

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
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TECHNICAL MEMORANDUM

**ESTIMATED COST ASSOCIATED WITH BIODEGRADATION OF
METHYL TERTIARY-BUTYL ETHER (MTBE)**

by
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PURPOSE

The purpose of this study was to estimate the cost of biological treatment of water and air contaminated with methyl tertiary butyl ether (MTBE).

BIODEGRADABILITY OF MTBE

Early reports on MTBE contamination in groundwaters often stated or strongly suggested that the compound was either non-biodegradable or very recalcitrant with respect to biodegradation. However, a substantial record of biodegradation in both laboratory and full scale treatment operations has now been accumulated and the following statements can be made.

- MTBE can be degraded by a number of bacterial groups. At least a few bacterial species are able to use MTBE as a growth substrate and mineralized the compound.
- Development of MTBE degrading cultures in unacclimated systems is very slow.
- Acclimated cultures can be used to inoculate treatment systems and inoculated processes have start-up times similar to processes treating more conventional substrates.
- Successful biodegradation of MTBE has been observed in at least two field biofilter installations. One is located at the Joint Water Pollution Control Plant of the Los Angeles County Sanitation Districts and the other is operated by Environmental Resolutions, Inc. at a gasoline soil vapor extraction site in Richmond, California.
- Liquid phase biological treatment in which MTBE was mineralized has been demonstrated at laboratory scale at both Rutgers University and The University of California, Davis.
- Characterization of the MTBE mineralizing cultures is not complete. Two bacterial isolates, PM1 and YM1, capable of growing on MTBE have been obtained from the UC Davis culture by Professor Kate Scow and her students. Examination of whole cell lipid profiles for PM1 and YM1 suggest they are not identical strains. Thermal gradient gel electrophoresis (TGGE) analysis of 16S rRNA gene fragments from the two strains, however, indicates no difference between them. 16S rDNA sequence analysis of strains PM1 and YM1 reveal that they are both most closely related to the

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genus *Sphingomonas*. Fingerprinting methods that analyze cell components (e.g. phospholipids, DNA) extracted directly from mixed cultures and environmental samples can provide insight into the composition and stability of microbial communities that degrade MTBE. Analysis of DNA by TGGE indicated that the two bacterial isolates described above are members, but do not appear to be the most dominant members of the MTBE-grown microbial consortium. An additional unidentified band was particularly dominant when the consortium was cultured on MTBE. This band is currently being sequenced.

Biological treatment of water contaminated with MTBE concentrations of up to several hundred mg/L has been accomplished using mixed microbial cultures by Park and Cowan (1997) and Fan (1998). Reliable and effective biodegradation of MTBE in the air phase has been demonstrated to be possible under laboratory conditions using a pilot scale biofilter (Eweis, 1998). Biodegradation of MTBE has been observed to occur in a full scale biofilter operating at a gasoline soil vapor extraction site in Richmond California (Romstad et al., 1998) and in a pilot scale biofilter operating at the Los Angeles County Sanitation Districts Joint Water Pollution Control Plant in Carson, California (Eweis et al., 1997).

Sufficient data is available from the literature to design a full scale vapor phase biofilter for treatment of MTBE. Such systems can be used for treatment of air from water stripping units or for treatment of soil vapor extraction off-gas.

Based on experience with vapor phase biofiltration and after considering the expected groundwater concentrations in aquifers and the required product water concentrations, a biofilm reactor was considered an appropriate method of treating water contaminated with MTBE. Literature citations on liquid phase biofilm processes for biodegradation of MTBE were not found and a laboratory scale system was operated to develop the necessary data for scale-up. Description of the laboratory system is provided below.

FLOW SCENARIOS

Flow scenarios for contaminated water were chosen to represent a wide range of possible applications. Low flows with high MTBE concentrations result from treatment of groundwater around leaking underground fuel tanks and high flows with low MTBE concentrations are expected to be associated with municipalities cleaning drinking water supplies. The flow scenarios used are given in Table 1.

Table 1 Flow scenarios

Flow gpm	MTBE concentration ppb _w			
10	100	500	1000	5000
100	100	500	1000	5000
1000	100			
5000	100			

Contaminated air flows are expected to be generated if water contaminated with MTBE is treated by air stripping. Based on current estimates (Malcolm Pirnie, et al., 1998) air to water ratios of 200:1 will be required to remove MTBE. For the selected range of water flow rates the corresponding air flow rates were generated on this basis.

EXPERIMENTAL PROGRAM

A pilot scale trickling filter was constructed using granular activated carbon as the filter media and inoculated with a microbial culture known to degrade MTBE. The volume of the experimental trickling filter media was 1 liter and the dimensions were 7.6 cm in diameter and 22 cm deep. Initially, the trickling filter was sprayed with tap water contaminated with MTBE and nutrients in a batch flow scheme, where the effluent was recycled, until a biological film spread throughout the trickling filter. When a biofilm was fully developed the flow scheme was changed from batch flow to continuous flow. Nutrients were not added to the feed tank after the flow scheme was changed. Because the depth of the media was insufficient to lower the initial influent MTBE concentration of 1000 ppb_w to 5 ppb_w in one pass, the trickling filter was operated in stages until the desired effluent concentration was reached. Flow to the trickling filter was 0.1 liters per minute, which corresponds to a hydraulic loading rate of 0.54 gal/min • ft², and the influent MTBE concentration was 1000 ppb_w until the MTBE removal reached steady state. After the removal reached steady state the trickling filter was operated for an additional period and an average percent removal was determined. The trickling filter was then operated at the same flow rate of 0.1 liters per minute and an influent MTBE concentration equal to the effluent MTBE concentration from the first experiment. After the trickling filter again reached steady state, an average second stage percent removal was determined. The procedure was repeated until the effluent MTBE concentration reached 5 ppb_w.

The loading rate-removal relationships developed in these experiments were scaled up to allow estimation of the cost for full scale implementation.

Analytical Methods

Liquid MTBE concentrations were determined by sample head space analysis using a Shimadzu 14A gas chromatograph equipped with a 0.5 ml gas sample loop and a flame ionization detector.

Experimental Results

The trickling filter operated with recycling flow for two months before a noticeable biofilm was observed on the granular activate carbon (GAC). After two additional months the biofilm had visibly spread throughout the filter media. A few pieces of GAC were placed in a 250 ml bottle with 15 ml of MTBE contaminated water and nutrients. Headspace analysis performed over 14 days confirmed the biofilm attached to the GAC degraded MTBE.

The trickling filter was converted to continuous flow and operated for 2.5 months at a flow rate of approximately 0.1 liters per minute. An attempt was made to maintain an influent MTBE concentration of 1000 ppb_w. However MTBE loses in the storage tank occurred due to microbial activity and volatilization. Samples collected for analysis were collected at the spray nozzle and at the bottom of the trickling filter. The tricking filter removed MTBE from the liquid flowing over the GAC media (Figure 1). Sudden

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increases in influent MTBE concentration resulted when a new tank of MTBE contaminated water was mixed. The sudden decrease in removal on August 6, 1998 was caused by a mechanical failure, which resulted in the tricking filter drying out for a several hours. Changes in temperature and flow rate caused variations in the percent removal. Data collected on hot days or days when the flow rate varied significantly from 0.1 liters per minute were not used to calculate the average percent removal for the stage under investigation. The flow rate investigated, 0.1 liters per minute, amounts to a hydraulic loading rate (HLR) of 0.022 meters per minute (0.07 ft/min or 0.54 gpm/ft²) which is near the standard tricking filter hydraulic loading rate (Metcalf and Eddy, Inc., 1993). The trickling filter carbon loading rate was determined to be 0.57 grams of carbon per cubic meter of filter media per hour.

When treating water contaminated with 1000 ppb_w, a trickling filter bed depth of 160 cm is required to remove 99.5% of the MTBE. The HLR, bed depth and carbon loading rate are the design parameters used to size trickling filters and GAC reactors to estimate the cost of full scale biological MTBE removal from the liquid phase.

Research by others determined the air phase design parameters of 16 grams of carbon per cubic meter of filter media per hour and an empty bed contact time of 1 minute (Eweis, 1998). A biofilter bed depth should not exceed 1 meter because of head loss considerations.

COST ANALYSIS

The cost analysis was performed using return periods of 5 and 20 years at an annual interest rate of 4 %.

Air Phase

Because the air to water ratio is very high when stripping MTBE, the air phase concentration is low. Low air phase MTBE concentrations cause the controlling design parameter to be the empty bed contact time (EBCT).

Biofilters have been constructed and operated by companies working in the field. Experienced companies were contacted and provided with design parameters specific to MTBE and asked to estimate construction and operating cost for biofilters. Costs were estimated using information provided by companies constructing and operating biofilters:

Water Flow gpm	Cost in Cents per 1000 gallons treated	
	5 year return period	20 year return period
10	449	147
100	73	24
1000	24	8
5000	18	5.9

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Liquid Phase

Because fixed film biological MTBE degradation has not been practiced in the industry the cost of liquid phase biological MTBE removal was estimated by two methods to obtain low cost and high cost boundaries. The low cost boundary was determined by estimating the construction and operating cost of a trickling filter with a rotary distribution system similar to those used for secondary wastewater treatment. A material cost estimating method was used for the various trickling filters required for the flow scenarios. The high cost boundary was determined by estimating the construction and operating cost of a carbon adsorption system similar to those used to treat drinking water. The carbon adsorption system would have biologically active carbon and would not function as an adsorption unit. United States Environmental Protection Agency produced software (Clark et al 1991) was used to estimate the cost of carbon adsorption units. In both cases, MTBE specific design parameters were used to size the equipment. For MTBE concentrations less than 1000 ppb_w, the hydraulic loading rate controls the design. For MTBE concentrations of 5000 ppb_w, the MTBE loading rate controlled the design.

Cost Analysis Results

The low cost and high cost estimate boundaries are reported in Tables 2 and 3 respectively and graphed in Figures 2-5.

Table 2
Low cost estimate boundary for liquid phase MTBE biodegradation
20 year return period

Flow gpm	MTBE Concentration ppb _w	
	Less than 1000 ppb _w	5000 ppb _w
	Cost in cents per 1000 gallons	
10	340	396
100	53	84
1000	13	
5000	8	

5 year return period

Flow gpm	MTBE Concentration ppb _w	
	Less than 1000 ppb _w	5000 ppb _w
	Cost in cents per 1000 gallons	
10	377	547
100	70	165
1000	25	
5000	20	

Table 3
High cost estimate boundary for liquid phase MTBE biodegradation
20 year return period

Flow gpm	MTBE Concentration ppb _w	
	less than 1000 ppb _w	5000 ppb _w

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	Cost in cents per 1000 gallons	
10	746	1068
100	167	429
1000	67	
5000	44	

5 year return period

Flow gpm	MTBE Concentration ppb _w	
	less that 1000 ppb _w	5000 ppb _w
	Cost in cents per 1000 gallons	
10	1373	2338
100	368	1078
1000	168	
5000	110	

REFERENCES

Malcolm Pirnie, Komex•H2O Science and Alpine Environmental, Inc (1998) MTBE Research Partnership Report, Maclolm Pirnie, Inc., Oakland, CA.

Eweis, J.B., N. Watanabe, E. D. Schroeder, D. P.Y. Chang, K. M. Scow (1998) "MTBE biodegradation in the presence of other gasoline compounds," *Proceedings*, National Ground Water Association Conference on MTBE and Perchlorate, Anaheim, CA, June 3-4.

Park, K. and R. Cowan (1997) "Effects of oxygen and temperature on the biodegradation of MTBE," *Proceedings*, 213th ACS National Meeting: Division of Environmental Chemistry, San Francisco, CA, April 13-17, pp 421-424.

Fan, M. (1998)

Eweis, J., Schroeder, E., Chang, D., Scow, K., Morton, R., and Caballero, R (1997), "Meeting the Challenge of MTBE Biodegradation," *Proceedings of the 90th Annual Meeting & Exhibition, Air & Waste Management Association*, Toronto, Canada, June 8-13.

Romstad, K., J. H. Scarano, W. F. Wright, D. P. Y. Chang, E. D. Schroeder (1998) "Performance of a Full-Scale Compost Biofilter Treating Gasoline Vapor," *Proceedings*, 1998 Biofilter Conference, University of Southern California, Oct. 22-23.

Clark, C and J. Adams (1991), *Drinking Water and Groundwater Remediation Cost Evaluation*, Lewis Publishers, Inc. Chelsea, Michigan.

Metcalf and Eddy, Inc., (1993), *Wastewater Engineering Treatment, Disposal, and Reuse*, McGraw-Hill, Inc. San Francisco, California.

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