Benzene

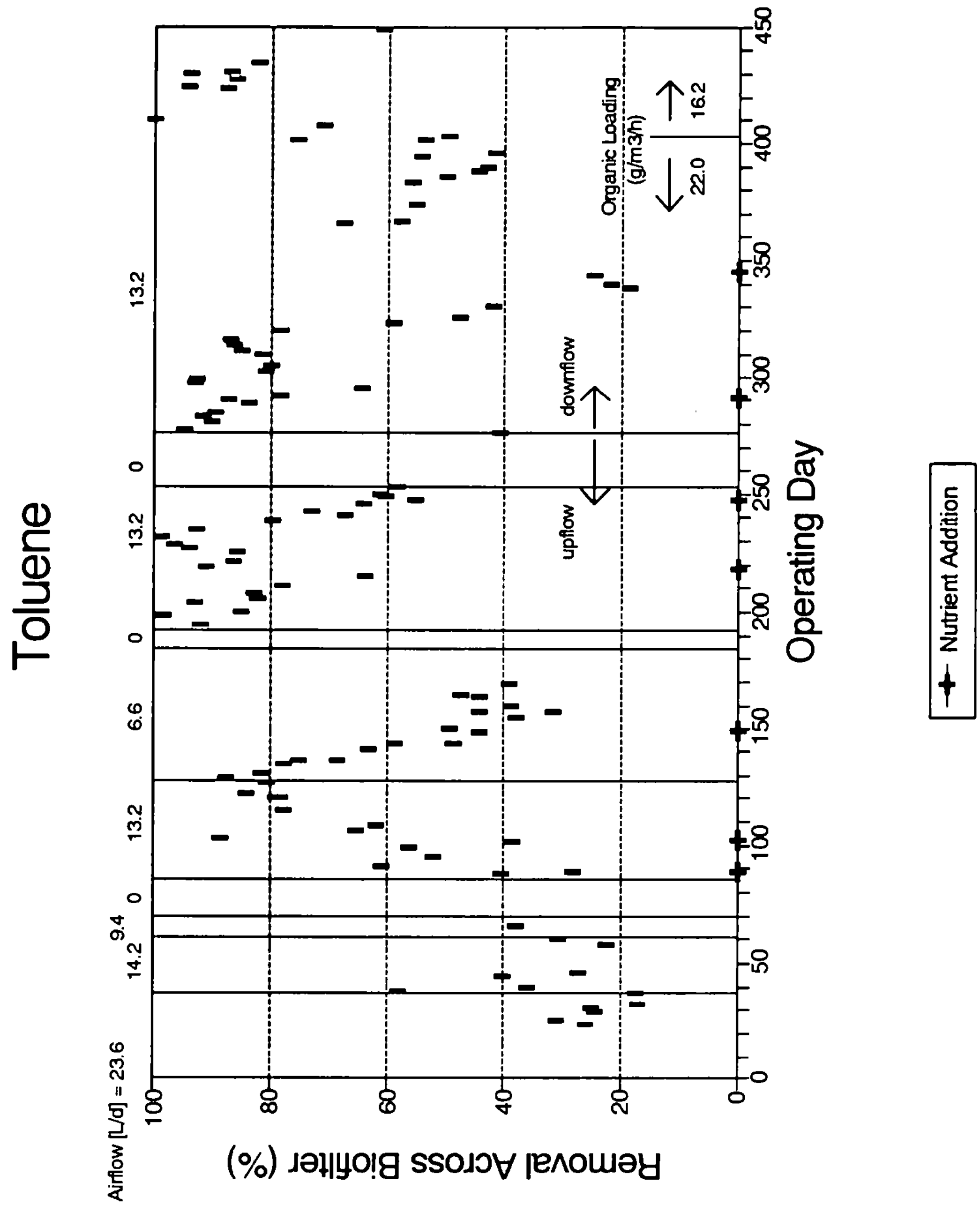

Figure 4.1b: Contaminant Removal During Study - Toluene

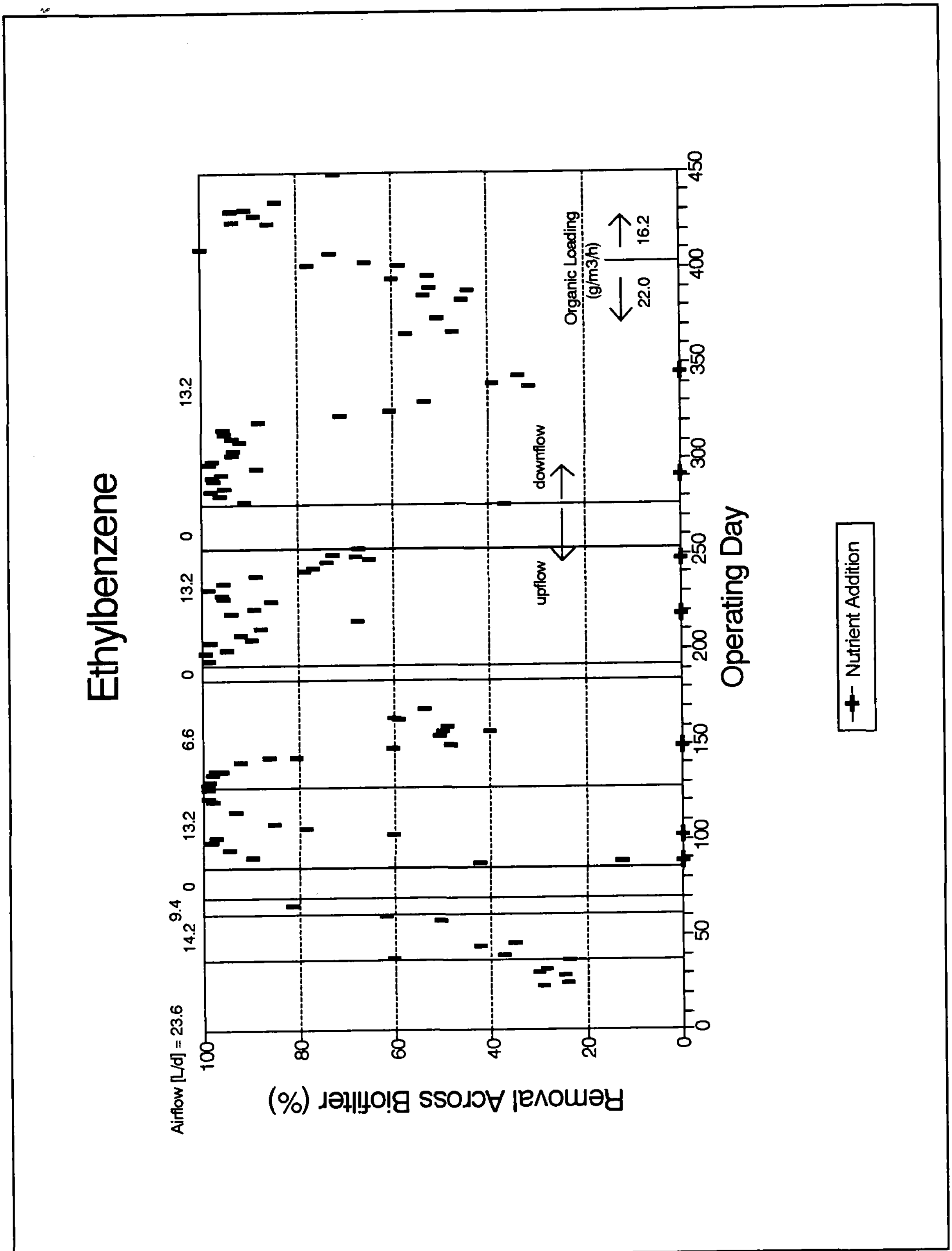

Figure 4.1c: Contaminant Removal During Study - Ethylbenzene

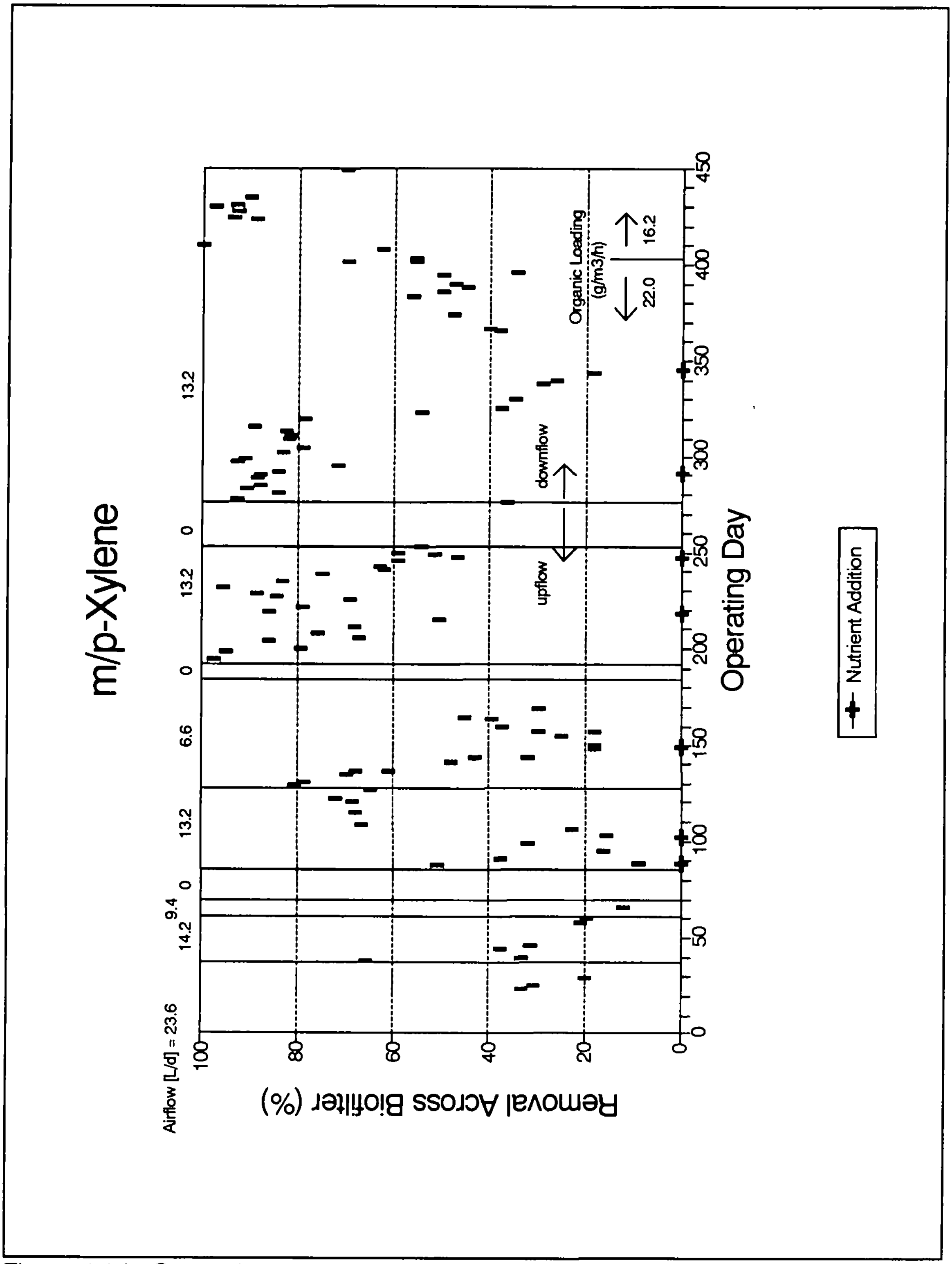

Figure 4.1d: Contaminant Removal During Study - m/p-Xylene

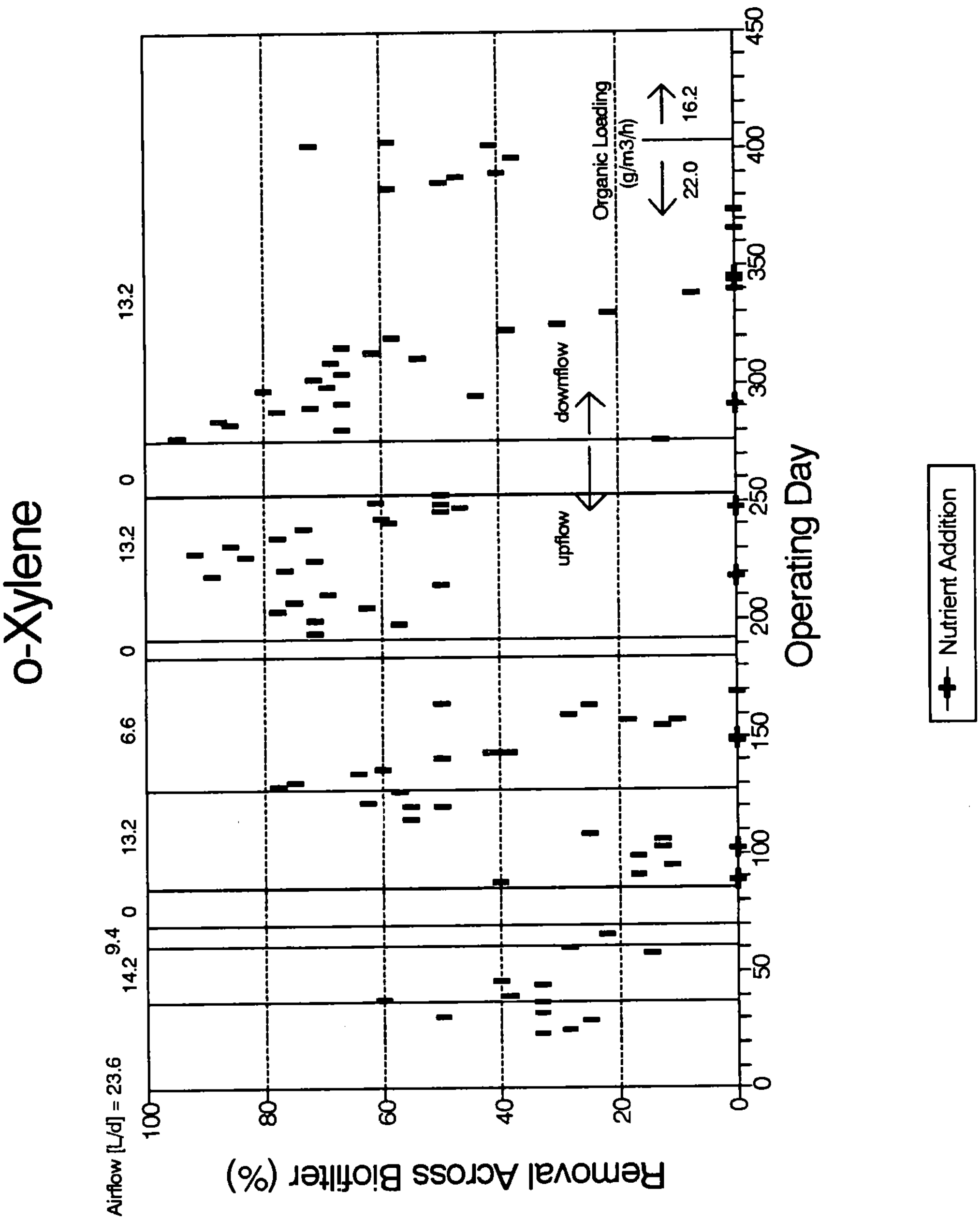

Figure 4.1e: Contaminant Removal During Study - o-Xylene

4.1 Duration of Sustained High Contaminant Removal Efficiency

Extended periods (i.e. greater than 5 consecutive days) of contaminant removal exceeding 80% are presented in Table 4.1. Only two extended periods where removal efficiencies for all contaminants exceeded 80% were observed. During these periods, off-gas concentrations were less than 20μg/L for each compound. The longest period of consistent contaminant removal exceeding 80% was 26 days.

As evident from Figures 4.1d and 4.1e, xylene, particularly o-xylene, was the least readily removed contaminant. Thus, excluding xylene, four extended periods of contaminant removal exceeding 80% were observed.

There were two periods separated by 13 days (day 194 - 206 & day 219 - 235) during which removal efficiencies exceeded 80% for benzene, toluene, ethylbenzene. Operational controls, discussed in Section 4.3.1 and 4.3.2 (nutrient and supplemental water addition), were implemented following day 215. These new controls likely caused the recovery in removal efficiency for the second period.

Removal rates for benzene, toluene and ethylbenzene during the period day 194 to 253 are presented in Figures 4.2a, 4.2b and 4.2c respectively. Removal rates for all compounds during this period are presented in Appendix C. These data indicate that removal efficiencies of benzene, toluene and ethylbenzene exceeding 80% were maintained over a 42 day period (day 194 to 235) with operational control between the 13th and 19th day of the period. These operational controls (nutrient and supplemental water addition) are discussed in Sections 4.3.1 and 4.3.2.

Table 4.1: Extended Periods of Compound Removal Efficiencies Greater Than 80%

Period*	Duration [d]
Benzene, Toluene, Ethylbenzene, m/p-Xylene, o-Xylene	
day 227 - 232$^{\alpha\pi\mu}$	6
day 410 - 435$^{\beta\Sigma\sigma}$	26
Benzene, Toluene, Ethylbenzene, m/p-Xylene	
day 227 - 235$^{\alpha\pi\mu}$	9
day 278 - 285$^{\beta\pi\mu}$	8
day 410 - 435$^{\beta\Sigma\sigma}$	26
Benzene, Toluene, Ethylbenzene	
day 194 - 206$^{\alpha\pi\mu}$	13
day 219 - 235$^{\alpha\pi\mu}$	17
day 278 - 285$^{\beta\pi\mu}$	8
day 410 - 435$^{\beta\Sigma\sigma}$	26

*: only periods greater than 5 days considered
α: biofilter operated in upflow mode
β: biofilter operated in downflow mode
Γ: media: compost/perlite
π: media: fine pine bark nuggets on top of compost/perlite mixture
Σ: media: compost/perlite + large bark pieces
σ: organic loading rate: 16.2 g/(m^3·h) (o-xylene not detected)
μ: organic loading rate: 22.0 g/(m^3·h)
note: all influent airstream flowrates were 13.2 L/s (28 CFM)

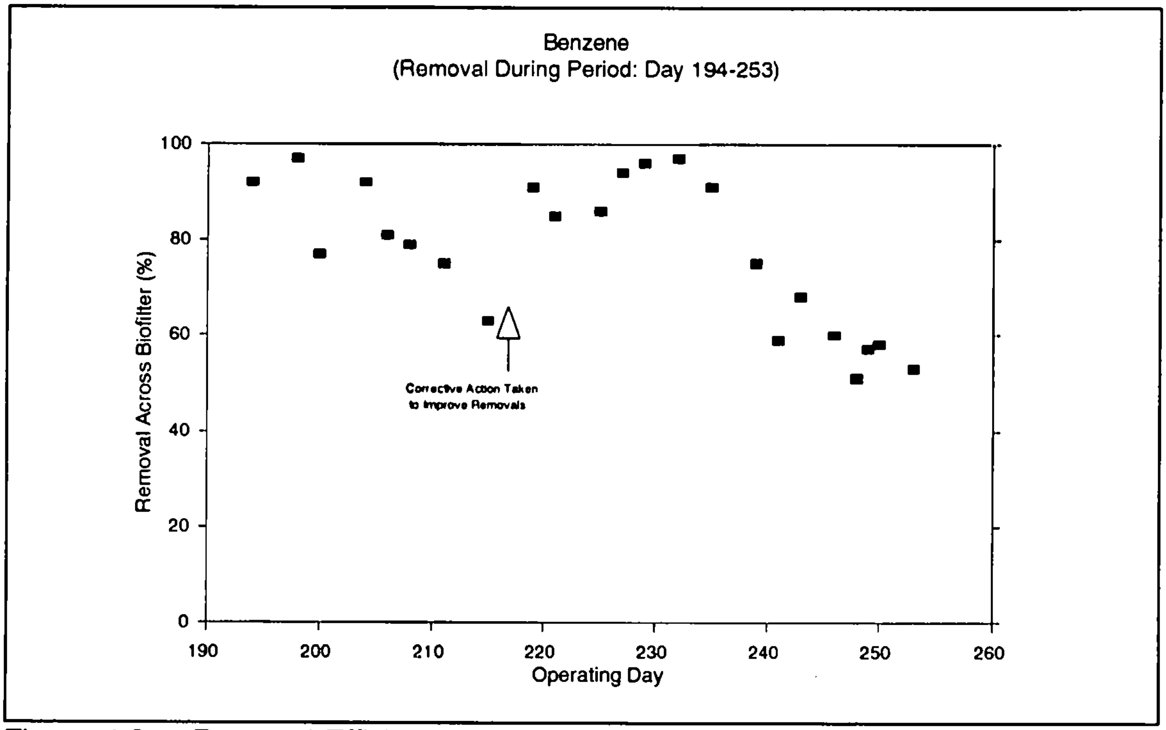

Figure 4.2a: Removal Efficiency Day 194 to 253 - Benzene

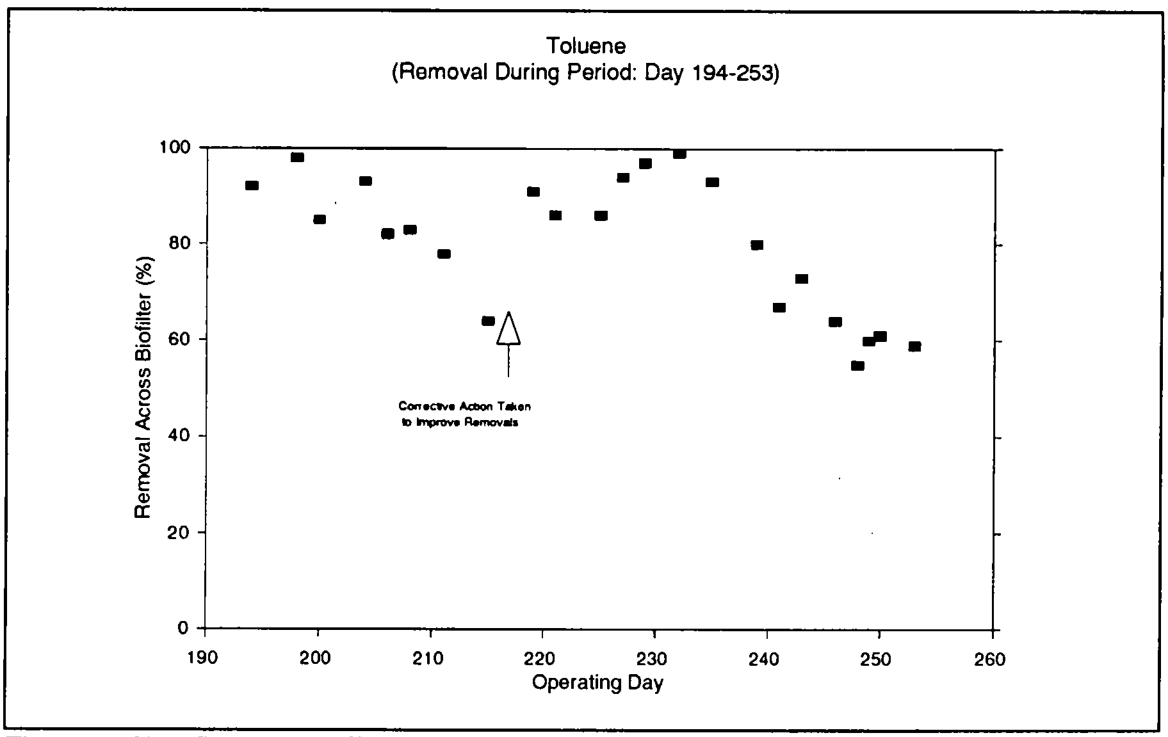

Figure 4.2b: Removal Efficiency Day 194 to 253 - Toluene

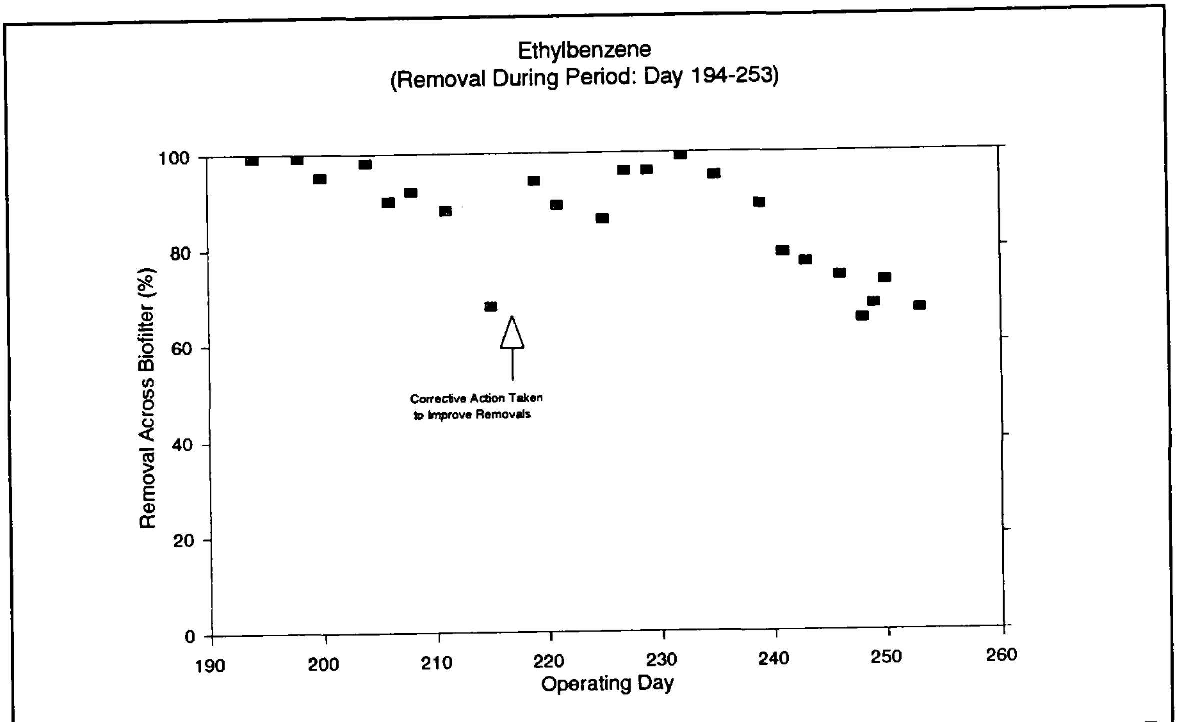

Figure 4.2c: Removal Efficiency Day 194 to 253 - Ethylbenzene

4.2 Relative Contaminant Removal Efficiencies

For each compound, the number of occasions where removal efficiencies were between specified intervals (e.g. 70 to 79%) was calculated. These frequency of occurrence values were expressed as a percentage of the total number of sample days for that compound. Results are summarized in the histogram of Table 4.2. For example, of the 111 days where sampling for benzene was conducted, 19, or 17% of the samples, indicated a removal efficiency between 70 and 79%. As stated earlier, sampling was not conducted at a constant frequency during the study. Thus, the histogram does not indicate the percentage of time during the study where removals were within specified ranges. In fact, sampling was frequently conducted during periods of high contaminant removal. However, the histogram does illustrate relative contaminant removal efficiencies.

Table 4.2 indicates that ethylbenzene was the most readily removed compound, with 39% of samples indicating a removal efficiency between 90% and 100%. Benzene and toluene were less readily removed, with approximately 15% of the samples indicating a removal efficiency between 90% and 100%. M/p xylene was removed slightly less readily, with 12% of the samples indicating a removal efficiency between 90% and 100%. O-xylene was much less readily removed than the other compounds, with only 2% of the samples indicating a removal efficiency between 90% and 100%.

Table 4.2: Histogram: Contaminant Removal Efficiency				
Compound	Percentage of Total Analyzed Samples Within Removal Range			
	70 - 79%	80 - 89%	90-100%	> 70%
Benzene	17	13	14	44
Toluene	9	21	15	45
Ethylbenzene	8	13	39	60
m/p-Xylene	11	15	12	38
o-Xylene	13	2	2	17

To provide insight into results presented in Table 4.2, contaminant removal efficiency data collected during operating days 278 to 295 are presented in Table 4.3. Tensiometer measurements on day 278 and 295 (day 278: 10 kPa; day 295: 17 kPa) indicated that bed moisture content declined during this period. At day 278, the contaminant removal efficiency of all compounds exceeded 90%. As time progressed, the contaminant removal efficiency of all compounds declined. The removal of o-xylene declined most rapidly while the removal of ethylbenzene declined least rapidly. On day 297, the biofilter was shut down and the media examined. The majority of the media was observed to be dry (estimated < 30% moisture content), verifying tensiometer indications.

To summarize results presented in Table 4.3, contaminant removal efficiencies exceeding 90% could be achieved with appropriate media characteristics, but removal efficiencies declined as these media characteristics deteriorated. O-xylene was most sensitive to deterioration in media characteristics, while ethylbenzene was least sensitive. It is postulated that moisture content was the critical media characteristic influencing contaminant removal efficiency although other conditions such as nutrient content may have influenced results. The following sections present supporting data for this postulation.

Table 4.3: Removal Efficiency - Day 278 to 295					
Day	Removal Efficiency [%]				
	Benzene	Toluene	Ethyl-benzene	m/p-Xylene	o-Xylene
278	97	95	91	93	94
281	87	90	96	84	67
283	87	92	98	91	86
285	85	89	95	88	88
289	77	84	98	88	78
290	76	87	98	88	72
292	72	78	96	84	67
295	54	64	89	72	44

4.3 Operational Factors Influencing Contaminant Removal Efficiency

The previous section postulated that media characteristics had the largest influence on contaminant removal. This implies that maintenance of appropriate media characteristics is the key to successful biofilter operation for BTEX removal. The principal media characteristic identified was moisture content although nutrient content could also be important. This following section explores the postulation in greater detail.

4.3.1 Effect of Nutrient Addition

Nutrients were added to the top of the media on seven separate occasions throughout the study. On three occasions (day 149, 248, 291) removal efficiencies were observed not to be affected by the nutrient addition and on three occasions (day 89, 102 and 218) removal efficiencies were observed to be dramatically increased by the nutrient addition. On one occasion (day 345), analytical problems prevented observation of the effects of nutrient addition.

4.3.1.1 No Improvement in Biofilter Performance (nutrient addition on days 149, 248 & 291)

In all cases where no improvement in removal efficiencies was observed after nutrient addition, the biofilter was shut down a short time later and the media examined. It was observed in all cases that the majority of the biofilter media had a moisture content less than 30%. This value is below the desired minimum moisture content level of 40%. Thus, it is postulated that the performance of the biofilter was, in these cases, limited by the low media moisture content level and that the effect of nutrient addition could not be determined.

4.3.1.2 Marked Improvement in Biofilter Performance (nutrient addition on days 89, 102 & 218)

As indicated previously, nutrient addition on days 89 and 102 corresponded with a marked improvement in removal efficiency. In the first case, removal efficiencies improved from less than 50% to 90% for ethylbenzene within 2 days. In the second case, removal efficiencies for benzene and toluene increased from less than 40% to greater than 80%. On both nutrient addition days 89 and 102, the nutrients were dissolved in water (4.5 and 25 L respectively) and added to the top of the media. Routine supplemental water addition had not yet been employed in the study. Thus, the effects of water and nutrient addition could not be separated. Performance improvements may have resulted from the water alone, and not from the nutrients it was carrying.

Nutrient addition on day 218 was the operational control previously referred to in section 4.1 (i.e. Figures 4.2a. 4,2b and 4.2c). Supplemental water addition was routinely employed during this part of the study. The volume of water used to introduce the nutrients was the same as was routinely employed. Thus, the impact of nutrient addition could be directly examined. The impact of nutrient addition on the removal of toluene and ethylbenzene is presented in Figures 4.3a and 4.3b. Contaminant removal data for all compounds are presented in Appendix D. Figures 4.3a and 4.3b clearly indicate the marked performance improvement following nutrient addition on day 218. When nutrients were added on day 248, no performance improvement was observed. However, as discussed in section 4.3.1.1, the bed had severely dried by this time. Thus, it is concluded that nutrient addition can increase contaminant removal efficiencies if appropriate bed moisture conditions exist.

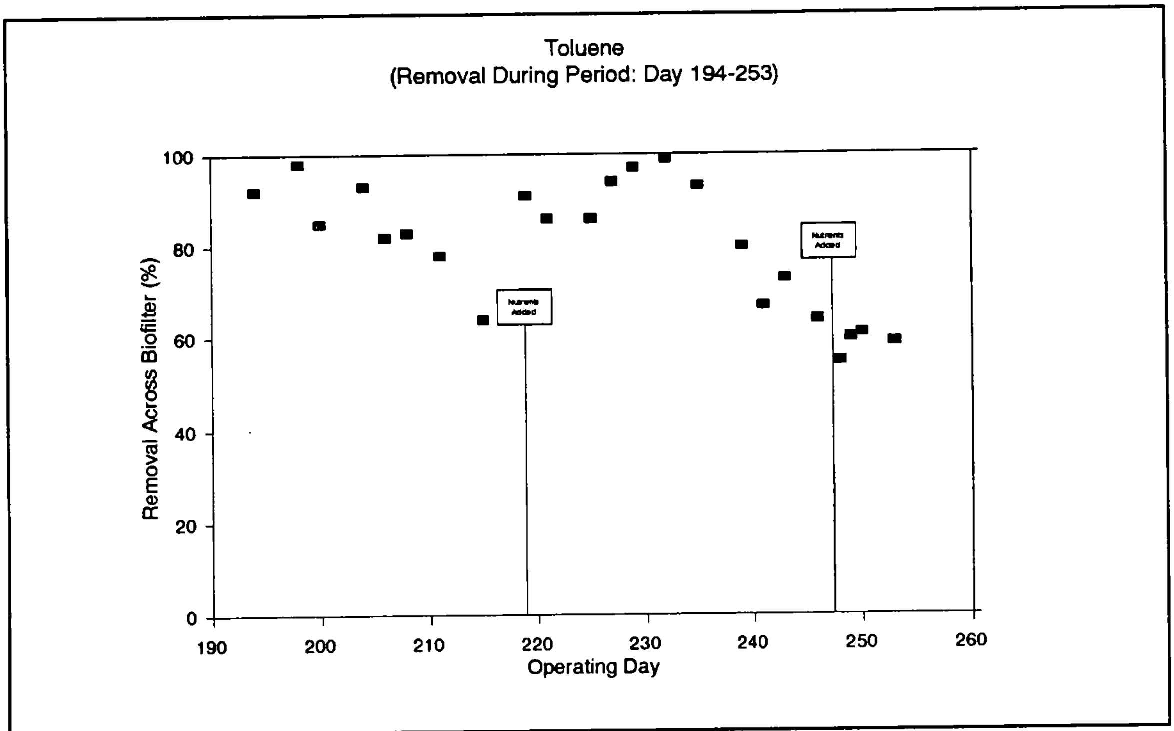

Figure 4.3a: Effect of Nutrient Addition of Removal Efficiency - Toluene

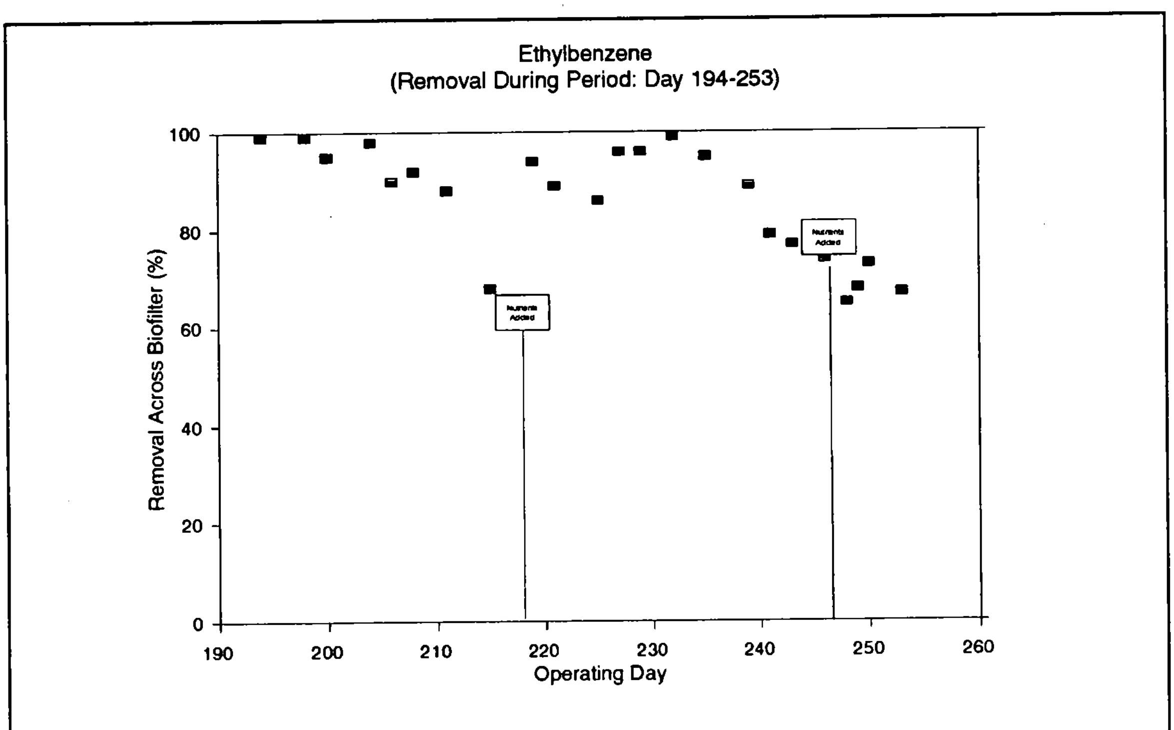

Figure 4.3b: Effect of Nutrient Addition on Removal Efficiency - Ethylbenzene

4.3.2 Effect of Supplemental Water Addition

This report section examines the impact of supplemental water addition on bed moisture content and contaminant removal efficiency.

Many researchers indicated the importance of maintaining the moisture content (by mass) of the biofilter media in the range of 40 to 60%. However, minimal publicly available literature has dealt specifically with the supplemental water requirements to maintain appropriate moisture conditions. Many researchers indicated that supplying a humidified influent air stream was sufficient to maintain appropriate media moisture content levels. Other researchers indicated supplemental water may be required but quantitative information on water requirements was extremely limited.

Report section 4.3.2.1 describes the biofilter operating experiences prior to using a tensiometer (operating day 201) to indicate supplemental water addition requirements. Report sections 4.3.2.2 and 4.3.2.3 describe supplemental water addition rates during the two longest periods of sustained contaminant removal efficiency (operating days 194 to 235 and operating days 410 to 435).

4.3.2.1 Supplemental Water Addition Prior to Operating Day 201

During the first 107 days following the introduction of contaminants into the biofilter influent airstream, (upflow mode, compost/perlite media) no supplemental water was added to the media. This was based on the assumption, as indicated by literature, that the humidified air provided sufficient water to maintain appropriate media moisture content. In addition, leachate/condensate was collected throughout this period (ranging from 0.8 to 4.7 L/d) suggesting excess water was being supplied to the biofilter. After day 107, supplemental water was added to ensure that lack of moisture was not causing observed low removal efficiencies. The addition of water had no observed impact on compound removal efficiencies. In a final attempt to increase contaminant removal efficiencies, air flowrates were reduced and nutrients added. These efforts had no observable effect.

To further verify that adequate moisture was present in the biofilter media, the media was sampled on operating day 157. Samples were taken by inserting a hollow tube into the media through the side of the containment vessel. The results indicated media moisture content levels between 53 and 60%. These levels were within the desired range of 40 to 60% and it was believed that there was adequate moisture in the media.

Because poor contaminant removals persisted (< 50%), the system was shut down and the biofilter media removed and examined between days 185 and 192. Moisture content measured at various locations throughout the bed is presented in Table 4.4. Results indicated that the top and outer edges of the media had moisture contents greater than 60%. Moisture contents were less than 30% at the core of the media. Thus, the previous samples were misrepresentative of the bulk moisture content since they were taken near the outer edge of the media, which was relatively moist.

Following the physical removal and examination of the media it was concluded that leachate/condensate collection volume could not be used as a media moisture content indicator. Routinely recorded operating parameters (e.g. temperature) were also inadequate for indicating media moisture content. Moisture content could have been monitored better by shutting down the system periodically and removing portions of the media. However, this would be impractical for actual biofilter applications. Therefore, a search was undertaken to identify a device to monitor media moisture content. A tensiometer, whose operating principles are discussed in section 3.1, was selected due to its simplicity (e.g. no reliance on electronic components) and low cost (≈ $100).

The tensiometer was installed on day 201 into the core of the biofilter media. The tensiometer column vacuum pressure was recorded daily. The data recorded by the tensiometer are discussed in the following sections (4.3.2.2 and 4.3.2.3).

Table 4.4: Biofilter Media Moisture Content - Day 185 to 192

Sample	Location	Moisture Content [% - mass basis]
1	30 cm below surface, 30 cm in from outer edge of media	18
2	30 cm below surface, 10-30 cm in from outer edge of media*	27
3	30 cm below surface, 5-20 cm in from outer edge of media*	66
4	30 cm below surface, near outer edge of media (<10cm)*	65
5	5-10 cm below surface, near outer edge of media (<10cm)*	68

*: exact distances not measured - estimated values given

4.3.2.2 Supplemental Water Addition: Operating Days 194 to 235

The longest period of sustained high contaminant removal was observed during the operating period from operating days 194 to 235 (42 days total). During this period, the compost/perlite mixture had fine pine bark nuggets place on top of the media (media composition 2 in section 3.2.1) and the system was operated in the upflow mode. Supplemental water was routinely added to the top of the media by the rotating arm described previously in section 3.1.

Figures 4.4a and 4.4b present removal efficiency for toluene and ethylbenzene. Removal efficiencies for all contaminants are presented in Appendix E. In Figures 4.4a and 4.4b, the day of operation is presented on the x-axis and the contaminant removal efficiency is presented on the primary y-axis (left y-axis). The percentage removal for each day is indicated by the filled rectangles on the graphs. The figures also indicate the following operating data:

- nutrient addition (operating days 218 and 248)
- recorded tensiometer reading (secondary y-axis; solid line; kPa vacuum))
- supplemental water addition (secondary y-axis; open circles; L/d).

On operating day 233, the rotating arm for the supplemental watering system was observed not to be rotating. As a result, only a small portion of the media was receiving the supplemental water. The period during which the arm was not rotating was not known. However, based on leachate collection and tensiometer measurements it was estimated that it failed sometime after day 220. Following day 220, the tensiometer readings increased from approximately 2 to greater than 40 kPa vacuum on operating day 239. This indicated that bed media drying occurred. On day 240, the rate of supplemental water addition was doubled and tensiometer readings dropped to 12 kPa vacuum. Although it was thought that the bed had been rewetted, as indicated by the tensiometer, removal rates continued to drop. The biofilter system was shut down on day 254 and the media moisture measured.

Measured media moisture contents ranged from a low of 19% (measured 40 cm below the media surface) to a high of 65% (near the surface). The majority of the media was observed to be dry, with moisture levels less than 30%. Thus, media drying is postulated to be responsible for the reduced contaminant removal efficiencies. The moisture content near the tensiometer was measured to be approximately 57%. Therefore, the tensiometer did correctly indicate moist media conditions at the tensiometer tip.

During the removal of the biofilter media, it was visually apparent that regions of dry and wet media had formed in the vessel. The two regions could easily be distinguished by their colour. A vertical cross section of the biofilter indicating the dry and wet regions is presented in Figure 4.5. The wet regions appear as inverted triangles in the media. The triangles appear near the outer edges of the vessel and at the centre portion. The tensiometer was located in this central portion and therefore gave a false indication that the bulk of the media had appropriate moisture content. It is postulated that the outer media portions remained wet due to condensation near the wall surface. The reason for the high moisture at the centre of the bed was not apparent.

As indicated previously, the period during which the media moisture was appropriate (range 40 to 60%) was estimated to be from operating day 194 to 220. During this period of 27 days, the average daily supplemental water addition rate was 13.0 L/d. This corresponds to a specific surface area application rate of 11.1 $L/(d \cdot m^2)$. The observed leachate collection rate during this same period was 4 L/d.

In summary, the period from operating day 194 to day 235 showed the utility of the tensiometer in indicating moisture content trends. Several tensiometers placed at different locations within the bed could provide a better measurement of overall bed moisture content. The estimated supplemental water addition rate which sustained adequate moisture contents was 11 $L/(d \cdot m^2)$. The estimated leachate/condensate collection was observed to be 4 L/d.

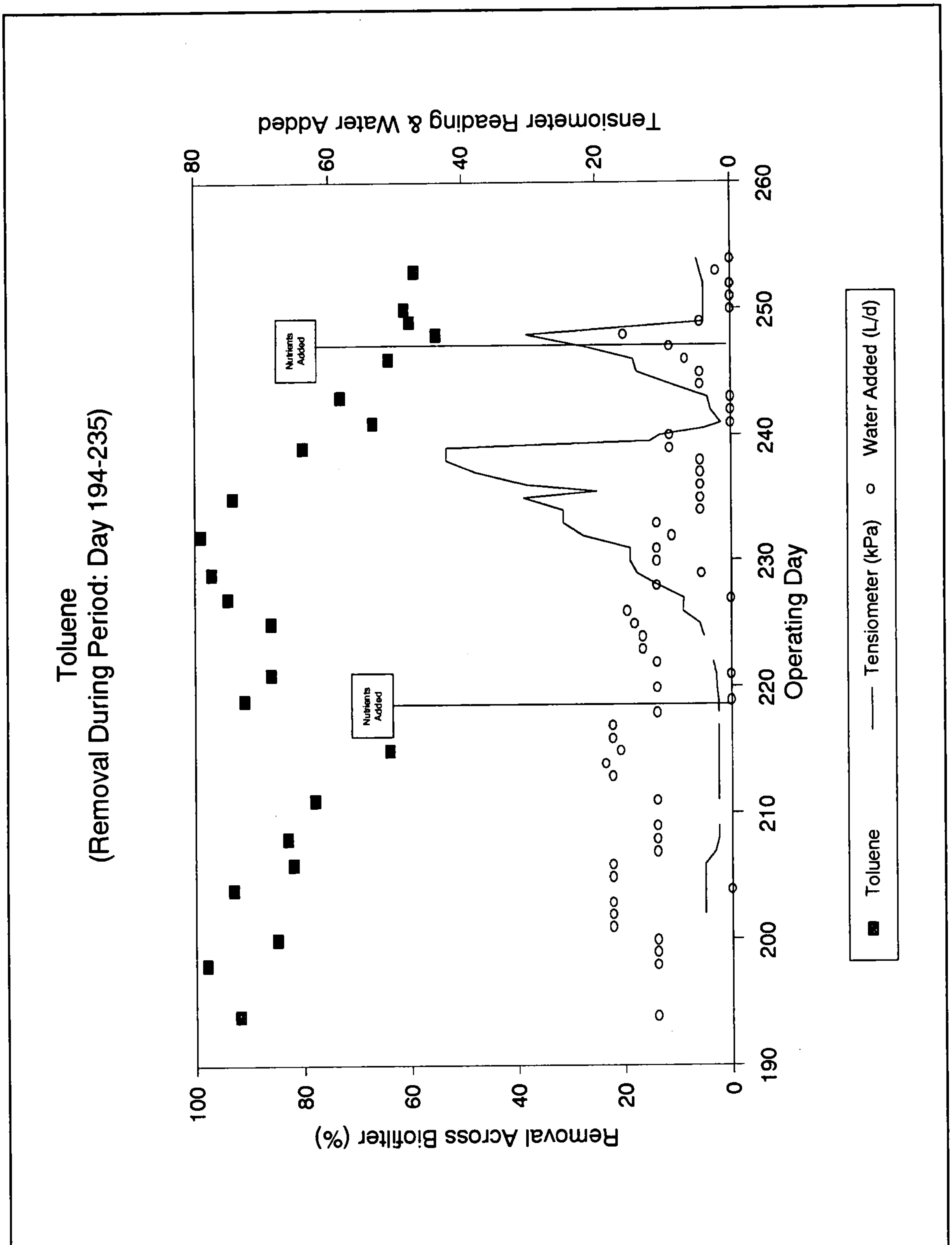

Figure 4.4a: Removal Across Biofilter: Day 194 to 235 - Toluene

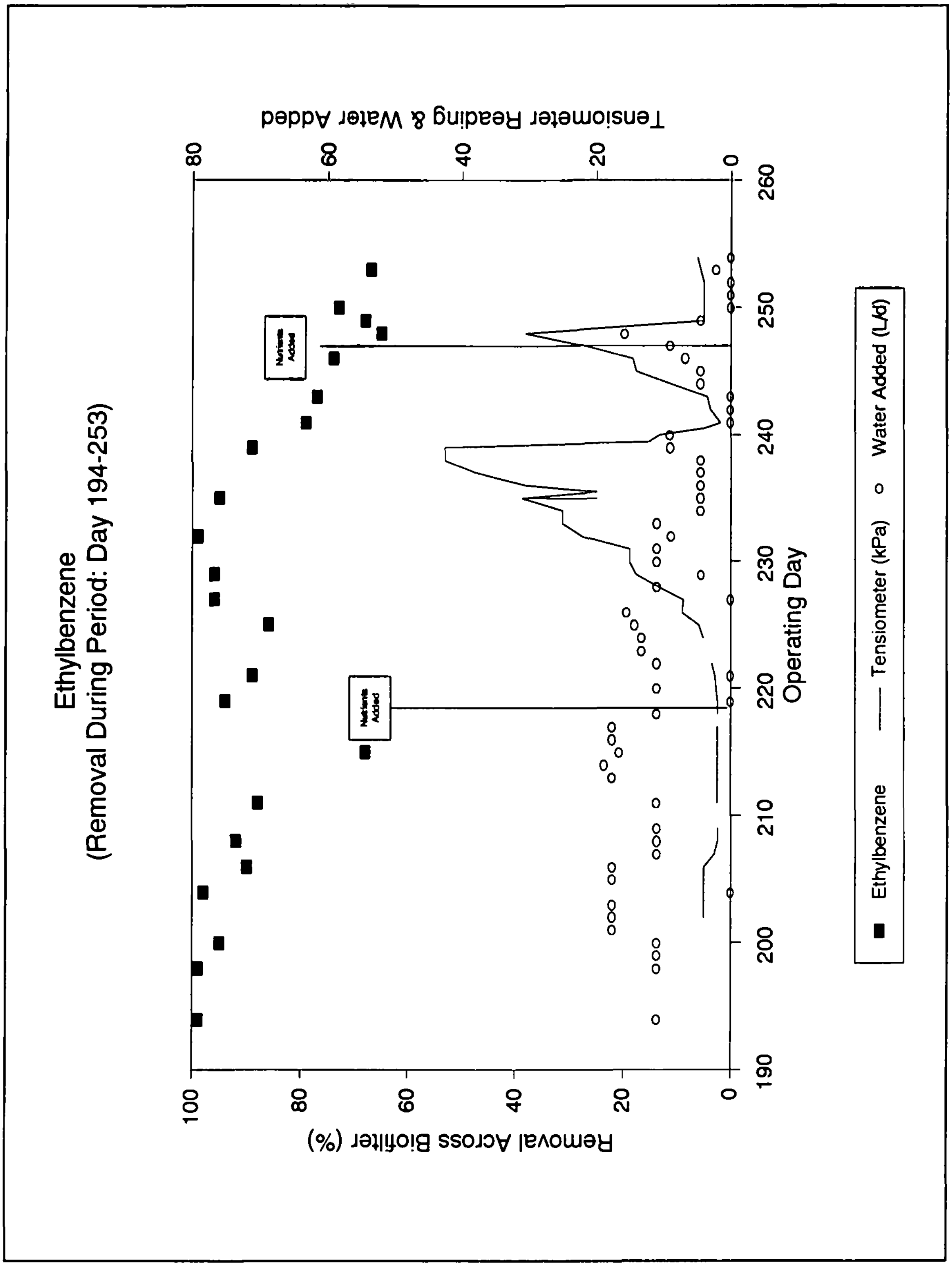

Figure 4.4b: Removal Across Biofilter: Day 194 to 235 - Ethylbenzene

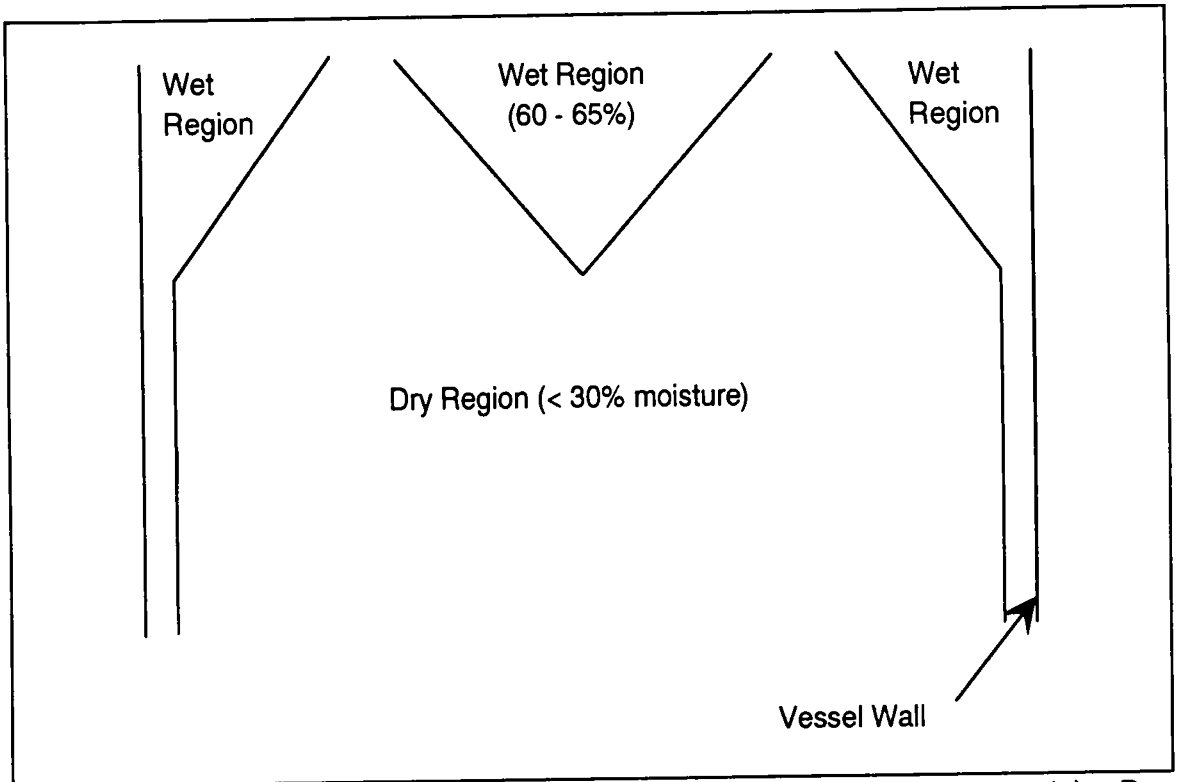

Figure 4.5: Biofilter Media Moisture Content Profile (illustrative: not to scale) - Day 254

4.3.2.3 Supplemental Water Addition: Operating Days 410 to 435

Removal efficiencies of greater than 80% for all compounds were observed for benzene, toluene and ethylbenzene during the period from operating day 410 to 435 (26 days total). During this period, the compost/perlite mixture was combined with large decorative bark (media composition 3 in section 3.2.1) in a 50:50 ratio and the system was operated in the downflow mode. Supplemental water was added to the top of the media by the rotating arm described in section 3.1. The total organic loading to the biofilter was 16.2 $g/(m^3{\cdot}h)$.

Figures 4.6a and 4.6b present removal efficiency for toluene and ethylbenzene. Removal efficiencies for all contaminants are presented in Appendix F. In Figures 4.6a and 4.6b, the day of operation is presented on the x-axis and the contaminant removal efficiency is presented on the primary y-axis (left y-axis). The percentage removal for each day is indicated by the filled rectangles on the graphs. The figures also indicate the following operating data:

- recorded tensiometer reading (secondary y-axis; solid line; kPa vacuum))
- supplemental water addition (secondary y-axis; open circles; L/d).

Operating data indicated that the biofilter media was quite moist throughout this period of sustained high BTE removal efficiency (> 80%). These data include low tensiometer readings (generally < 3 kPa) and substantial leachate/condensate collection volume (ranged from 2 to 9 L/d). The leachate/condensate collection volume was approximately 50% greater than that observed during the previously discussed period (day 194 to 235). The biofilter media was removed and examined on day 465. Moisture content values ranged from 28 to 62%. The low value of 28% was observed in a small band of dry media located in the same plane as the sample collection lines. The vast majority (estimated to be greater than 90%) of the media had moisture contents ranging from 49 to 62%.

Throughout this period of sustained BTE removal, a minimal amount of supplemental water was added to the bed (average = 0.9 L/d; 0.8 L/(m^2·h)) and yet adequate moisture levels were still maintained. It is postulated that moisture loss from the system was reduced due to the reduced organic loading rate and the lower air temperatures in the trailer housing the biofilter.

Organic Loading and Moisture Loss

The rate of moisture loss depends on the rate of biodegradation. The organic loading rate was reduced on operating day 402 from 22.0 to 16.2 g/(m^3·h). The reduced loading rate likely decreased the rate of moisture loss from the media. Heat is released during the biodegradation of compounds. This heat warms the influent air stream and increases the water carrying capacity of the air. Water is therefore drawn out from the media and, if the water is not replaced, the media will dry.

Ambient Air Temperature

Operating days 410 to 435 were in the months of December 1994 and January 1995. Due to heating difficulties, temperatures in the trailer housing the biofilter were as low as 10°C. The air entering the biofilter was approximately 30°C, but exited at temperatures as low as 21°C. The cooling of the air stream likely produced enough condensate to maintain adequate moisture levels in the media.

Figures 4.6a and 4.6b, show that contaminant removal rates dropped considerably during the period following day 430. It is postulated that this decline was due to reduced nutrient levels in the system. The addition of nutrients to the system would have been desirable, however, the analytical portion of the study was completed at this point and no BTE gas samples could have been analyzed.

Summary

In summary, sustained contaminant removal of greater than 80% was observed from operating day 410 to 435. Tensiometer readings indicated adequate media moisture conditions which was confirmed by direct sampling. Minimal supplemental water addition was required (0.8 L/(m^2·d)) to maintain these moisture content levels. It is believed that supplemental water requirements were reduced because lower organic loading rates reduced the magnitude of biodegradation and associated heat generation. Increased condensation may have also reduced supplemental water requirements.

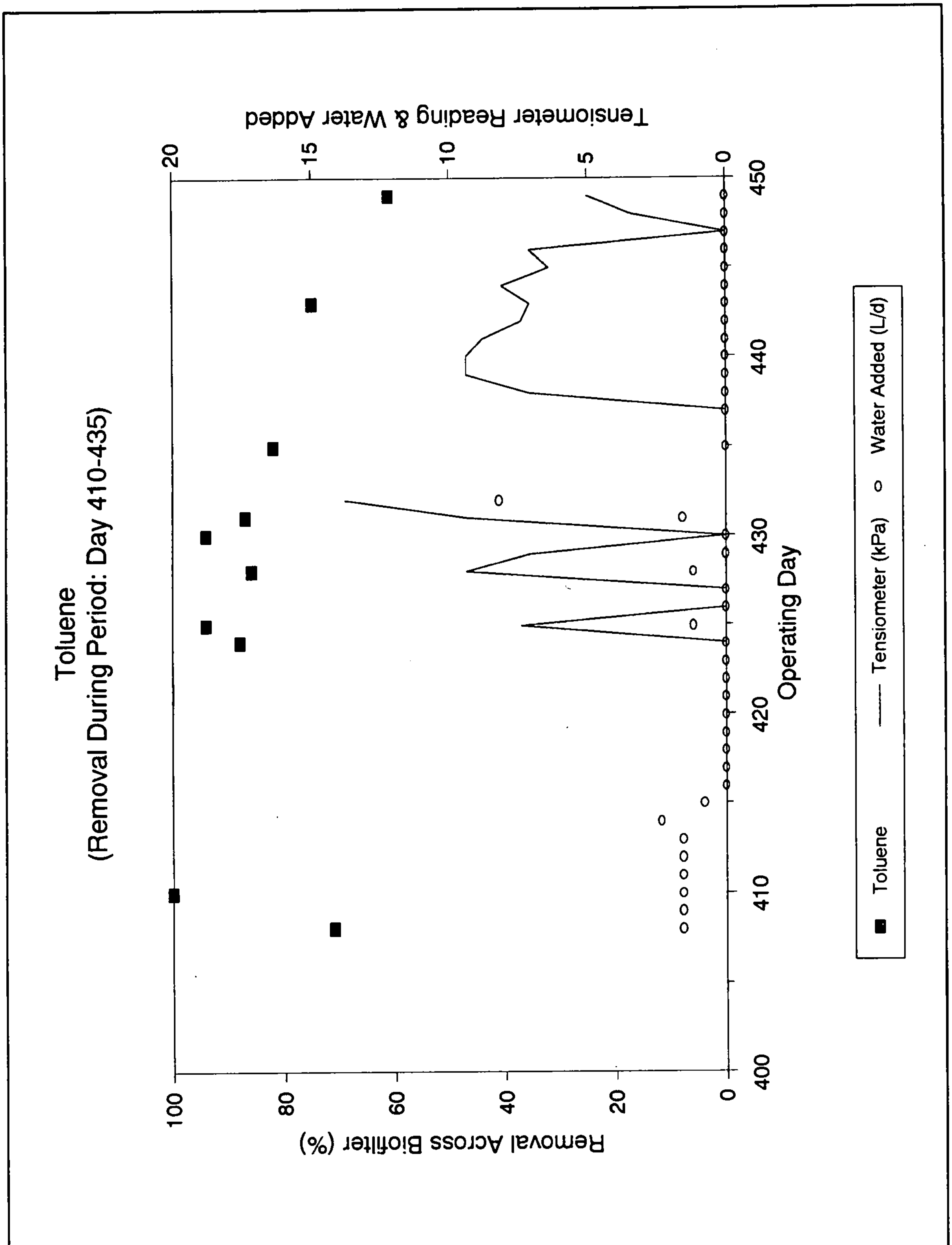

Figure 4.6a: Removal Across Biofilter: Day 410 to 435 - Toluene

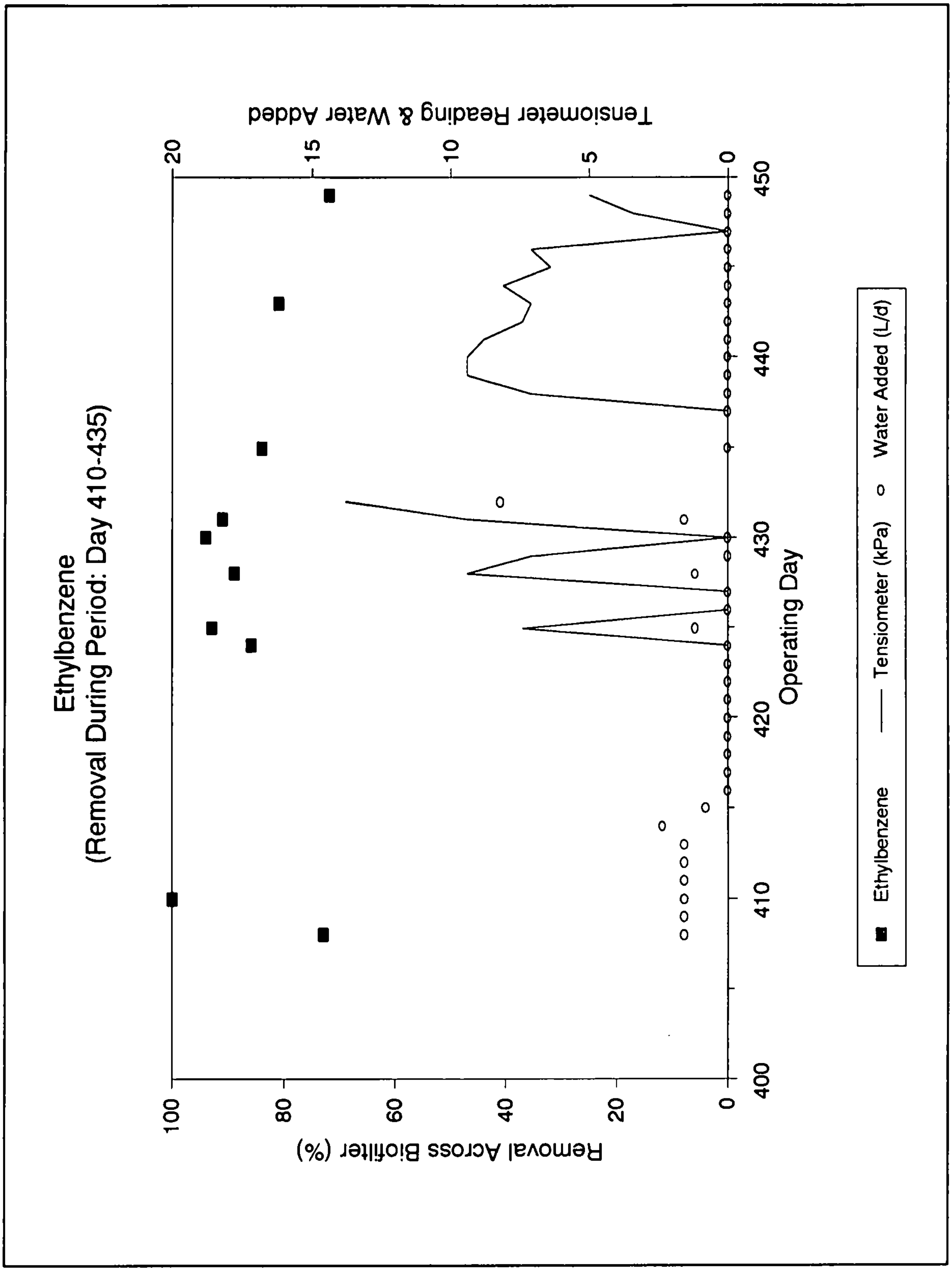

Figure 4.6b: Removal Across Biofilter: Day 410 to 435 - Ethylbenzene

4.3.2.4 Summary of Biofilter Supplemental Water Requirements

The required supplemental water addition rate was 11 L/(d·m^2) from operating day 194 to 235. This rate was considerably reduced to 0.8 L/(d·m^2) from operating day 410 to 435. The first addition rate was required during the summer months when the ambient temperature surrounding the biofilter vessel was only marginally lower (0 to 10°C lower) than the influent air stream temperature to the biofilter. The second addition rate was required during the winter months when ambient temperatures were frequently 20°C lower than the influent air stream to the biofilter. Thus, supplemental water requirements depend on the degree of heat transfer to or from the biofilter.

The first scenario, where there is minimal difference between ambient and biofilter process temperatures approximates the condition where the system is very well insulated. Operating under these conditions is desirable since the moisture content is controlled by supplemental water addition and not by condensation, which may not provide an even moisture distribution in the bed.

A tensiometer was shown to be an effective indicator of media moisture content. However, a single tensiometer can only indicate media moisture content at one location in the bed. Several tensiometers could be used to indicate overall media moisture content.

4.3.3 Residence Time

During the study, empty bed residence time ranged from 38 to 136 seconds. Throughout most of the study, the influent airstream flowrate corresponded to an empty bed residence time of 68 seconds (Q_{air} = 13.2 L/s, 28 CFM). Thus, it is concluded that sustained high contaminant removal efficiency could be achieved at an empty bed residence time of 68 seconds if appropriate bed moisture and nutrient conditions were maintained.

4.3.4 Organic Loading

The organic loading rate to the biofilter ranged from 16.2 to 22.0 g/(m^3·h) based on empty bed biofilter media volume. The lower organic loading rate was initiated on operating day 404. All compounds were observed to have removal efficiencies of greater than 80% for both the lower and upper organic loading rates. Thus, sustained high contaminant removal efficiency could be achieved at organic loading rates of 22 g/(m^3·h) if appropriate bed moisture and nutrient conditions were maintained. However, reduced organic loading rates may allow better control of bed moisture content, as discussed in section 4.3.2.3.

4.3.5 Influent Airstream Direction

Initially the biofilter was operated in an upflow mode. On operating day 277, the biofilter airstream direction was reversed and the system was operated in the downflow mode. As discussed previously in sections 4.3.2.2 and 4.3.2.3, the biofilter was operated for extended periods with compound removal efficiencies exceeding 80% during the periods from operating days 194 to 235 and from operating days 410 to 435. During the first period, the biofilter was operated in the upflow mode and during the second period it was operated in the downflow mode. Therefore, the biofilter could achieve sustained high removal efficiency in the upflow or downflow mode.

4.3.6 Periods of Extended Discontinued Operation

During the study there were three extended periods (greater than 5 days) during which no air was drawn through the biofilter. These periods were:

i) day 71 to 87 (17 days)
ii) day 185 to 193 (9 days)
iii) day 254 to 275 (22 days).

Removal efficiencies before and after the first period (day 71 to 87) were less than 50% and therefore did not indicate any effect (positive or negative) on media performance. Removal efficiencies prior the second period (day 185 to 193) were also generally less than 50%. Upon system start-up 9 days later, removal efficiencies exceeded 80%. Removal efficiencies prior to the third period (day 254 to 275), were also less than 50%. Upon system start-up 22 days later, removal efficiencies exceeded 80% within 24 hours. Thus, it is concluded that sustained idle periods (minimum of 22 days), had no negative impact on contaminant removal efficiency following reintroduction of contaminants.

4.3.7 Media Short Circuiting

As indicated previously in Section 3.3.1, smoke tests were conducted to indicate the degree of short circuiting occurring in the media. The tests, as explained in section 3.3.1, could only be used when the biofilter was operated in the upflow configuration. Smoke tests were conducted on five separate operating days (185, 191, 192, 212, and 254). The results of the smoke tests are presented in Table 4.5.

Table 4.5 indicates the biofilter operating conditions during which each test was taken. These include both ideal media conditions (e.g. just after media remixing and rewetting) and conditions under which poor removals persist (i.e. test days 185 and 254). The empty bed residence time and the actual retention times are indicated for each smoke test. The time at which the smoke first appeared and when the appearance of large amounts of smoke appeared is also indicated. For each of these times, the location of the first and bulk smoke is indicated. For example, on day 192 the smoke appeared 20 seconds after being introduced and was observed near the vessel walls. After approximately 30 seconds, the first indication of a large bulk of smoke was observed at the central portions of the media surface.

The times at which large amounts of smoke were observed generally corresponded with the actual residence time in the biofilter vessel. Therefore, a large fraction of the influent air remained in the biofilter media for the expected residence time. Some short circuiting was observed in all tests as indicated by the first appearance of smoke prior to the bulk of the smoke. Thus, some short circuiting occurs even under ideal operating conditions (e.g. after remixing and rewetting of media). Short circuiting was observed both along the biofilter containment vessel walls and at the central portions of the media.

Impact of Condensation Along Walls

Figure 4.7 presents the benzene, toluene, ethylbenzene and m/p-xylene concentration profiles through the biofilter bed on operating day 443. All of the off-gas concentrations were observed to be greater than the concentration within the media. This would suggest that a significant portion of the air short-cirquited along the walls and thus had a low removal efficiency. This air then mixed with the air that proceeded through the media and was treated to a high degree. The mixed air stream exiting the biofilter (i.e. 100% progression on x-axis in Figure 4.7) thus had a higher contaminant concentration than was observed within the media itself (i.e. 90% progression on x-axis in Figure 4.7).

As discussed in section 4.3.2.3, considerable leachate/condensate was collected (ranged from 2 to 9 L/d) during the period day 410 to 435, due to the cold ambient temperatures to which the biofilter vessel was exposed. The cooler temperatures likely resulted in condensation potentially creating channels along the vessel walls. A portion of the influent air, following the path of least resistance along the vessel walls, would remain largely untreated.

Table 4.5: Smoke Test Results

Test Day	Operating Conditions	EBRT* (s)	Actual RT** (s)	Smoke Visible Times (s)	
				First Appearance	Bulk of Smoke$^{\alpha}$
185	removals < 60%	136	68	20 (sides)	n/a
191	after media remixed and rewetted	68	34	25 (sides)	45 (middle)
192	after media remixed and rewetted	68	34	20 (sides)	30 (middle)
212	removals > 70%	68	34	7 (centre)	30
254	removals < 70%	68	34	15 (centre)	30 (entire surface)

notes:

*: EBRT = empty bed residence time (Q_{air}/volume occupied by media)

**: Actual residence time = EBRT · porosity (porosity ≈ 50% as indicated in Appendix A)

α: visual observation when large amount of smoke starts to appear

n/a: no observation recorded

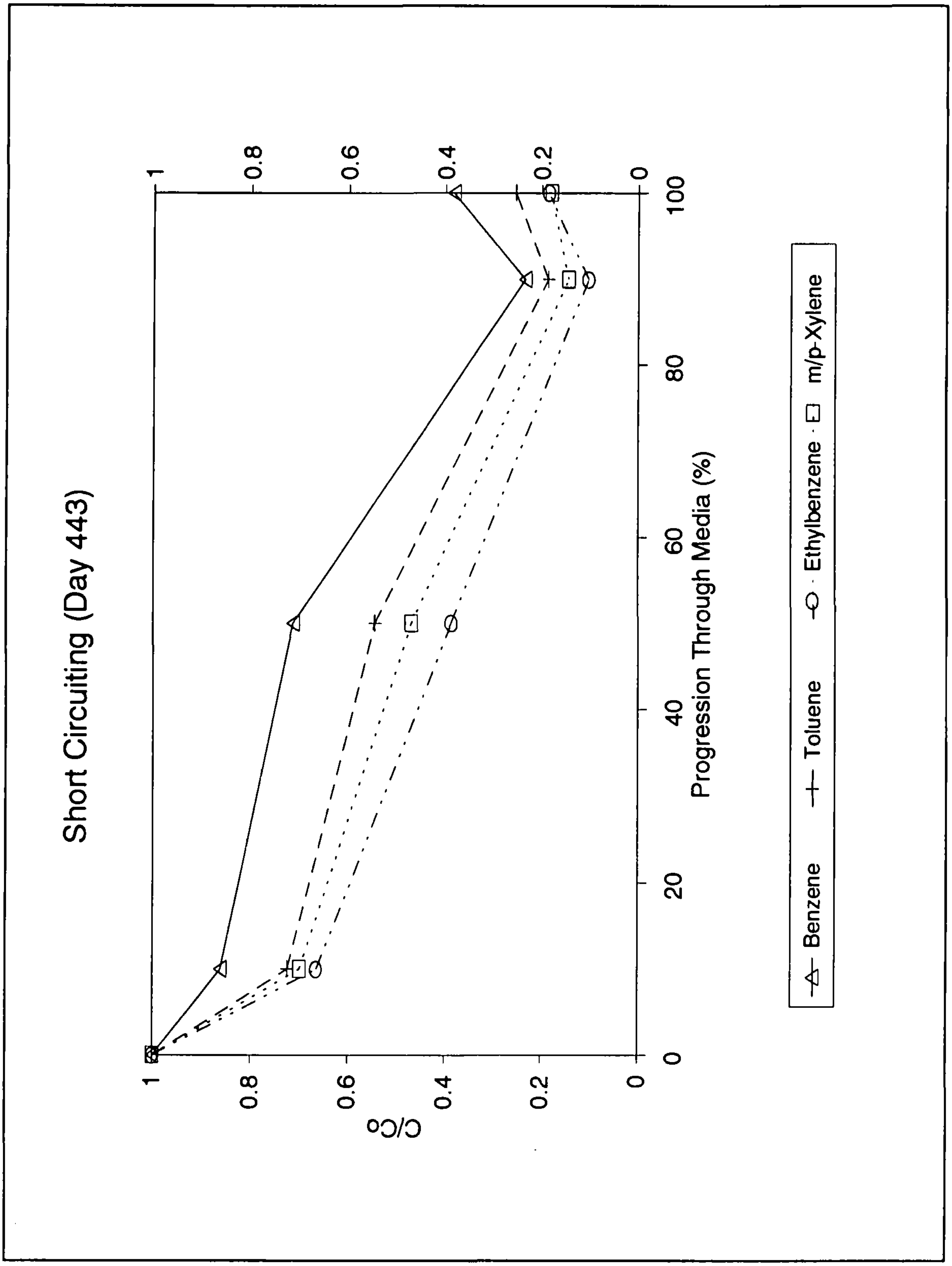

Figure 4.7: Effect of Short Circuiting on Biofilter Performance

4.4 Contaminant Removal Modelling

During the study, it was demonstrated that the biofilter was able to biodegrade the BTEX compounds and achieve removal efficiencies greater than 80%, if appropriate media moisture and nutrient conditions were maintained. This report section presents zero and first order biodegradation models calibrated to these periods of sustained high removal efficiency.

4.4.1 Biofilter Model Formulation

If the air flow pattern in a biofilter is considered to be plug flow, the distance into the biofilter can be expressed in terms of airflow time. The use of time is preferred since a common parameter used to describe a biofilter is by its Empty Bed Residence Time (EBRT).

If the only contaminant removal mechanism considered is biodegradation, the general mass balance equation for the biofilter can be expressed by Equation 1. The model may be applied to estimate contaminant removal rates assuming appropriate media moisture and nutrient conditions are maintained.

$$\frac{dC}{dt} = -R \qquad (1)$$

where:

C = gas phase contaminant concentration [g/m^3]
t = airflow time assuming empty bed volume [s]
R = biodegradation rate [$g/(m^3 \cdot s)$].

The biodegradation rate R can be expressed in many forms. For this modelling exercise, zero order and first order biodegradation rate forms have been used. The zero order rate form is independent of concentration and is presented in Equation 2. The first order biodegradation rate is dependent on the contaminant concentration and is presented in Equation 3.

$$\textit{zero order:}\quad R = k \qquad (2)$$

$$\textit{first order:}\quad R = kC \qquad (3)$$

where:

k = biodegradation rate constant [1/s]

Substituting Equations 2 and 3 separately into Equation 1 and integrating yields zero and first order expressions for the contaminant concentration as a function of influent concentration and EBRT. The results are presented in Equations 4 and 5.

$$zero\ order:\ C = C_0 - kt \tag{4}$$

$$first\ order:\ C = C_0 e^{(-kt)} \tag{5}$$

where:

C_o= biofilter influent concentration [g/m^3]

It should be noted that the models presented do no attempt to account for any inhibition that may exist in the multi-compound contaminated influent air stream used during the study. In addition, the values for 'k' may depend on biofilter operating conditions such as:

- approach velocity (Q_{air}/x-sectional area [m/s])
- media composition
- organic loading rate.

Deviations from the above operating conditions during this study will reduce confidence in predicted removal efficiencies.

4.4.2 Biofilter Model Parameter Estimation

As indicated in section 4.0, overall contaminant removal rates varied greatly during the study. Several factors have been discussed in this report that potentially limited the biofilter performance including inadequate media moisture content and nutrient deficiency. When these factors were controlled within acceptable ranges, contaminant removal efficiency exceeding 80% was achieved. Model parameter estimates were based upon data collected during these periods.

As indicated in section 2.4, the biofilter media containment vessel had three gas sample ports for sampling air at depths of 10, 50 and 90% of the total media height. There were also influent and effluent sample ports. Generally, samples were only taken at the influent and effluent sample locations. Periodically, samples were taken at all five ports and a concentration profile through the media depth was obtained. These concentration profiles were used to estimate the parameter value 'k' for the zero and first order models.

A total of 25 concentration profiles were collected during the study. However, only four of these were collected during sustained high contaminant removal efficiency (day 204, 229, 232 and 425). The first three operating days (204, 229 and 232) were part of the first extended period of contaminant removal (day 194 to 235) discussed in section 4.3.2.2. The fourth sample day (425) was part of the second extended period of contaminant removal (day 410 to 435) discussed in section 4.3.2.3. The two periods were modelled separately. The model parameter 'k' was fit to the observed data using a non-linear least squares technique.

4.4.2.1 Biofilter Modelling (Operating Days 194 to 235)

During the period from day 194 to 235 the biofilter was operated under the following conditions:

- upflow mode
- the compost/perlite mixture had fine pine bark nuggets on top of media
- EBRT was 68 seconds (approach velocity = 40.6 m/h)
- organic loading rate was 22.0 g/($m^3 \cdot h$).

The calculated 'k' parameter for the zero and first order models for this period are based on the concentration profiles from days 204, 229 and 235. The results are presented in Table 4.6. The data points used and the fitted curves for the models are presented in Appendix G with the results for ethylbenzene reproduced in Figure 4.8. Figure 4.8 presents removal as expressed by the ratio of the air contaminant concentration to the inlet air stream contaminant concentration.

The zero order 'k' parameters presented in Table 4.6 vary from a minimum of 0.102 for o-xylene to a maximum of 2.035 for ethylbenzene. The 90% confidence interval for the values vary from 17% of the 'k' value for benzene to a maximum of 189% of the 'k' value for o-xylene. Based on the calculated value for 'k', the order from least readily degraded compound to most readily degraded compound is: o-xylene, m/p-xylene, benzene, toluene, ethylbenzene. Benzene and toluene have very similar values. This order is identical to the order determined by the contaminant removal histogram presented in section 4.2. If the 90% confidence interval is considered, no significant difference was observed in the 'k' values between ethylbenzene, toluene and benzene.

The first order 'k' parameters presented in Table 4.6 vary from a minimum of 0.0213 for o-xylene to a maximum of 0.0469 for ethylbenzene. The 90% confidence interval for the values vary from 18% of the 'k' value for ethylbenzene to a maximum of 27% of the 'k' value for m/p-xylene. The order of biotreatability, based on the calculated value for 'k', is identical to that observed for the zero order model. As in the zero order model case, no significant difference between ethylbenzene, toluene and benzene was observed when the 90% confidence interval is considered.

Based on Table 4.6 there is no clear choice as to whether the data is best represented by a zero or first order model. Visual inspection of the graphs presented in Appendix G suggests that the first order model may be appropriate for benzene, toluene and ethylbenzene while zero order may be appropriate for the xylenes.

Table 4.6: Contaminant Model Parameters - Day 194 to 235				
Compound	Zero Order Model $C = C_o - kt$		First Order Model $C = C_o e^{-kt}$	
	k[μg/(L·s)]	90% CI*	k[s^{-1}]	90% CI*
Benzene	1.512	± 0.257 (± 17%)	0.0372	± 0.0084 (± 22%)
Toluene	1.579	± 0.303 (± 19%)	0.0404	± 0.0091 (± 22%)
Ethylbenzene	2.035	± 0.497 (± 24%)	0.0469	± 0.0085 (± 18%)
m/p-Xylene	0.819	± 0.153 (± 19%)	0.0253	± 0.0068 (± 27%)
o-Xylene	0.102	± 0.193 (± 189%)	0.0213	± 0.0052 (± 24%)

*: CI = confidence interval; based on "Student's" *t* distribution (small sample distribution)

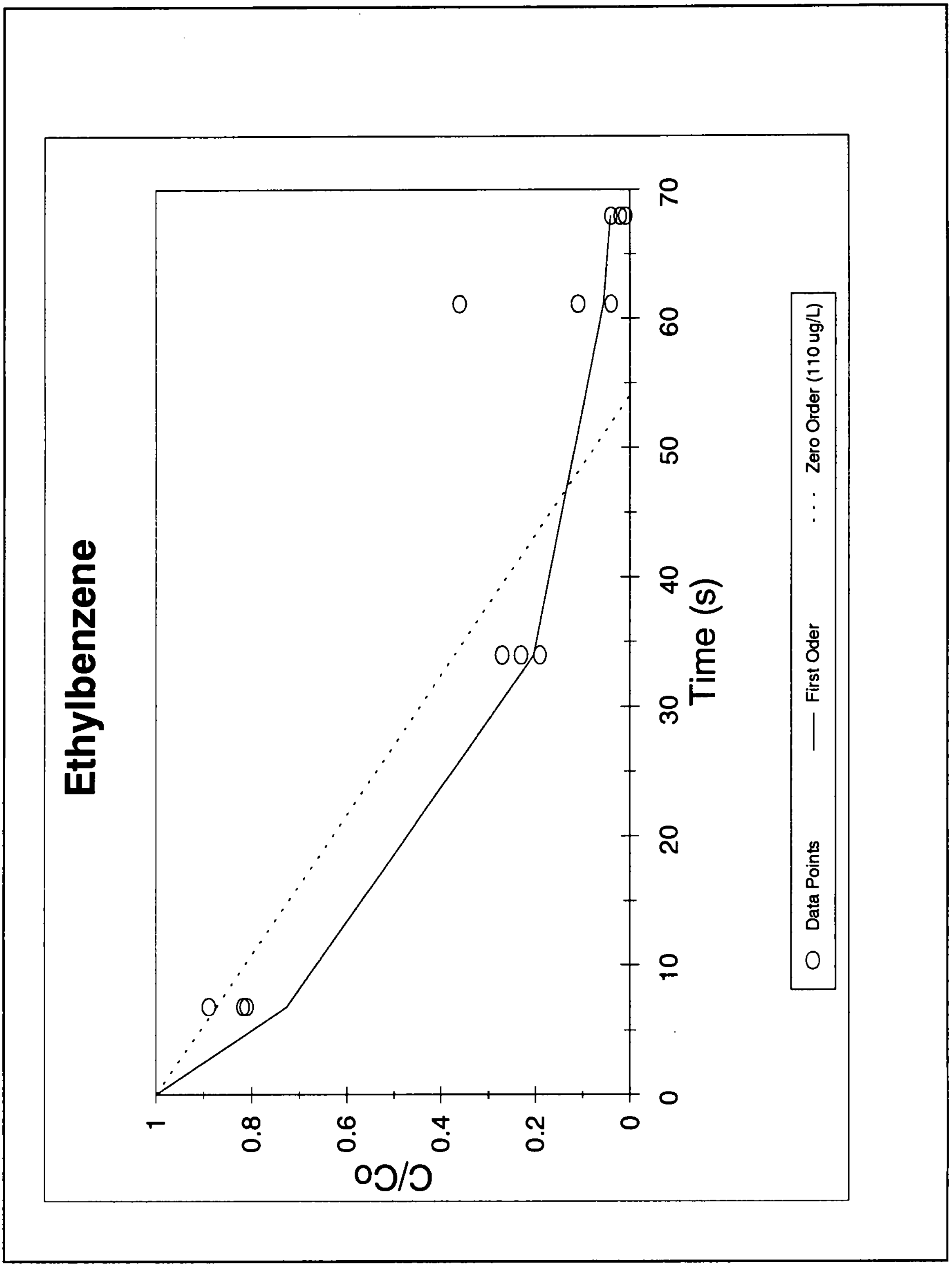

Figure 4.8: Contaminant Removal Modelling Day 194 to 235 - Ethylbenzene

4.4.2.2 Biofilter Modelling (Operating Days 410 to 435)

During the period from day 410 to 435 the biofilter was operated under the following conditions:

- downflow mode
- the compost/perlite mixture was supplemented with large bark pieces
- EBRT was 68 seconds (approach velocity = 40.6 m/h [Q_{air}/x-sectional area])
- organic loading rate was 16.2 g/(m^3·h).

The calculated 'k' parameter for the zero and first order models for this period are based on the concentration profiles from operating day 425 (removal efficiencies > 80%). The results are presented in Table 4.7. The data points used and the fitted curves for the models are presented graphically in Appendix H with the results for ethylbenzene reproduced in Figure 4.9. Figure 4.9 presents removal as expressed by the ratio of the air contaminant concentration to the inlet contaminant concentration.

The zero order 'k' parameters presented in Table 4.7 vary from a minimum of 0.953 for m/p-xylene to a maximum of 2.087 for ethylbenzene. The 90% confidence interval for the values vary from 28% of the 'k' value for toluene to a maximum of 40% of the 'k' value for benzene. Based on the calculated value for 'k', the order from least readily degraded compound to most readily degraded compound is: benzene, m/p-xylene, toluene, ethylbenzene. This order is similar to the order determined by the contaminant removal histogram presented in section 4.2. If the 90% confidence interval is considered, no significant difference was observed in the 'k' values for any of the compounds. This is likely due to the limited number of sample days available for analysis.

The first order 'k' parameters presented in Table 4.7 vary from a minimum of 0.0645 for m/p-xylene to a maximum of 0.0881 for benzene. The 90% confidence interval for the values vary from 47% of the 'k' value for benzene to a maximum of 75% of the 'k' value for toluene. The order of biotreatability, based on the calculated value for 'k', was m/p-xylene, toluene, ethylbenzene, benzene. If the 90% confidence interval is considered, no significant difference was observed in the 'k' values for any of the compounds. This is likely due to the limited number of sample days available for analysis.

Table 4.7: Contaminant Model Parameters - Day 410 to 435				
Compound	Zero Order Model $C = C_o - kt$		First Order Model $C = C_o e^{-kt}$	
	k[μg/(L·s)]	90% CI	k[s^{-1}]	90% CI
Benzene	0.906	± .364 (± 40%)	0.0881	± 0.0415 (± 47%)
Toluene	1.295	± 0.360 (± 28%)	0.0659	± 0.0496 (± 75%)
Ethylbenzene	2.087	± 0.596 (± 29%)	0.0701	± 0.0519 (± 74%)
m/p-Xylene	0.953	± 0.279 (± 29%)	0.0645	± 0.0451 (± 70%)

*: CI = confidence interval; based on "Student's" *t* distribution (small sample distribution)

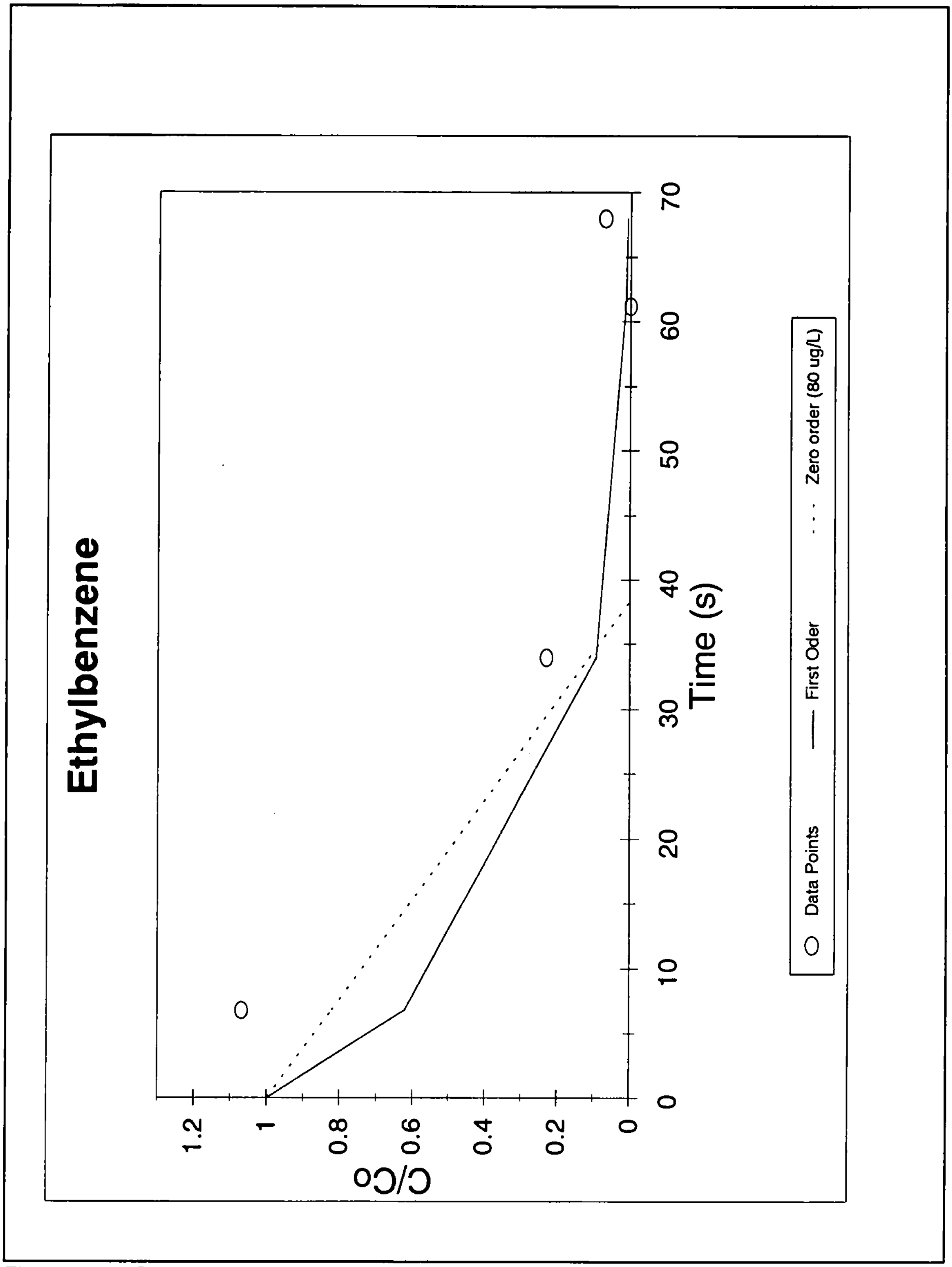

Figure 4.9: Contaminant Removal Modelling Day 410 to 435 - Ethylbenzene

4.4.2.3 Application of Modelling Results

Table 4.8 summarizes results from model calibration to the two available data sets. The fitted models could be used to predict potential contaminant removal efficiency from a compost based biofilter, assuming appropriate moisture and nutrient conditions are maintained. Based upon visual inspection of model fit, it is recommended that the first order model be applied for estimating potential removal of benzene, toluene and ethylbenzene and the zero order model be applied for m/p-xylene and o-xylene. The models should only be applied for operating conditions similar to study operating conditions.

Table 4.8: Summary of Model Results

Compound	'k' Parameter Value Range (90% CI*) [s^{-1}]	
	Day 194 to 235$^{\alpha}$	Day 410 to 435$^{\beta}$
	Zero Order	
Benzene	1.255 - 1.769	0.542 - 1.270
Toluene	1.276 - 1.882	0.935 - 1.655
Ethylbenzene	1.538 - 2.532	1.491 - 2.683
m/p-Xylene	0.666 - 0.972	0.674 - 1.232
o-Xylene	-0.091 - 0.295	----
	First Order	
Benzene	0.0288 - 0.0456	0.0466 - 0.1296
Toluene	0.0313 - 0.0495	0.0163 - 0.1155
Ethylbenzene	0.0384 - 0.0554	0.0182 - 0.1220
m/p-Xylene	0.0185 - 0.0321	0.0194 - 0.1096
o-Xylene	0.0161 - 0.0265	----

*: CI = confidence interval; based on "Student's" *t* distribution (small sample distribution)

α: operating conditions: 68 second EBRT, compost/perlite media, upflow mode, organic loading 22.0 g/(m^3·h)

β: operating conditions: 68 second EBRT, compost/perlite & large bark mixture, downflow mode, organic loading 16.2 g/(m^3·h)

5.0 CONCLUSIONS

The following conclusions are made as a result of this study:

- The original design incorporated humidification of the influent airstream to maintain desired media moisture conditions (40% - 60%) for biodegradation. Humidification of the airstream alone was inadequate for maintaining the desired moisture conditions at an organic loading rate of 22 g/(m^3·h).

  Supplemental water addition to the biofilter was critical. Near the end of the study, contaminant removal efficiencies exceeding 80% were maintained for periods of 26 and 42 days through control of supplemental water and nutrient addition. During these periods, off-gas concentrations were less than 20μg/L for each compound.

- Media moisture control was the critical operating parameter affecting contaminant removal efficiencies. Xylene removal was most sensitive to reduced media moisture content. Once the media had dried excessively, it became hydrophobic, and supplemental water addition was ineffective at regaining the desired moisture content range. Once dry, the media had to be mechanically broken before re-wetting. A tensiometer, installed part way through the study, was a useful indicator of media moisture content and supplemental water addition requirements.

- Nutrient addition was observed to increase contaminant removal efficiency if appropriate media moisture conditions were present. Nutrient addition had no effect if the media moisture content was inadequate.

- Biofilter performance was not adversely affected for media idle times of up to three weeks.

- A zero and first order model for predicting contaminant removal rates was calibrated to data collected during periods of sustained high contaminant removal. The fitted models can be used to predict potential contaminant removal efficiency from a compost based biofilter, assuming appropriate moisture and nutrient conditions can be maintained. The model should only be applied to operating conditions similar to those used in this study.

Design and Operation Guidelines

Table 5.1 summarizes the design and operating conditions under which contaminant removal efficiencies exceeding 80% were observed. The table can be used as a guideline for designing a compost biofilter for BTEX removal.

Table 5.1: Recommended Operating Conditions for Sustained Elevated BTEX Removal Efficiency (> 80%)		
Parameter	Recommended Range/Method	Comments
Design		
Empty Bed Gas Residence Time	≥ 68 seconds	lowest empty bed residence time thoroughly examined during study
Organic loading	≤ 22 (g total of BTEX)/(m^3·h)	highest organic loading rate examined during study
Media Composition	compost 30% (by volume) perlite 20% (by volume) inert bark 50% (by volume)	large bark pieces reduced media clumping and improved moisture distribution
Media pressure drop	< 1cm of water	Minimal pressure drop
Operation		
Media moisture control	- acceptable range 40 - 60% - monitor with tensiometer - maintain vacuum reading ≤15 kPa	can not rely on humidified air to supply all water requirements; supplemental water must be added; use several tensiometers placed throughout the media (e.g. top, middle, bottom)
Supplemental water addition	≈ 13 L/d (11.1 L/(m^2·d))	maintain recommended water addition rate unless tensiometer indicates media drying; recommended value where system is well insulated; heat loss from system will reduce water requirements
Leachate/condensate collection	2 to 8 L/d (0.85 to 8.5 L/(m^2·d))	anticipated range of leachate collection with recommended method of moisture control
Nutrient addition	200 to 400 g/application (171 to 342 g/(m^2·application))	20-20-20 water soluble fertilizer is recommended due to the ease of dissolution in water and addition through the supplemental water addition line; required dosage frequency not determined in study; apply when sustained decline in removal efficiency persists and media moisture content is appropriate; improved removal efficiencies should be observed within 1-4 days

6.0 RECOMMENDATIONS

The following recommendations are made as a result of this study:

- It is recommended that a study be conducted to verify that regular adjustment of moisture and nutrient addition rates, based on tensiometer measurements and contaminant removal efficiency data, can sustain consistently high removal data for an extended period (i.e. > 60 days). Near the end of the study, contaminant removal efficiencies exceeding 80% were maintained for periods of 26 and 42 days, through such a control strategy. Further demonstration was not possible because of mechanical difficulties and time limitations.

- It is recommended that an optimization study be conducted following the study recommended above. Occasionally, contaminant removal efficiencies exceeding 90% were observed. It is recommended that an optimization study be conducted to investigate the operating conditions that result in these high removal efficiencies. The impact of nutrient dosage rate and media composition could be more firmly established. In addition, a relatively narrow range of volumetric and organic loading rate were examined in this study. It is recommended that a wider range be examined to determine the effluent concentrations that can be achieved.

- It is recommended that a mechanistic, dynamic model be developed, calibrated and verified to predict performance of a biofilter containing compost. There are existing models, but they have generally been calibrated with assumed steady state operating data.

- It is recommended that a study be conducted to investigate contaminant removal efficiency with a multiple compound influent air stream, particularly containing sulphurous compounds. These sulphurous compounds are frequently associated with BTEX contaminated air streams. Their presence may impact on BTEX removal, especially because of acid generated during oxidation of the sulphurous compounds.

- It is recommended to investigate other biological gas cleaning treatment technologies such as trickling filters. Trickling filters may have advantages over biofilters in some applications. These potential advantages include easier moisture control and reduced sensitivity to acid build-up during treatment of streams containing sulphurous compounds.

- Low cost and non-obtrusive devices such as capacitance probes should be investigated for monitoring media moisture content.

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Appendix A1

Results: Biofilter Operating Conditions - Daily Reports

Biofilter Operation Results

Reference date: first date of VOC injection

Date		year	month	day	time	DAY	Trailer T at knockou	Trailer T at sink	Ambient T	Influent T	Media T	off-gas T	Tensiometer (kPa-vacuum) Weiss gauge	Tensiometer (kPa-vacuum) Hg vac gauge	Tensiometer (kPa-vacuum) Irrometer gauge	Rotameter Airflow (CFM)	Vortex flow Meas (SCFM)	Spike Rpm
				Nov 7/93		DAY 1												
Nov 8/93	Mon	93	11	8	14:20	1												
					14:20						drain knock-out box and media							
					15:37						start VOC injection							50
											end of day stop injection							
Nov 9/93	Tues	93	11	9	13:30	2					drain knock-out box and media							
					13:45				11	30		27						50
											stop injection at end of day							
Nov 10/93	Wed	93	11	10		3					drain knock-out box and media							
Nov 11/93	Thurs	93	11	11	08:10	4			5	26.5		27.5						
											replace thermometer for incoming air							
											replace injection fitting to copper tubing squished at end done to reduce influent concen. variation							
					14:00													
Nov 12/93	Fri	93	11	12	08:20	5											34.5	50
					14:00				10	31.5		28.5						
Nov 13/93	Sat	93	11	13	11:15	6			12	30		28						
Nov 14/93	Sun	93	11	14	13:45	7			10	33		32						
Nov 15/93	Mon	93	11	15	13:45	8			9.5	32		32						
Nov 16/93	Tues	93	11	16	07:30	9			6	30		30					34.5	
Nov 17/93	Wed	93	11	17	10:00	10												
Nov 18/93	Thurs	93	11	18	08:30	11			-3	28.5		29						
					13:35				4	30.5		28.5						
Nov 19/93	Fri	93	11	19	08:35	12					modify media drain line							
					13:20				7	31.5		29.5						
					15:35					31		29.5						
Nov 22/93	Mon	93	11	22	10:15	15												
					13:00				10	32		29.5					34.5	
Nov 23/93	Tues	93	11	23	12:45	16					noticed vortex flow meter flow actually increased as valve cloed							50
					16:00				5	30		28.5						
Nov 24/93	Wed	93	11	24	09:30	17			4	29.5		28.5						
Nov 25/93	Thurs	93	11	25	08:45	18			-3	25		25.5						
					13:15				-1	26		25.5						
Nov 26/93	Fri	93	11	26	13:00	19					fuse for hot water tank gone							
					16:00													
Nov 29/93	Mon	93	11	29	12:30	22												
Nov 30/93	Tues	93	11	30	13:20	23												

Biofilter Operation Results

Reference date: first date of VOC injection

Date	year	month	day	time	DAY	leachate volume (L)	leachate analysis (nutrients)	leachate analysis (BTEX)	leachate SS (mg/L)	leachate pH	sprinkler time (min)	est. spr. volume (L)	drain separator (Y or N)	Pressure across media (" of H2O)	Pressure across system (" of H2O)	VOCs added (L)	VOC inj. rate (mL/min)	Fertilizer (g/L water)	Moisture content (%) Lower port	Moisture content (%) Upper Port
			Nov 7/93		DAY 1															
Nov 8/93 Mon	93	11	8	14:20	1									0.5		2				
				14:20																
				15:37																
Nov 9/93 Tues	93	11	9	13:30	2															
				13:45																
Nov 10/93 Wed	93	11	10		3															
Nov 11/93 Thurs	93	11	11	08:10	4															
				14:00		1.8														
Nov 12/93 Fri	93	11	12	08:20	5															
				14:00		1.5														
Nov 13/93 Sat	93	11	13	11:15	6	1.5										2				
Nov 14/93 Sun	93	11	14	13:45	7	2.4														
Nov 15/93 Mon	93	11	15	13:45	8	2.8														
Nov 16/93 Tues	93	11	16	07:30	9	2.3														
Nov 17/93 Wed	93	11	17	10:00	10	2.5							Y							
Nov 18/93 Thurs	93	11	18	08:30	11								Y			2				
				13:35																
Nov 19/93 Fri	93	11	19	08:35	12															
				13:20																
				15:35									Y							
Nov 22/93 Mon	93	11	22	10:15	15								Y			2				
				13:00		2.1														
Nov 23/93 Tues	93	11	23	12:45	16	2.9							Y				0.4			
				16:00																
Nov 24/93 Wed	93	11	24	09:30	17	2.2							Y							
Nov 25/93 Thurs	93	11	25	08:45	18	2.5							Y			3				
				13:15																
Nov 26/93 Fri	93	11	26	13:00	19															
				16:00		Y							Y							
Nov 29/93 Mon	93	11	29	12:30	22	Y							Y			3				
Nov 30/93 Tues	93	11	30	13:20	23	Y							Y							

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93 DAY 1

Date		year	month	day	time	DAY	Trailer T at knockou	Trailer T at sink	Ambient T	Influent T	Media T	off-gas T	Tensiometer (kPa-vacuum) Weiss gauge	Tensiometer (kPa-vacuum) Hg vac gauge	Tensiometer (kPa-vacuum) Irrometer gauge	Rotameter Airflow (CFM)	Vortex flow Meas (SCFM)	Spike Rpm
Dec 1/93	Wed	93	12	1	08:45	24			-1	25.5		26.5					38.2	
Dec 2/93	Thurs	93	12	2	08:55	25			6	28		27						
Dec 3/93	Fri	93	12	3	08:55	26			3	35		32.5					18	
Dec 6/93	Mon	93	12	6	10:20	29			3	28		29						
Dec 7/93	Tues	93	12	7	08:50	30			2	27.5		28.5					38.1	
Dec 8/93	Wed	93	12	8	08:45	31			2	26.5		27.5					39.2	
					16:45					29		27.5						
Dec 9/93	Thurs	93	12	9	08:20	32			4	28.5		27.5						
Dec 10/93	Fri	93	12	10	09:40	33			9.5	30.5		28.5					38.9	
					14:20					31		28.5						
Dec 13/93	Mon	93	12	13	09:30	36			4	26.5		25					39	50
Dec 14/93	Tues	93	12	14	08:55	37			1.5	27.5		26.5						50
Dec 15/93	Wed	93	12	15	08:50	38			4.5	36		33.5					9	50
Dec 16/93	Thurs	93	12	16	08:45	39			2	32.5		34					10	50
Dec 17/93	Fri	93	12	17	11:00	40			1	28.5		26					9	50
Dec 20/93	Mon	93	12	20	14:00	43			6	26		26.5					10.4	
Dec 21/93	Tues	93	12	21	10:30	44			-4	24.5		26						
Dec 22/93	Wed	93	12	22	11:00	45			0	25		25.5					9	50
Dec 23/93	Thurs	93	12	23	09:15	46			-6	26		20.5					10	
Dec 24/93	Fri	93	12	24	08:30	47		8.5	-3	23		22						
Dec 26/93	Sun	93	12	26		49					media drain contents froze, Andy put portable heater near it							
Dec 29/93	Wed	93	12	29	10:45	52			-3	19		17					8	
Dec 30/93	Thurs	93	12	30	09:00	53		9.5	-6	30.5		30					7	
Dec 31/93	Fri	93	12	31	08:20	54		8.5	-3.5	29.5		28.5					10	50

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93 — DAY 1

Date		year	month	day	time	DAY	leachate volume (L)	leachate analysis (nutrients)	leachate analysis (BTEX)	leachate SS (mg/L)	leachate pH	sprinkler time (min)	est. spr. volume (L)	drain seperator (Y or N)	Pressure across media (" of H2O)	Pressure across system (" of H2O)	VOCs added (L)	VOC inj. rate (mL/min)	Fertilizer (g/L water)	Moisture content (%) Lower port	Moisture content (%) Upper Port
Dec 1/93	Wed	93	12	1	08:45	24	Y							Y							
Dec 2/93	Thurs	93	12	2	08:55	25	2							Y							
Dec 3/93	Fri	93	12	3	08:55	26	2.1							Y			4				
Dec 6/93	Mon	93	12	6	10:20	29	Y							Y							
Dec 7/93	Tues	93	12	7	08:50	30	2.8							Y							
Dec 8/93	Wed	93	12	8	08:45	31	2.1							Y	0.5						
					16:45																
Dec 9/93	Thurs	93	12	9	08:20	32	2.8							Y			4				
Dec 10/93	Fri	93	12	10	09:40	33	2.2							Y							
					14:20																
Dec 13/93	Mon	93	12	13	09:30	36	4							Y							
Dec 14/93	Tues	93	12	14	08:55	37	2.2							Y							
Dec 15/93	Wed	93	12	15	08:50	38	2.9														
Dec 16/93	Thurs	93	12	16	08:45	39	3.2							Y			4				
Dec 17/93	Fri	93	12	17	11:00	40	3.2							Y							
Dec 20/93	Mon	93	12	20	14:00	43															
Dec 21/93	Tues	93	12	21	10:30	44	1.2							Y							
Dec 22/93	Wed	93	12	22	11:00	45	1.8							Y							
Dec 23/93	Thurs	93	12	23	09:15	46	Y							Y							
Dec 24/93	Fri	93	12	24	08:30	47															
Dec 26/93	Sun	93	12	26		49															
Dec 29/93	Wed	93	12	29	10:45	52	10							Y			4	0.32			
Dec 30/93	Thurs	93	12	30	09:00	53	1.4														
Dec 31/93	Fri	93	12	31	08:20	54	4.2														

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93 DAY 1

Date		year	month	day	time	DAY	Trailer T at knockou	Trailer T at sink	Ambient T	Influent T
Jan 3/94	Mon	94	1	3	08:40	57			-7	25.5
Jan 4/94	Tues	94	1	4	13:40	58			-6	25.5
Jan 5/94	Wed	94	1	5	09:00	59			-7	25
Jan 6/94	Thurs	94	1	6	09:15	60			-10	25
Jan 7/94	Fri	94	1	7	09:20	61		3	-11.5	24.5
Jan 10/94	Sat	94	1	10	13:30	64		4	-6	26.5
Jan 11/94	Tues	94	1	11		65	1		9	28.5
Jan 12/94	Wed	94	1	12		66	6		0	26.5
Jan 13/94	Thurs	94	1	13		67	11			27
Jan 14/94	Fri	94	1	14		68	5			25.5
Jan 17/94	Mon	94	1	17		71				
Feb 2/94	Wed	94	2	2		87	9			31
Feb 3/94	Thurs	94	2	3		88	10		-8	28.5
Feb 4/94	Fri	94	2	4		89	11.5		-6	28
Feb 7/94	Mon	94	2	7		92	8		-12	26.5
Feb 8/94	Tues	94	2	8		93	7		-15	25.5
Feb 9/94	Wed	94	2	9		94	11.5			27
Feb 10/94	Thurs	94	2	10		95	15		-10	28.5
Feb 11/94	Fri	94	2	11		96	13		-10	27.5
Feb 14/94	Mon	94	2	14		99	8		-15	24.5
Feb 15/94	Tues	94	2	15		100	17		-5	27
Feb 16/94	Wed	94	2	16		101	16.5		-4.5	26
Feb 17/94	Thurs	94	2	17		102	19.5		-1	27.5
Feb 18/94	Fri	94	2	18		103				36
Feb 19/94	Sat	94	2	19		104				36
Feb 20/94	Sun	94	2	20		105				36
Feb 21/94	Mon	94	2	21		106	19.5		1.5	35
Feb 22/94	Tues	94	2	22		107	17		-8	34
Feb 23/94	Wed	94	2	23		108	16		-4.5	33.5
Feb 24/94	Thurs	94	2	24		109	18			20
Feb 25/94	Fri	94	2	25		110	13		-11	32
Feb 28/94	Mon	94	2	28		113	11		-8	31.5

Date	Media T	off-gas T	Tensiometer (kPa-vacuum) Weiss gauge	Hg vac gauge	Irrometer gauge	Rotameter Airflow (CFM)	Vortex flow Meas (SCFM)	Spike Rpm
Jan 3/94		24.5					5	
Jan 4/94		23					9	
Jan 5/94		23					10	
Jan 6/94		23					9	
Jan 7/94		23					7	50
Jan 10/94		23					9	
Jan 11/94		26.5					2.63	50
Jan 12/94		24					2.9	50
Jan 13/94		25					2.17	50
Jan 14/94		24.5					1.3	50
	air flow based on vortex meter, trying to get 2-4SCFM							
Jan 17/94								
	water lines burst - system out of service							
Feb 2/94						40		50
	system restart,							
Feb 3/94		22.5				28		50
	flowrate was varied throughout day but adjusted to 28CFM at 15:30, temps taken at end of da							
Feb 4/94		25				28		50
	first attempt at injection of fertilizer (used diaphragm pump)							
Feb 7/94		28				28		50
Feb 8/94		26.5				28		50
Feb 9/94		26.5				28		50
Feb 10/94		26				27.5		50
Feb 11/94		27				28		50
Feb 14/94		27				28		50
Feb 15/94		27				28		50
Feb 16/94		28				28		50
Feb 17/94		28.5				28		50
	rift discovered, sprayers orifice enlarged, media approx 1" below orig, fertilizer injected							
Feb 18/94								
	begin lowering the temp on hot water tank to reduce Influent T							
Feb 19/94								
Feb 20/94								
Feb 21/94		35.5				28		50
Feb 22/94		35				28		50
Feb 23/94		34				28		50
Feb 24/94		25.5				28		50
	hot water fuse blown							
Feb 25/94		29.5				28		50
Feb 28/94		29.5				28		50

Biofilter Operation Results

Reference date: first date of VOC injection — Nov 7/93 — DAY 1

Date		year	month	day	time	DAY	leachate volume (L)	leachate analysis (nutrients)	leachate analysis (BTEX)	leachate SS (mg/L)	leachate pH	sprinkler time (min)	est. spr. volume (L)	drain seperator (Y or N)	Pressure across media (" of H2O)	Pressure across system (" of H2O)	VOCs added (L)	VOC inj. rate (mL/min)	Fertilizer (g.L water)	Moisture content (%) Lower port	Moisture content (%) Upper Port
Jan 3/94	Mon	94	1	3	08:40	57	0.8							Y			4				
Jan 4/94	Tues	94	1	4	13:40	58	3														
Jan 5/94	Wed	94	1	5	09:00	59	2.7							Y							
Jan 6/94	Thurs	94	1	6	09:15	60	3.5							Y							
Jan 7/94	Fri	94	1	7	09:20	61	4.3							Y				0.3			
Jan 10/94	Sat	94	1	10	13:30	64															
Jan 11/94	Tues	94	1	11		65	2.83														
Jan 12/94	Wed	94	1	12		66	3.63														
Jan 13/94	Thurs	94	1	13		67											6				
Jan 14/94	Fri	94	1	14		68	3.7														
Jan 17/94	Mon	94	1	17		71															
Feb 2/94	Wed	94	2	2		87															
Feb 3/94	Thurs	94	2	3		88								Y		1.75					
Feb 4/94	Fri	94	2	4		89	4.7							Y		1.75			410,4.5		
Feb 7/94	Mon	94	2	7		92	1.8					0	0	Y		1.75					
Feb 8/94	Tues	94	2	8		93	2.4				6.7	0	0	Y		1.75					
Feb 9/94	Wed	94	2	9		94	2.8					0	0	Y	0.25		6				
Feb 10/94	Thurs	94	2	10		95	3.9					0	0	Y	0.25						
Feb 11/94	Fri	94	2	11		98	2.7				6.8	0	0	Y							
Feb 14/94	Mon	94	2	14		99	4.5				6.8	0	0	Y							
Feb 15/94	Tues	94	2	15		100	2.5					0	0	Y							
Feb 16/94	Wed	94	2	16		101	1.8					0	0	Y	0.25	1.75					
Feb 17/94	Thurs	94	2	17		102	1.4				7	0	0	Y					440,4.5		
Feb 18/94	Fri	94	2	18		103											6				
Feb 19/94	Sat	94	2	19		104															
Feb 20/94	Sun	94	2	20		105															
Feb 21/94	Mon	94	2	21		106	4.4					0	0	Y							
Feb 22/94	Tues	94	2	22		107	3.4				6.5	0	0	Y	0.25						
Feb 23/94	Wed	94	2	23		108	3					1	2.2	Y							
Feb 24/94	Thurs	94	2	24		109	2.4					1	2.2	Y							
Feb 25/94	Fri	94	2	25		110	2.5					1	2.2	Y							
Feb 28/94	Mon	94	2	28		113	8.46					1	2.2	Y			6				

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93 DAY 1

Date		year	month	day	time	DAY	Trailer T at knockou	Trailer T at sink	Ambient T	Influent T	Media T	off-gas T	Tensiometer (kPa-vacuum) Weiss gauge	Hg vac gauge	Irrometer gauge	Rotameter Airflow (CFM)	Vortex flow Meas (SCFM)	Spike Rpm
Mar 1/94	Tues	94	3	1		114	21		4	35		34.5				28		50
Mar 2/94	Wed	94	3	2		115	22		1	34		33				28		50
Mar 3/94	Thurs	94	3	3		116	16		-3	32		29.5				28		50
Mar 4/94	Fri	94	3	4		117	25		1	34		33.5				28		50
Mar 7/94	Mon	94	3	7		120	17		3	33.5		33.5				28		50
Mar 8/94	Tues	94	3	8		121	17.5		0	33		32				28		50
Mar 9/94	Wed	94	3	9		122	12		-6	31.5		30.5				28		50
Mar 10/94	Thurs	94	3	10		123	19		0	33.5		30				28		50
Mar 11/94	Fri	94	3	11		124										28		
											temperature sensor put on-line							
Mar 12/94	Sat	94	3	12		125				30								
Mar 13/94	Sun	94	3	13		126				32								
Mar 14/94	Mon	94	3	14		127	19		-3	30		32				28		50
											reduce air flow to 14 CFM at end of day							
Mar 15/94	Tues	94	3	15		128	24		5	32.5		35				14		50
Mar 16/94	Wed	94	3	16		129	17		-6	32		27				14		50
Mar 17/94	Thurs	94	3	17		130	15		-7	31		27				14		50
											leachate showing signs of media in it							
Mar 18/94	Fri	94	3	18		131	18		-2	33.0		32.0				14		50
Mar 21/94	Mon	94	3	21		134	23		5	32.0		35.0				14		50
Mar 22/94	Tues	94	3	22		135	21		6	32.0		35.0				14		50
Mar 23/94	Wed	94	3	23		136	22			32.0		34.0				14		50
Mar 24/94	Thurs	94	3	24		137				32.5		34.5				14		50
Mar 25/94	Fri	94	3	25		138				32.0		27.0				14		50
Mar 28/94	Mon	94	3	28		141	18		2	32.5		32.0				14		50
Mar 29/94	Tues	94	3	29		142			4	33.0		33.0				14		50
Mar 30/94	Wed	94	3	30		143	21		7	31.5		31.5				14		50
Mar 31/94	Thurs	94	3	31		144	22		4	32.0		31.5				14		50

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93 DAY 1

Date	year	month	day	time	DAY	leachate volume (L)	leachate analysis (nutrients)	leachate analysis (BTEX)	leachate SS (mg/L)	leachate pH	sprinkler time (min)	est. spr. volume (L)	drain seperator (Y or N)	Pressure across media (" of H2O)	Pressure across system (" of H2O)	VOCs added (L)	VOC inj. rate (mL/min)	Fertilizer (g/L water)	Moisture content (%) Lower port	Moisture content (%) Upper Port
Mar 1/94 Tues	94	3	1		114	3.41					1	2.2	Y							
Mar 2/94 Wed	94	3	2		115	2.67					1	2.2	Y							
Mar 3/94 Thurs	94	3	3		116	2.62					1	2.2	Y							
Mar 4/94 Fri	94	3	4		117	2.4				6.2	1	2.2	Y							
Mar 7/94 Mon	94	3	7		120	5.8					1	2.2	Y							
Mar 8/94 Tues	94	3	8		121	4.04					1	2.2	Y							
Mar 9/94 Wed	94	3	9		122	1.7					1	2.2	Y	0.25		6				
Mar 10/94 Thurs	94	3	10		123	3.8					1	2.2	Y							
Mar 11/94 Fri	94	3	11		124	3					1	2.2	Y							
Mar 12/94 Sat	94	3	12		125							0	Y							
Mar 13/94 Sun	94	3	13		126							0	Y							
Mar 14/94 Mon	94	3	14		127	3					1	2.2	Y	0.166667						
Mar 15/94 Tues	94	3	15		128	1.9					1	2.2	Y							
Mar 16/94 Wed	94	3	16		129	1.8					1	2.2	Y							
Mar 17/94 Thurs	94	3	17		130	2.4					1	2.2	Y		0.5					
Mar 18/94 Fri	94	3	18		131	2.3					0	0	Y			6				
Mar 21/94 Mon	94	3	21		134	4					0	0	Y							
Mar 22/94 Tues	94	3	22		135	1.8					0	0	Y							
Mar 23/94 Wed	94	3	23		136	1.8					0	0	Y							
Mar 24/94 Thurs	94	3	24		137	1.8					1	2.2	Y							
Mar 25/94 Fri	94	3	25		138	1.8					1	2.2	Y			6				
Mar 28/94 Mon	94	3	28		141	1.9					1	2.2	Y							
Mar 29/94 Tues	94	3	29		142	2.22					1	2.2	Y							
Mar 30/94 Wed	94	3	30		143	1.8					1	2.2	Y							
Mar 31/94 Thurs	94	3	31		144	2					1	2.2	Y							

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93 DAY 1

Date		year	month	day	time	DAY	Trailer T at knockou	Trailer T at sink	Ambient T	Influent T	Media T	off-gas T	Tensiometer (kPa-vacuum) Weiss gauge	Tensiometer (kPa-vacuum) Hg vac gauge	Tensiometer (kPa-vacuum) Irrometer gauge	Rotameter Airflow (CFM)	Vortex flow Meas (SCFM)	Spike Rpm
Apr 1/94	Fri	94	4	1		145												
Apr 2/94	Sat	94	4	2		146												
Apr 3/94	Sun	94	4	3		147												
Apr 4/94	Mon	94	4	4		148	21		1	31.5		32.5				14		50
Apr 5/94	Tues	94	4	5		149	23		6	33.0		32.0				14		50
Apr 6/94	Wed	94	4	6		150	21		0	31.5		32.5				14		50
Apr 7/94	Thurs	94	4	7		151				31.5		32.5				14		50
Apr 8/94	Fri	94	4	8		152				32.5		32.5				14		50
Apr 11/94	Mon	94	4	11		155				32.0		30.0				14		50
Apr 12/94	Tues	94	4	12		156	22		5	33.5		31.5				14		50
Apr 13/94	Wed	94	4	13		157				32.5		31.5				14		50
Apr 14/94	Thurs	94	4	14		158				33.0		32.0				14		50
Apr 15/94	Fri	94	4	15		159	21		9	30.0		30.5				28		50
Apr 18/94	Mon	94	4	18		162	22		7	30.0		30.5				28		50
Apr 19/94	Tues	94	4	19		163	22		10	30.5		30.0				28		50
Apr 20/94	Wed	94	4	20		164				30.0		29.0				28		50
Apr 21/94	Thurs	94	4	21		165				30.5		29.0				28		50
Apr 22/94	Fri	94	4	22		166				29.5		28.0				28		50
Apr 25/94	Mon	94	4	25		169				31.0		30.5				28		50
Apr 26/94	Tues	94	4	26		170				30.5		28.5				28		50
Apr 27/94	Wed	94	4	27		171				31.0		29.5				28		50
Apr 28/94	Thurs	94	4	28		172				29.5		28.0				28		50
Apr 29/94	Fri	94	4	29		173				30.0		27.5				28		50

Biofilter Operation Results

Reference date: first date of VOC injection

Date		year	month	day Nov 7/93	time	DAY DAY 1	leachate volume (L)	leachate analysis (nutrients)	leachate analysis (BTEX)	leachate SS (mg/L)	leachate pH	sprinkler time (min)	est. spr. volume (L)	drain separator (Y or N)	Pressure across media (" of H2O)	Pressure across system (" of H2O)	VOCs added (L)	VOC inj. rate (mL/min)	Fertilizer (g.L water)	Moisture content (%) Lower port	Moisture content (%) Upper Port
Apr 1/94	Fri	94	4	1		145						1	2.2	Y							
Apr 2/94	Sat	94	4	2		146						1	2.2	Y							
Apr 3/94	Sun	94	4	3		147						1	2.2	Y							
Apr 4/94	Mon	94	4	4		148	2.1					1	2.2	Y							
Apr 5/94	Tues	94	4	5		149	2.2				6.8	1.9	4.2	Y			6		400,4.2		
Apr 6/94	Wed	94	4	6		150	2.2				6.3-6.7	1	2.2	Y	0.12	0.4					
Apr 7/94	Thurs	94	4	7		151	2.2					1	2.2	Y							
Apr 8/94	Fri	94	4	8		152	3.4					1	2.2	Y							
Apr 11/94	Mon	94	4	11		155	4					1	2.2	Y							
Apr 12/94	Tues	94	4	12		156	2.5				6.3-6.8	1	2.2	Y			6				
Apr 13/94	Wed	94	4	13		157	1.84					1	2.2	Y						52.8	60.4
Apr 14/94	Thurs	94	4	14		158	2.3					1	2.2	Y				0.43			
Apr 15/94	Fri	94	4	15		159	2.1					1	2.2	Y							
Apr 18/94	Mon	94	4	18		162	5.9					1	2.2	Y							
Apr 19/94	Tues	94	4	19		163	1.6					1	2.2	Y							
Apr 20/94	Wed	94	4	20		164	1.7					1	2.2	Y							
Apr 21/94	Thurs	94	4	21		165	2.2					1	2.2	Y			6				
Apr 22/94	Fri	94	4	22		166	1.4					1	2.2	Y							
Apr 25/94	Mon	94	4	25		169	3.5					1	2.2	Y							
Apr 26/94	Tues	94	4	26		170	1.88					1	2.2	Y							
Apr 27/94	Wed	94	4	27		171	1.8					1	2.2	Y							
Apr 28/94	Thurs	94	4	28		172	1.88					1	2.2	Y							
Apr 29/94	Fri	94	4	29		173	2.18					1	2.2	Y							

Biofilter Operation Results

Reference date: first date of VOC injection — Nov 7/93 — DAY 1

Date		year	month	day	time	DAY	Trailer T at knockou	Trailer T at sink	Ambient T	Influent T	Media T	off-gas T	Tensiometer (kPa-vacuum) Weiss gauge	Hg vac gauge	Irrometer gauge	Rotameter Airflow (CFM)	Vortex flow Meas (SCFM)	Spike Rpm
May 2/94	Mon	94	5	2		176				30.0		25.5				28		0
May 3/94	Tues	94	5	3		177				30.0		27.5				28		0
May 4/94	Wed	94	5	4		178				31.0		28.5				28		0
May 5/94	Thurs	94	5	5		179				31.0		28.5				28		0
May 6/94	Fri	94	5	6		180				30.0		28.5				28		0
May 9/94	Mon	94	5	9		183				30.5		28.0				28		0
May 10/94	Tues	94	5	10		184				31		28				28		0
May 11/94	Wed	94	5	11		185			take the top of the biofilter. Dry areas in center portions of the media. Outer edge moisture contents = 65-70%. Insid smoke tests show smoke comes up 7 (test#1) and 20 Seconds (test#2). The smoke first appeared at the									
May 17/94	Tues	94	5	17		191			put in new media watering system and put bark chips on the top to help in distributing the water evenly adjusted water heater temp and put the tab back on the set point indicater system started up without VOC addition (yet)									
May 18/94	Wed	94	5	18		192			smoke test: visible at sides after 20 seconds and visible after 30 seconds in the central portion									
May 19/94	Thurs	94	5	19		193			VOCs started at 14:00									
May 20/94	Fri	94	5	20		194	21.5			31.5		29				28		50
May 24/93	Tues	94	5	24		198				32.5		32.5				28		50
May 25/94	Wed	94	5	25		199	29			32		32.5				28		50
May 25/94	Wed	94	5	25		199			Install media thermometer (media mid-depth and near core of media). The probe is 24" long.									
May 26/94	Thurs	94	5	26		200	18.5			31.5	32.5	31				28		50
May 27/94	Fri	94	5	27		201	18			31.5	32	29				28		50
May 27/94	Fri	94	5	27		201			Install tensiometer approx. 10" below top of media									
May 28/94	Sat	94	5	28		202									<4			
May 29/94	Sun	94	5	29		203									<4			
May 30/94	Mon	94	5	30		204	27			32	33	32			<4	28		50
May 31/94	Tues	94	5	31		205	29			32.5	33.5	32.5			<4	28		50

Biofilter Operation Results

Reference date: first date of VOC injection — DAY 1: Nov 7/93

Date	year	month	day	time	DAY	leachate volume (L)	leachate analysis (nutrients)	leachate analysis (BTEX)	leachate SS (mg/L)	leachate pH	sprinkler time (min)	est. spr. volume (L)	drain seperator (Y or N)	Pressure across media (" of H2O)	Pressure across system (" of H2O)	VOCs added (L)	VOC inj. rate (mL/min)	Fertilizer (g.L water)	Moisture content (%) Lower port	Moisture content (%) Upper Port
May 2/94 Mon	94	5	2		176	7.6					1	2.2	Y							
May 3/94 Tues	94	5	3		177	2.1					1	2.2	Y							
May 4/94 Wed	94	5	4		178	3.1					1	2.2	Y							
May 5/94 Thurs	94	5	5		179	2.6					1	2.2	Y							
May 6/94 Fri	94	5	6		180	3.1					1	2.2	Y							
May 9/94 Mon	94	5	9		183	7.5					1	2.2	Y							
May 10/94 Tues	94	5	10		184	2.8					1	2.2	Y							
May 11/94 Wed	94	5	11		185															
May 17/94 Tues	94	5	17		191															
May 18/94 Wed	94	5	18		192															
May 19/94 Thurs	94	5	19		193												0.34			
May 20/94 Fri	94	5	20		194	3.7					5	11	Y		1.5					
May 24/93 Tues	94	5	24		198	3.52					5	11	Y		1.5					
May 25/94 Wed	94	5	25		199	1.8					5	11	Y			6				
May 25/94 Wed	94	5	25		199															
May 26/94 Thurs	94	5	26		200	1.78					5	11	Y		1.75					
May 27/94 Fri	94	5	27		201	4					8	17.6	Y							
May 27/94 Fri	94	5	27		201															
May 28/94 Sat	94	5	28		202	??					8	17.6	Y							
May 29/94 Sun	94	5	29		203	1.6					8	17.6	Y							
May 30/94 Mon	94	5	30		204	15.8					0	0	Y							
May 31/94 Tues	94	5	31		205	2.1					8	17.6	Y	0.25	1.5					

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93 — DAY 1

Date	year	month	day	time	DAY	——Trailer T—— at knockout at sink	Ambient T	Influent T	Media T	off-gas T	Tensiometer (kPa-vacuum) Weiss gauge	Hg vac gauge	Irrometer gauge	Rotameter Airflow (CFM)	Vortex flow Meas (SCFM)	Spike Rp
June 1/94 Wed	94	6	1		206	20		31	32	31.5			<4	28		50
June 1/94 Wed	94	6	1		206		move the tensiometer to read at approx. half way point up media									
June 2/94 Thurs	94	6	2		207	23		30	30	29.5	2.5			28		50
June 3/94 Fri	94	6	3		208	23		31	31	30	2			28		50
June 4/94 Sat	94	6	4		209						2					
June 6/94 Mon	94	6	6		211	23		30.5	32	31.5	2			28		50
June 7/94 Tues	94	6	7		212	29		32	33.5	32.5	2			28		50
							remove lid and do tests 09:00 - 11:15.									
								smoke test: first sign of smoke approx. 7sec (around center)								
								massive amounts of smoke 25-30 sec								
								gradual buildup of smoke leaving media between 7sec and 25-30 sec								
								media: bark chips appear more than damp but not wet								
								moisture content approx. 10" below surface = 62%								
								mega amounts of bugs								
June 8/94 Wed	94	6	8		213			30	31	31	2			28		50
June 9/94 Thurs	94	6	9		214			30.5	30.5	29	2			28		50
Jun 10/94 Fri	94	6	10		215			32	33	31.5	2			28		50
Jun 11/94 Sat	94	6	11		216						2					
Jun 12/94 Sun	94	6	12		217						2					
Jun 13/94 Mon	94	6	13		218	28.5		32.5	33	31	2			28		50
								fertilizer was dissolved in 2L of water and then fed through the in-line water filter								
								all of the water added to the biofilter (5min = 11L was done during the fertilizer addition)								
Jun 14/94 Tues	94	6	14		219	27		32.5	34	32.5	2			28		50
Jun 15/94 Wed	94	6	15		220	24		31.5	32	32.5	2.2			28		50
Jun 16/94 Thurs	94	6	16		221	24.5		32	33.5	32.5	2.3			28		50
											2.5					
								Tensiometer readings were taken in the morning and afternoon								
								the first reading is at 9:00 and the second at 15:10								
Jun 17/94 Fri	94	6	17		222	33.5		33	34	33	2.8			28		50
Jun 18/94 Sat	94	6	18		223											
Jun 19/94 Sun	94	6	19		224						4.1					
								Tensiometer reading was read both Sat and Sun by the weekend staff								
								but I did not tell Steve to flick the dial in order to get the proper reading.								
								The Sunday reading is the one Todd took on Sun.								
Jun 20/94 Mon	94	6	20		225	28.5		32.5	34	34.5	6.7			28		50
Jun 21/94 Tues	94	6	21		226	28.5		33	34	34	7.2			28		50
								Tensiometer reading at 08:15 = 7.2								
								Tensiometer reading at 11:05 = 7								
								2 minutes of water was applied to the media in the afternoon. The total time of 7 minutes includes t								
Jun 22/94 Wed	94	6	22		227	25.5		32	33.5	34	7			28		50
						33.5		34	34.5	34	6.8					
								first readin = 08:25								
								second reading = 14:35								
Jun 23/94 Thurs	94	6	23		228	32		33	34	33.5	10.8			28		50
Jun 24/94 Fri	94	6	24	09:25	229	23.5		32.5	33	33.5	14			28		50
				11:15							14					
				16:35							14.8					
Jun 25/94 Sat	94	6	25	10:30	230						15					
Jun 26/94 Sun	94	6	26	12:00	231						15					
Jun 27/94 Mon	94	6	27	8:20	232	23		32	33	32	22			28		50
				14:30												
Jun 28/94 Tues	94	6	28	08:10	233	24.5		32	33.5	31.5	25			28		50
								10:10 - release cap on tensiometer to ensure the zero point has not changed. is OK								
								10:30 - 13:25 - no VOC injection -								
								checking the distribution rotor.								
								installed viewing port so that we can tell if the media wetting rotor is turning								
								found rotor was not moving and increased water flow rate to make it move								
								flow during tests was 3 minutes of water (put in as 12:00 TIME)								
								new flow rate for media sprinkler = 4.5 L/min								
				12:00												
				15:00												
Jun 29/94 Wed	94	6	29	09:15	234	28		32	33.5	32	25		-	28		50
								unstable dosing pump speed (controller replaced)								
Jun 30/94 Thurs	94	6	30	09:10	235	25		32.5	33.5	32.5	31		-	28		50
				21:20							20		-			

Biofilter Operation Results

Reference date: first date of VOC injection

Date	year	month	day (Nov 7/93)	time	DAY (DAY 1)	leachate volume (L)	leachate analysis (nutrients)	leachate analysis (BTEX)	leachate SS (mg/L)	leachate pH	sprinkler time (min)	est. spr. volume (L)	drain separator (Y or N)	Pressure across media (" of H2O)	Pressure across system (" of H2O)	VOCs added (L)	VOC inj. rate (mL/min)	Fertilizer (g/L water)	Moisture content (%) Lower port	Moisture content (%) Upper Port
June 1/94 Wed	94	6	1		206	3.3					8	17.6	Y	0.25						
June 1/94 Wed	94	6	1		206															
June 2/94 Thurs	94	6	2		207	6					5	11	Y			6				
June 3/94 Fri	94	6	3		208	4					5	11	Y							
June 4/94 Sat	94	6	4		209	1.68					5	11								
June 6/94 Mon	94	6	6		211	7.6					5	11	Y							
June 7/94 Tues	94	6	7		212	2							Y	0.25	1.6					
											5	11								
June 8/94 Wed	94	6	8		213	77					8	17.6	Y							
June 9/94 Thurs	94	6	9		214	2.97					8.5	18.7	Y							
Jun 10/94 Fri	94	6	10		215	4.48					7.5	16.5	Y							
Jun 11/94 Sat	94	6	11		216	5					8	17.6								
Jun 12/94 Sun	94	6	12		217	3.2					8	17.6								
Jun 13/94 Mon	94	6	13		218	8.9					5	11	Y			6		423		
Jun 14/94 Tues	94	6	14		219	10.4					0	0	Y							
Jun 15/94 Wed	94	6	15		220	3.3	Y			7.3-7.8	5	11	Y							
Jun 16/94 Thurs	94	6	16		221	6.5					0	0	Y							
Jun 17/94 Fri	94	6	17		222	2.3					5	11	Y							
Jun 18/94 Sat	94	6	18		223	9.3					6	13.2								
Jun 19/94 Sun	94	6	19		224	7.7					6	13.2								
Jun 20/94 Mon	94	6	20		225	4.7					6.5	14.3	Y							
Jun 21/94 Tues	94	6	21		226	9.5	Y			7.8	7	15.4	Y			6				
Jun 22/94 Wed	94	6	22		227	9.9				7.8	0	0	Y	0.4	1.6					
Jun 23/94 Thurs	94	6	23		228	2.3					5	11	Y	0.3	1.6					
Jun 24/94 Fri	94	6	24	09:25	229	6.9	Y			7.67	2	4.4	Y							
				11:15							2	4.4								
				16:35							1	2.2								
Jun 25/94 Sat	94	6	25	10:30	230	6.6					5	11								
Jun 26/94 Sun	94	6	26	12:00	231	0.86					5	11								
Jun 27/94 Mon	94	6	27	8:20	232	30.1					2	4.4	Y							
				14:30							2	4.4								
Jun 28/94 Tues	94	6	28	08:10	233	8.92				7.4	2	4.4	Y	0.3125	1.125	9	0.38			
				12:00							3	6.6								
				15:00		6.1														
Jun 29/94 Wed	94	6	29	09:15	234	3.3					1	4.5	Y	0.25						
Jun 30/94 Thurs	94	6	30	09:10	235	2.24					1	4.5	Y	0.25						
				21:20																

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93 DAY 1

Date		year	month	day	time	DAY	Trailer T at knockout / at sink	Ambient T	Influent T	Media T	off-gas T	Tensiometer (kPa-vacuum) Weiss gauge	Hg vac gauge	Irrometer gauge	Rotameter Airflow (CFM)	Vortex flow Meas (SCFM)	Spike Rpm
Jul 1/94	Fri-weeken	94	7	1	09:50	236						30.5		–			
Jul 2/94	Sat-weeken	94	7	2	10:30	237						38		–			
Jul 3/94	Sun-weeke	94	7	3	10:55	238						42.5		–			
Jul 4/94	Mon	94	7	4	08:40	239	25		32.5	33.5	32.5	42.5		–	28		50
					09:15							12					
					09:15					put on Irrometer vacuum gauge							
					10:45							–		8			
					12:15							–		12			
					13:20							–		12			
					15:30							–		10.5			
					16:30							–		10			
Jul 5/94	Tues	94	7	5	11:25	240	30		32.5	34.5	33	–		10.6	28		50
					13:40							–		4			
					16:05							–		<4			
Jul 6/94	Wed	94	7	6	08:30	241						–		near 0			
					08:30					replace Irrometer vacuum gauge with Weiss pressure gauge							
					08:50		28.5		33	34	33.5				28		50
					09:00							1.5		–			
					09:20							2.5		–			
					10:30							3		–			
					12:00							3		–			
					14:30							3		–			
					14:40		36.5		34	36	34						
Jul 7/94	Thur	94	7	7	09:35	242	28.5		32.5	34.5	34	3		–	28		50
					09:35					verified 15 kPa was 0 vacuum on Weiss pressure gauge							
					16:20		35.5					3		–			
Jul 8/94	Fri	94	7	8	08:40	243	28.5		32.5	34	34	3.5		–	28		50
					15:45		36.5					4		–			
Jul 9/94	Sat-weeken	94	7	9	11:45	244						9		–			
Jul 10/94	Sun-Weeke	94	7	10	10:30	245						14					
Jul 11/94	Mon	94	7	11	09:00	246	24.5		32.5	33.5	32.5	14.5		–	28		50
					11:30							15					
					13:30							15					
Jul 12/94	Tues	94	7	12	08:40	247	27.5		32.5	33.5	33	22		–	28		50
					14:00		34.5					23					
					17:00							24					
Jul 13/94	Wed	94	7	13	08:15	248			32	34	33.5	30.5		–	28		50
					09:15							5					
					10:22							4.25					
					11:55							4					
					13:30		32.5										
					13:40							4					
					14:40							4					
Jul 14/94	Thurs	94	7	14	08:25	249	24		33	33.5	33	4			28		50
Jul 15/94	Fri	94	7	15	??	250	28		32.5	33.5	32.5	4			28		50
Jul 16/94	Sat-Weeke	94	7	16	11:15	251						4					
Jul 17/94	Sun-Weeke	94	7	17	13:00	252						4					
Jul 18/94	Mon	94	7	18	08:50	253	28.5		33	33.5	33.5	4.5			28		50
Jul 19/94	Tues	94	7	19	09:30	254	31		34	34	34	5			28		50
					11:05					smoke test 15 sec. smoke first appears near middle							

30 sec. expanding from center with evidence of smoke near the sides
45-60 sec smoke allover. reasonable distribution
sytem shut down
bed dryness starts approx. 16" below surface (it cones down to the bottom with the center still being
see the note book for a drawing of the estimated dry shape
moisture content in dry areas < 20% and in other areas 60 to 65%.

Biofilter Operation Results

Reference date: first date of VOC injection

Nov 7/93 — DAY 1

Date		year	month	day	time	DAY	leachate volume (L)	leachate analysis (nutrients)	leachate analysis (BTEX)	leachate SS (mg/L)	leachate pH	sprinkler time (min)	est. spr. volume (L)	drain separator (Y or N)	Pressure across media (" of H2O)	Pressure across system (" of H2O)	VOCs added (L)	VOC Inj. rate (mL/min)	Fertilizer (g,L water)	Moisture content (%) Lower port	Moisture content (%) Upper Port
Jul 1/94	Fri-weeken	94	7	1	08:50	236	1.8					1	4.5								
Jul 2/94	Sat-weeken	94	7	2	10:30	237	1.2					1	4.5								
Jul 3/94	Sun-weeke	94	7	3	10:55	238	1.2					1	4.5								
Jul 4/94	Mon	94	7	4	08:40	239	1.3					2	9	Y	0.25	1.5					
					09:15																
					09:15																
					10:45																
					12:15																
					13:20																
					15:30																
					16:30																
Jul 5/94	Tues	94	7	5	11:25	240	2	Y			6.86	2	9	Y							
					13:40																
					16:05																
Jul 6/94	Wed	94	7	6	08:30	241															
					08:30																
					08:50		1.2				6.66	0	0	Y	0.3	1.6					
					09:00																
					09:20																
					10:30																
					12:00																
					14:30																
					14:40																
Jul 7/94	Thur	94	7	7	09:35	242	1.6				6.69	0	0	Y							
					09:35																
					16:20																
Jul 8/94	Fri	94	7	8	08:40	243	1.2				6.67	0	0	Y			9				
					15:45																
Jul 9/94	Sat-weeken	94	7	9	11:45	244	1.2					1	4.5								
Jul 10/94	Sun-Weeke	94	7	10	10:30	245	0.9					1	4.5								
Jul 11/94	Mon	94	7	11	09:00	246	1.4				6.83	1.5	6.75	Y	0.3	1.5					
					11:30																
					13:30																
Jul 12/94	Tues	94	7	12	08:40	247	1.3	Y			6.86	2	9	Y							
					14:00																
					17:00							1	4.5								
Jul 13/94	Wed	94	7	13	08:15	248	0.9				6.71	3.5	15.75	Y							
					09:15																
					10:22																
					11:55																
					13:30		0.4					0.5	2.25		0.4	1.6			209g		
					13:40																
					14:40																
Jul 14/94	Thurs	94	7	14	08:25	249	1.8	Y			7.00	1	4.5	Y					198g		
Jul 15/94	Fri	94	7	15	??	250	2.9				7.23	0	0	Y							
Jul 16/94	Sat-Weeke	94	7	16	11:15	251	2.74					0	0								
Jul 17/94	Sun-Weeke	94	7	17	13:00	252	2.1					0	0								
Jul 18/94	Mon	94	7	18	08:50	253	1.3	Y			7.48	0.5	2.2	Y							
Jul 19/94	Tues	94	7	19	09:30	254	1.4				7.22	0	0	Y	0.4	1.6					
					11:05																

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93 DAY 1

Date		year	month	day	time	DAY	Trailer T at knockout	Trailer T at sink	Ambient T	Influent T	Media T	off-gas T	Tensiometer (kPa-vacuum) Weiss gauge	Tensiometer (kPa-vacuum) Hg vac gauge	Tensiometer (kPa-vacuum) Irrometer gauge	Rotameter Airflow (CFM)	Vortex flow Meas (SCFM)	Spike Rpm
Aug 8/94	Mon	94	8	8		274					fill media back in (mixing all areas together as much as possible							
											tensiometer in water shows vacuum of 5KPa. This is odd; it should be 0							
Aug 9/94	Tues	94	8	9		275							10					
					14:00						CHANGED DIRECTION OF AIRFLOW: (downwards) start injection of VOC							
					14:45					31.5	24	25						
Aug 10/94	Wed	94	8	10	08:20	276				32	31.5	30.5	8.5			28		50
					08:20						There was a leak in the VOC injection line near a compression fitting. This was fixed							
Aug 11/94	Thurs	94	8	11	08:30	277				32	33	34	9			28		50
											The leachate was golden in colour, had very little solids and did not smell of VOCs							
											Willy indicated last week there was still oil in the steel piping from the machining							
Aug 12/94	Fri	94	8	12	08:30	278	26.5			33	34	35	10			28		50
					14:30						VOCs added to reservoir so that Todd would not have to worry about it while I was on holidays							
Aug 13/94	Sat-Weeke	94	8	13	11:00	279							10.5					
Aug 14/94	Sun-Weeke	94	8	14	11:00	280							11.1					
Aug 15/94	Mon	94	8	15	09:00	281	21.5			32	33	33.5	11.2			28		50
Aug 16/94	Tues	94	8	16	18:00	282	30.5			33.5	35	35	11			28		50
Aug 17/94	Wed	94	8	17	10:00	283	25.5			32	33.5	34	12			28		50
Aug 18/94	Thurs	94	8	18	10:10	284	29			32.5	34	35	12.5			28		50
Aug 19/94	Fri	94	8	19	09:15	285	24.5			32.5	34	34.5	12.9			28		50
Aug 20/94	Sat-Weeke	94	8	20	09:50	286							13					
Aug 21/94	Sun-Weeke	94	8	21	11:00	287							13.5					
Aug 22/94	Mon	94	8	22	09:30	288	27			32	34	34.5	14.5			28		50
					16:10								13.5					
Aug 23/94	Tues	94	8	23	08:20	289	25			32	34.5	35	14.5			28		50
					16:10								14					
Aug 24/94	Wed	94	8	24	08:25	290	25.5			32	34	34	15.5			28		50
					15:45								15					
Aug 25/94	Thurs	94	8	25	08:30	291				33	34.5	35.5	15.5			28		50
Aug 26/94	Fri	94	8	26	08:10	292				32.5	35	35.5	16			28		50
					15:25								16					
Aug 27/94	Sat-weeke	94	8	27	11:15	293							15					
Aug 28/94	Sun-Weeke	94	8	28	10:20	294							15					
Aug 29/94	Mon	94	8	29	08:20	295	21.5			32	34	34	17			28		50
					16:30								16					
Aug 30/94	Tues	94	8	30	09:20	296	22.5			32	34	34	16			28		50
					09:30						stop VOC injection							
					10:10						shut off air and take top off							
											bark chips quite wet							
											top 2" of media quite wet							
											below this most of media is bone dry (except a portion facing the lake --see note book							
											wet media 1 min. and 2" of wet goes to three							
											wet media another minute and the 3" of wet goes to 4"							
Aug 31/94	Wed	94	8	31	09:40	297					start air							
											tensiometer in water reads 11 (with zero of 15) - 4KPa vacuum							
											new tensiomter position (apporx 8" above mid-depth)							
					09:55						start VOC injection							
					15:10		25.5			32	34	34	8			28		50

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93, DAY 1

Date	year	month	day	time	DAY	leachate volume (L)	leachate analysis (nutrients)	leachate analysis (BTEX)	leachate SS (mg/L)	leachate pH	sprinkler time (min)	est. spr. volume (L)	drain separator (Y or N)	Pressure across media (" of H2O)	Pressure across system (" of H2O)	VOCs added (L)	VOC inj. rate (mL/min)	Fertilizer (g.L water)	Moisture content (%) Lower port	Moisture content (%) Upper Port
Aug 8/94 Mon	94	8	8		274															
Aug 9/94 Tues	94	8	9		275															
				14:00										0.25	1.375		0.34			
				14:45																
Aug 10/94 Wed	94	8	10	08:20	276	0.4					0	0	Y			6				
				08:20																
Aug 11/94 Thurs	94	8	11	08:30	277	2.4				7.17	0	0	Y							
Aug 12/94 Fri	94	8	12	08:30	278	2.4				7.24			Y	0.25	1.5					
				14:30							0.5	2.2				6				
Aug 13/94 Sat-Week	94	8	13	11:00	279	2.5					0.5	2.2								
Aug 14/94 Sun-Week	94	8	14	11:00	280	2.5					0.5	2.2								
Aug 15/94 Mon	94	8	15	09:00	281	2.78					0.5	2.2	Y	0.25	1.125					
Aug 16/94 Tues	94	8	16	18:00	282	3.98					0.5	2.2	Y	0.625	1.375					
Aug 17/94 Wed	94	8	17	10:00	283	1.92					0.5	2.2	Y	0.125	1.25					
Aug 18/94 Thurs	94	8	18	10:10	284	2.54					0.5	2.2	Y	0.25	1.5					
Aug 19/94 Fri	94	8	19	09:15	285	2					1	4.4	Y	0.25	1.375					
Aug 20/94 Sat-Week	94	8	20	09:50	286	1.9					0.5	2.2								
Aug 21/94 Sun-Week	94	8	21	11:00	287	2.1					0.5	2.2								
Aug 22/94 Mon	94	8	22	09:30	288	2.1	Y			6.93	1	4.4	Y	0.25	1.5					
				16:10																
Aug 23/94 Tues	94	8	23	08:20	289	2			16	6.95	1	4.4	Y							
				16:10																
Aug 24/94 Wed	94	8	24	08:25	290	2.7				6.88	1	4.4	Y							
				15:45							0.5	2.2								
Aug 25/94 Thurs	94	8	25	08:30	291	2.5				6.77	1	4.4	Y	0.25	1.375			204g		
Aug 26/94 Fri	94	8	26	08:10	292	1.9	Y			6.55	1	4.4	Y			6				
				15:25							0.5	2.2								
Aug 27/94 Sat-weeke	94	8	27	11:15	293	2.25					1.5	6.6								
Aug 28/94 Sun-Week	94	8	28	10:20	294	1.8					1.5	6.6								
Aug 29/94 Mon	94	8	29	08:20	295	2.3			24	6.51	1	4.4	Y							
				16:30							0.5	2.2								
Aug 30/94 Tues	94	8	30	09:20	296	3.3				6.54			Y	0.25	1.375					
				09:30																
				10:10																
Aug 31/94 Wed	94	8	31	09:40	297															
				09:55																
				15:10		1.1														

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93 DAY 1

Date		year	month	day	time	DAY	Trailer T at knockout	Trailer T at sink	Ambient T	Influent T	Media T	off-gas T	Tensiometer (kPa-vacuum) Weiss gauge	Tensiometer Hg vac gauge	Tensiometer Irrometer gauge	Rotameter Airflow (CFM)	Vortex flow Meas (SCFM)	Spike Rpm
Sep 1/94	Thurs	94	9	1	08:10	298				32	33.5	34	9			28		50
Sep 2/94	Fri	94	9	2	09:30	299				32	33.5	33	9			28		50
					12:45								5					
					16:20								6					
											removed insulation around biofilter tank							
Sep 3/94	Sat	94	9	3	08:15	300				31.5	34	32.5	7.5					
					08:35								5					
Sep 4/94	Sun-Weeke	94	9	4	13:00	301							5.5					
Sep 5/94	Mon-Week	94	9	5	12:15	302							4.5					
Sep 6/94	Tues	94	9	6	08:30	303				31.5	34.5	32.5	5			28		50
					13:45								5					
Sep 7/94	Wed	94	9	7	08:15	304				31.5	34.5	33	5			28		50
					10.54						noticed forgot to turn off water to media							
											The system was flooded and had to drain the bed and the GAC bed barrel.							
											System air and VOC injection stopped							
					12:00						system air started							
					13:00						VOC injection restarted							
					13:00								4					
					15:30								4.5					
Sep 8/94	Thurs	94	9	8	08:55	305				30.5	35	33	4.5			28		50
					16:30								4.5					
Sep 9/94	Fri	94	9	9	08:30	306				32	35	34	4.5			28		50
Sep 10/94	Sat-Weeke	94	9	10	11:20	307							4.75					
Sep 11/94	Sun-Weeke	94	9	11	13:00	308							4.75					
Sep 12/94	Mon	94	9	12	08:20	309				32	34	32.5	6			28		50
					16:15								7					
Sep 13/94	Tues	94	9	13	10:15	310	28			33	35	35.5	7.5			28		50
					15:50								5.5					
Sep 14/94	Wed	94	9	14	08:40	311	28			27.5	33	35	5			28		50
Sep 15/94	Thurs	94	9	15	10:10	312	27			32.5	35	34.5	5			28		50
Sep 16/94	Fri	94	9	16	08:40	313	25.5			32	35	34.5	5.25			28		50
Sep 17/94	Sat-Weeke	94	9	17	12:00	314							6					
Sep 18/94	Sun-Weeke	94	9	18	11:00	315							6					
Sep 19/94	Mon	94	9	19	08:20	316	21			31.5	34	33	8			28		50
					16:20								6					
Sep 20/94	Tues	94	9	20	08:15	317	22			31.5	33.5	33	5.5			28		50
					13:30						Blower off for 45 min for Willy to fill blower with oil							
Sep 21/94	Wed	94	9	21	10:00	318	25.5			32	34	33.5	5			28		50
Sep 22/94	Thurs	94	9	22	09:00	319				32	34	32.5	5.5			28		50
Sep 23/94	Fri	94	9	23	09:15	320	26			32.5	34	33	6			28		50
					15:45								6.75					
Sep 24/94	Sat-Weeke	94	9	24	13:25	321							7.5					
Sep 25/94	Sun-Weeke	94	9	25	12:30	322							9.5					
Sep 26/94	Mon	94	9	26	10:40	323	27.5			32.5	34.5	34.5	9.75			28		50
					11:20								5					
Sep 27/94	Tues	94	9	27	08:10	324	24.5			32	33.5	33.5	5			28		50
Sep 28/94	Wed	94	9	28	07:40	325	22			32	33.5	33.5	5.5			28		50
Sep 29/94	Thurs	94	9	29	14:40	326				32.5	33.5	33	6			28		50
Sep 30/94	Fri	94	9	30	10:10	327	21			32.5	32.5	32	6.5			28		50

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93 DAY 1

Date	year	month	day	time	DAY	leachate volume (L)	leachate analysis (nutrients)	leachate analysis (BTEX)	leachate SS (mg/L)	leachate pH	sprinkler time (min)	est. spr. volume (L)	drain seperator (Y or N)	Pressure across media (" of H2O)	Pressure across system (" of H2O)	VOCs added (L)	VOC Inj. rate (mL/min)	Fertilizer (g.L water)	Moisture content (%) Lower port	Moisture content (%) Upper Port
Sep 1/94 Thurs	94	9	1	08:10	298	2.2				6.79	2	8.8	Y							
Sep 2/94 Fri	94	9	2	09:30	299	3.7				6.79	2	8.8	Y			6				
				12:45																
				16:20																
Sep 3/94 Sat	94	9	3	08:15	300	3					2	8.8	Y							
				08:35																
Sep 4/94 Sun-Week	94	9	4	13:00	301	3.8					1.5	6.6								
Sep 5/94 Mon-Week	94	9	5	12:15	302	3.1					0.5	2.2								
Sep 6/94 Tues	94	9	6	08:30	303	2.9		Y		6.56	0	0	Y							
				13:45																
Sep 7/94 Wed	94	9	7	08:15	304	3.6				6.59										
				10:54																
				12:00																
				13:00																
				13:00																
				15:30		1.8														
Sep 8/94 Thurs	94	9	8	08:55	305	3.2					0	0	Y							
				16:30																
Sep 9/94 Fri	94	9	9	08:30	306	2.9				7.01	0.5	2.2	Y							
Sep 10/94 Sat-Week	94	9	10	11:20	307	4.2					0.5	2.2								
Sep 11/94 Sun-Week	94	9	11	13:00	308	4					0.5	2.2								
Sep 12/94 Mon	94	9	12	08:20	309	??				6.77	1	4.4	Y			6				
				16:15																
Sep 13/94 Tues	94	9	13	10:15	310	3				6.69	2	8.8	Y							
				15:50																
Sep 14/94 Wed	94	9	14	08:40	311	??				6.75	0.5	2.2	Y	0.375	1.625					
Sep 15/94 Thurs	94	9	15	10:10	312	2.9					0.5	2.2	Y							
Sep 16/94 Fri	94	9	16	08:40	313	2.8				6.69	0.5	2.2	Y							
Sep 17/94 Sat-Week	94	9	17	12:00	314	2.7					1	4.4								
Sep 18/94 Sun-Week	94	9	18	11:00	315	3					1	4.4								
Sep 19/94 Mon	94	9	19	08:20	316	2.9				6.62	1	4.4	Y							
				16:20																
Sep 20/94 Tues	94	9	20	08:15	317	3.4				6.7	0.5	2.2	Y	0.55	1.9					
				13:30																
Sep 21/94 Wed	94	9	21	10:00	318	3.5					0	0	Y	0.625		6				
Sep 22/94 Thurs	94	9	22	09:00	319	3.1				6.73	0.5	2.2	Y							
Sep 23/94 Fri	94	9	23	09:15	320	3					0	0	Y			6				
				15:45							0.5	2.2								
Sep 24/94 Sat-Week	94	9	24	13:25	321	3.8					1	4.4								
Sep 25/94 Sun-Week	94	9	25	12:30	322	2.7					2	8.8								
Sep 26/94 Mon	94	9	26	10:40	323	2.5				6.84	2	8.8	Y	0.875	2.125					
				11:20																
Sep 27/94 Tues	94	9	27	08:10	324	2.86					0.5	2.2	Y	1	2.375					
Sep 28/94 Wed	94	9	28	07:40	325	3.12					0.5	2.2	Y	1	2.125					
Sep 29/94 Thurs	94	9	29	14:40	326	4.7					0.5	2.2	Y	1.125	2.25					
Sep 30/94 Fri	94	9	30	10:10	327	3.25					2	8.8	Y	1.125	2.375					

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93 DAY 1

Date		year	month	day	time	DAY	Trailer T at knockout	Trailer T at sink	Ambient T	Influent T	Media T	off-gas T	Tensiometer (kPa-vacuum) Weiss gauge	Tensiometer (kPa-vacuum) Hg vac gauge	Tensiometer (kPa-vacuum) Irrometer gauge	Rotameter Airflow (CFM)	Vortex flow Meas (SCFM)	Spike Rpm
Oct 1/94	Sat-Weeke	94	10	1	10:50	328							6					
Oct 2/94	Sun-Weeke	94	10	2	09:00	329							6					
Oct 3/94	Mon	94	10	3	09:15	330	19.5			31.5	32	31.5	6			28		50
Oct 4/94	Tues	94	10	4	09:10	331	19			31.5	32	32	6			28		50
					09:40						turned off VOC injection							
					12:40						turned off air and opened up the top							
											Pressure increase across the top part of bed was due to a very wet bed							
											tensiometer reads the pressure 23.5" below the lip of the reactor (approx. 12" below the media sur							
											media was dry 23-25" below the lip (12-14" below the top of media)							
											media mixed with pine nuggets (58% void by volume, 50/50 by volume mix of media and nuggets)							
Oct 7/94	Fri	94	10	7	17:00	334					start VOC injection							
					17:30					32	19	20.5	1			28		50
Oct 8/94	Sat-Weeke	94	10	8	13:45	335							3					
Oct 9/94	Sun-Weeke	94	10	9	20:10	336							5.5					
Oct 10/94	Mon-Week	94	10	10	12:45	337							8					
Oct 11/94	Tues	94	10	11	08:45	338	15			30	31.5	28	9.5			28		50
					11:44								5					
Oct 12/94	Wed	94	10	12	06:00	339				31.5	33.5	31.5	5			28		50
Oct 13/94	Thurs-Wee	94	10	13	15:30	340							8					
Oct 14/94	Fri	94	10	14		341				31.5	34	32	7.5			28		50
Oct 15/94	Sat-Weeke	94	10	15	13:15	342							11.5			28		50
Oct 16/94	Sun-Weeke	94	10	16	15:00	343							11			28		50
Oct 17/94	Mon	94	10	17	09:30	344	20.5			31.5	34	31	11.5			28		50
											last day of reliable data before the GC died							
Oct 18/94	Tues	94	10	18	08:30	345	21.5			32	34	33	12			28		50
											fertilizer addition 200g of fertilizer prepared although it took several days to be all put into system							
Oct 19/94	Wed	94	10	19	09:40	346				32.5	34	33	11.5			28		50
Oct 20/94	Thurs	94	10	20	09:45	347				32	34.5	33.5	7.5			28		50
Oct 21/94	Fri	94	10	21	09:00	348	26			31.5	35	33	5			28		50
Oct 22/94	Sat-Weeke	94	10	22	13:00	349							6					
Oct 23/94	Sun-Weeke	94	10	23	10:00	350							6					
											Weekend staff neglected to empty the entire system. Only the cannister was emptied							
Oct 24/94	Mon	94	10	24	09:00	351	20.5			31.5	34.5	31.5	6			28		50
Oct 25/94	Tues	94	10	25	08:30	352	26			31.5	34.5	32	8			28		50
Oct 26/94	Wed	94	10	26	08:45	353	19			31	33.5	30	10.5			28		50
Oct 27/94	Thurs	94	10	27	08:25	354	24			32.5	34.5	33.5	12.5			28		50
					16:00								15					
Oct 28/94	Fri	94	10	28	08:30	355	20			32	34	31.5	19			28		50
					15:00								18					
Oct 29/94	Sat-Weeke	94	10	29	12:45	356							20					
Oct 30/94	Sun-Weeke	94	10	30	11:00	357							25					
Oct 31/94	Mon	94	10	31	08:30	358	26			32	34	33.5	27.5			28		50
					09:10											0		0
											verified humidifier working ok. Flow rate through sprinkler = 4.7 L/min							
					10:30						air back on VOCs still off					28		0
					12:00					31.5	33	31.5						
					14:00					31.5	32.5	31						
					15:45					32	33	31	30					

Biofilter Operation Results

Reference date: first date of VOC injection

Date		year	month	day (Nov 7/93)	time	DAY (DAY 1)	leachate volume (L)	leachate analysis (nutrients)	leachate analysis (BTEX)	leachate SS (mg/L)	leachate pH	sprinkler time (min)	est. spr. volume (L)	drain separator (Y or N)	Pressure across media (" of H2O)	Pressure across system (" of H2O)	VOCs added (L)	VOC Inj. rate (mL/min)	Fertilizer (g,L water)	Moisture content (%) Lower port	Moisture content (%) Upper Port
Oct 1/94	Sat-Week	94	10	1	10:50	328	3.57					1	4.4								
Oct 2/94	Sun-Week	94	10	2	09:00	329	3.94					1	4.4								
Oct 3/94	Mon	94	10	3	09:15	330	4.5				6.97	1	4.4	Y							
Oct 4/94	Tues	94	10	4	09:10	331	5					0	0	Y	1.625	3					
					09:40																
					12:40																
Oct 7/94	Fri	94	10	7	17:00	334															
					17:30										0.125	1.375					
Oct 8/94	Sat-Week	94	10	8	13:45	335	1.7					1	4.4								
Oct 9/94	Sun-Week	94	10	9	20:10	336	3.25					1	4.4								
Oct 10/94	Mon-Week	94	10	10	12:45	337	2.75					1	4.4								
Oct 11/94	Tues	94	10	11	08:45	338	3.4				7.18	1	4.4	Y	0.125	1.5	6				
					11:44																
Oct 12/94	Wed	94	10	12	08:00	339	??					0.5	2.2	Y							
Oct 13/94	Thurs-We	94	10	13	15:30	340	5.65					1	4.4								
Oct 14/94	Fri	94	10	14		341	2.78					0.5	2.2	Y	0.125	1.375					
Oct 15/94	Sat-Week	94	10	15	13:15	342	4					1	4.4								
Oct 16/94	Sun-Week	94	10	16	15:00	343	4.6					1	4.4								
Oct 17/94	Mon	94	10	17	09:30	344	3.1				7.24	0.5	2.2	Y							
Oct 18/94	Tues	94	10	18	08:30	345	4.2					0.5	2.2	Y	0.125	1.5			200,1		
Oct 19/94	Wed	94	10	19	09:40	346	3.3				7.23	1	5	Y			6				
Oct 20/94	Thurs	94	10	20	09:45	347	??				7.22	0.25	1.6	Y				0.36,0.48 avg = 0.40			
Oct 21/94	Fri	94	10	21	09:00	348	3.6				7.22	0	0	Y							
Oct 22/94	Sat-Week	94	10	22	13:00	349	1.06					0	0								
Oct 23/94	Sun-Week	94	10	23	10:00	350	1.01					0	0								
Oct 24/94	Mon	94	10	24	09:00	351	8.1					0.166667	1.1	Y							
Oct 25/94	Tues	94	10	25	08:30	352	4.3				7.18	??=0	??=0	Y							
Oct 26/94	Wed	94	10	26	08:45	353	4.9				7.3	??=0	??=0	Y	0.1875	1.75					
Oct 27/94	Thurs	94	10	27	08:25	354	4.3					??=0	??=0	Y			6				
					16:00							0.25	1.85								
Oct 28/94	Fri	94	10	28	08:30	355	4.4				7.21	0.333333	2.2	Y							
					15:00							0.333333	2.2								
Oct 29/94	Sat-Week	94	10	29	12:45	356	5.24					0.333333	2.2								
Oct 30/94	Sun-Week	94	10	30	11:00	357	3.32					0.333333	2.2								
Oct 31/94	Mon	94	10	31	08:30	358	2.8					0.5	3.3	Y							
					09:10																
					10:30																
					12:00																
					14:00																
					15:45							0.5	3.3								

Biofilter Operation Results

Reference date: first date of VOC injection — Nov 7/93 — DAY 1

Date	year	month	day	time	DAY	Trailer T at knocko	Trailer T at sink	Ambient T	Influent T	Media T	off-gas T	Tensiometer (kPa-vacuum) Weiss gauge	Hg vac gauge	Irrometer gauge	Rotameter Airflow (CFM)	Vortex flow Meas (SCFM)	Spike Rp
Nov 1/94 Tues	94	11	1	05:45	359	21			31.5	32	30.5	30			28		0
				06:00						start VOC injection							50
				08:55		20.5			31.5	33	30.5						
				11:00		20			31.5	33	31						
				12:45		19			31.75	33.5	31						
Nov 2/94 Wed	94	11	2	09:00	360	25			31.5	33.5	31.5	30			28		50
				14:00						insulated offgas line							
				16:30													
Nov 3/94 Thurs	94	11	3	09:05	361	19.5			31.5	33.5	32	32			28		50
Nov 4/94 Fri	94	11	4	09:10	362	22.5			32	33.5	32	32			28		50
				10:35						turn off VOC injection							0
				15:20													
Nov 5/94 Sat-Week	94	11	5	11:15	363							35.5					0
Nov 6/94 Sun-Eeek	94	11	6	19:00	364							37					0
Nov 7/94 Mon	94	11	7	08:30	365	19			31.5	32.5	31	37			28		0
				08:40						turned off air flow					0		
				16:15													
Nov 8/94 Tues	94	11	8	08:30						start air and VOC injection							
				10:15		21			31.5	34.5	28	47??			28		50
										pH of tap water = 7.20, could it be that the 47 was actually 2 since gauge read 13							
Nov 9/94 Wed	94	11	9	08:35	367	21			31.5	33.5	32	16.5			28		50
				15:00						installed proper Hg gauge							
Nov 10/94 Thurs	94	11	10	08:40	368	27			32	33.5	32	--			28		50
										Hg gauge reading 1.5" = 1.5/30*100 KPa vacuum = 5							
										reinstalled Weiss pressure gauge							
				16:45								6					
										the Weiss P gauge and the Hg gauge give similar results							
Nov 11/94 Fri	94	11	11	10:15	369	21			31.5	33.5	32	14			28		50
				13:15								15					
Nov 12/94 Sat																	
Nov 13/94 Sun																	
Nov 14/94 Mon	94	11	14	09:30	372				32	33.5	32	27			28		50
				15:00						turn off VOCs and air off - for Al to put in ball valve to isolate the big biofilter							
				15:30						turn on air and VOCs							
Nov 15/94 Tues	94	11	15	08:00	373	21			31.5	33.5	32	12			28		50
Nov 16/94 Wed	94	11	16	??	374	17.5			32	33	32	14.5			28		50
Nov 17/94 Thurs	94	11	17	09:45	375				31.5	33	32	22			28		50
Nov 18/94 Fri	94	11	18	09:45	376	25			32	33.5	32	28			28		50
Nov 19/94 Sat-Lars	94	11	19	05:30	377	24			31.5	33.5	32	29			28		50
Nov 20/94 Sun-Lars	94	11	20	05:30	378	21.5			32	33.5	32	33.5			28		50
Nov 21/94 Mon	94	11	21	09:30	379	28			32	33	32	33			28		50
				10:00						put on Hg vacuum gauge							
				13:15									5.9				
				16:30									6.7				
Nov 22/94 Tues	94	11	22	08:30	380	23			31.5	33.5	32		11.8		28		50
				16:15									9.4				
Nov 23/94 Wed	94	11	23	09:30	381	18.5			32	33.5	32		10		28		50
Nov 24/94 Thurs	94	11	24	10:10	382				31.5	33	31.5		9.1		28		50
				15:45								4					
Nov 25/94 Fri	94	11	25	09:00	383	21.5			31.5	33	31.5	9			28		50
Nov 26/94 Sat-Week	94	11	26	??	384							11					
Nov 27/94 Sun-Lars	94	11	27	13:45	385				31.5	33	32	12			28		50
Nov 28/94 Mon	94	11	28	07:55	386				31	33	32	9.5			28		50
Nov 29/94 Tues	94	11	29	10:00	387	23			31.5	33	31.5	9			28		50
Nov 30/94 Wed	94	11	30	08:50	388				32	33	31.5	7			28		50

Biofilter Operation Results

Reference date: first date of VOC injection

Date	year	month	day (Nov 7/93)	time	DAY (DAY 1)	leachate volume (L)	leachate analysis (nutrients)	leachate analysis (BTEX)	leachate SS (mg/L)	leachate pH	sprinkler time (min)	est. spr. volume (L)	drain separator (Y or N)	Pressure across media (" of H2O)	Pressure across system (" of H2O)	VOCs added (L)	VOC inj. rate (mL/min)	Fertilizer (g/L water)	Moisture content (%) Lower port	Upper Por
Nov 1/94 Tues	94	11	1	05:45	359	2.7					0.5	3.3	Y							
				08:00																
				08:55																
				11:00																
				12:45																
Nov 2/94 Wed	94	11	2	09:00	360	4.7				7.46	0.5	3.3	Y							
				14:00																
				16:30							0.25	1.65								
Nov 3/94 Thurs	94	11	3	09:05	361	3.7					0.25	1.65	Y	0.125	1.125					
Nov 4/94 Fri	94	11	4	09:10	362	2.8					0.25	1.65	Y							
				10:35																
				15:20							0.25	1.65								
Nov 5/94 Sat-Week	94	11	5	11:15	363	3.4					0.5	3.3								
Nov 6/94 Sun-Eeek	94	11	6	19:00	364	3.3					0.5	3.3								
Nov 7/94 Mon	94	11	7	08:30	365	2.7					0.333333	2.2	Y							
				08:40																
				16:15							0.333333	2.2								
Nov 8/94 Tues	94	11	8	08:30												6				
				10:15		4.9				6.89	0.333333	2.2	Y							
Nov 9/94 Wed	94	11	9	08:35	367	4.26					0.333333	2.2	Y							
				15:00																
Nov 10/94 Thurs	94	11	10	08:40	368	3.3				7.75	0??	0??								
				16:45																
Nov 11/94 Fri	94	11	11	10:15	369	3.3				7.68	0.166667	1.1	Y							
				13:15							0.166667	1.1								
Nov 12/94 Sat																				
Nov 13/94 Sun																				
Nov 14/94 Mon	94	11	14	09:30	372	2.5				7.57	0.333333	2.2	Y							
				15:00																
				15:30																
Nov 15/94 Tues	94	11	15	08:00	373	2.4					0.25	1.65	Y	0.1875	1.625	6				
Nov 16/94 Wed	94	11	16	??	374	3.52					0.166667	1.1	Y							
Nov 17/94 Thurs	94	11	17	09:45	375	3				7.52	0.333333	2.2	Y							
Nov 18/94 Fri	94	11	18	09:45	376	3.3					0.416667	2.75	Y							
Nov 19/94 Sat-Lars	94	11	19	05:30	377	2.6					0.5	3.3	Y							
Nov 20/94 Sun-Lars	94	11	20	05:30	378	3.3					0.5	3.3	Y							
Nov 21/94 Mon	94	11	21	09:30	379	3.7				7.33	0	0	Y							
				10:00																
				13:15																
				16:30							0.5	3.3								
Nov 22/94 Tues	94	11	22	08:30	380	3.2					0.5	3.3	Y			6				
				16:15																
Nov 23/94 Wed	94	11	23	09:30	381	3.77					0.333333	2.2	Y							
Nov 24/94 Thurs	94	11	24	10:10	382	3.5				7.35	0	0	Y	0.1875						
				15:45																
Nov 25/94 Fri	94	11	25	09:00	383	3.5					0	0	Y							
Nov 26/94 Sat-Week	94	11	26	??	384	4					0.166667	1.1								
Nov 27/94 Sun-Lars	94	11	27	13:45	385	4.4					0.166667	1.1	Y							
Nov 28/94 Mon	94	11	28	07:55	386	3.15					0.166667	1.1	Y							
Nov 29/94 Tues	94	11	29	10:00	387	3.5				7.34	0.166667	1.1	Y			6				
Nov 30/94 Wed	94	11	30	08:50	388	3.87					0.166667	1.1	Y							

Biofilter Operation Results

Reference date: first date of VOC injection

Date		year	month	day	time	DAY	Trailer T at knockou	Trailer T at sink	Ambient T	Influent T	Media T	off-gas T	Tensiometer (kPa-vacuum) Weiss gauge	Hg vac gauge	Irrometer gauge	Rotameter Airflow (CFM)	Vortex flow Meas (SCFM)	Spike Rpm
				Nov 7/93		DAY 1												
Dec 1/94	Thurs	94	12	1	09:15	389				32	33	31.5	8.5			28		50
Dec 2/94	Fri	94	12	2	08:05	390	27			31.5	33	31.5	9			28		50
Dec 3/94	Sat-Weeke	94	12	3	10:30	391							11.1					
Dec 4/94	Sun-Week	94	12	4	10:20	392							10					
Dec 5/94	Mon	94	12	5	12:30	393				32	33	31.5	10			28		50
Dec 6/94	Tues	94	12	6	08:45	394				31	33	31.5	10			28		50
					14:15						noticed tensiometer had lots of air in it. Possible soil is much drier than it shows since air in tube may not allow for an accurate reading filled it up with water							
					15:05								1					
					15:35								2					
					16:00								3					
Dec 7/94	Wed	94	12	7	12:20	395	25			32	33	31.5	6			28		50
Dec 8/94	Thurs	94	12	8	08:50	396	21	14		31.5	33	31.5	9			28		50
Dec 9/94	Fri	94	12	9	09:00	397				31.5	33	31	9			28		50
											leachate analysis							
					09:10						turn off VOCs					0		0
					12:20						turn off air and open lid							
											media height to top of reactor: 13.5", 13.5", 12", 12.5"							
											large insect population on top of media (white, little and hopping)							
											media wet near surface							
											media dry approx 8" below surface							
											suface of media wet (no moisture content done but appeared > 60%)							
											results indicated that removal is mostly in the bottom 10% of the bed							
Dec 12/94	Mon	94	12	12		400					media wetted and put back in reactor							
											an extra bucket of 50:50 (by V) nuggets and media mix added							
											flow verification for media water application --> 4680 mL/min							
											plugged last five holes in the media addition rotor. (water goes no closer than 7.5"							
											media height from lip of reactor: 10", 11", 12", 10.5", 11"							
					15:00											28		0
											verified air flow rate with hot wire anemometer							
					16:30						start VOC injection					28		50
Dec 13/94	Tues	94	12	13	08:30	401				30.5	32	30.5	----tenisometer not in----			28		50
Dec 14/94	Wed	94	12	14	10:30	402				31	32.5	32				28		50
Dec 15/94	Thurs	94	12	15	08:50	403				31	33	32				28		50
					16:40													25
Dec 16/94	Fri	94	12	16	15:10	404		18.5		31	32	31.5				28		25
Dec 17/94	Sat-Weeke	94	12	17	10:00	405												
Dec 18/94	Sun-Week	94	12	18	10:25	406												

Biofilter Operation Results

Reference date: first date of VOC injection

Date		year	month	day	time	DAY	leachate volume (L)	leachate analysis (nutrients)	leachate analysis (BTEX)	leachate SS (mg/L)	leachate pH	sprinkler time (min)	est. spr. volume (L)	drain separator (Y or N)	Pressure across media (" of H2O)	Pressure across system (" of H2O)	VOCs added (L)	VOC inj. rate (mL/min)	Fertilizer (g/L water)	Moisture content (%) Lower port	Moisture content (%) Upper Port
				Nov 7/93		DAY 1															
Dec 1/94	Thurs	94	12	1	09:15	389	3.9					0	0	Y							
Dec 2/94	Fri	94	12	2	08:05	390	3.8				7.39	0	0	Y							
Dec 3/94	Sat-Week	94	12	3	10:30	391	4.8					0	0								
Dec 4/94	Sun-Week	94	12	4	10:20	392	3.9					0	0								
Dec 5/94	Mon	94	12	5	12:30	393	3.9					0	0	Y							
Dec 6/94	Tues	94	12	6	08:45	394	3.8				7.48	0	0	Y			9				
					14:15																
					15:05																
					15:35																
					16:00																
Dec 7/94	Wed	94	12	7	12:20	395	4.8					0	0	Y							
Dec 8/94	Thurs	94	12	8	08:50	396	4.4					0	0	Y							
Dec 9/94	Fri	94	12	9	09:00	397	4.6					0	0	Y							
									Y												
					09:10																
					12:20																
Dec 12/94	Mon	94	12	12		400															
					15:00																
					16:30																
Dec 13/94	Tues	94	12	13	08:30	401	–					0	0	Y							
Dec 14/94	Wed	94	12	14	10:30	402	3.6					0.166667	0.78	Y	0.1875						
Dec 15/94	Thurs	94	12	15	08:50	403	3.1				7.52	0.333333	1.56	Y	0.125						
					16:40																
Dec 16/94	Fri	94	12	16	15:10	404	4.35				7.16	0.25	1.17	Y							
Dec 17/94	Sat-Week	94	12	17	10:00	405	2.2					0.333333	1.56								
Dec 18/94	Sun-Week	94	12	18	10:25	406	2.49					0.333333	1.56								

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93 DAY 1

Date	year	month	day	time	DAY	Trailer T at knocko	Trailer T at sink	Ambient T	Influent T	Media T	off-gas T	Tensiometer (kPa-vacuum) Weiss gauge	Tensiometer Hg vac gauge	Tensiometer Irrometer gauge	Rotameter Airflow (CFM)	Vortex flow Meas (SCFM)	Spike Rp
Dec 19/94 Mon	94	12	19	09:35	407	24.5	16.5		31	32.5	31.75				28		25
				14:00						testing the tensiomter with Hg gauge on:							
										- in pail of water 0" hg							
										- in air 1 hour: 5" hg							
										- put in bucket of water							
										6 min -- 4" hg vacuum							
										15 min -- 3" hg							
										37 min -- 2" hg							
				16:30													
Dec 20/94 Tues	94	12	20	08:30	408		20		31.25	32.5	31.75	---not in---			28		25
				10:30						testing tensiometer							
										in the 24 hours from Dec 20 @10:30 to Dec 21 @10:30 lost 7" through ceram							
Dec 21/94 Wed	94	12	21	10:50	409	24.5	18		31.5	33	32.5	---not in---			28		25
				16:30													
										tensiometer test							
										0 min - 8" Hg							
										12 min - 4" Hg							
										35 min - 2.5" Hg							
Dec 22/94 Thurs	94	12	22	08:45	410	26	19		31.25	32.5	32.5	---not in---			28		25
Dec 23/94 Fri	94	12	23	??	411	28	19		31	32	31.5	---not in---			28		25
										tensiometer test: Dave Dickson put thick teflon tape around the Hg gauge							
										in 2hr 50 min went from 0 to 15"hg --- good							
										put in water							
										2 min: 14"hg							
										6 min: 10" Hg							
										10 min: 6" Hg							
				10:50						turn off VOC injection							
				11:05						put in tensiometer							
				11:15						turn on VOC injection							
Dec 24/94 Sat-Week	94	12	24	10:00	412								<3.4				
Dec 25/94 Sun-Week	94	12	25	10:35	413								<3.4				
				13:00						220V heater not functioning							
										not able to be repaired until new year since WTC on holidays							
Dec 26/94 Mon	94	12	26	08:10	414	10		0.5	26								
				09:00						raise hot water tank temp from 110F to 150F							
				10:15				1.5	30								
				10:30						put in some space heaters							
				10:30											28		25
				10:55					32.5	25.5	23.5						
Dec 27/94 Tues	94	12	27	08:35	415	17	14		33.5	32	31		<3.4		28		25
Dec 28/94 Wed	94	12	28	08:25	416	23	15.5		34	32	31		<3.4		28		25
Dec 29/94 Thurs	94	12	29	08:30	417	21	11		32.5	32	30		<3.4		28		25
Dec 30/94 Fri	94	12	30	08:30	418	20.5	6.5		32.5	31	26.5		<3.4		28		25
				09:00						hot water heater set point lowered to 140F							
				16:30													
Dec 31/94 Sat-Week	94	12	31	10:00	419								<3.4				

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93 DAY 1

Date	year	month	day	time	DAY	leachate volume (L)	leachate analysis (nutrients)	leachate analysis (BTEX)	leachate SS (mg/L)	leachate pH	sprinkler time (min)	est. spr. volume (L)	drain separator (Y or N)	Pressure across media (" of H2O)	Pressure across system (" of H2O)	VOCs added (L)	VOC inj. rate (mL/min)	Fertilizer (g/L water)	Moisture content (%) Lower port	Moisture content (%) Upper Port
Dec 19/94 Mon	94	12	19	09:35	407	2.2			21.1	7.24	0.333333	1.56	Y	0.125		9				
				14:00																
				16:30							0.333333	1.56								
Dec 20/94 Tues	94	12	20	08:30	408	2.72				7.31	0.333333	1.56	Y							
				10:30																
Dec 21/94 Wed	94	12	21	10:50	409	2.7					0.333333	1.56	Y							
				16:30							0.333333	1.56								
Dec 22/94 Thurs	94	12	22	08:45	410	3.1				7.37	0.333333	1.56	Y							
Dec 23/94 Fri	94	12	23	??	411	2.82				7.35	0.333333	1.56	Y							
				10:50																
				11:05																
				11:15																
Dec 24/94 Sat-Week	94	12	24	10:00	412	3.1					0.333333	1.56								
Dec 25/94 Sun-Week	94	12	25	10:35	413	2.42					0.333333	1.56								
				13:00																
Dec 26/94 Mon	94	12	26	08:10	414															
				09:00																
				10:15																
				10:30																
				10:30		2.8					0.5	2.34	Y							
				10:55																
Dec 27/94 Tues	94	12	27	08:35	415	4.9					0.166667	0.78	Y							
Dec 28/94 Wed	94	12	28	08:25	416	5.7				7.22	0	0	Y							
Dec 29/94 Thurs	94	12	29	08:30	417	6.34				7.33	0	0	Y				0.28			
Dec 30/94 Fri	94	12	30	08:30	418	7.34				7.34	0	0	Y							
				09:00																
				16:30		2.9														
Dec 31/94 Sat-Week	94	12	31	10:00	419	6.3					0	0								

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93 DAY 1

Date		year	month	day	time	DAY	Trailer T at knockou	Trailer T at sink	Ambient T	Influent T	Media T	off-gas T	Tensiometer (kPa-vacuum) Weiss gauge	Hg vac gauge	Irrometer gauge	Rotameter Airflow (CFM)	Vortex flow Meas (SCFM)	Spike Rpm
Jan 1/95	Sun	95	1	1	09:00	420	18	17.5		33	32	30		<3.4		28		25
					09:40					30.5								
Jan 2/95	Mon	95	1	2	09:50	421		12		32.5	31.5	29		<3.4		28		25
Jan 3/95	Tues	95	1	3	08:50	422	20.5	12		32.5	31	28		<3.4		28		25
											Ursula replcaed fuse in overhead heater - now heater is going again							
Jan 4/95	Wed	95	1	4	08:20	423					found main overhead heater down again							
							14.5	1.5		31.5	29	24.5		<3.4		28		25
											Ursula replaced fuse in main overhead heater							
Jan 5/95	Thurs	95	1	5	08:50	424	22.5	9		33	31.5	29.5		<3.4		28		25
Jan 6/95	Fri	95	1	6	08:30	425	25	16.5		33.5	33.5	31		7.4		28		25
					16:00									9.1				
Jan 7/95	Sat	95	1	7	10:05	426	13			33	32.5	32		<3.4		28		25
											main overhead heaer was not operating. Space heater put in							
Jan 8/95	Sun	95	1	8	09:25	427	18	9.5		30	31	27.5		<3.4		28		25
Jan 9/95	Mon	95	1	9	08:20	428	18.5	8.5		32	30.5	26		<3.4		28		25
					16:40		25	15.5		32	32.5	31		9.4		28		25
					17:00									6.7				
					17:02									6.1				
Jan 10/95	Tues	95	1	10	08:25	429	19	7		31	31.5	30		<3.4		28		25
											overhead heaer gone again							
					10:45		11.5	11.5		31	30.5	29		7.1				
Jan 11/95	Wed	95	1	11	08:40	430	14.5			31	31	27		<3.4		28		25
					09:05					32.5								
Jan 12/95	Thurs	95	1	12	09:00	431	19	16		33.5	33	30.5		9.4		28		25
					13:50													
Jan 13/95	Fri	95	1	13	08:20	432	24.5	20		32.5	33	31.75		13.1		28		25
					13:00					34.5	33	32		13.8				
					14:30									3.4				
					15:50			21.5		32	33	32		3.4		28		25
Jan 14/95	Sat-Weekend																	
Jan 15/95	Sun-Weekend																	
Jan 16/95	Mon	95	1	16	08:15	435	24	19		33	31	30.75		6.1		28		25
											hot water heater turned down to 110deg F							
					10:30			19		31.25	32	30.75		6.1				
					12:00									4.0				
					16:25			16		16.5	25	28		0				
					17:30						System shut down							
											actuated vavle to fil the humidifier out of order							

Biofilter Operation Results

Reference date: first date of VOC injection — Nov 7/93 — DAY 1

Date	year	month	day	time	DAY	leachate volume (L)	leachate analysis (nutrients)	leachate analysis (BTEX)	leachate SS (mg/L)	leachate pH	sprinkler time (min)	est. spr. volume (L)	drain seperator (Y or N)	Pressure across media (" of H2O)	Pressure across system (" of H2O)	VOCs added (L)	VOC Inj. rate (mL/min)	Fertilizer (g/L water)	Moisture content (%) Lower port	Moisture content (%) Upper Port
Jan 1/95 Sun	95	1	1	09:00	420	7.6					0	0	Y	0.25						
				09:40																
Jan 2/95 Mon	95	1	2	09:50	421	7.73					0	0	Y	0.25	2.25					
Jan 3/95 Tues	95	1	3	08:50	422	7.7				7.48	0	0	Y							
Jan 4/95 Wed	95	1	4	08:20	423															
						8.7					0	0	Y							
Jan 5/95 Thurs	95	1	5	08:50	424	8.5				7.51	0	0	Y							
Jan 6/95 Fri	95	1	6	08:30	425	8.52				7.5	0.25	1.17	Y							
				16:00							0.166667	0.78								
Jan 7/95 Sat	95	1	7	10:05	426	7.1					0	0	Y							
Jan 8/95 Sun	95	1	8	09:25	427	5.68					0	0	Y							
Jan 9/95 Mon	95	1	9	08:20	428	8.76				7.55	0	0	Y							
				16:40		3.72					0.25	1.17								
				17:00																
				17:02																
Jan 10/95 Tues	95	1	10	08:25	429	6.5		Y			0	0	Y							
				10:45							0	0		0.1875						
Jan 11/95 Wed	95	1	11	08:40	430	8.2					0	0	Y	0.1875						
				09:05																
Jan 12/95 Thurs	95	1	12	09:00	431	8.2					0.333333	1.56								
				13:50												3				
Jan 13/95 Fri	95	1	13	08:20	432	7.46				7.78	0.75	3.51	Y							
				13:00							1	4.68								
				14:30																
				15:50		2.21														
Jan 14/95 Sat-Weekend																				
Jan 15/95 Sun-Weekend																				
Jan 16/95 Mon	95	1	16	08:15	435	5.34				7.8	0	0	Y							
				10:30																
				12:00																
				16:25																
				17:30																

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93, DAY 1

Date		year	month	day	time	DAY	Trailer T at knockou	Trailer T at sink	Ambient T	Influent T	Media T	off-gas T	Tensiometer (kPa-vacuum) Weiss gauge	Tensiometer (kPa-vacuum) Hg vac gauge	Tensiometer (kPa-vacuum) Irrometer gauge	Rotameter Airflow (CFM)	Vortex flow Meas (SCFM)	Spike Rpm
Jan 17/95	Tues	95	1	17		436					system still down							
Jan 18/95	Wed	95	1	18	09:45	437					system started up							
					10:00		13.5			21	25.5	14.75		0		28		25
					16:50			18.5		31.5	30	24		6.1		28		25
Jan 19/95	Thurs	95	1	19	08:15	438	24.5	18.5		31.5	31	30		5.4		28		25
					15:10			19		31.5	31.5	30.5		7.1		28		25
Jan 20/95	Fri	95	1	20	08:20	439	24.5	19		31.5	31.5	30.75		7.7		28		25
					10:40			19		31.5	31.5	31		7.7		28		25
					14:00			20		31.5	31.5	31		9.4		28		25
					16:15			20		31.5	31.5	31		9.4		28		25
Jan 21/95	Sat	95	1	21	10:25	440	24.5	18.5		31.5	31.5	31		9.4		28		25
Jan 22/95	Sun	95	1	22	11:45	441	17	15		30.5	31	29		8.8		28		25
Jan 23/95	Mon	95	1	23	08:20	442	18.5	15.5		30.25	30.5	29		6.1		28		25
					10:10			15		30.25	30.5	28.75		6.1				
					13:00			17		30.5	30.5	28.75		6.4				
					15:45			18.5		31	31	28.75		7.4				
Jan 24/95	Tues	95	1	24		443	22	16.5		30.5	30.5	29		6.7		28		25
					13:00			18		30.75	31	29		7.1				
					16:20		22	17.5		30.75	31	29		7.1				
Jan 25/95	Wed	95	1	25	08:30	444	21.5	16.5		30.75	31	29.5		6.7		28		25
					16:50			19		31	31.5	29.5		8.1				
Jan 26/95	Thurs	95	1	26	08:30	445	21	15		30.25	31	29		6.4		28		25
					16:15			15		30.25	31	29		6.4				
Jan 27/95	Fri	95	1	27	08:25	446	21.5	14.5		30	30.5	28.75		6.4		28		25
					15:40			16		30	30.5	28.75		7.1				
Jan 28/95	Sat	95	1	28	10:00	447					26			<3.4				
Jan 29/95	Sun	95	1	29	10:55	448								3.4				
Jan 30/95	Mon	95	1	30	08:20	449	18	10		28.75	28	26.5		5.0		28		25
Jan 31/95	Tues	95	1	31	08:25	450	21	14		30	30.5	27.5		8.4		28		25
					08:30						increase injection rate							50
					10:20					30	30.5	27.75		7.1				50
					12:40					30	30.5	27.75						50
					15:25					30	30.5	28		8.1				
					16:40					30	30.5	28		9.4				

Biofilter Operation Results

Reference date: first date of VOC injection

Date	year	month	day	time	DAY	leachate volume (L)	leachate analysis (nutrients)	leachate analysis (BTEX)	leachate SS (mg/L)	leachate pH	sprinkler time (min)	est. spr. volume (L)	drain seperator (Y or N)	Pressure across media (" of H2O)	Pressure across system (" of H2O)	VOCs added (L)	VOC Inj. rate (mL/min)	Fertilizer (g/L water)	Moisture content (%) Lower port	Moisture content (%) Upper Port
			Nov 7/93		DAY 1															
Jan 17/95 Tues	95	1	17		436															
Jan 18/95 Wed	95	1	18	09:45	437															
				10:00		4.74							Y							
				16:50																
Jan 19/95 Thurs	95	1	19	08:15	438	4.56				7.51	0	0	Y							
				15:10																
Jan 20/95 Fri	95	1	20	08:20	439	4.24					0	0	Y							
				10:40																
				14:00																
				16:15																
Jan 21/95 Sat	95	1	21	10:25	440	4.7														
Jan 22/95 Sun	95	1	22	11:45	441	4.1							Y							
Jan 23/95 Mon	95	1	23	08:20	442	4.4				7.67	0	0	Y			6				
				10:10																
				13:00																
				15:45																
Jan 24/95 Tues	95	1	24		443	5.58					0	0	Y							
				13:00																
				18:20																
Jan 25/95 Wed	95	1	25	08:30	444	5.46				7.68	0	0	Y							
				15:50																
Jan 26/95 Thurs	95	1	26	08:30	445	4.94					0	0	Y							
				16:15																
Jan 27/95 Fri	95	1	27	08:25	446	4.9				7.68	0	0	Y							
				15:40																
Jan 28/95 Sat	95	1	28	10:00	447	6.1														
Jan 29/95 Sun	95	1	29	10:55	448	6.0														
Jan 30/95 Mon	95	1	30	08:20	449	6.5				7.67	0	0	Y							
Jan 31/95 Tues	95	1	31	08:25	450	7.6					0	0	Y							
				08:30																
				10:20																
				12:40																
				15:25																
				16:40																

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93 — DAY 1

Date		year	month	day	time	DAY	Trailer T at knockou	Trailer T at sink	Ambient T	Influent T	Media T	off-gas T	Tensiometer (kPa-vacuum) Weiss gauge	Tensiometer (kPa-vacuum) Hg vac gauge	Tensiometer (kPa-vacuum) Irrometer gauge	Rotameter Airflow (CFM)	Vortex flow Meas (SCFM)	Spike Rpm
Feb 1/95	Wed	95	2	1	08:05	451	21.5	16.5		30.5	31	29		11.1		28		50
					14:10					30.75	31.5	29.75		12.1				
					16:25					30.75	31.5	30		12.1				
Feb 2/95	Thurs	95	2	2	08:10	452	17	8		28.25	29	28		5.4		28		50
					11:20					29.25	29	27		7.4				
					15:20			16.5		30.75	30.5	27.25		11.4				
					16:40					30.75	31	28		10.8				
Feb 3/95	Fri	95	2	3	08:15	453	16	9		27.25	28.5	28.25		6.7		28		50
					15:40			17.5		31	31	28		12.8				
Feb 4/95	Sat	95	2	4	07:15	454	17.5	16		30.5	30.5	28.5		13.8		28		50
Feb 5/95	Sun			5	10:45		12	7.5		27.5	27.5	24.5		<3.4		28		50
Feb 6/95	Mon	95	2	6	08:10	456	. 15	5.5		26	26	21		4.4		28		50
					16:25			11.5		29	27	23.5		9.8				
					16:25						educed BTEX to 25rpm not enough to last until tomorrow							25
Feb 7/95	Tues	95	2	7	08:15	457	18	11		29.25	27	23.75		4.7		28		25
					13:15			16.5		30.75	27.5	25.25		12.8				
					14:45						BTEX back to 50 rpm							50
					16:15			16		30.5	29	26.5		12.8				
Feb 8/95	Wed	95	2	8	08:05	458	17.5	10.5		29.25	29	27		3.7		28		50
					14:05					30	30	27.5		10.8				
					16:25			14.5		30	30	27.75		10.4				
Feb 9/95	Thurs	95	2	9	08:15	459	18.5	12		28.75	29	28		10.1		28		50
					11:25			14		29.5	29.5	26.75		12.8				
					15:55			17		30	30	27.75		13.8				
Feb 10/95	Fri	95	2	10	08:00	460	23.5	17		30.25	30.5	28.75		16.2		28		50
					13:25			21		31.5	31.5	30.25		13.1				
					16:40			21.5		31.5	32	31.5		13.5				
Feb 11/95	Sat	95	2	11	15:00	461	17.5	13		29.75	30.5	27.75		11.8		28		50
Feb 12/95	Sun	95	2	12	09:00	462	7	4.5		27	27	24		9.4		28		50
											smell of BTEX coming out from the collection leachate port (when emptying it): minimal BT							
											GC still in trailer; still on; nothing looks different							
Feb 13/95	Mon	95	2	13	08:20	463	17.5	10		28.5	28	25.5		13.5		28		50
					11:00					29.25	28.5	26		15.8				
					16:20			17		30.25	29	27		19.9				
Feb 14/95	Tues	95	2	14	08:15	464	17.5	8.5		28.25	28	24.75		5.7		28		50
					11:30			15		29.75	27.5	24.75		9.8				
					16:10			18.5		30.5	29	26.5		11.8				
Feb 15/95	Wed	95	2	15	08:15	465	19.5	14.5		30	29	28		8.1		28		50
					10:35					30.5	29	26.5		12.8				
											spike rpm truned down to 25. Very little BTEX left							
Feb 16/95											System shut down							

10:00 take the lid off

media height: distance from media to top of fiberglass tank = 13, 13.5, 13 amd 13"

near the surface the media was quite wet

near walls the media was also wet: approx 4-6 inches

below approx. 8" the media become more normal moisture wise

vertical band of dryness extending from just below the surface to near the bottom of the media

band was approx. 4" wide and followed the sample line vertical

four samples for moisture content were taken (big nuggets were taken out)

1) 3-4" below surface and approx. 8" in from edge [62% water by mass]
2) 12 inches bleow surface; nearish the centre [46% water by mass]
3) 24 inches below surface; nearish the surface [49% moisture by mass]
4) dry media near the bottom of the media at edge of the media band [28% water by mass]

Biofilter Operation Results

Reference date: first date of VOC injection Nov 7/93 DAY 1

Date		year	month	day	time	DAY	leachate volume (L)	leachate analysis (nutrients)	leachate analysis (BTEX)	leachate SS (mg/L)	leachate pH	sprinkler time (min)	est. spr. volume (L)	drain seperator (Y or N)	Pressure across media (" of H2O)	Pressure across system (" of H2O)	VOCs added (L)	VOC inj. rate (mL/min)	Fertilizer (g/L water)	Moisture content (%) Lower port	Moisture content (%) Upper Port
Feb 1/95	Wed	95	2	1	08:05	451	6.48					0.75	3.51	Y							
					14:10							0.5	2.34								
					16:25																
Feb 2/95	Thurs	95	2	2	08:10	452	5.86				7.28	0	0	Y							
					11:20																
					15:20																
					16:40							0.166667	0.78								
Feb 3/95	Fri	95	2	3	08:15	453	5.42					0	0	Y							
					15:40																
Feb 4/95	Sat	95	2	4	07:15	454	5.4					1	4.68	Y							
Feb 5/95	Sun			5	10:45		7.36					0	0	Y							
Feb 6/95	Mon	95	2	6	08:10	456	7.46				7.93	0	0	Y							
					16:25																
					16:25																
Feb 7/95	Tues	95	2	7	08:15	457	8.56					0	0	Y			6				
					13:15																
					14:45																
					16:15																
Feb 8/95	Wed	95	2	8	08:05	458	8.56					0	0	Y							
					14:05																
					16:25																
Feb 9/95	Thurs	95	2	9	08:15	459	6.9				7.48	0	0	Y							
					11:25																
					15:55							0.333333	1.56								
Feb 10/95	Fri	95	2	10	08:00	460	6.52					0.75	3.51	Y							
					13:25																
					16:40							0.166667	0.78								
Feb 11/95	Sat	95	2	11	15:00	461	7.46					0	0	Y							
Feb 12/95	Sun	95	2	12	09:00	462	3.4					0	0	Y	0.75						
Feb 13/95	Mon	95	2	13	08:20	463	6.9				7.83	0	0	Y							
					11:00							0.5	2.34	Y							
					16:20							0.75	3.51								
Feb 14/95	Tues	95	2	14	08:15	464	6.88					0	0	Y	1						
					11:30																
					16:10																
Feb 15/95	Wed	95	2	15	08:15	465	8.3					0	0	Y							
					10:35																
Feb 16/95																					

10:00 take the lid off

media height: distance from media to top of fiberglass tank = 13, 13.5, 13 amd 13"
near the surface the media was quite wet
near walls the media was also wet: approx 4-6 inches
below approx. 8" the media become more normal moisture wise
vertical band of dryness extending from just below the surface to near the bottom of the media

four samples for moisture content were taken (big nuggets were taken out)

Appendix A2

Results: Performance Data Not Directly Related to Contaminant Removal

This appendix presents the biofilter performance data not directly related to contaminant removal.

A.1 Media Characteristics

Table 3.2 from the body of the report is reproduced below. It presents a summary of the media compositions used during the study. A leaf and yard waste compost, obtained from a commercial supplier, was used as the primary media for bacterial support throughout the study. Perlite was used to increase porosity and provide structure strength (media 1).

The composition was changed twice in attempts to improve performance. On day 131, 5cm of small 'pine bark nuggets' (2-4cm diameter) were placed on top of the perlite/compost mixture to improve water distribution over the media surface (media 2). On day 331, the layer of 'pine bark nuggets' was removed and the original perlite/compost media was mixed with oval bark pieces (5-15 cm long, 2-5 cm thick) in a 50%/50% volume ratio (media 3). It was anticipated that the addition of the large pieces would increase the effective void space of the media and therefore encourage moisture transfer throughout the bed.

Table 3.2: Media Composition During Study

Period	Media Identification Number	Media Composition*
Nov 9, 1993 - May 16, 1994 (Day 1 - 190)	1	mixture of: 60%: leaf and yard waste compost 40%: perlite (Volume basis)
May 17 - Oct 3, 1994 (Day 191 - 330)	2	fine pine bark nuggets on top of media #1
Oct 4, 1994 - Feb 15, 1995 (Day 331 - 465)	3	50%: media #1 50%: large decorative bark (Volume basis)

A.1.1 Porosity and Pressure Drop

The observed pressure drop across the biofilter bed for each of the two media is presented in Table A.1. The compost/perlite mixture was observed to have bed pressure drops ranging from 0.4 to 1.3 cm of water. An increase in influent airflow and therefore a corresponding increase in approach velocity (Q_{air}/x-sectional area) was observed to increase the pressure. The compost/perlite & large bark pieces mixture was observed to have a bed pressure drop less than that of the compost/perlite mixture.

Table A.1: Biofilter Media Pressure Drop	
Influent Airflow [L/s (CFM)]	Media Pressure Drop* [cm of water]
Compost/Perlite (50% porosity) - media 1 & 2	
6.6 (14)	0.4
13.2 (28)	0.6
23.6 (50)	1.3
Compost/Perlite + Large Bark Pieces** - media 3	
13.2 (28)	0.4
notes: *: Media depth = 0.9m **: Large bark pieces were observed to have a 60% porosity	

A.1.2 Temperature

During the study, the measured biofilter media temperatures (mid bed depth) were observed to range from 3°C cooler to 2°C warmer than the influent air stream. The influent air stream during the study was maintained at approximately 30°C. During periods when the trailer containing the biofilter was less than 15°C, the media temperature was in the lower end of this range (3°C cooler to same temperature). The temperature decrease was attributed to excessive heat transfer out of the biofilter containment vessel to the trailer. Increases in media temperature of 0.5°C to 2°C were generally observed when the trailer temperature was greater than 15°C. Under these conditions, the heat transfer from the biofilter vessel to the trailer could not compensate for the heat released during the biodegradation of the contaminants in the influent air stream. The lower temperature increase (0.5°C) was observed during low organic loading rates (16.2 $g/(m^3 \cdot h)$) and the higher temperature increase (2°C) was observed during high organic loading rates (22 $g/(m^3 \cdot h)$).

A.1.3 Compaction

Compaction of the compost/perlite mixture was observed to be approximately 9% over a period from day 1 to day 185 (6 months). The compost/perlite and large bark pieces mixture compacted approximately 5% over a period of 2 months from day 334 to 397.

A.1.4 Rewetting Dry Media

As indicated in the body of the report in sections 4.3.1, 4.3.2 and 4.3.3, the biofilter media experienced periods during which a large fraction of it had moisture levels less than 30%. The biofilter bed was removed, mechanically broken and rewetted 5 times throughout the study: day 191, day 254, day 276, day 331 and day 400.

When the compost/perlite mixture was used (media 1 and 2 in section 3.2.2), large hard clumps were formed when the media was dry. These clumps tended to be hydrophobic. When the clumps were mechanically broken, the dry media took on a powdery consistency which tended to be hydrophillic and therefore easily rewetted. Thus, once the media was dry (moisture contents less than 30%), it was very difficult to rewet the media even with excessive watering unless the dry media clumps were broken mechanically.

A test was conducted (day 362 to 365) to determine if a humidified, non-contaminated air stream, applied over several days, would improve the wetting characteristics of dry media. It was postulated that, if the trailer temperature was less than that of the humidified air stream, condensation would wet the media. Observations from the test (days 362 to 365) indicated that no improvement in media moisture content occurred.

The compost/perlite media mixture was supplemented with large bark pieces on day 331. The large bark pieces created openings which were filled by the compost/perlite mixture. It was anticipated that the bark would act as a pathway for the supplemental water to travel from the media surface to its core. In addition, the bark would prevent the compost/perlite mixture from forming large blocks of dry media and thus, improve the rewetting characteristics of the media. Observations on day 400 indicated that the mixture did not form into large clumps, however, the bark did not prevent the media from becoming dry. Further tests on the media (i.e. substantially increase supplemental water addition) were not possible due to trailer heating malfunctions which resulted in condensation within the biofilter vessel.

A.2 Leachate/Condensate Characteristics

Leachate from the bottom of the biofilter containment vessel was collected daily. Data regarding the leachate volume, pH, contaminant concentration and nutrient levels were collected and are presented in the following sections.

A.2.1 Volume

During the study, the volume of collected leachate/condensate generally varied from 1 to 10 L/d. It was observed to be a function of the airflow rate, trailer temperature and volume of supplemental water added to the top of the media. It was not possible to separate the effects of the three parameters. The trailer temperature and volume of supplemental water addition were observed to have the greatest impact on leachate volume.

Increasing the airflow to the biofilter system generally reduced the leachate collection volume, unless cold ambient air temperature caused condensation of the influent air stream in the bed. Since warmer air has a greater water carrying capacity than cooler air, water had a tendency to be drawn from the media. A greater air flow rate would therefore have a greater overall water removal rate and would likely result in reduced leachate that may flow through the media.

As the trailer temperature cooled (<15°C), leachate collection approached its maximum. The increased volume was attributed to condensation in the biofilter vessel.

The volume of supplemental water varied throughout the study. An increase in the volume of water applied to the top of the media generally resulted in an increase in the volume of leachate/condensate collected. An increased collection volume was also observed when the media was dry (moisture content less than 30%). As discussed previously, dry media tended to form large hard clumps. These clumps were hydrophobic until the clumps were physically broken. Thus, under dry media conditions, more leachate/condensate would be collected.

A.2.2 pH

pH values observed during the study ranged from 6.5 to 7.8.

A.2.3 Contaminant Concentration

Samples of leachate were submitted on five separate occasions for BTEX analysis (days 64, 100, 206, 397, 429). A summary of the results is presented in Table A.2. Three of the samples were collected while the biofilter was operated in the upflow mode and two while the biofilter was operated in the downflow mode.

Contaminant concentrations for the upflow mode varied from 3250 ug/L for benzene to 111,000 ug/L for ethylbenzene. However, the mass of contaminants collected daily in the leachate was less than one percent of the loading to the biofilter.

Leachate contaminant concentrations dropped below the method of detection limits (< 1.5 ug/L) when the biofilter was operated in the downflow mode. The reduction was attributed to the lower concentration of BTEX in the air at the bottom of the biofilter containment vessel. The reduced leachate/condensate contaminant concentration may be a significant advantage to downflow operation.

Table A.2: Leachate Contaminant Concentration for Biofilter in Upflow and Downflow Modes

Compound	Leachate Contaminant Concentration [ug/L]				
	day 64 (Jan 10/94)	day 100 (Feb 15/94)	day 206 (Jun 1/94)	day 397 (Dec 9/94)	day 429 (Jan 10/95)
Benzene	4840	6860	3250	0.08[t]	w
Toluene	19700	40000	11900	0.24[t]	w
Ethylbenzene	111000	105000	99100	0.01[t]	w
Xylenes	96100	86600	95800	0.18[t]	w
mode of operation					
	upflow	upflow	upflow	downflow	downflow

notes:
t: detected but less than method detection limit
w: constituent not detected

A.2.4 Nutrient Levels

During the three month period June to August, 1994 (days 206 to 297), leachate samples were submitted for nutrient analysis. Nutrients were added twice to the media during this period. The samples were analyzed for total phosphorus (TP), ammonia (NH_3-N), nitrites (NO_2-N) and nitrates (NO_3-N). Leachate collection volumes were stable (2-4 L/d). The nutrient sample results and biofilter operating conditions are presented in Table A.3.

<u>SAMPLE SET 1</u>

The first nutrient addition occurred on June 13, 1994 (day 218). During the 27 days following the injection, five leachate samples were collected and analyzed. TP concentrations ranged from 24.5 to 27.9 mg/L and no particular trend was observed. NH_3-N concentrations were observed to peak (68 mg/L) immediately following injection, and declined for each sample until it was observed to be only 1.5 mg/L 27 days later. Nitrite levels remained at or below method of detection limits. Following a delay of about 2 days, the nitrate concentrations peaked at 94 mg/L and declined continuously until it was observed to be 0.41 mg/L 27 days following nutrient addition.

During the sample set 1 period, the biofilter was performing well with respect to removal of influent contaminants. The creation of nitrates following nutrient addition perhaps reflects the high level of bioactivity within the biofilter (nitrification). The subsequent decline in nitrate concentration was attributed to the washout of nitrates with the leachate.

SAMPLE SET 2

The second nutrient addition occurred on day 248 (July 13, 1994). During the period day 254 to 276, the system was shut down and no leachate/condensate was collected. During the 22 days following the injection, five leachate samples were collected and analyzed. TP concentrations peaked at 32 mg/L immediately following nutrient injection and declined to 0.6 mg/L 22 days later. Ammonia levels were initially 3 mg/L and declined to 1 mg/L before the system was shut down. After the system was started again on day 288, ammonia levels were 6.5 mg/L. Nitrite and nitrate were not present before the system was shut down and were significant when it started again.

Before the system was shut down, the biofilter was performing poorly. The biofilter was then changed to an upflow mode, the media rewetted and the system restarted. Contaminant removals immediately improved. It is postulated that the low nitrate levels observed prior to system shut down reflect the overall low bioactivity (minimal nitrification) within the media. The high nitrate levels following the system start up reflect the improved bioactivity (nitrification) within the media. There was no apparent explanation for the low observed leachate phosphorus concentrations following startup.

Table A.3: Leachate Nutrient Sample Results					
Sample Date (1994)	Days After Fertilization	TP [mg/L]	NH_3-N [mg/L]	NO_2-N [mg/L]	NO_3-N [mg/L]
SAMPLE SET 1					
day 218 (Jun 13) fertilizer added, removals 70-90%. day 232 (Jun 27) removals >90%, upflow					
day 220 (Jun 15)	2	25	68	w	w
day 226 (Jun 21)	8	25	29.4	0.08t	93.8
day 229 (Jun 24)	11	27.9	13	0.76	44.9
day 239 (July 4) removals declining (70-90%)., upflow					
day 240 (July 5)	20	24.5	3.1	0.11	0.15
day 247 (July 12)	27	26.8	1.47	0.08t	0.41
SAMPLE SET 2					
day 248 (July 13) fertilizer added, poor removals (<70%), upflow					
day 249 (July 14)	1	32.3	3.02	0.03	0.04
day 250 (July 15)	2	27.1	2.14	0.21	0.11
day 253 (July 18)	5	23.3	1.25	0.02t	0.05t
system down: day 254- 276 (Jul 19 - Aug 10); changed to downflow on day 276 prior to day 288 (Aug 22): good removals					
day 288 (August 22)	18	0.72	6.45	1.2	30.3
day 292 (August 26)	22	0.61	2.88	6.1	30.2
notes: t: constituent detected but less than method of detection limit w: constituent not detected					

Appendix B

Gas Chromatograph Results

Measured Concentrations of Benzene (ug/L)

Date	DAY	Inlet	Port 1	Port 2	Port 3	Exhaust
Dec 1/93	24	46				39
Dec 2/93	25	90				65
Dec 6/93	29	62				48
Dec 8/93	31	52				37
Dec 10/93	33	48				38
Dec 14/93	37	45				41
Dec 15/93	38	90				44
Dec 17/93	40	90				65
Dec 21/93	44	106				72
Dec 23/93	46	77				62
Jan 4/94	58	107				91
Jan 6/94	60	104				81
Jan 10/94	64					
Jan 12/94	66	140				91
Feb 3/94	88	98				67
Feb 4/94	89	139				101
Feb 6/94	91	120				52
Feb 10/94	95	159				83
Feb 14/94	99	118				63
Feb 16/94	101	116				76
Feb 18/94	103	131				24
Feb 21/94	106	135				56
Feb 24/94	109	138				64
Mar 02/94	115	136	92	21	31	38
Mar 03/94	116		60			52
Mar 07/94	120	130	95	84	55	34
Mar 08/94	121	133	95	94	62	35
Mar 09/94	122	136	99	76	72	30
Mar 14/94	127	139	95	80	72	35
Mar 16/94	129	307	233	233		56
Mar 18/94	131	331	224	239	181	148
Mar 22/94	135	268	217	223	167	81
Mar 23/94	136	279	190	198	117	94
Mar 24/94	137	283	229	180	170	112
Mar 28/94	141	294	204	218	142	139
Mar 30/94	143	288	221	272	181	140
Mar 31/94	144	277	207	211	167	158

Measured Concentrations of Benzene (ug/L)

Date	DAY	Inlet	Port 1	Port 2	Port 3	Exhaust
Apr 4/94	148	256	220	241	164	151
Apr 6/94	150	250			118	147
Apri 8/94	152					172
Apr 11/94	155	220		193	91	105
Apr 13/94	157	269	261	249	173	158
Apr 15/94	159	123	94	111	74	79
Apr 19/94	163	120				80
Apr 20/94	164	116				50
Apr 25/94	169	177				83
May 20/94	194	125				10
May 24/94	198	116				3
May 26/94	200	133	118	111		30
May 30/94	204	154	123	83	58	12
June 1/94	206	134				25
June 3/94	208	160				33
June 6/94	211	108				27
Jun 10/94	215	117				43
Jun 14/94	219	111				10
Jun 16/94	221	108				16
Jun 20/94	225	98				14
Jun 22/94	227	114		56	22	7
Jun 24/94	229	92	67	31	35	4
Jun 27/94	232	86	41	10	4	3
Jun 30/94	235	80				7
Jul 4/94	239	99	94	73	55	25
Jul 6/94	241	86				35
Jul 8/94	243	112				36
Jul 11/94	246	110				44
Jul 13/94	248	108				53
Jul 14/94	249	111				48
Jul 15/94	250	105				44
Jul 18/94	253	122				57
Aug 10/94	276	104				79
Aug 12/94	278	95		4		3
Aug 15/94	281	92	87	50		12
Aug 17/94	283	86		49		11
Aug 19/94	285	72	68	43	5	11
Aug 23/94	289	88	75	49	27	20
Aug 24/94	290	85				20
Aug 26/94	292	88				25
Aug 29/94	295	95				44

Measured Concentrations of Benzene (ug/L)

Date	DAY	Inlet	Port 1	Port 2	Port 3	Exhaust
Sep 1/94	298	78				8
Sep 2/94	299	82				10
Sep 5/94	302	80				21
Sep 8/94	305	75				18
Sep 9/94	306					19
Sep 12/94	309	96				21
Sep 14/94	311	88				16
Sep 16/94	313	87				15
Sep 19/94	316	102				21
Sep 23/94	320	85				25
Sep 26/94	323	90				39
Sep 28/94	325	74				41
Oct 3/94	330	111				66
Oct 11/94	338	91				78
Oct 13/94	340	91				80
Oct 14/94	341					82
Oct 17/94	344	112				80
Nov 8/94	366	135				17
Nov 9/94	367	116				32
Nov 10/94	368					43
Nov 11/94	369					73
Nov 15/94	373	121				61
Nov 16/94	374	165				92
Nov 25/94	383	171				78
Nov 28/94	386	148				77
Nov 30/94	388	176				104
Dec 2/94	390	217				111
Dec 6/94	394	153		156	126	56
Dec 8/94	396	101				56
Dec 13/94	401	168	215			64
Dec 14/94	402	203	170		32	42
Dec 15/94	403	186	185	71	45	96
Dec 20/94	408	63				4
Dec 22/94	410	66				0
Jan 5/95	424	66				5
Jan 6/95	425	63	79	44	0	0
Jan 9/95	428	50				5
Jan 11/95	430	49				3
Jan 12/95	431	70				9
Jan 16/95	435	85				15
Jan 24/95	443	94	81	67	22	36
Jan 30/95	449	105	86	87	56	43

Measured Concentrations of Toluene (ug/L)

Date	DAY	Inlet	Port 1	Port 2	Port 3	Exhaust
Dec 1/93	24	54				40
Dec 2/93	25	107				74
Dec 6/93	29	66				50
Dec 8/93	31	52				39
Dec 10/93	33	47				39
Dec 14/93	37	52				43
Dec 15/93	38	107				45
Dec 17/93	40	100				64
Dec 21/93	44	110				66
Dec 23/93	46	85				62
Jan 4/94	58	116				90
Jan 6/94	60	111				77
Jan 10/94	64					
Jan 12/94	66	148				92
Feb 3/94	88	99				59
Feb 4/94	89	160				115
Feb 6/94	91	134				52
Feb 10/94	95	173				83
Feb 14/94	99	128				56
Feb 16/94	101	114				70
Feb 18/94	103	139				16
Feb 21/94	106	144				50
Feb 24/94	109	153				58
Mar 02/94	115	170	114	15	30	38
Mar 03/94	116		60			56
Mar 07/94	120	163	127	96	54	34
Mar 08/94	121	148	112	96	54	32
Mar 09/94	122	152	110	77	59	24
Mar 14/94	127	143	109	85	58	28
Mar 16/94	129	345	252	216		43
Mar 18/94	131	372	268	208	130	68
Mar 22/94	135	274	242	209	133	61
Mar 23/94	136	296	247	177	88	73
Mar 24/94	137	299	289	155	140	94
Mar 28/94	141	301	237	207	129	111
Mar 30/94	143	300	254	259	170	124
Mar 31/94	144	272	232	201	163	140

Measured Concentrations of Toluene (ug/L)

Date	DAY	Inlet	Port 1	Port 2	Port 3	Exhaust
Apr 4/94	148	254	245	228	170	142
Apr 6/94	150	256			124	130
Apri 8/94	152					166
Apr 11/94	155	169		160	103	105
Apr 13/94	157	266	273	221	180	148
Apr 15/94	159	131	109	112	80	80
Apr 19/94	163	136				76
Apr 20/94	164	120				63
Apr 25/94	169	130				79
May 20/94	194	127				10
May 24/94	198	122				2
May 26/94	200	149	153	93		22
May 30/94	204	170	145	65	51	12
June 1/94	206	134				24
June 3/94	208	174				30
June 6/94	211	128				28
Jun 10/94	215	146				53
Jun 14/94	219	136				12
Jun 16/94	221	132				18
Jun 20/94	225	111				16
Jun 22/94	227	132		40	17	8
Jun 24/94	229	90	77	40	29	3
Jun 27/94	232	80	64	19	5	1
Jun 30/94	235	96				7
Jul 4/94	239	122	123	80	62	25
Jul 6/94	241	122				40
Jul 8/94	243	130				35
Jul 11/94	246	131				47
Jul 13/94	248	128				57
Jul 14/94	249	131				52
Jul 15/94	250	124				48
Jul 18/94	253	152				63
Aug 10/94	276	157				93
Aug 12/94	278	118		4		6
Aug 15/94	281	111	103	47		11
Aug 17/94	283	110		52		9
Aug 19/94	285	95	86	47	4	10
Aug 23/94	289	105	95	57	20	17
Aug 24/94	290	126				16
Aug 26/94	292	116				25
Aug 29/94	295	118				42

Measured Concentrations of Toluene (ug/L)

Date	DAY	Inlet	Port 1	Port 2	Port 3	Exhaust
Sep 1/94	298	102				7
Sep 2/94	299	106				8
Sep 5/94	302	100				19
Sep 8/94	305	90				18
Sep 9/94	306					19
Sep 12/94	309	115				21
Sep 14/94	311	106				16
Sep 16/94	313	110				15
Sep 19/94	316	123				16
Sep 23/94	320	97				21
Sep 26/94	323	110				45
Sep 28/94	325	86				45
Oct 3/94	330	129				75
Oct 11/94	338	119				97
Oct 13/94	340	120				94
Oct 14/94	341					100
Oct 17/94	344	133				100
Nov 8/94	366	139				45
Nov 9/94	367	128				54
Nov 10/94	368					56
Nov 11/94	369					64
Nov 15/94	373	137				56
Nov 16/94	374	188				84
Nov 25/94	383	193				85
Nov 28/94	386	172				86
Nov 30/94	388	197				109
Dec 2/94	390	231				132
Dec 6/94	394	162		173	145	74
Dec 8/94	396	120				70
Dec 13/94	401	201	233			93
Dec 14/94	402	224	189		33	55
Dec 15/94	403	208	206	72	40	105
Dec 20/94	408	76				22
Dec 22/94	410	77				0
Jan 5/95	424	80				10
Jan 6/95	425	87	102	40	0	5
Jan 9/95	428	65				9
Jan 11/95	430	66				4
Jan 12/95	431	85				11
Jan 16/95	435	106				19
Jan 24/95	443	134	97	73	25	34
Jan 30/95	449	121	102	85	51	47

Measured Concentrations of Ethlybenzene (ug/L)

Date	DAY	Inlet	Port 1	Port 2	Port 3	Exhaust
Dec 1/93	24	76				54
Dec 2/93	25	163				124
Dec 6/93	29	93				70
Dec 8/93	31	80				56
Dec 10/93	33	78				56
Dec 14/93	37	76				58
Dec 15/93	38	167				66
Dec 17/93	40	142				89
Dec 21/93	44	142				82
Dec 23/93	46	120				78
Jan 4/94	58	176				87
Jan 6/94	60	157				60
Jan 10/94	64					
Jan 12/94	66	212				39
Feb 3/94	88	114				66
Feb 4/94	89	215				188
Feb 6/94	91	169				17
Feb 10/94	95	215				12
Feb 14/94	99	160				3
Feb 16/94	101	146				4
Feb 18/94	103	195				77
Feb 21/94	106	196				42
Feb 24/94	109	200				29
Mar 02/94	115	206	138	5	6	14
Mar 03/94	116		62			23
Mar 07/94	120	192	114	20	2	4
Mar 08/94	121	198	118	27	2	4
Mar 09/94	122	190	112	18	2	2
Mar 14/94	127	171	107	18	1	2
Mar 16/94	129	437	222	27		4
Mar 18/94	131	415	366	29	38	5
Mar 22/94	135	309	220	49	69	6
Mar 23/94	136	374	264	60	9	10
Mar 24/94	137	365	319	43	21	14
Mar 28/94	141	325	193	76	40	25
Mar 30/94	143	304	224	102	71	41
Mar 31/94	144	291	190	89	84	56

Measured Concentrations of Ethlybenzene (ug/L)

Date	DAY	Inlet	Port 1	Port 2	Port 3	Exhaust
Apr 4/94	148	248	188	158	126	98
Apr 6/94	150	234			103	121
Apri 8/94	152					188
Apr 11/94	155	206		161	120	102
Apr 13/94	157	310	351	205	178	156
Apr 15/94	159	177	138	133	84	90
Apr 19/94	163	195				80
Apr 20/94	164	148				59
Apr 25/94	169	175				81
May 20/94	194	154				2
May 24/94	198	151				1
May 26/94	200	177	197	39		9
May 30/94	204	214	173	40	77	4
June 1/94	206	183				19
June 3/94	208	187				15
June 6/94	211	143				17
Jun 10/94	215	171				55
Jun 14/94	219	167				10
Jun 16/94	221	166				18
Jun 20/94	225	141				20
Jun 22/94	227	137		33	15	6
Jun 24/94	229	118	95	32	13	5
Jun 27/94	232	81	72	19	3	1
Jun 30/94	235	107				5
Jul 4/94	239	156	159	51	40	17
Jul 6/94	241	160				34
Jul 8/94	243	137				32
Jul 11/94	246	164				43
Jul 13/94	248	161				56
Jul 14/94	249	153				49
Jul 15/94	250	168				46
Jul 18/94	253	174				57
Aug 10/94	276	179				113
Aug 12/94	278	160		3		14
Aug 15/94	281	131	120	10		5
Aug 17/94	283	154		10		3
Aug 19/94	285	143	111	7	1	7
Aug 23/94	289	164	141	18	2	4
Aug 24/94	290	178				4
Aug 26/94	292	174				7
Aug 29/94	295	158				18

Measured Concentrations of Ethlybenzene (ug/L)

Date	DAY	Inlet	Port 1	Port 2	Port 3	Exhaust
Sep 1/94	298	141				2
Sep 2/94	299	139				3
Sep 5/94	302	137				9
Sep 8/94	305	132				9
Sep 9/94	306					
Sep 12/94	309	153				12
Sep 14/94	311	137				9
Sep 16/94	313	143				7
Sep 19/94	316	164				7
Sep 23/94	320	128				15
Sep 26/94	323	143				41
Sep 28/94	325	109				43
Oct 3/94	330	161				75
Oct 11/94	338	146				100
Oct 13/94	340	158				96
Oct 14/94	341					108
Oct 17/94	344	163				108
Nov 8/94	366	170				73
Nov 9/94	367	186				98
Nov 10/94	368					77
Nov 11/94	369					69
Nov 15/94	373	134				56
Nov 16/94	374	216				107
Nov 25/94	383	182				99
Nov 28/94	386	166				77
Nov 30/94	388	242				135
Dec 2/94	390	314				150
Dec 6/94	394	222		239	183	89
Dec 8/94	396	184				87
Dec 13/94	401	297	317			123
Dec 14/94	402	318	208		29	70
Dec 15/94	403	302	241	66	31	103
Dec 20/94	408	115				31
Dec 22/94	410	142				0
Jan 5/95	424	122				17
Jan 6/95	425	133	142	31	0	9
Jan 9/95	428	98				11
Jan 11/95	430	93				6
Jan 12/95	431	164				15
Jan 16/95	435	154				24
Jan 24/95	443	194	129	75	20	36
Jan 30/95	449	191	134	83	41	53

Measured Concentration of m/p-Xylene (ug/L)

Date	DAY	Inlet	Port 1	Port 2	Port 3	Exhaust
Dec 1/93	24	33				22
Dec 2/93	25	72				50
Dec 6/93	29	35				28
Dec 8/93	31	20				23
Dec 10/93	33	15				23
Dec 14/93	37	22				24
Dec 15/93	38	85				29
Dec 17/93	40	57				38
Dec 21/93	44	56				35
Dec 23/93	46	51				35
Jan 4/94	58	77				61
Jan 6/94	60	67				54
Jan 10/94	64					
Jan 12/94	66	92				81
Feb 3/94	88	49				24
Feb 4/94	89	93				85
Feb 6/94	91	69				43
Feb 10/94	95	88				74
Feb 14/94	99	63				43
Feb 16/94	101	55				63
Feb 18/94	103	77				65
Feb 21/94	106	70				54
Feb 24/94	109	72				24
Mar 02/94	115	75	40	10	41	24
Mar 03/94	116		7			43
Mar 07/94	120	80	65	53	40	25
Mar 08/94	121	83	75	62	48	26
Mar 09/94	122	79	70	47	44	22
Mar 14/94	127	68	57	48	51	24
Mar 16/94	129	190	110	135		37
Mar 18/94	131	169	172	114	74	36
Mar 22/94	135	139	100	118	96	42
Mar 23/94	136	156	132	142	82	50
Mar 24/94	137	146	159	97	99	57
Mar 28/94	141	136	99	115	76	71
Mar 30/94	143	126	108	140	91	72
Mar 31/94	144	123	101	109	90	84

Measured Concentration of m/p-Xylene (ug/L)

Date	DAY	Inlet	Port 1	Port 2	Port 3	Exhaust
Apr 4/94	148	101	96	123	88	83
Apr 6/94	150	95			53	78
Apri 8/94	152					122
Apr 11/94	155	88		98	71	66
Apr 13/94	157	131	162	116	112	92
Apr 15/94	159	78	54	65	52	49
Apr 19/94	163	86				52
Apr 20/94	164	64				35
Apr 25/94	169	74				52
May 20/94	194	77				2
May 24/94	198	78				4
May 26/94	200	82	90	64		17
May 30/94	204	102	72	77	54	14
June 1/94	206	86				28
June 3/94	208	103				25
June 6/94	211	82				26
Jun 10/94	215	109				54
Jun 14/94	219	100				14
Jun 16/94	221	100				21
Jun 20/94	225	81				25
Jun 22/94	227	78		47	30	12
Jun 24/94	229	70	60	47	25	8
Jun 27/94	232	47	45	32	12	2
Jun 30/94	235	60				10
Jul 4/94	239	92	91	65	51	23
Jul 6/94	241	97				37
Jul 8/94	243	84				31
Jul 11/94	246	95				39
Jul 13/94	248	92				49
Jul 14/94	249	87				42
Jul 15/94	250	100				41
Jul 18/94	253	103				47
Aug 10/94	276	102				65
Aug 12/94	278	96		8		7
Aug 15/94	281	76	75	29		12
Aug 17/94	283	86		36		8
Aug 19/94	285	84	69	23	3	10
Aug 23/94	289	95	85	35	10	11
Aug 24/94	290	100				12
Aug 26/94	292	100				16
Aug 29/94	295	92				26

Measured Concentration of m/p-Xylene (ug/L)

Date	DAY	Inlet	Port 1	Port 2	Port 3	Exhaust
Sep 1/94	298	81				6
Sep 2/94	299	78				7
Sep 5/94	302	78				13
Sep 8/94	305	67				14
Sep 9/94	306					
Sep 12/94	309	88				16
Sep 14/94	311	76				14
Sep 16/94	313	81				14
Sep 19/94	316	92				10
Sep 23/94	320	70				15
Sep 26/94	323	81				37
Sep 28/94	325	61				38
Oct 3/94	330	89				58
Oct 11/94	338	90				64
Oct 13/94	340	92				68
Oct 14/94	341					76
Oct 17/94	344	93				76
Nov 8/94	366	92				57
Nov 9/94	367	147				88
Nov 10/94	368					68
Nov 11/94	369					59
Nov 15/94	373	106				41
Nov 16/94	374	145				76
Nov 25/94	383	140				61
Nov 28/94	386	122				61
Nov 30/94	388	147				81
Dec 2/94	390	173				91
Dec 6/94	394	108		129	112	54
Dec 8/94	396	87				57
Dec 13/94	401	158	177			70
Dec 14/94	402	166	147		32	50
Dec 15/94	403	158	152	70	36	70
Dec 20/94	408	56				21
Dec 22/94	410	73				0
Jan 5/95	424	54				6
Jan 6/95	425	63	74	24	0	4
Jan 9/95	428	40				3
Jan 11/95	430	40				1
Jan 12/95	431	114				8
Jan 16/95	435	71				7
Jan 24/95	443	83	58	39	12	15
Jan 30/95	449	81	44	42	28	24

Measured Concentrations of o-Xylene (ug/L)

Date	DAY	Inlet	Port 1	Port 2	Port 3	Exhaust
Dec 1/93	24	3				2
Dec 2/93	25	7				5
Dec 6/93	29	4				3
Dec 8/93	31	4				2
Dec 10/93	33	3				2
Dec 14/93	37	3				2
Dec 15/93	38	7.5				3
Dec 17/93	40	6.5				4
Dec 21/93	44	6				4
Dec 23/93	46	5				3
Jan 4/94	58	7				6
Jan 6/94	60	7				5
Jan 10/94	64					
Jan 12/94	66	9				7
Feb 3/94	88	5				3
Feb 4/94	89	9				10
Feb 6/94	91	6				5
Feb 10/94	95	9				8
Feb 14/94	99	6				5
Feb 16/94	101	6				7
Feb 18/94	103	8				7
Feb 21/94	106	8				7
Feb 24/94	109	8				6
Mar 02/94	115	9	9	5	7	4
Mar 03/94	116		7			6
Mar 07/94	120	8	8	6	6	4
Mar 08/94	121	9	8	6	6	4
Mar 09/94	122	8	8	5	5	3
Mar 14/94	127	7	6	6	6	3
Mar 16/94	129	18	12	13		4
Mar 18/94	131	16	20	13	9	4
Mar 22/94	135	14	12	11	10	5
Mar 23/94	136	15	17	14	9	6
Mar 24/94	137	15	19	10	10	6
Mar 28/94	141	14	13	10	9	7
Mar 30/94	143	12	13	13	10	7
Mar 31/94	144	13	15	10	9	8

Measured Concentrations of o-Xylene (ug/L)

Date	DAY	Inlet	Port 1	Port 2	Port 3	Exhaust
Apr 4/94	148	8	12	11	9	8
Apr 6/94	150	7			7	10
Apri 8/94	152					13
Apr 11/94	155	8		9	7	7
Apr 13/94	157	11	17	11	11	9
Apr 15/94	159	7	6	7	5	5
Apr 19/94	163	8				6
Apr 20/94	164	6				3
Apr 25/94	169	6				6
May 20/94	194	7				2
May 24/94	198	7				3
May 26/94	200	7	9	6		2
May 30/94	204	9	9	7	5	2
June 1/94	206	8				3
June 3/94	208	8				2
June 6/94	211	13				4
Jun 10/94	215	18				9
Jun 14/94	219	18				2
Jun 16/94	221	17				4
Jun 20/94	225	14				4
Jun 22/94	227	12		8	5	2
Jun 24/94	229	12	10	7	5	1
Jun 27/94	232	7	8	5	2	1
Jun 30/94	235	9				2
Jul 4/94	239	15	16	10	9	4
Jul 6/94	241	17				7
Jul 8/94	243	15				6
Jul 11/94	246	16				8
Jul 13/94	248	15				8
Jul 14/94	249	14				7
Jul 15/94	250	18				7
Jul 18/94	253	18				9
Aug 10/94	276	16				14
Aug 12/94	278	18		2		1
Aug 15/94	281	12	12	9		4
Aug 17/94	283	14		11		2
Aug 19/94	285	16	11	7	1	2
Aug 23/94	289	18	15	11	6	4
Aug 24/94	290	18				5
Aug 26/94	292	18				6
Aug 29/94	295	16				9

Measured Concentrations of o-Xylene (ug/L)

Date	DAY	Inlet	Port 1	Port 2	Port 3	Exhaust
Sep 1/94	298	15				3
Sep 2/94	299	13				4
Sep 5/94	302	14				4
Sep 8/94	305	15				5
Sep 9/94	306					
Sep 12/94	309	16				5
Sep 14/94	311	13				6
Sep 16/94	313	13				5
Sep 19/94	316	15				5
Sep 23/94	320	12				5
Sep 26/94	323	13				8
Sep 28/94	325	10				7
Oct 3/94	330	14				11
Oct 11/94	338	14				13
Oct 13/94	340	15				15
Oct 14/94	341					15
Oct 17/94	344	15				15
Nov 8/94	366	9				--
Nov 9/94	367	6				8
Nov 10/94	368					6
Nov 11/94	369					4
Nov 15/94	373	13				5
Nov 16/94	374	--				7
Nov 25/94	383	17				7
Nov 28/94	386	14				7
Nov 30/94	388	17				9
Dec 2/94	390	20				12
Dec 6/94	394	10		14	13	
Dec 8/94	396	8				5
Dec 13/94	401	17	21			10
Dec 14/94	402	18	20		0	5
Dec 15/94	403	17	21	10	0	7
Dec 20/94	408					
Dec 22/94	410					
Jan 5/95	424					
Jan 6/95	425					
Jan 9/95	428					
Jan 11/95	430					
Jan 12/95	431					
Jan 16/95	435					
Jan 24/95	443					
Jan 30/95	449					

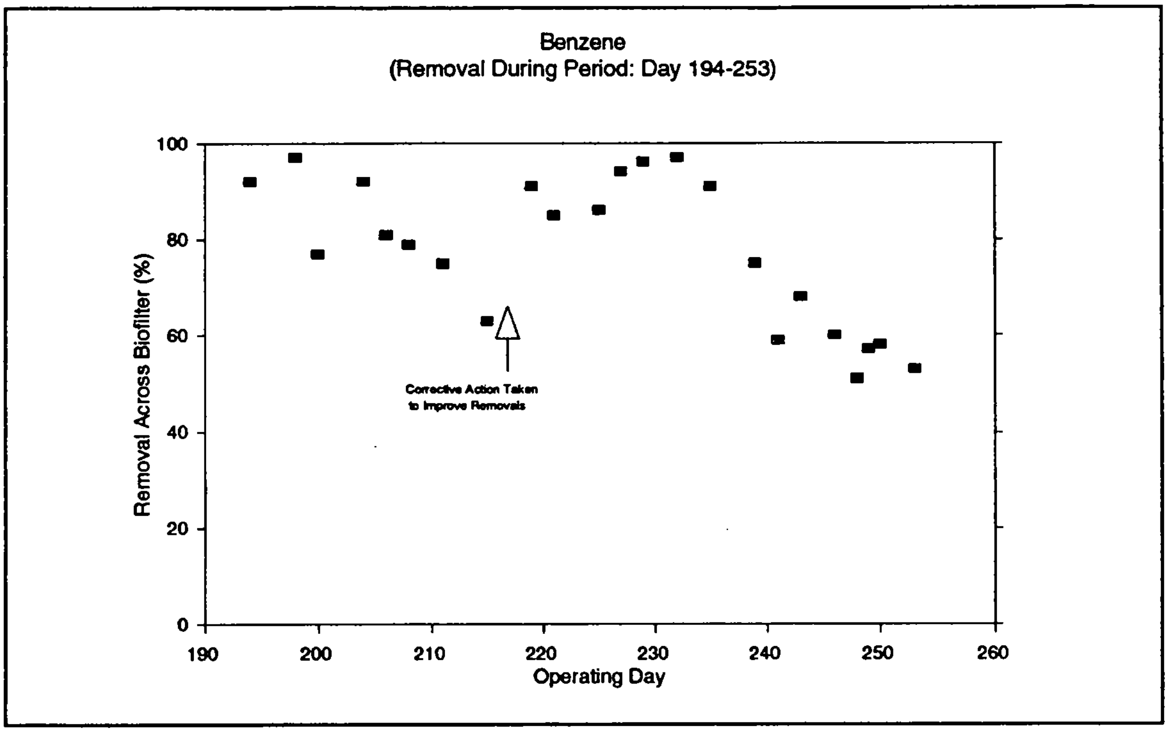
		----------Overall Removal (%)----------				
Date	DAY	B	T	E	X(m/p)	X(o)
Dec 1/93	24	15	26	29	33	33
Dec 2/93	25	28	31	24	31	29
Dec 6/93	29	23	24	25	20	25
Dec 8/93	31	29	25	30	-15	50
Dec 10/93	33	21	17	28	-53	33
Dec 14/93	37	9	17	24	-9	33
Dec 15/93	38	51	58	60	66	60
Dec 17/93	40	28	36	37	33	38
Dec 21/93	44	32	40	42	38	33
Dec 23/93	46	19	27	35	31	40
Jan 4/94	58	15	22	51	21	14
Jan 6/94	60	22	31	62	19	29
Jan 12/94	66	35	38	82	12	22
Feb 3/94	88	32	40	42	51	40
Feb 4/94	89	27	28	13	9	-11
Feb 6/94	91	57	61	90	38	17
Feb 10/94	95	48	52	94	16	11
Feb 14/94	99	47	56	98	32	17
Feb 16/94	101	34	39	97	-15	-17
Feb 18/94	103	82	88	61	16	13
Feb 21/94	106	59	65	79	23	13
Feb 24/94	109	54	62	86	67	25
Mar 02/94	115	72	78	93	68	56
Mar 03/94	116					
Mar 07/94	120	74	79	98	69	50
Mar 08/94	121	74	78	98	69	56
Mar 09/94	122	78	84	99	72	63
Mar 14/94	127	75	80	99	65	57
Mar 16/94	129	82	88	99	81	78
Mar 18/94	131	55	82	99	79	75
Mar 22/94	135	70	78	98	70	64
Mar 23/94	136	66	75	97	68	60
Mar 24/94	137	60	69	96	61	60
Mar 28/94	141	53	63	92	48	50
Mar 30/94	143	51	59	87	43	42
Mar 31/94	144	43	49	81	32	38

Date	DAY	Overall Removal (%) B	T	E	X(m/p)	X(o)
Apr 4/94	148	41	44	60	18	0
Apr 6/94	150	41	49	48	18	-43
Apri 8/94	152					
Apr 11/94	155	52	38	50	25	13
Apr 13/94	157	41	44	50	30	18
Apr 15/94	159	36	39	49	37	29
Apr 19/94	163	33	44	59	40	25
Apr 20/94	164	57	48	60	45	50
Apr 25/94	169	53	39	54	30	0
May 20/94	194	92	92	99	97	71
May 24/94	198	97	98	99	95	57
May 26/94	200	77	85	95	79	71
May 30/94	204	92	93	98	86	78
June 1/94	206	81	82	90	67	63
June 3/94	208	79	83	92	76	75
June 6/94	211	75	78	88	68	69
Jun 10/94	215	63	64	68	50	50
Jun 14/94	219	91	91	94	86	89
Jun 16/94	221	85	86	89	79	76
Jun 20/94	225	86	86	86	69	71
Jun 22/94	227	94	94	96	85	83
Jun 24/94	229	96	97	96	89	92
Jun 27/94	232	97	99	99	96	86
Jun 30/94	235	91	93	95	83	78
Jul 4/94	239	75	80	89	75	73
Jul 6/94	241	59	67	79	62	59
Jul 8/94	243	68	73	77	63	60
Jul 11/94	246	60	64	74	59	50
Jul 13/94	248	51	55	65	47	47
Jul 14/94	249	57	60	68	52	50
Jul 15/94	250	58	61	73	59	61
Jul 18/94	253	53	59	67	54	50
Aug 10/94	276	24	41	37	36	13
Aug 12/94	278	97	95	91	93	94
Aug 15/94	281	87	90	96	84	67
Aug 17/94	283	87	92	98	91	86
Aug 19/94	285	85	89	95	88	88
Aug 23/94	289	77	84	98	88	78
Aug 24/94	290	76	87	98	88	72
Aug 26/94	292	72	78	96	84	67
Aug 29/94	295	54	64	89	72	44

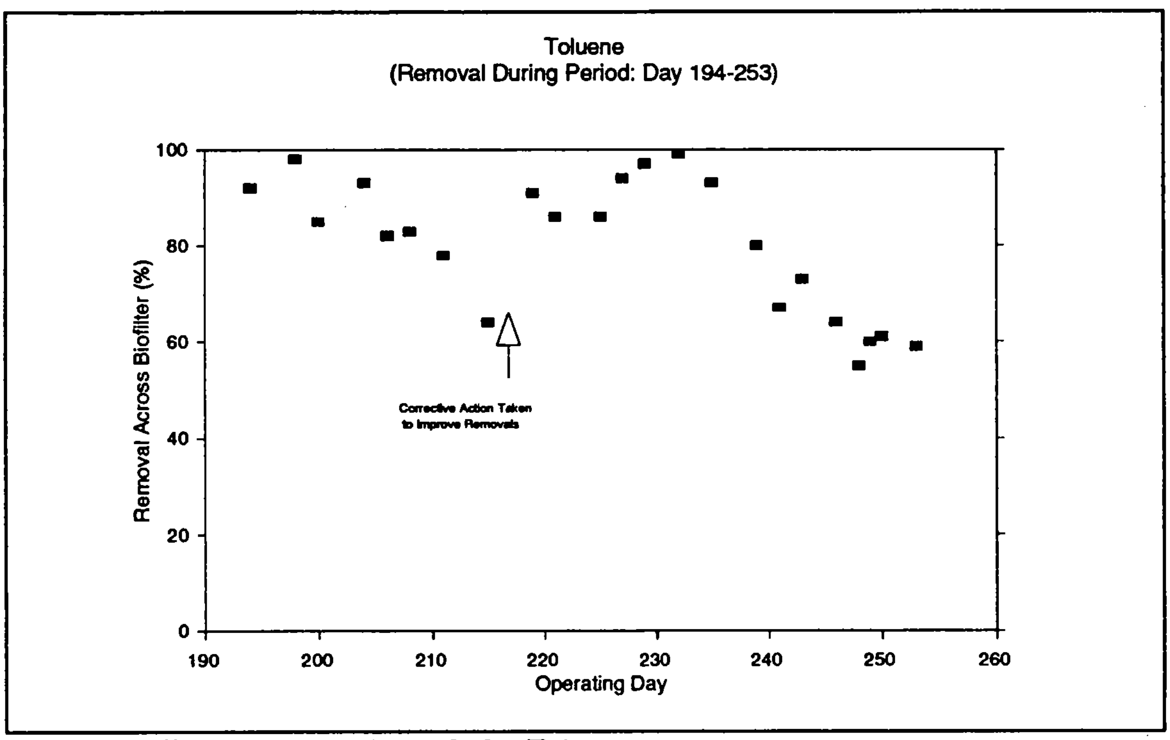
Date	DAY	Overall Removal (%) B	T	E	X(m/p)	X(o)
Sep 1/94	298	90	93	99	93	80
Sep 2/94	299	88	92	98	91	69
Sep 5/94	302	74	81	93	83	71
Sep 8/94	305	76	80	93	79	67
Sep 9/94	306					
Sep 12/94	309	78	82	92	82	69
Sep 14/94	311	82	85	93	82	54
Sep 16/94	313	83	86	95	83	62
Sep 19/94	316	79	87	96	89	67
Sep 23/94	320	71	78	88	79	58
Sep 26/94	323	57	59	71	54	38
Sep 28/94	325	45	48	61	38	30
Oct 3/94	330	41	42	53	35	21
Oct 11/94	338	14	18	32	29	7
Oct 13/94	340	12	22	39	26	0
Oct 14/94	341					
Oct 17/94	344	29	25	34	18	0
Nov 8/94	366	87	68	57	38	--
Nov 9/94	367	72	58	47	40	-33
Nov 10/94	368					
Nov 11/94	369					
Nov 15/94	373					
Nov 16/94	374	44	55	50	48	--
Nov 25/94	383	54	56	46	56	59
Nov 28/94	386	48	50	54	50	50
Nov 30/94	388	41	45	44	45	47
Dec 2/94	390	49	43	52	47	40
Dec 6/94	394	63	54	60	50	100
Dec 8/94	396	45	42	53	34	38
Dec 13/94	401	62	54	59	56	41
Dec 14/94	402	79	75	78	70	72
Dec 15/94	403	48	50	66	56	59
Dec 20/94	408	94	71	73	63	
Dec 22/94	410	100	100	100	100	
Jan 5/95	424	92	88	86	89	
Jan 6/95	425	100	94	93	94	
Jan 9/95	428	90	86	89	93	
Jan 11/95	430	94	94	94	98	
Jan 12/95	431	87	87	91	93	
Jan 16/95	435	82	82	84	90	
Jan 24/95	443	62	75	81	82	
Jan 30/95	449	59	61	72	70	

Appendix C

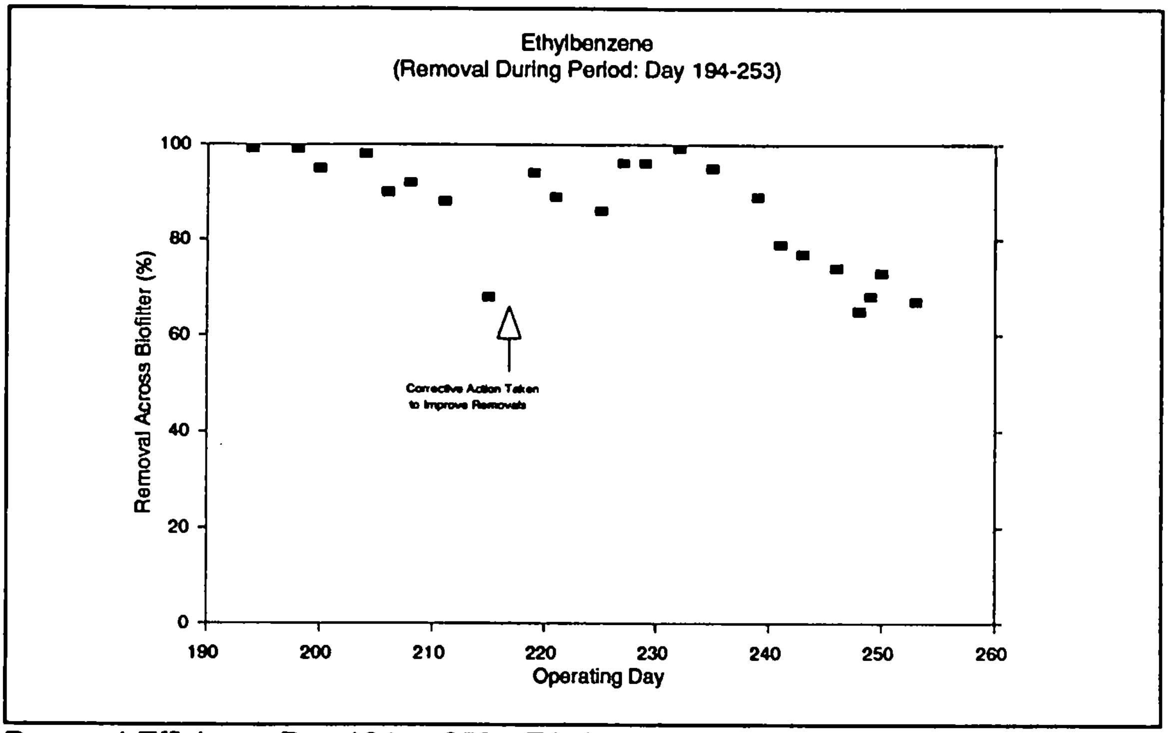
Graphic Representation of Longest Sustained Contaminant Removal



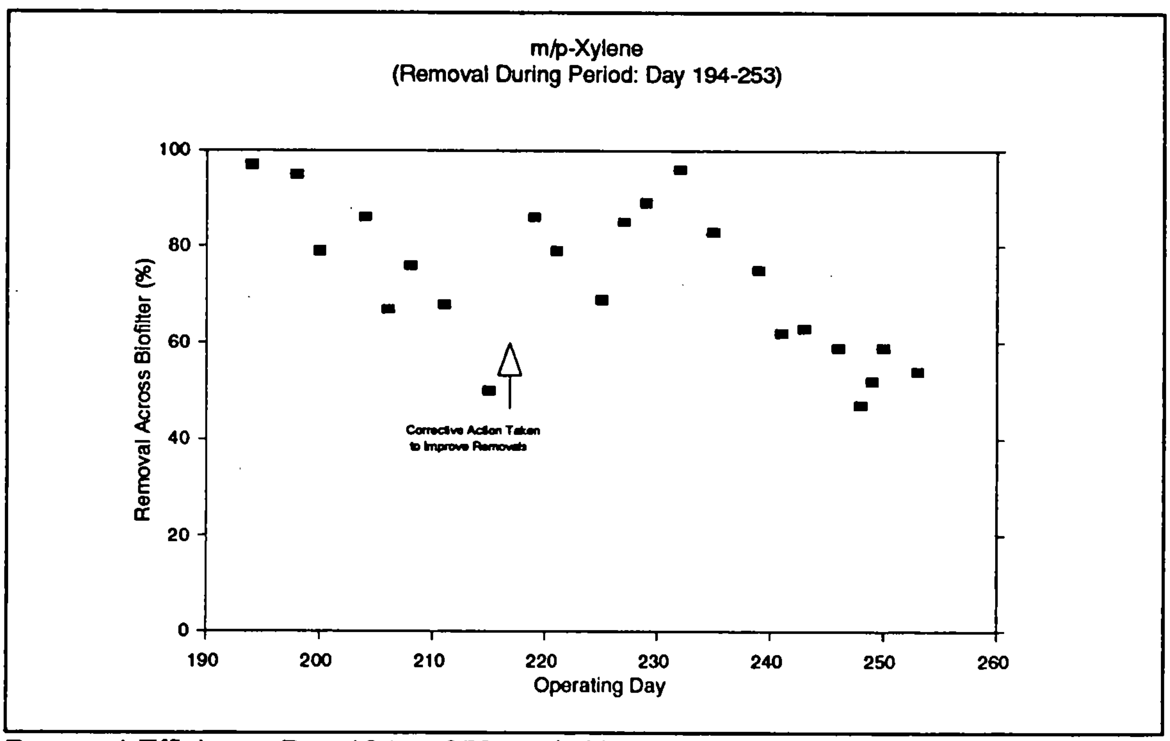
Removal Efficiency Day 194 to 253 - Benzene



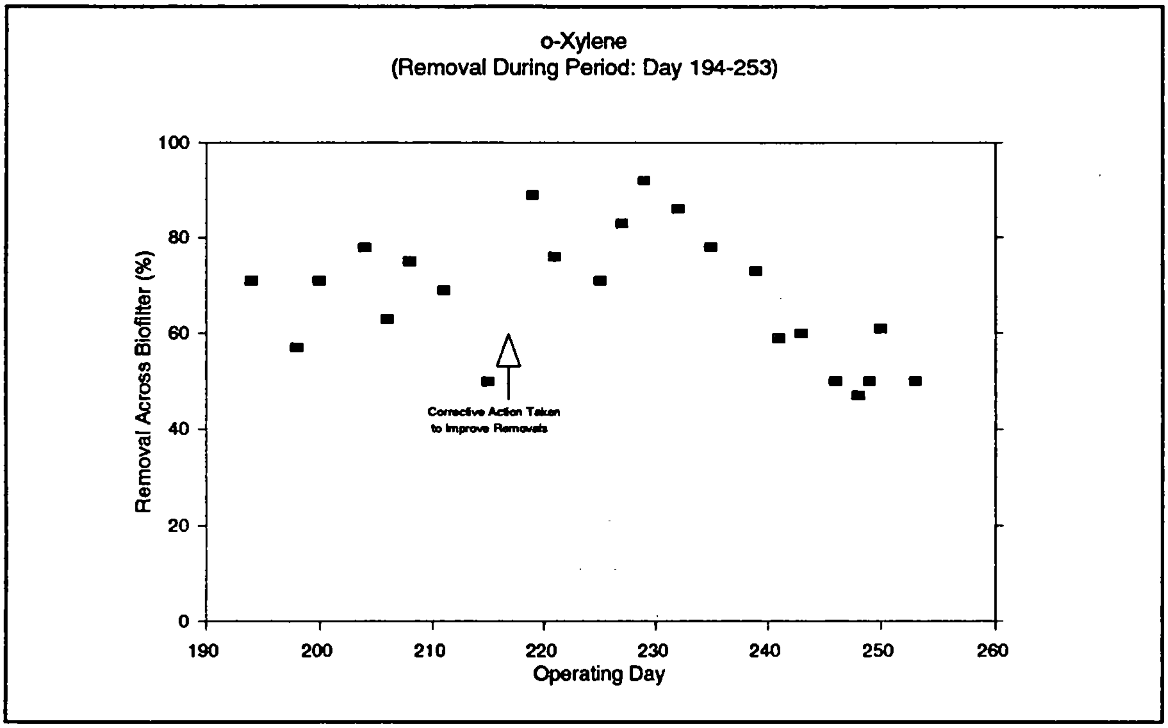
Removal Efficiency Day 194 to 253 - Toluene



Removal Efficiency Day 194 to 253 - Ethylbenzene



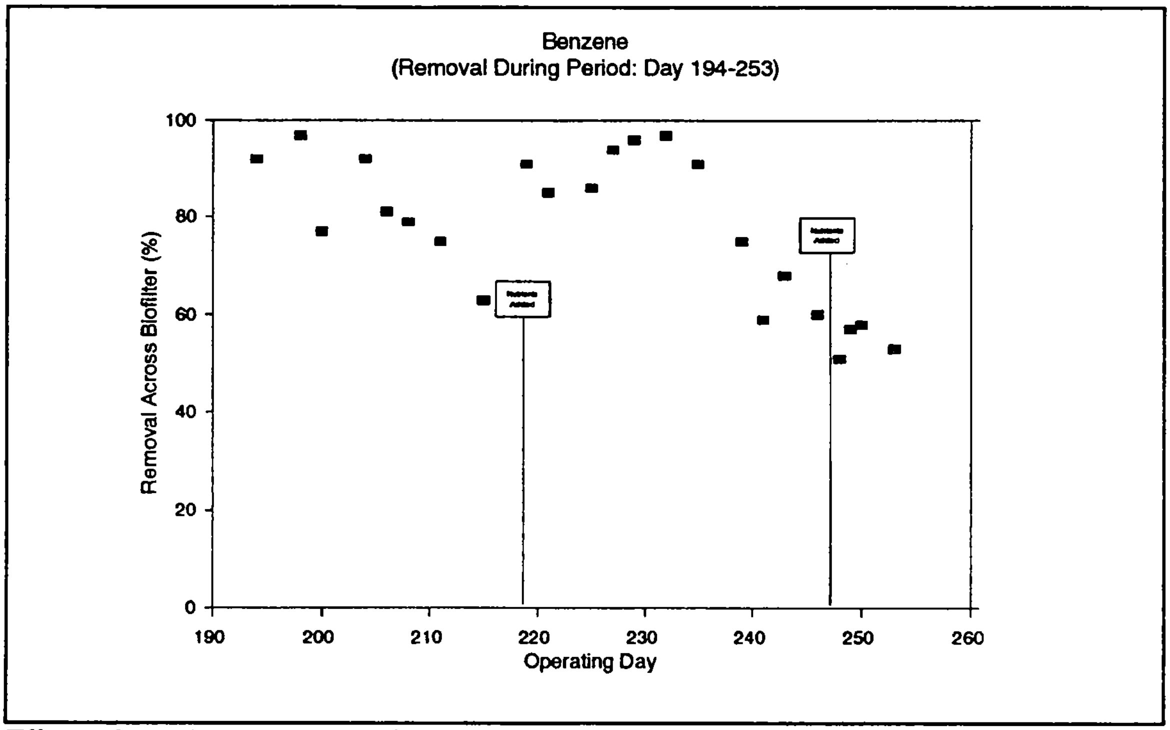
Removal Efficiency Day 194 to 253 - m/p-Xylene



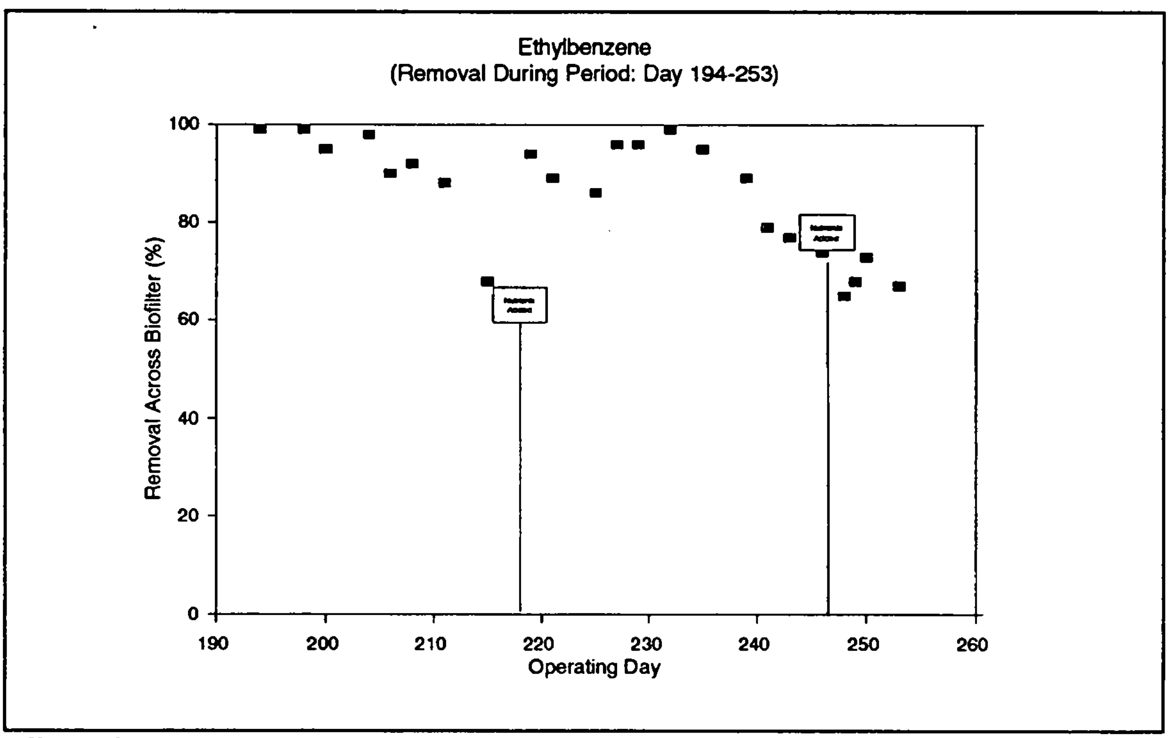
Removal Efficiency Day 194 to 253 - o-Xylene

Appendix D

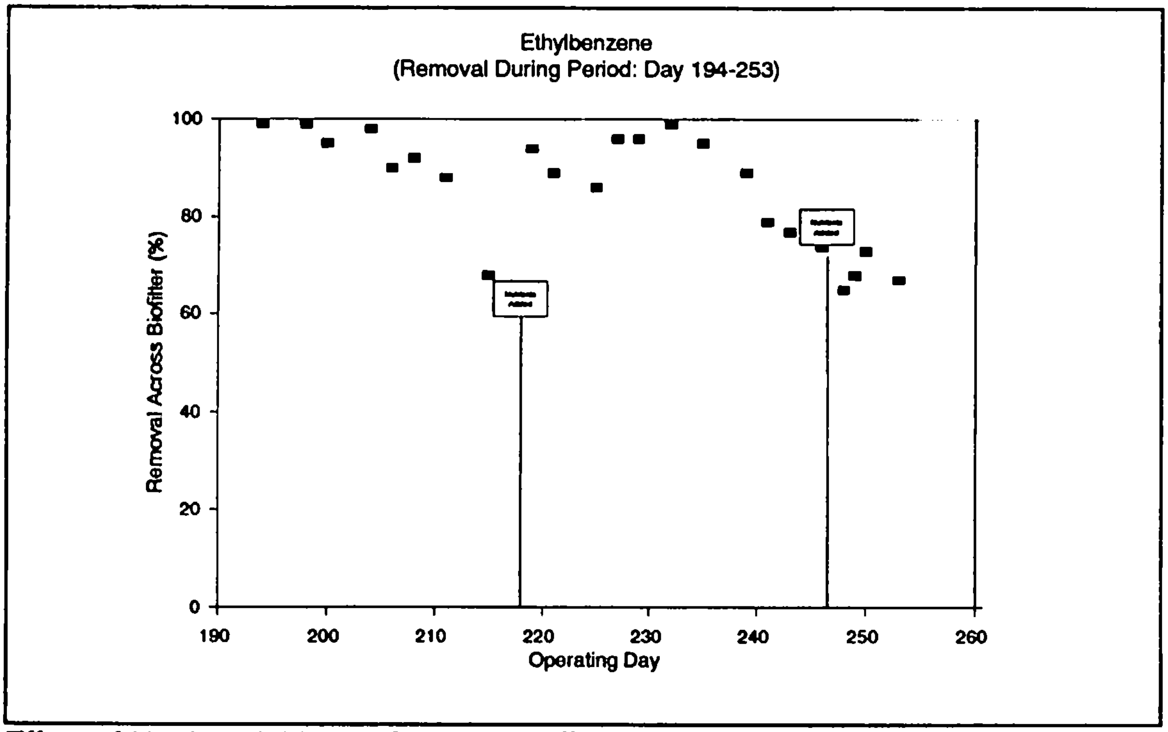
Graphic Representation of Effect of Nutrient Addition



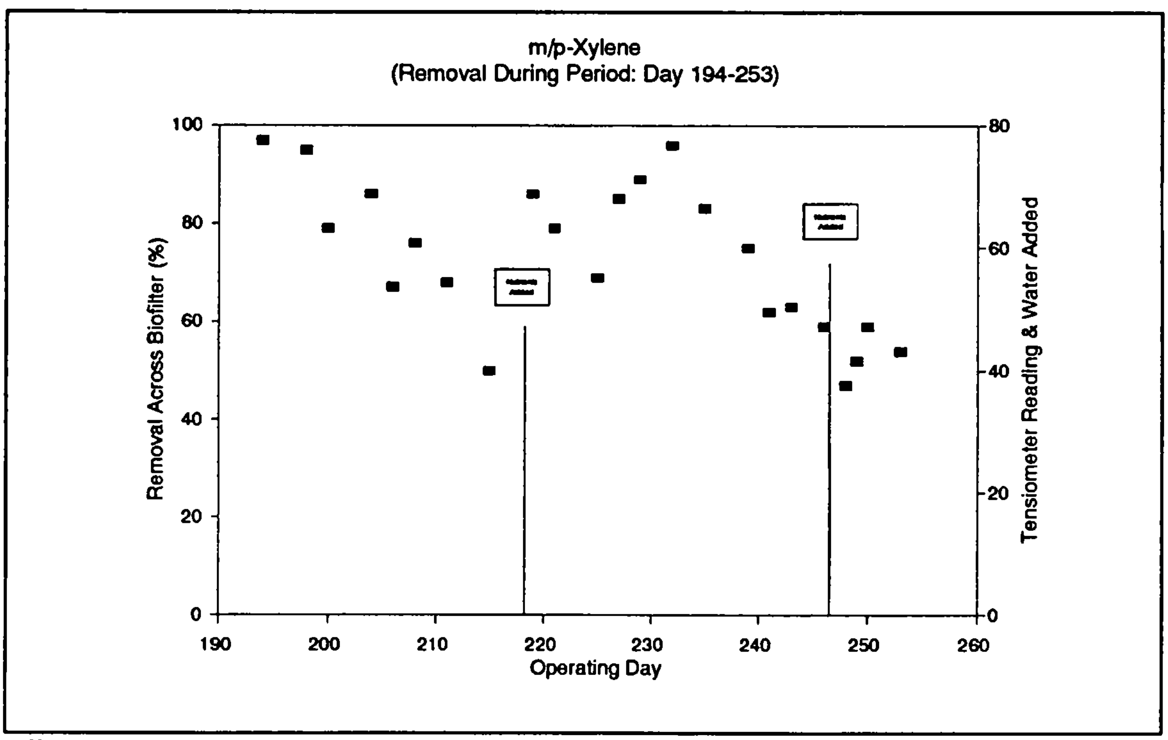
Effect of Nutrient Addition of Removal Efficiency - Benzene



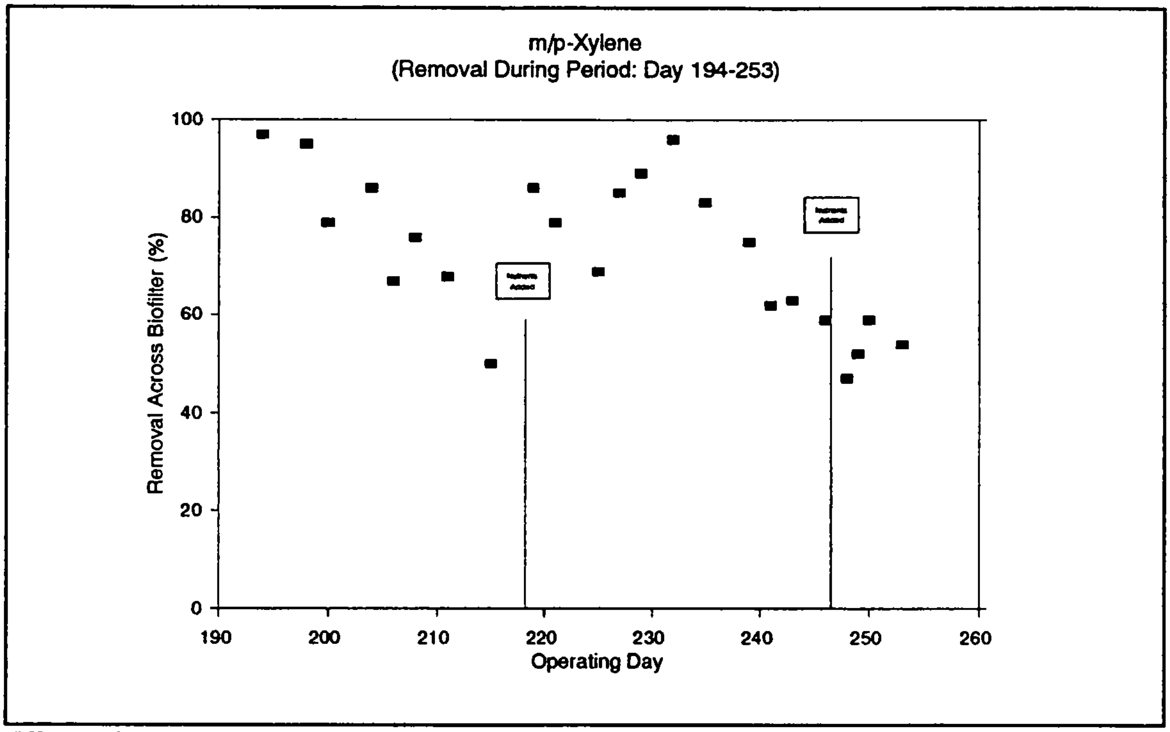
Effect of Nutrient Addition on Removal Efficiency - Toluene



Effect of Nutrient Addition of Removal Efficiency - Ethylbenzene



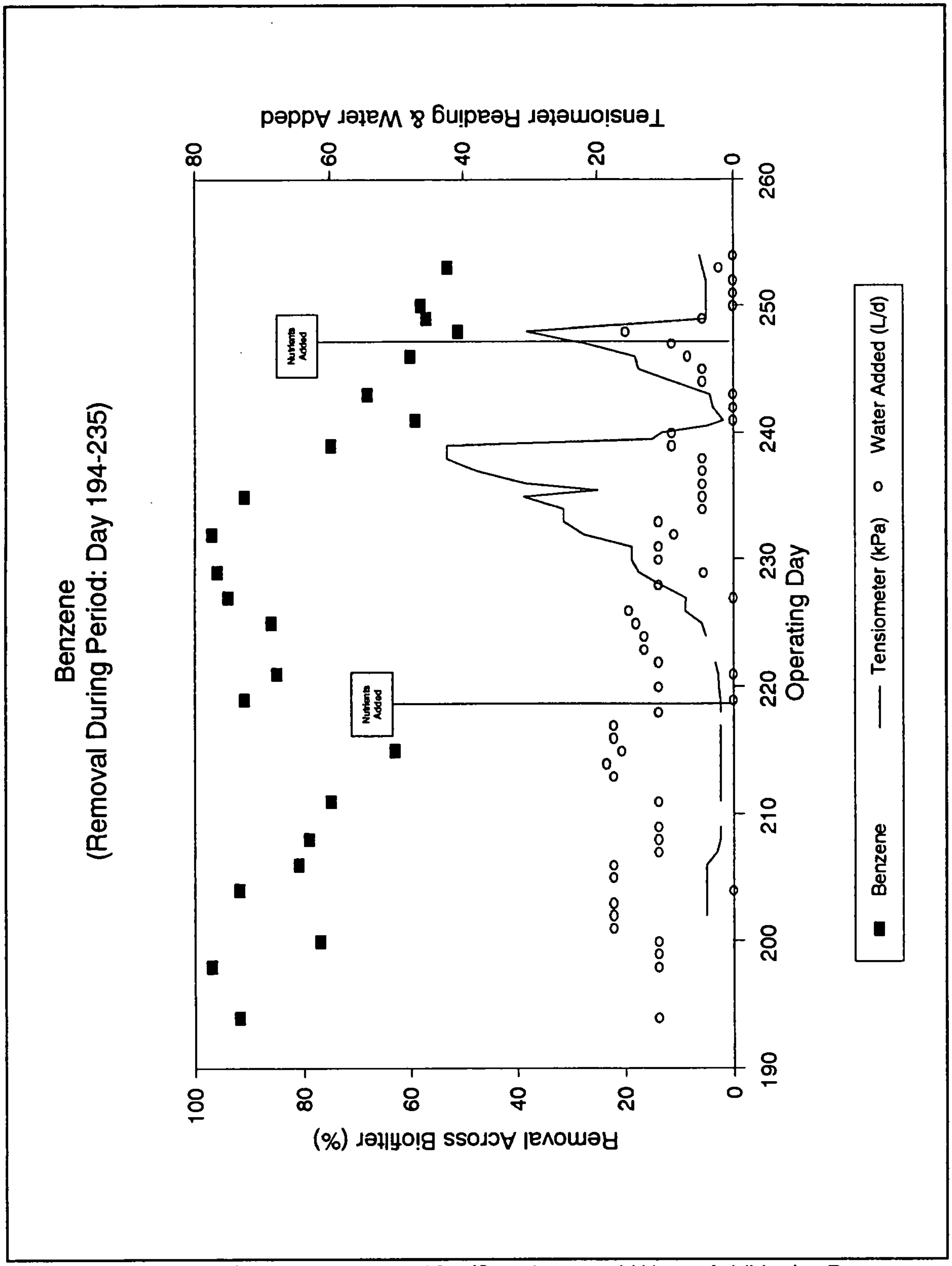
Effect of Nutrient Addition on Removal Efficiency - m/p-Xylene



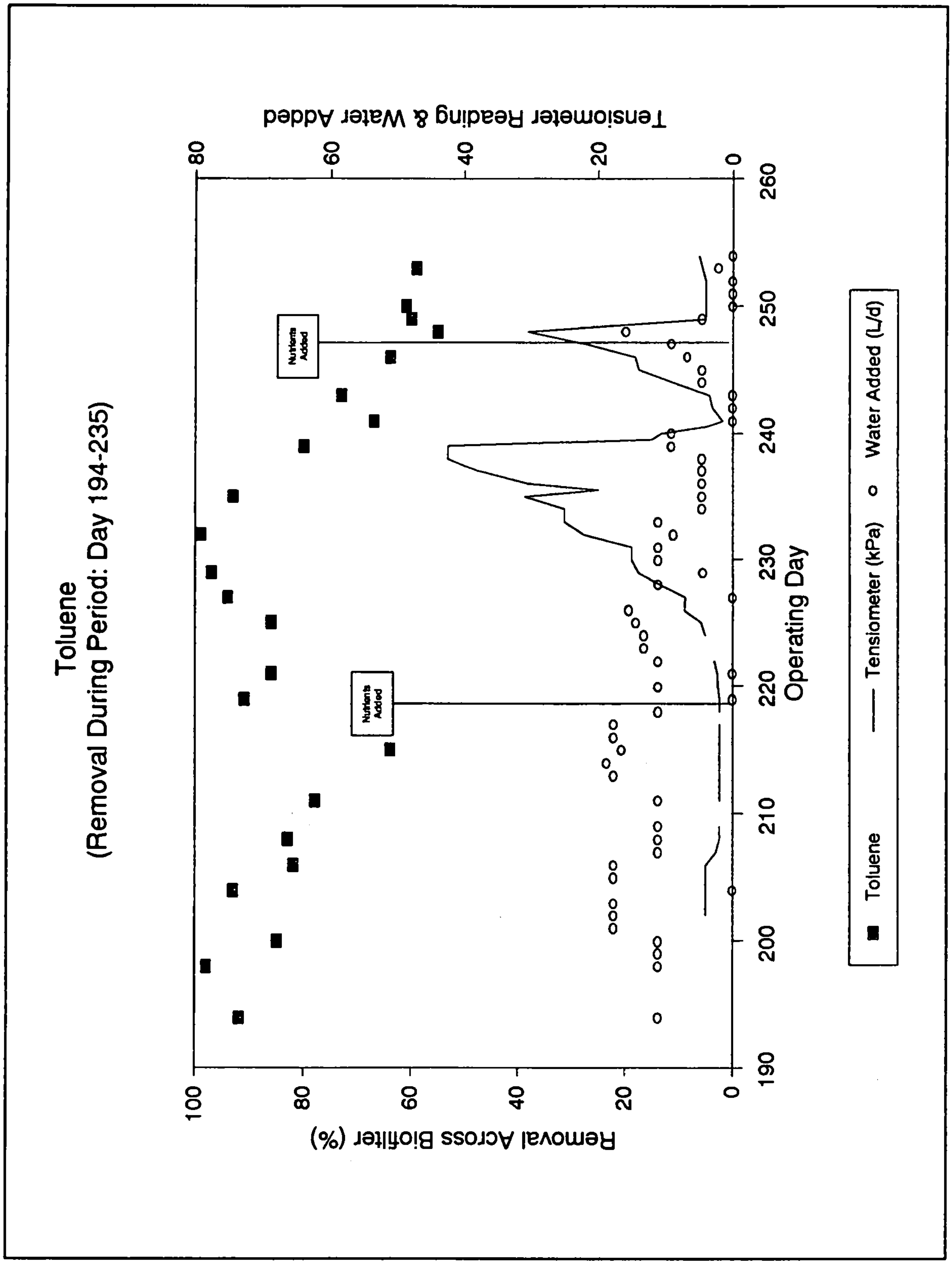
Effect of Nutrient Addition on Removal Efficiency - o-Xylene

Appendix E

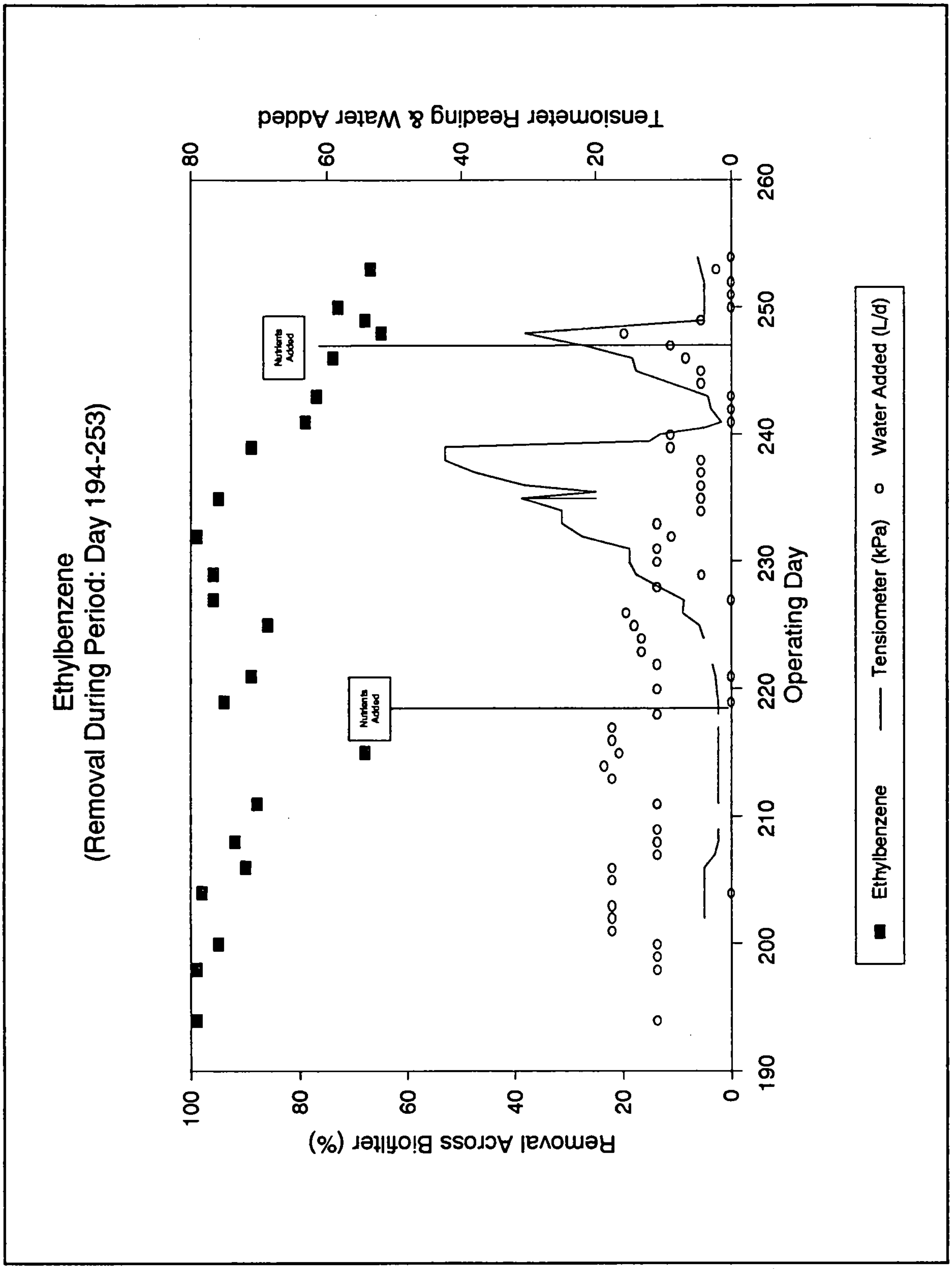
Media Moisture Control - Day 194 to 235



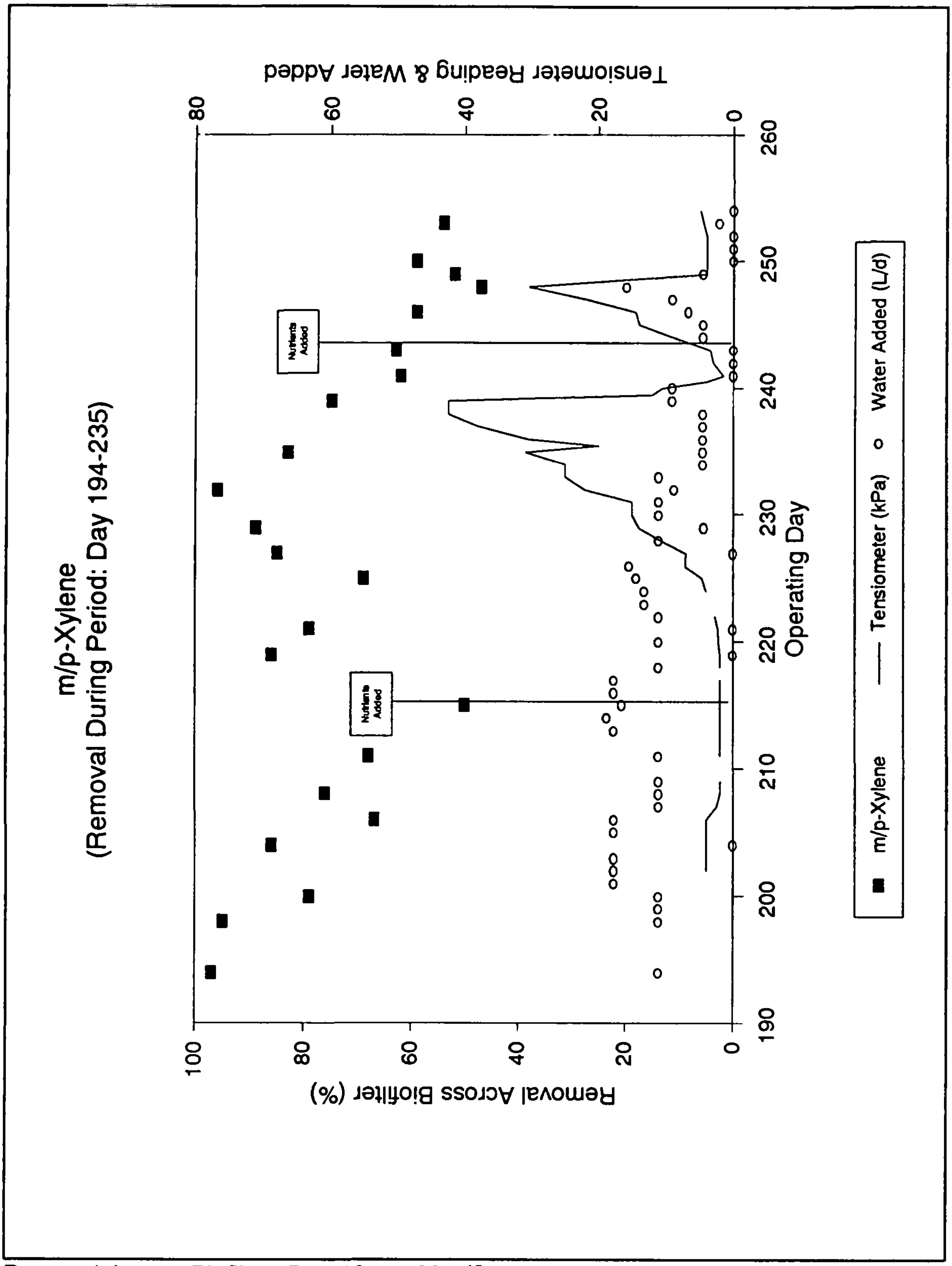
Removal Across Biofilter: Day 194 to 235 (Supplemental Water Addition) - Benzene



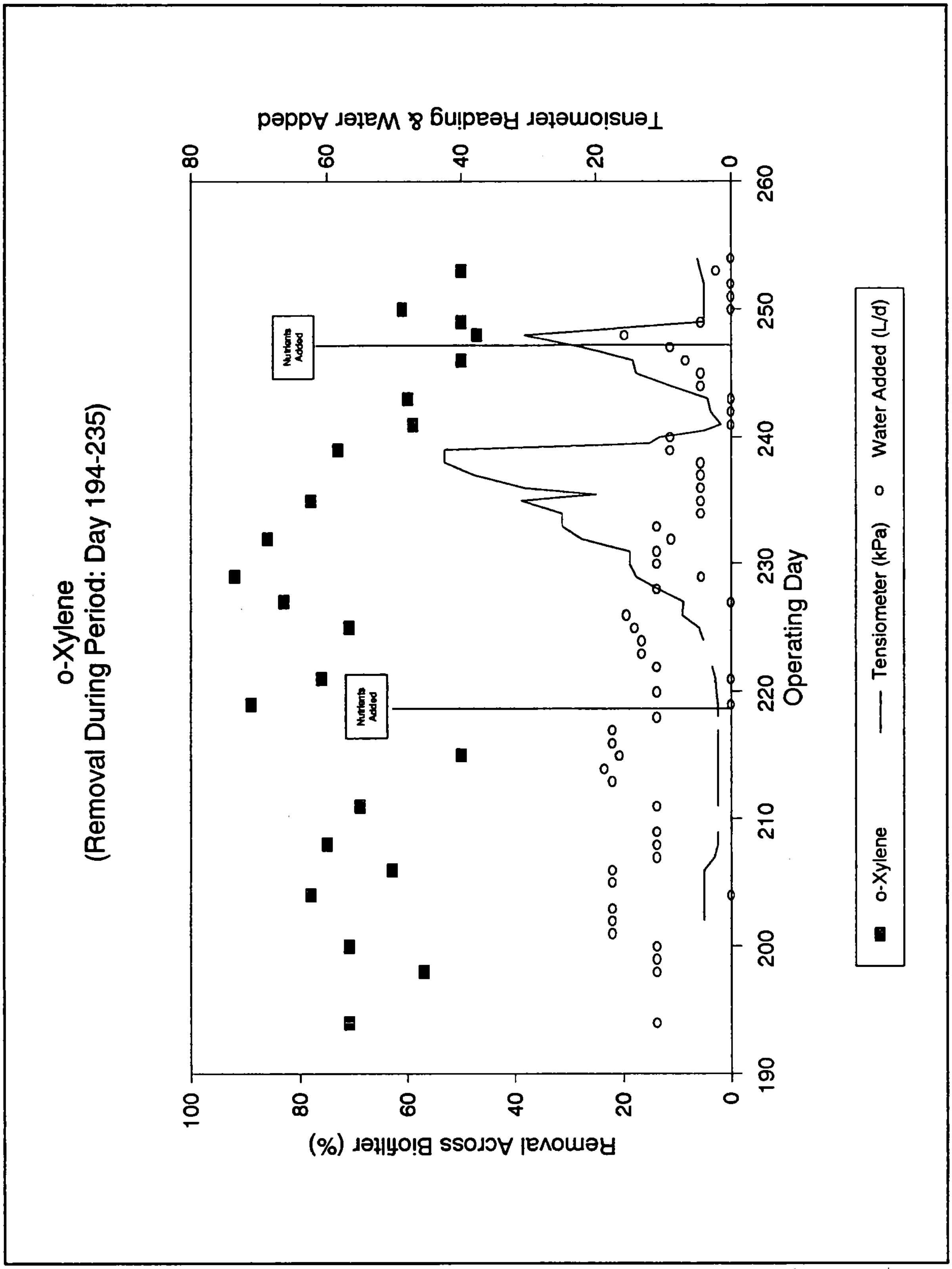
Removal Across Biofilter: Day 194 to 235 (Supplemental Water Addition) - Toluene



Removal Across Biofilter: Day 194 to 235 (Supplemental Water Addition) - Ethylbenzene



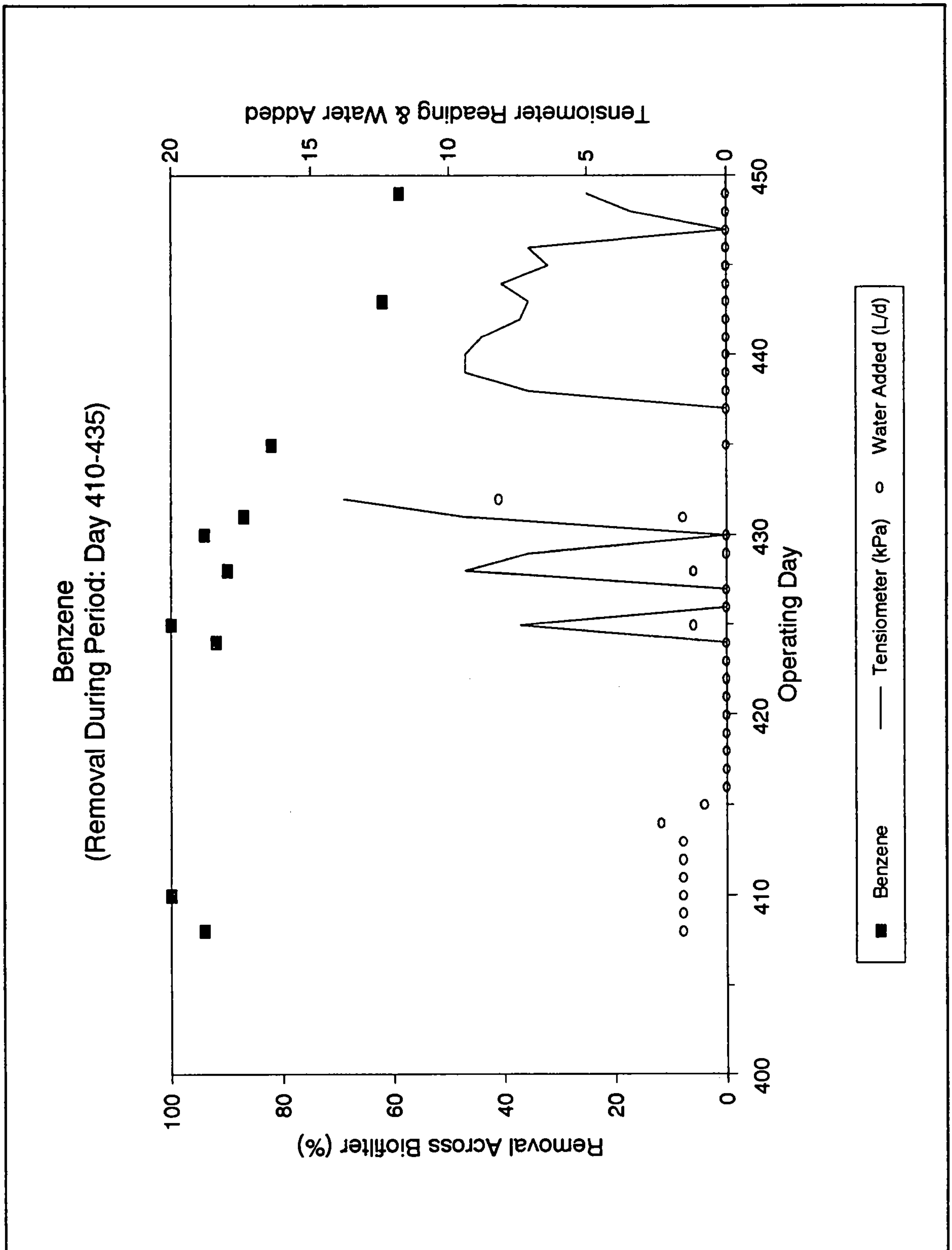
Removal Across Biofilter: Day 194 to 235 (Supplemental Water Addition) - m/p-Xylene



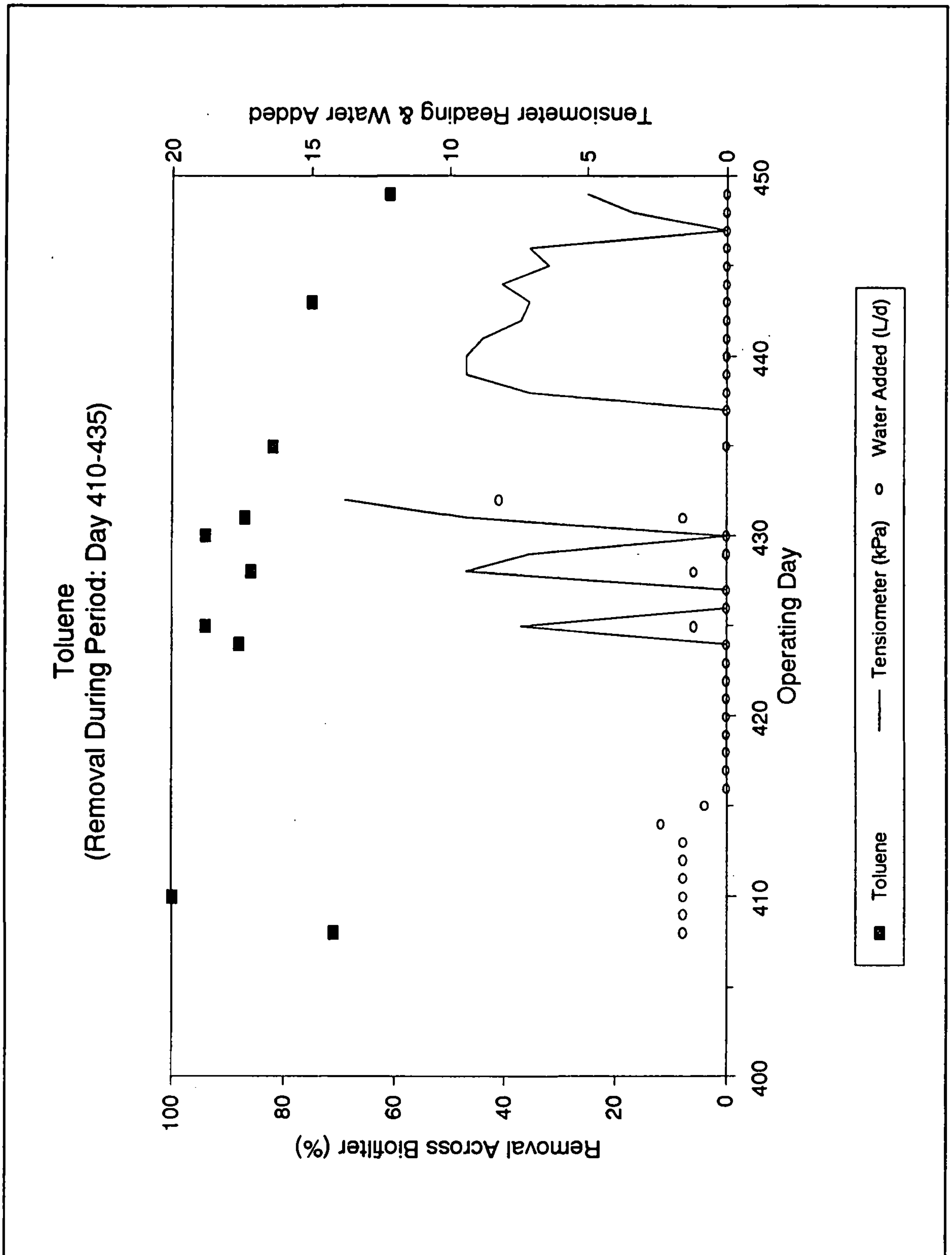
Removal Across Biofilter: Day 194 to 235 (Supplemental Water Addition) - o-Xylene

Appendix F

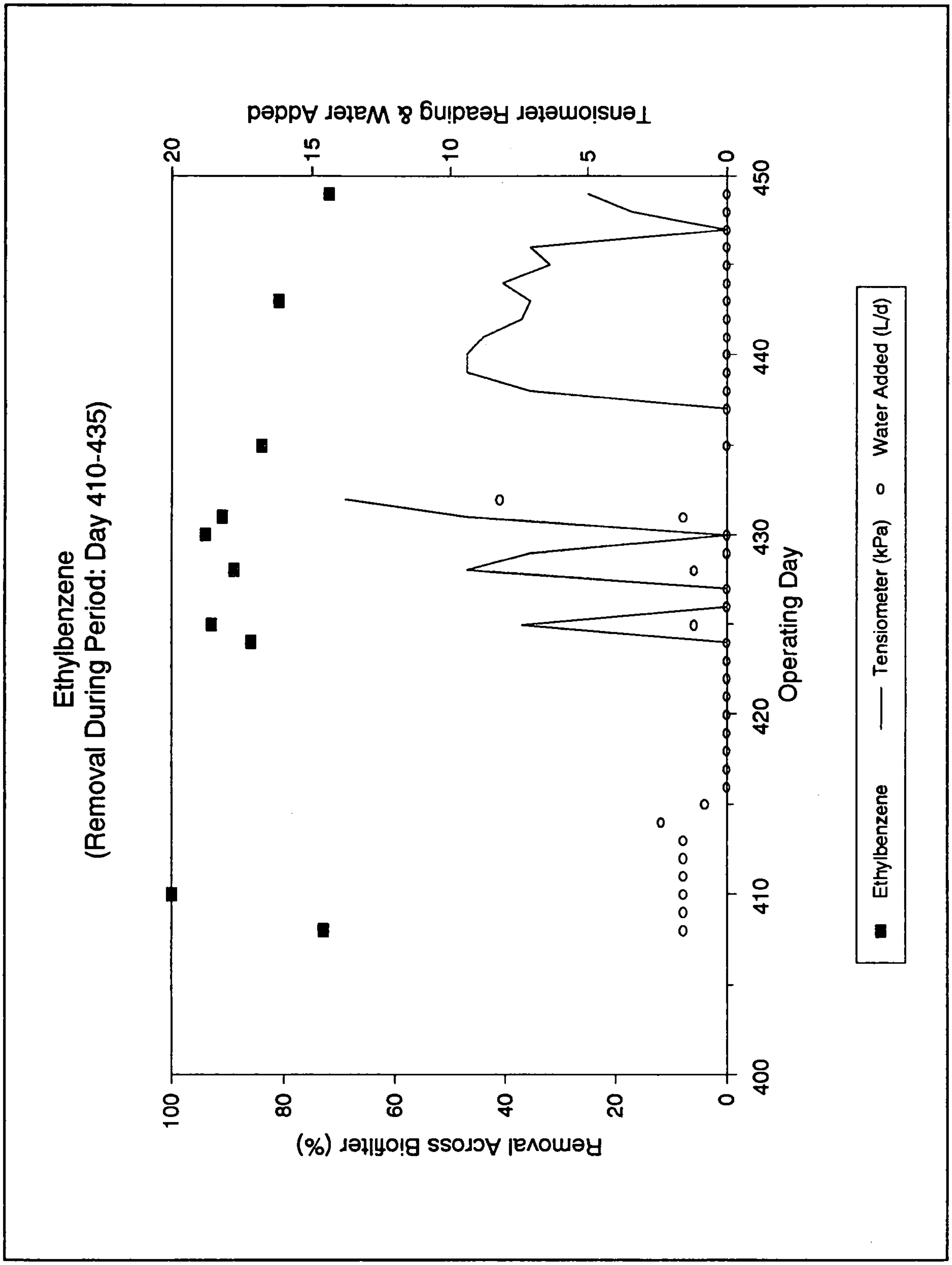
Media Moisture Control - Day 410 to 435



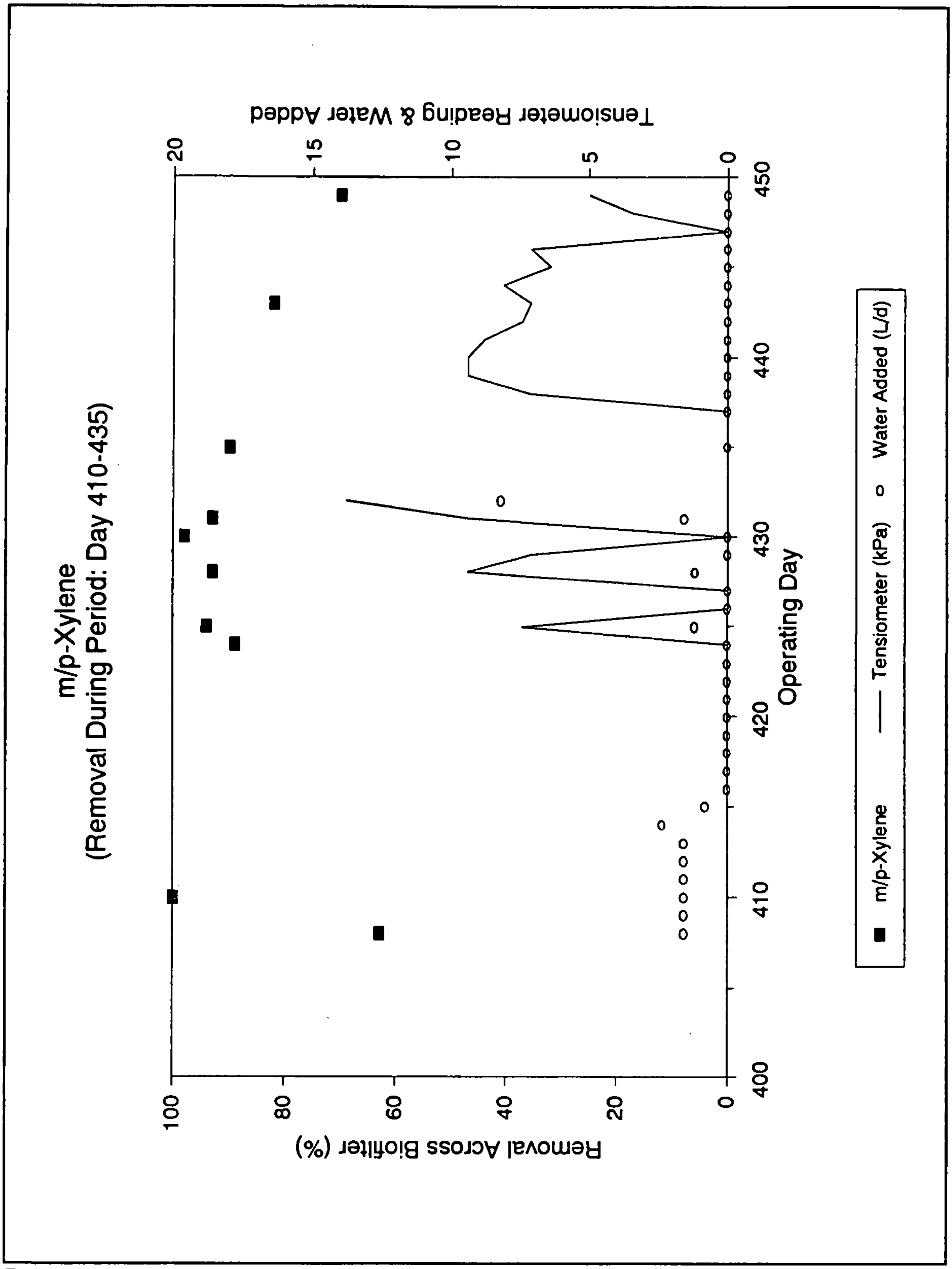
Removal Across Biofilter: Day 410 to 435 - Benzene



Removal Across Biofilter: Day 410 to 435 - Toluene



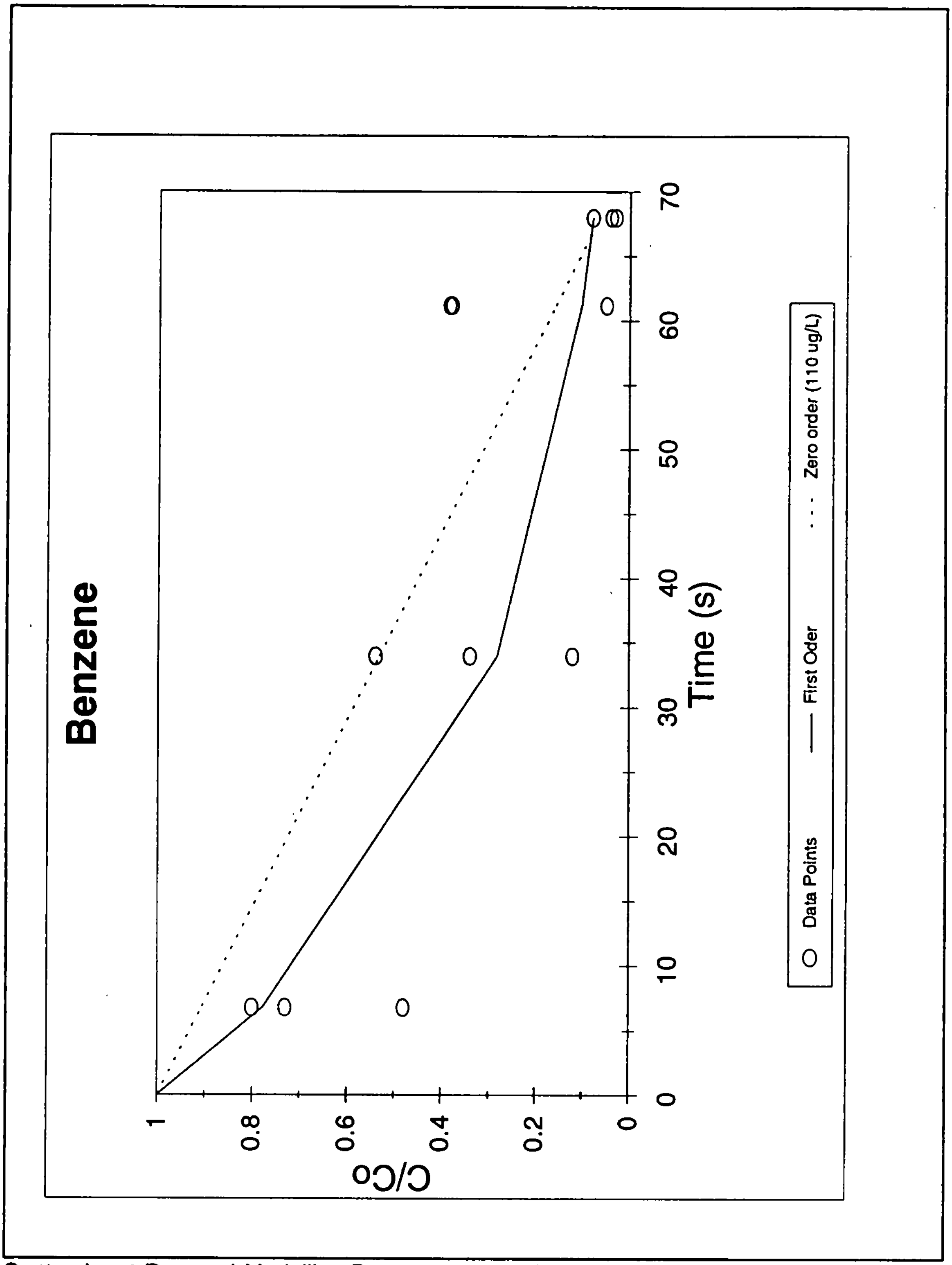
Removal Across Biofilter: Day 410 to 435 - Ethylbenzene



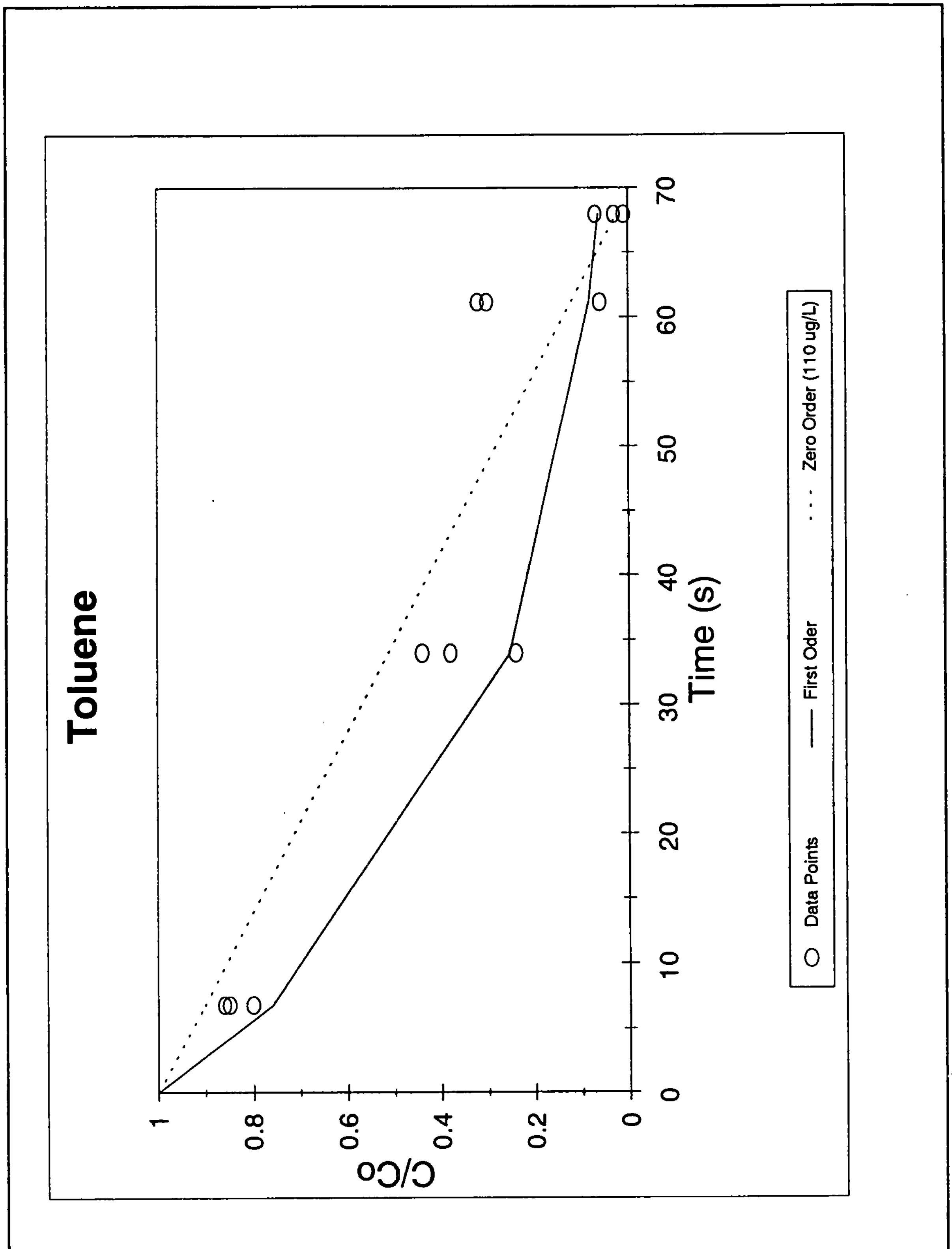
Removal Across Biofilter: Day 410 to 435 - m/p-Xylene

Appendix G

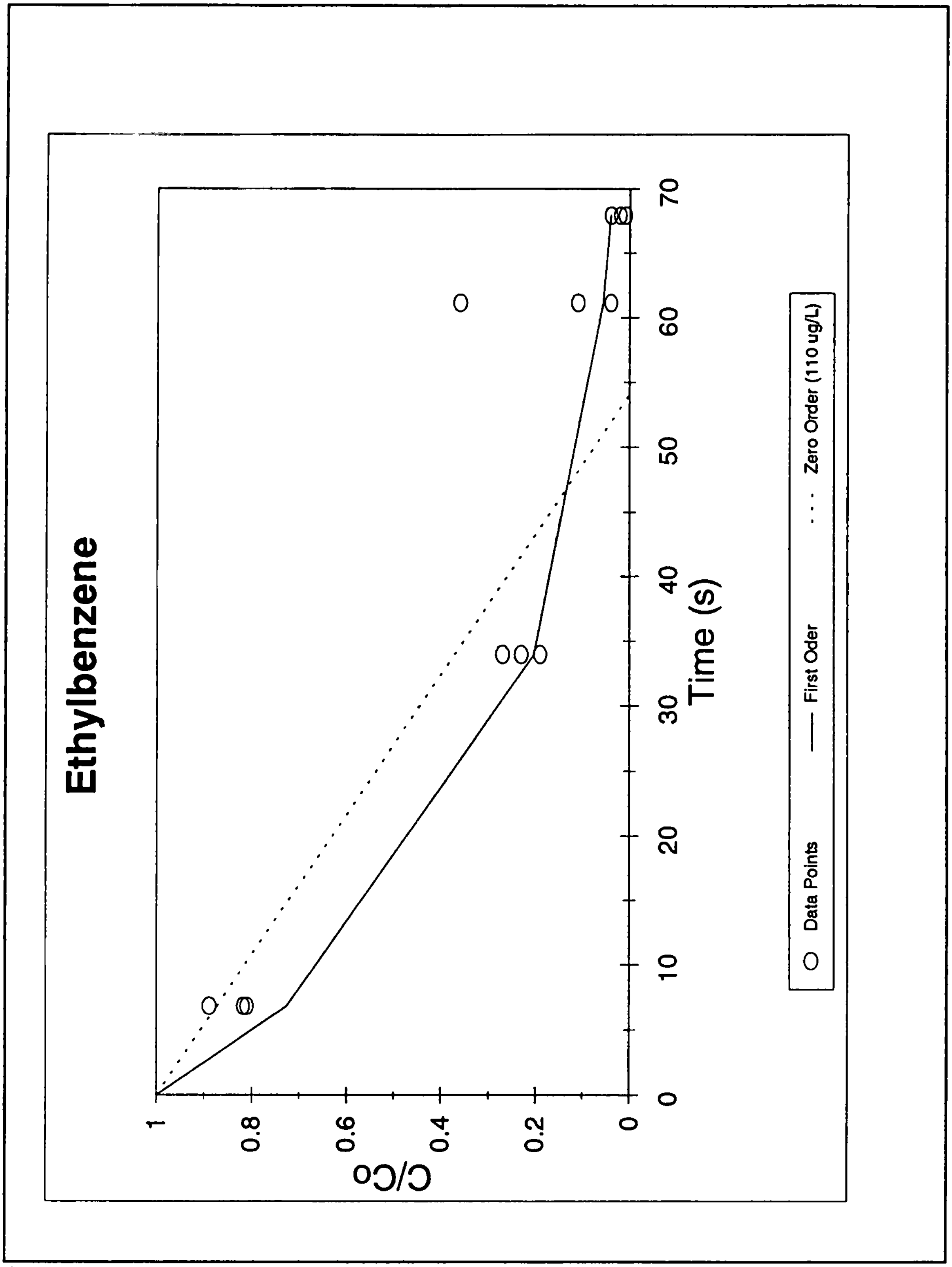
Biofilter Modelling - Day 194 to 235



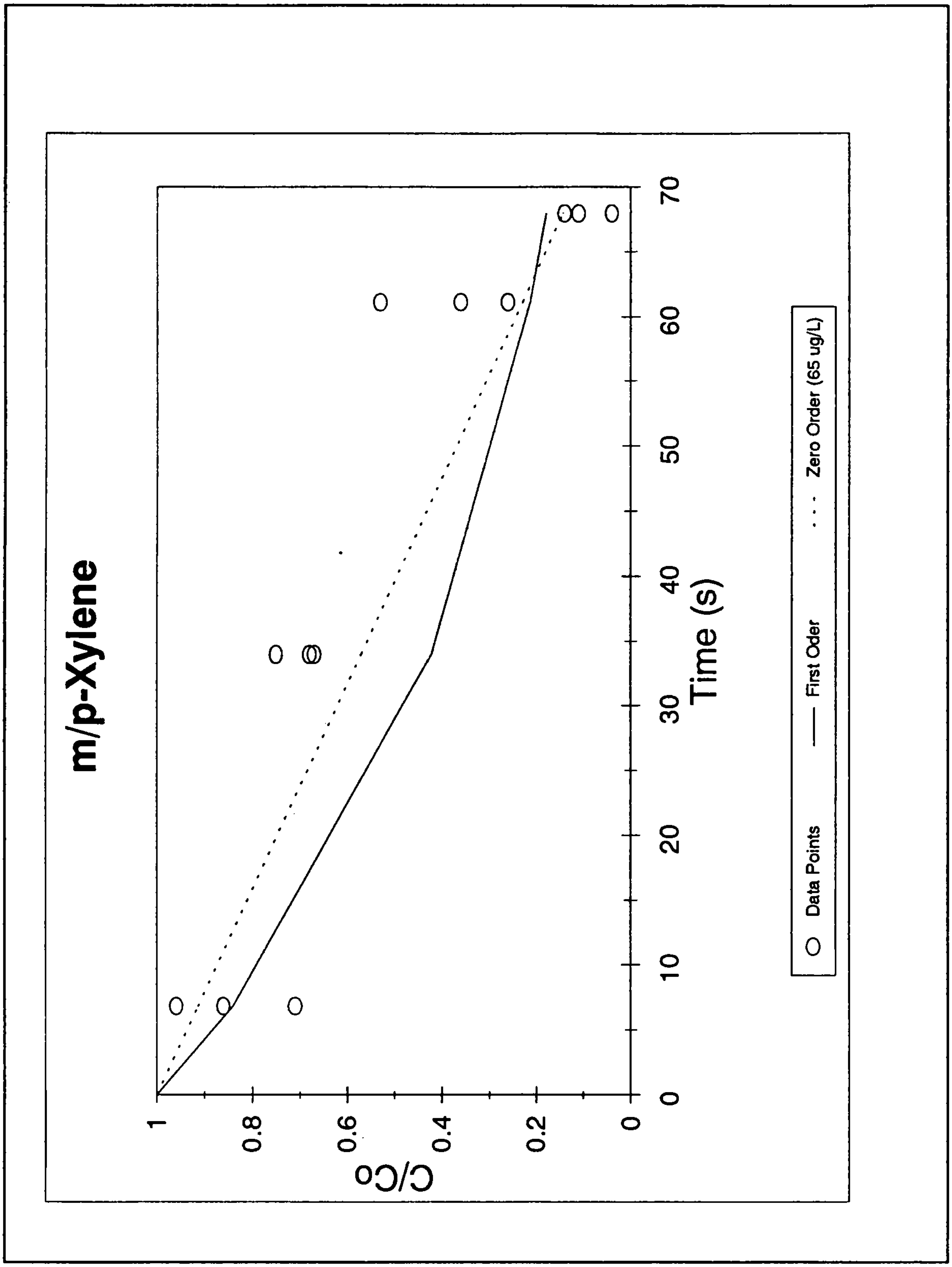
Contaminant Removal Modelling Day 194 to 235 - Benzene



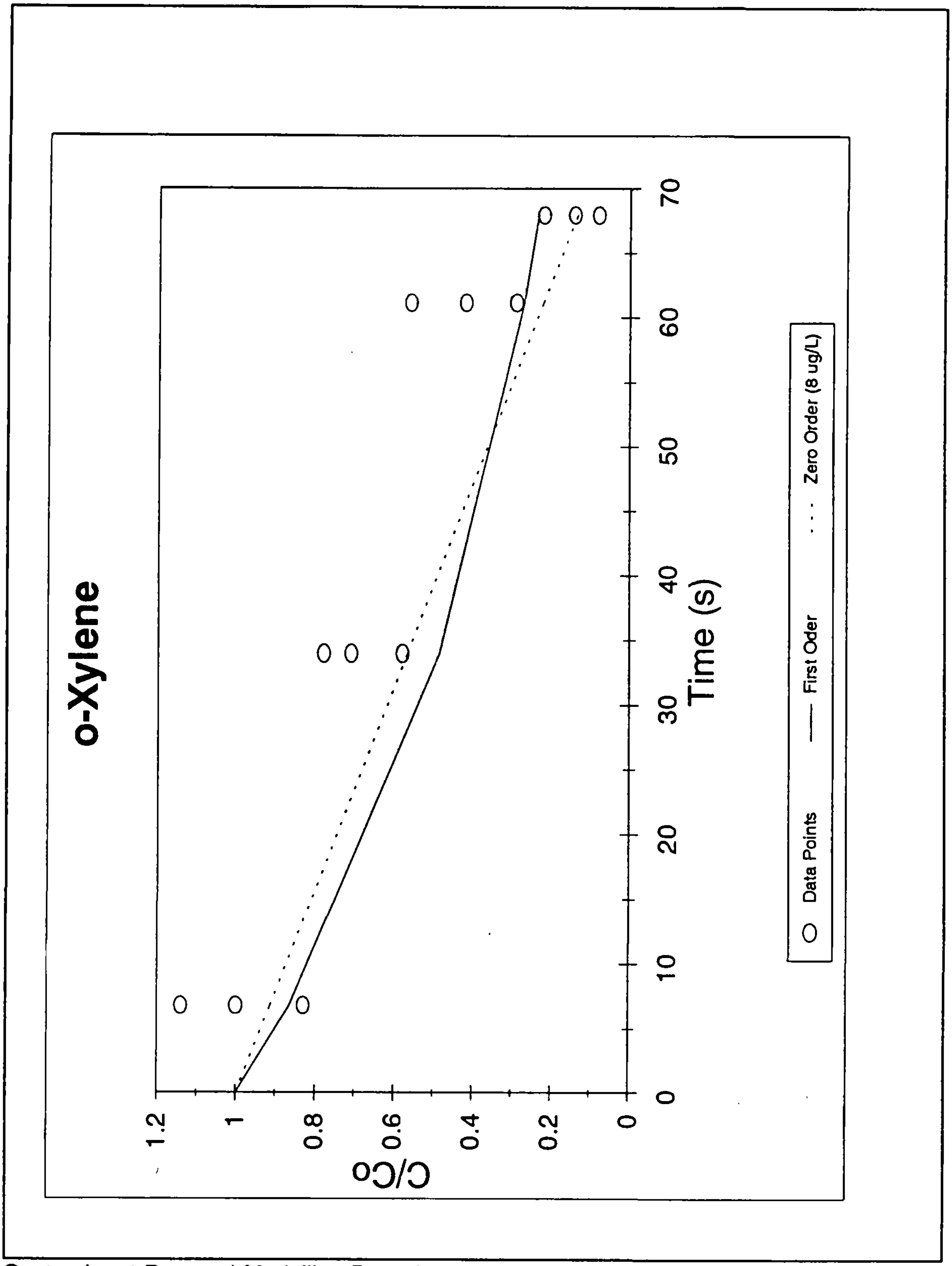
Contaminant Removal Modelling Day 194 to 235 - Toluene



Contaminant Removal Modelling Day 194 to 235 - Ethylbenzene



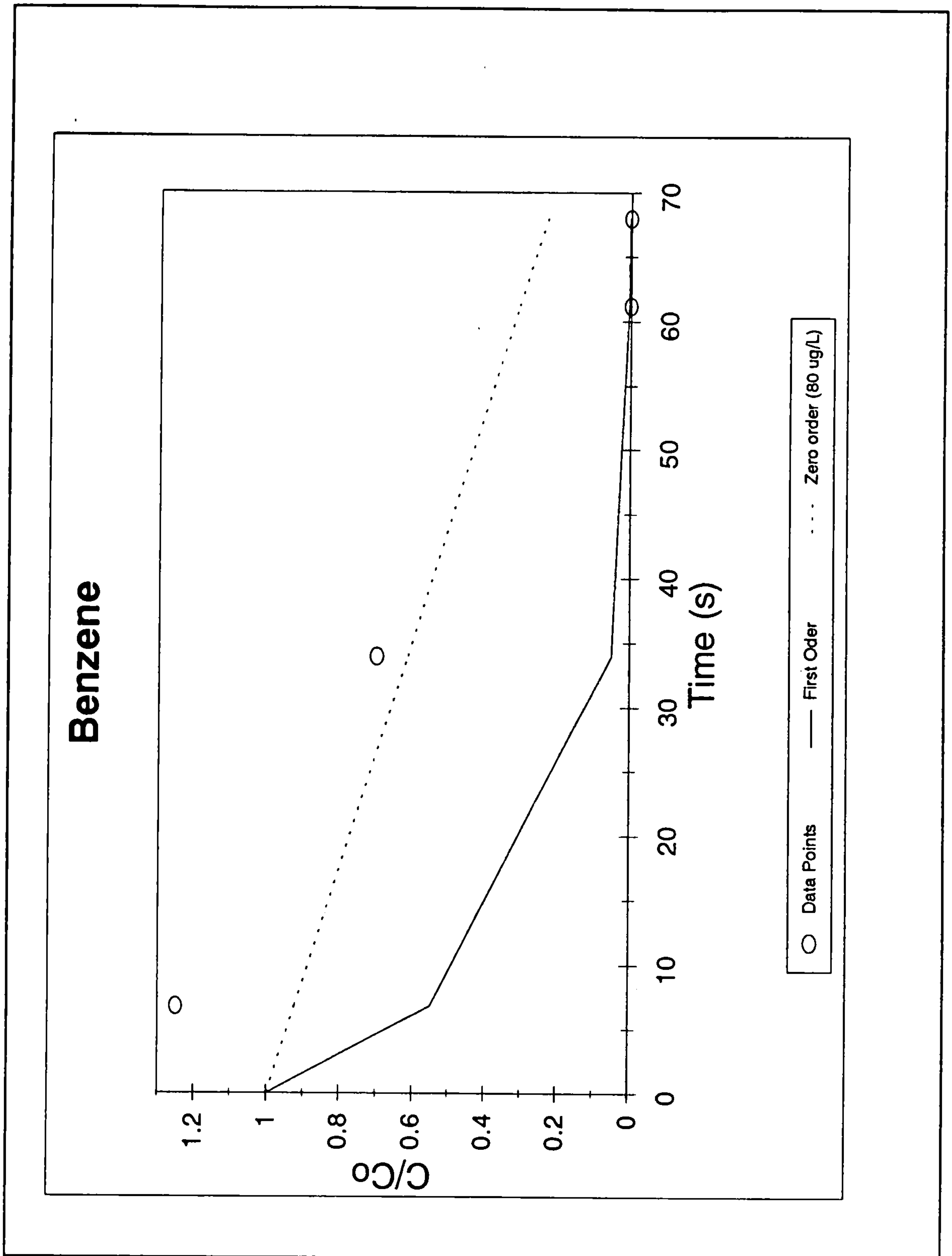
Contaminant Removal Modelling Day 194 to 235 - m/p-Xylene



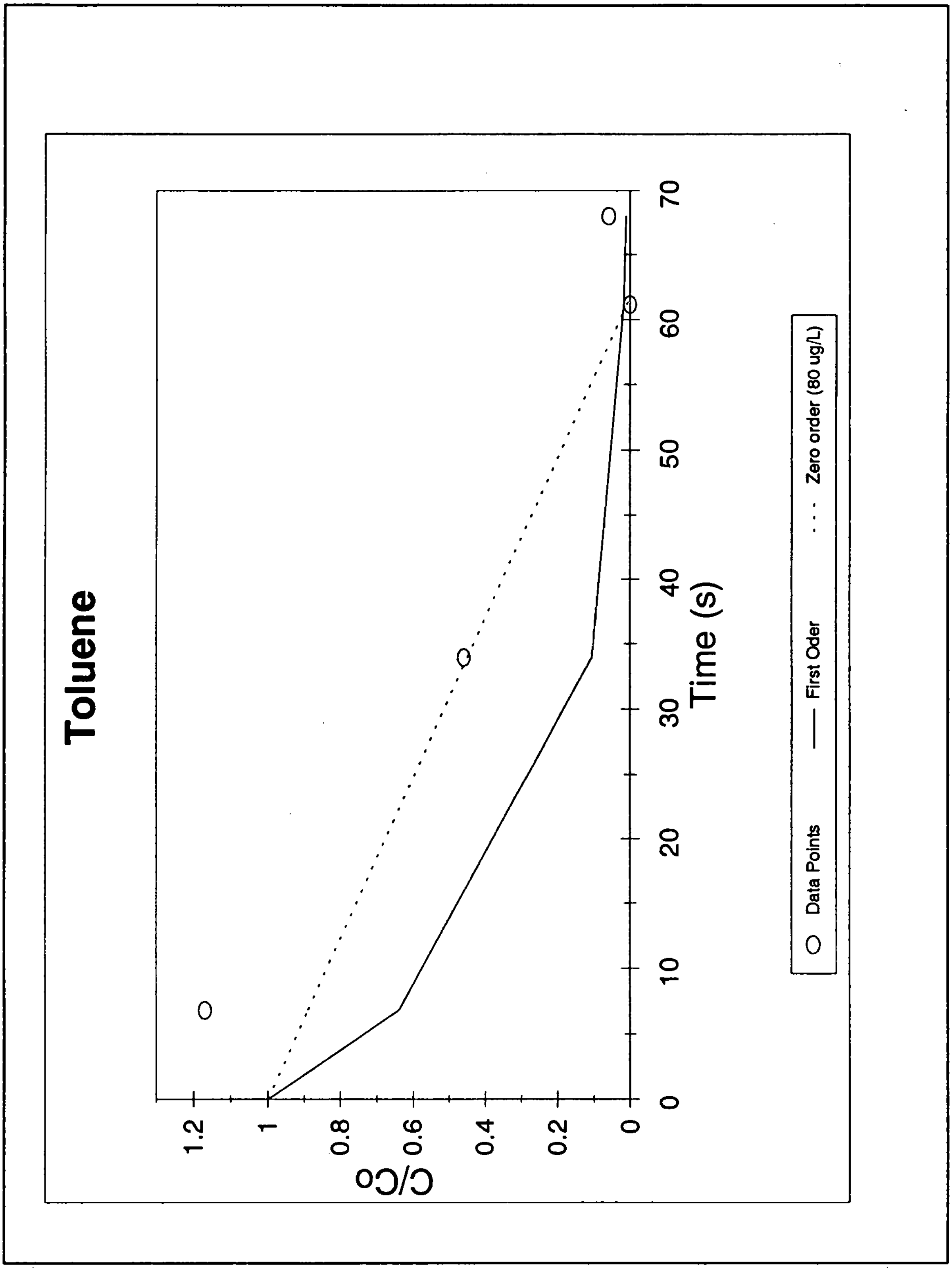
Contaminant Removal Modelling Day 194 to 235 - o-Xylene

Appendix H

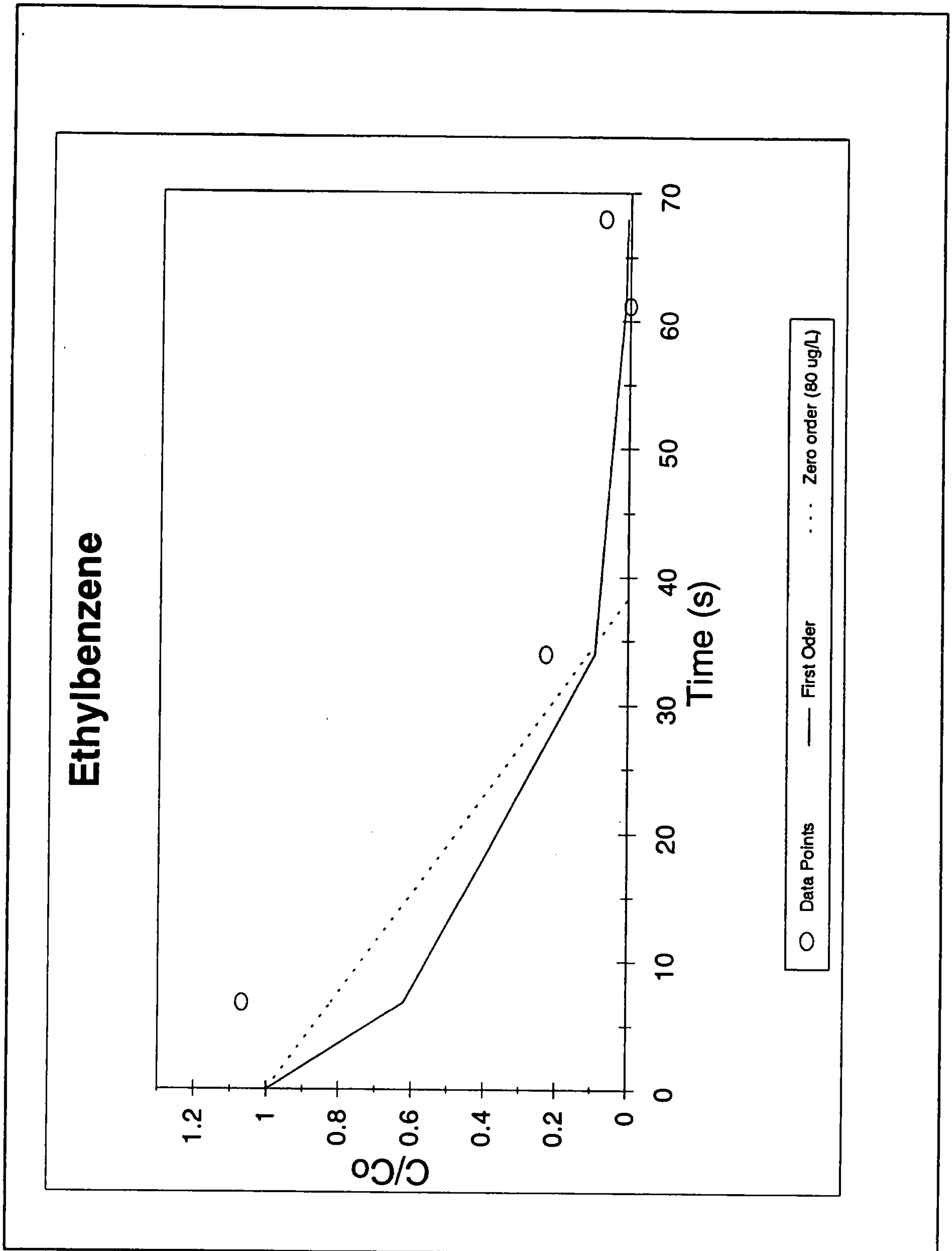
Biofilter Modelling - Day 410 to 435



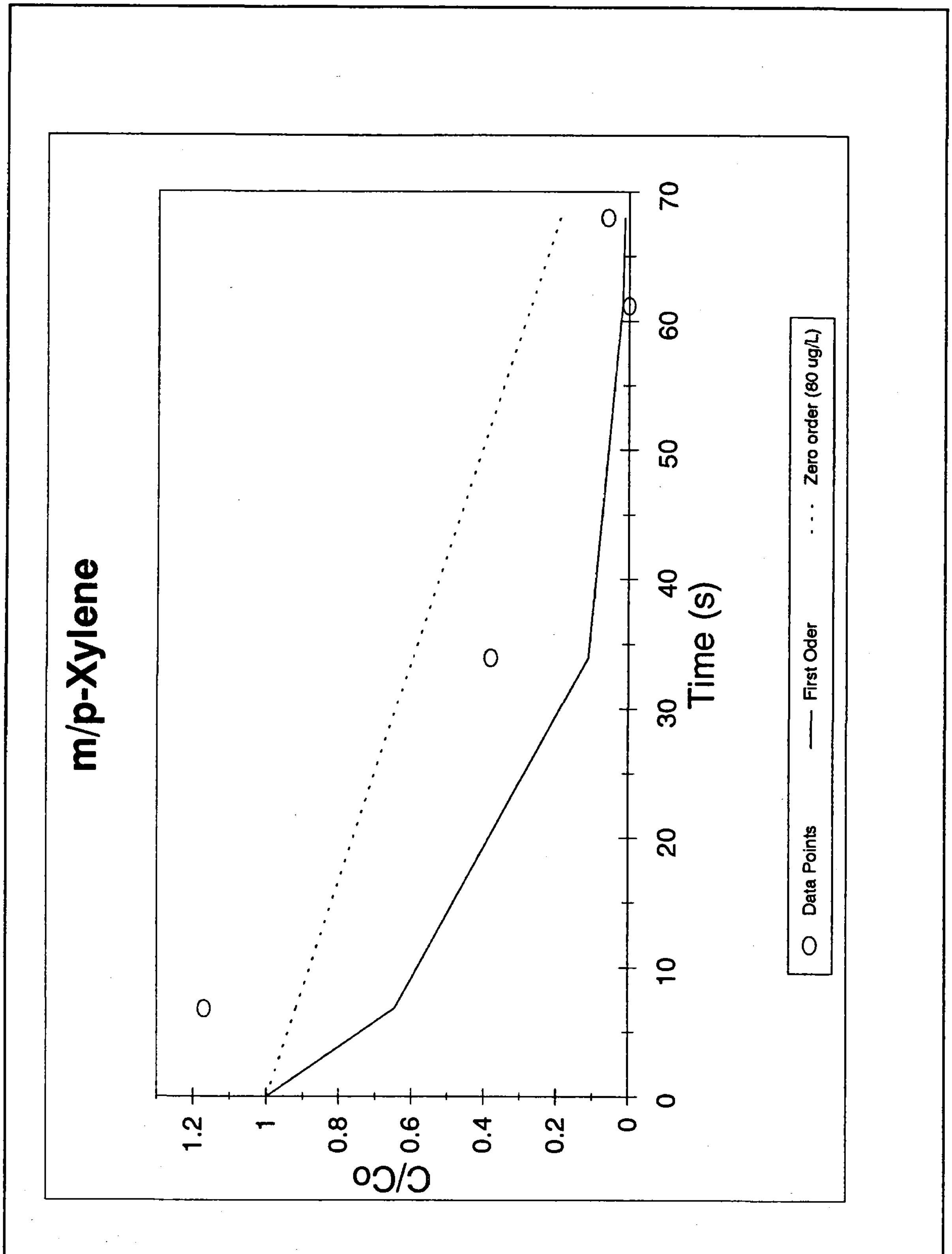
Contaminant Removal Modelling Day 410 to 435 - Benzene



Contaminant Removal Modelling Day 410 to 435 - Toluene



Contaminant Removal Modelling Day 410 to 435 - Ethylbenzene



Contaminant Removal Modelling Day 410 to 435 - m/p-Xylene