

# DESIGN AND PERFORMANCE EVALUATION OF VAPOR-PHASE BIOFILTERS

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**ABSTRACT:** Several past studies have indicated that off-gases resulting from soil and groundwater remedial operations can be treated economically by using biofilters to reduce air pollution. The efficiency of a biofilter depends on several factors such as: vapor retention time, uniformity of vapor flow, composition of the filter, type of microorganisms available for biodegradation, moisture content, and temperature. This paper presents the results of bench scale tests performed on two biofilters at room temperature to evaluate their performance at different gas flow rates and gasoline contaminant concentrations. Based on the test results it was possible to identify some of the key parameters affecting the design and operation of biofilters and to develop rational procedures for the application of biofilters to the treatment of gasoline vapors.

## INTRODUCTION

Biofiltration is the process in which an air stream containing volatile organic chemicals (VOCs) is passed through a biologically active medium. The contaminants are transferred from the air phase to the water/biofilm phase, where they are biologically degraded by microorganisms to less harmful substances, usually to carbon dioxide and water (Shareefdeen et al., 1993). Biofiltration has been identified as an economical and efficient method for treating VOCs present in air streams at low concentrations. An excellent review of the various aspects of biofiltration was presented by Wani et al. (1997).

The motivation for research on biofilters at O'Connor Associates Environmental Inc. (OAEI) was mainly due to the simplicity and economy involved in the biofiltration of VOCs at low concentrations resulting from long-term vapor extraction of contaminated soils. The purpose of the study was to identify some of the key parameters affecting the design and operation of biofilters and to develop rational procedures for the application of biofilters to treatment of the VOCs resulting from vapor extraction of gasoline contaminants from soils. The evaluations and conclusions presented here were based on the research data collected during the summer and fall of 1996 and during the years 1997 and 1998.

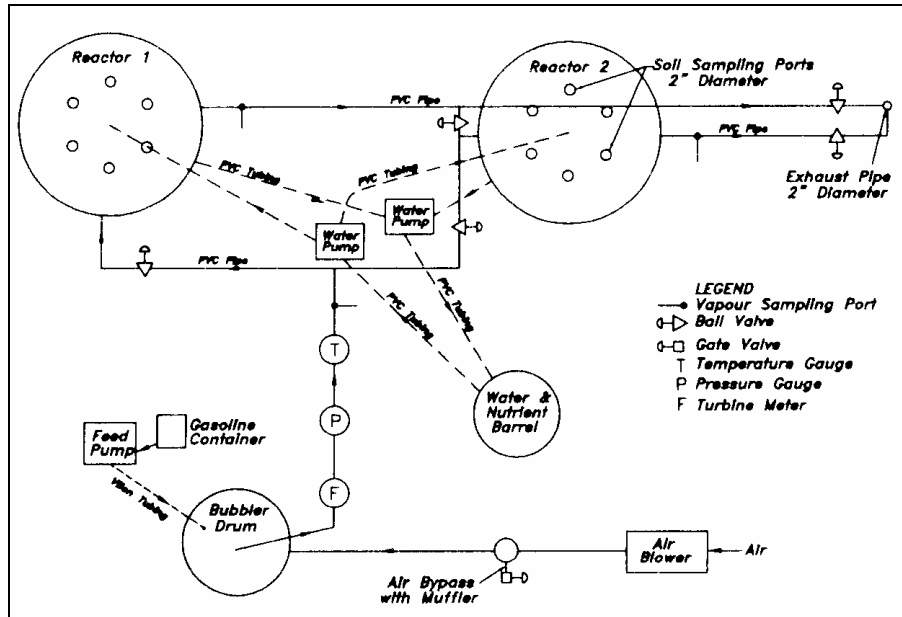
## MATERIALS AND METHODS

Initially, biofiltration experiments were conducted in 1996 by modifying a low profile air stripper made up of a rectangular water storage tank at the bottom, three rectangular stacked trays with perforated bases, and a top cover. The trays were filled with 1 m<sup>3</sup> of biofilter material. Air mixed with gasoline vapors was bubbled through the water in the storage tank. The contaminated moist air entered at the base of the bottom tray and passed upward through the three trays. Experiments carried out at

various flow rates and vapor concentrations indicated that the contaminant removal efficiency of the biofilter was significantly lowered due to non-uniform airflow caused by flow channels and short-circuiting. The removal efficiency of the biofilter during operation is calculated using

$$E_o = 100(C_i - C_o) / C_i \quad (1)$$

where  $E_o$  is the biofilter efficiency during operation in %,  $C_i$  and  $C_o$  are the contaminant concentrations of inflow and outflow gas in ppm respectively.



**Figure 1. Schematic of Biofilter Experiment Setup**

Because of the low efficiencies obtained in the earlier experiments, the experimental set up was modified to that shown in Figure 1. Two biofilter reactors were constructed using plastic drums; each was 0.79 m in diameter and 1.12 m in height. Tables 1 and 2 summarize respectively the composition and the properties of the biofilter material used in the experiments. The spent

**Table 1. Composition and Cost of Biofilter Material**

Material	% by Volume
Peat moss	18.0
Vermiculite	7.5
Lime stone	2.0
Pine bark	20.0
Organic compost	30.0
Spent activated carbon	15.0
Bacteria triggering mechanism (BTM)	2.0 L/m <sup>3</sup> of filter
Humic acid	0.5 L/m <sup>3</sup> of filter
KNO <sub>3</sub>	90 g/m <sup>3</sup> of filter

activated carbon was previously exposed to gasoline vapors. The unit cost of the

biofilter material was about \$100 (Canadian) per cubic meter. Biofilter material was placed in each reactor to a thickness of 0.76 m and was supported by a deck built at a height of 0.15 m above the base. A water sprinkler was installed at the top of each reactor to add water and nutrients when necessary.

Six ports were installed on the top of each reactor for measuring vapour concentration and sampling. As shown in Figure 1, the biofilter reactors could be connected either in series or in parallel configuration. A 1-h.p. blower was used to supply air to the biofilters. Air was bubbled through water in a plastic drum to which fresh unleaded gasoline was added using a chemical feed pump. The supply of humidified gasoline vapors to the biofilters prevented loss of moisture in the filters and helped in maintaining high relative humidities (95 to 98%) in the exhaust vapors. Typically, each test would last between 60 to 90 min.

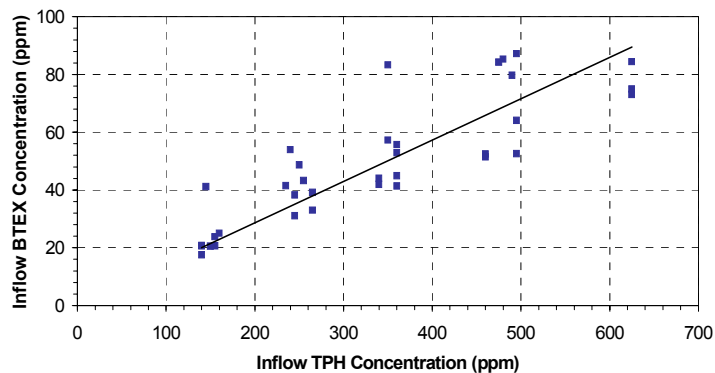
Vapor inflow and outflow rates were determined by measuring velocities using an anemometer and by metering airflow through a turbine meter. Vapor concentrations were measured using a gas detection meter (GasTech Model 1238ME). Also vapor bag samples were collected and analysed for BTEX using a HNU Model 311 portable gas chromatography (GC) system. BTEX is the group of aromatic hydrocarbons including benzene, toluene, ethylbenzene and xylene. All experiments were conducted at ambient air temperatures ranging between 20°C and 24°C. For the biofilter material, total and hydrocarbon-degrading micro-organisms counts, pH, organic carbon content, and nitrate concentration were also measured. An increase in plate count of total microorganisms from  $3.2 \times 10^8$  to  $1.8 \times 10^9$  CFU/g was observed to occur in about two months.

The hydrocarbon-degrading microorganisms count was  $1.0 \times 10^8$  CFU/g. The pH of the filter medium varied between 6.5 and 7.5. The organic carbon content varied between 23 and 33%. Nitrate concentrations were between 100 and 170 ppm.

The relationship between the inflow gasoline vapor concentrations as measured by the gas detector and the BTEX

**Table 2. Properties of Biofilters in Reactors**

Final volume per reactor	0.37 m <sup>3</sup> (13.1 ft <sup>3</sup> )
Porosity	0.63
Gravimetric water content	133.2%
Volumetric water content	45.2%
Air porosity	0.173
Air pore volume per reactor	0.064 m <sup>3</sup> (2.265 ft <sup>3</sup> )

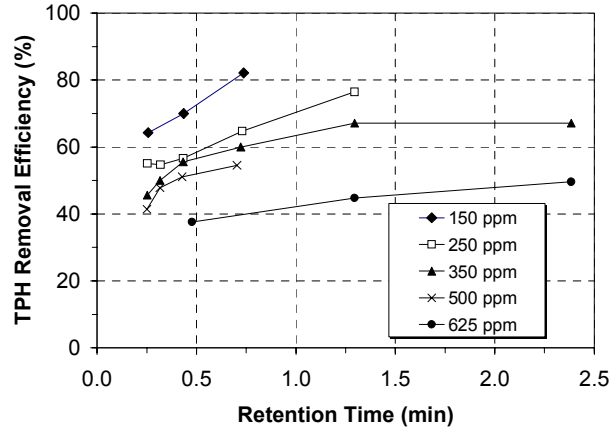


**Figure 2. Inflow BTEX Versus TPH Concentrations**

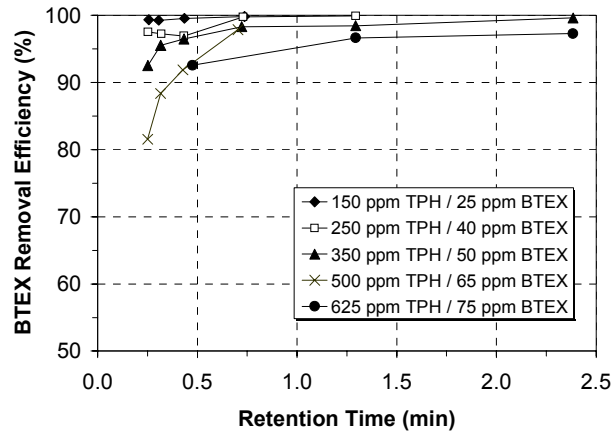
concentrations as determined by GC analyses is presented in Figure 2. For the experiments reported in this paper, unleaded gasoline was used. The averaged BTEX concentrations were between 12% and 17% of the total petroleum hydrocarbon (TPH) concentration. The percentage of BTEX concentration was slightly higher at low inflow concentrations.

Figure 3 presents the TPH removal efficiency versus vapor retention time when the two reactors were connected in series. It is apparent that the removal efficiency is increased with longer retention time and lower inflow vapor concentration. Figure 4 shows the total BTEX removal efficiency versus vapor retention time when the reactors were connected in series. Significantly higher removal efficiencies were achieved for BTEX than for total hydrocarbons. The BTEX removal efficiencies also increased with longer retention time and lower inflow concentrations.

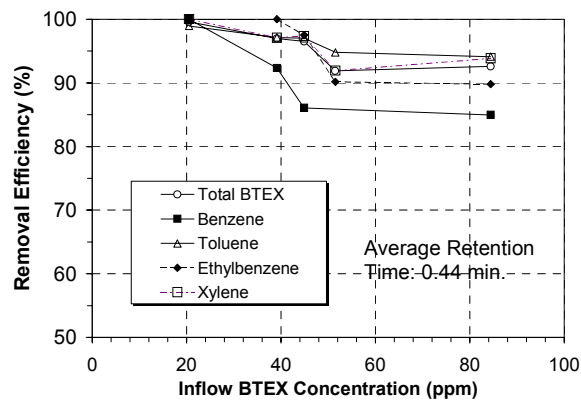
Figure 5 presents the efficiency in the removal of individual components of BTEX, namely benzene, toluene, ethylbenzene and xylenes versus the inflow total BTEX concentration. The removal efficiencies for benzene were slightly



**Figure 3. TPH Removal Efficiency Versus Retention Time, Reactors in Series**



**Figure 4. BTEX Removal Efficiency Versus Retention Time**

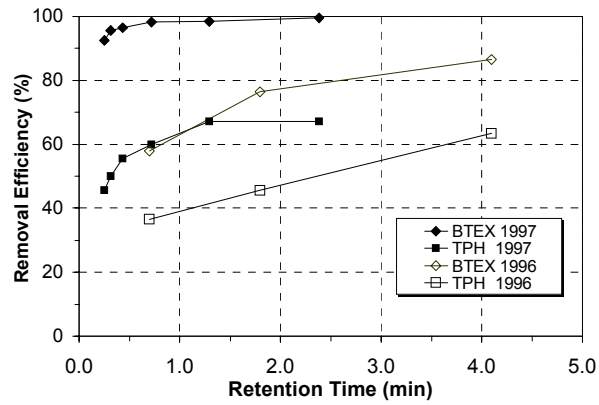


**Figure 5. Removal Efficiency Versus Inflow BTEX Concentration**

lower than the other aromatic hydrocarbons.

The performance of the individual biofilters (Reactors 1 and 2) was also studied by connecting the reactors in parallel. Trends in the variation of the removal efficiencies with retention time and vapor concentration were similar to those described for the experiments conducted in series.

Figure 6 compares the removal efficiencies of experiments conducted in 1996 to those from experiments conducted in 1997/98. In 1996, the reactor used was made up of stacked rectangular trays, while cylindrical drums were used in 1997/98. The efficiencies were compared for experiments conducted at an inflow total hydrocarbon concentration of 350 ppm and an inflow BTEX concentration of 50 ppm. A significant improvement in efficiencies was noted in the 1997/98 experiments because of the improved uniformity in vapor flow conditions achieved in the cylindrical drum type reactors. Figure 6 clearly demonstrates the importance of the uniformity of vapor flow through biofilters in achieving higher efficiencies.



**Figure 6. Effect of Non-Uniformity in Vapor Flow on Biofilter Efficiency**

### BIOFILTER DESIGN

The required or targeted efficiency of a biofilter in the removal of a given contaminant by degradation may be expressed as:

$$E_t = 100 \left[ 1 - \frac{694.4M}{mC_iQ} \right] \quad (2)$$

where  $E_t$  is the targeted biofilter efficiency in %,  $M$  is the permissible mass output of the contaminant into atmosphere in kg/day,  $m$  is the conversion factor from ppm to mg/m<sup>3</sup> (for benzene = 3.24 at 20°C),  $C_i$  is the contaminant concentration of inflow gas in ppm, and  $Q$  is the gas flow rate through the biofilter in m<sup>3</sup>/min.

The required biofilter volume is calculated from

$$v = Qt / n_a \quad (3)$$

where  $v$  is the volume of biofilter,  $t$  is the retention time and  $n_a$  is the air porosity of biofilter.

The targeted biofilter efficiency is obtained from Equation 2. A suitable retention time for the biofilter to achieve the required efficiency is chosen and the volume of biofilter is determined from Equation 3. Selection of the retention time based on inflow concentration may be made from the data presented in this paper for gasoline vapors. The performance of the biofilter is considered satisfactory if the operating efficiency obtained from Equation 3 is maintained above the targeted efficiency.

Removal efficiencies may fall temporarily below the targeted value due to biofilter properties, operational and climatic factors. These factors include the drying of the bio-filter, break through caused by surges of inflow rate and/or inflow concentration, development of non-uniform flow caused by air channels and short-circuiting in the biofilter, aging of the biofilter due to biomass development, and reduction in biofilter temperature due to cold weather. Table 3 presents the desirable range for the various parameters necessary for the successful operation of biofilters for treating gasoline vapors. This table is compiled using data collected from the tests discussed in this paper as well as from the literature. In addition to these parameters, proper maintenance of biofilters is highly important to ensure their successful operation at desired efficiencies.

**Table 3. Biofilter Design and Operation Parameters**

Inflow vapor concentration	< 500 ppm
Retention time	0.5 – 2.0 min.
Empty bed contact time	2.5 - 10.0 min.
Air pore volume of biofilter	15 – 30 %
Gravimetric moisture content (by dry weight)	110 – 140 %
Porosity of filter	60 – 70 %
Organic carbon content	20 – 30 %
Nutrients in water phase	100 – 200 ppm
Oxygen in outflow vapors	> 20 %
pH value	6.5 – 7.5
Temperature of filter	15 – 30 °C
Relative humidity of inflow vapor	95 – 98 %

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- Shareefdeen, Z., B.C. Baltzis, Y.S. Oh, and R. Bartha . 1993. "Biofiltration of Methanol Vapor." *Biotechnology and Bioengineering*, 41(5): 512-524.
- Wani, A.H., R.M.R. Branion, and A.K. Lau. 1997. "Biofiltration: A Promising and Cost-Effective Control Technology for Odors, VOCs and Air Toxics." *J. Environ. Sci. Health*, A32(7): 2027-2055.