

Ex-Situ Treatment of MTBE in Groundwater using a Trickling Filter Bioreactor

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Abstract

The trickling filter is a conventional wastewater treatment technology that has been used for decades for municipal and high BOD wastewaters. However, this technology has seen limited application in the United States for gasoline-impacted groundwater. Further, the initially widespread skepticism in the United States regarding biodegradability of methyl *tert*-butyl alcohol (MTBE) caused bioremediation technologies to be discounted as feasible remediation solutions. However, a number of applications of trickling filter bioreactor (TFB) systems in Europe have shown that TFB technology is a technologically sound and cost-effective method for remediating MTBE in groundwater. TFB technology was recently applied at a gasoline-contaminated site where MTBE concentrations in groundwater reached 980 mg/L at the source. Due to the site's proximity to a stream designated as high quality by the Pennsylvania Department of Environmental Protection (DEP), active remediation of the contaminant plume was necessary to avoid stream degradation and the consequential penalties for natural resource damages. A groundwater remediation system was designed and constructed, which included a trickling filter bioreactor as an innovative approach to groundwater remediation. Plume capture and control was achieved through the installation of two interceptor trenches for groundwater recovery. To date, MTBE removal efficiency has reached 85%, and is anticipated to reach 95% after additional system modifications. MTBE concentrations in groundwater at the site have also shown a significant decrease.

This project was recently granted an Environmental Action Award by the Bucks County Chapter of the National Audubon Society.

Key Words

Trickling filter, bioreactor, MTBE, bioremediation.

Introduction

In the late 1990s, MTBE began to emerge as a major groundwater contaminant. Great concern arose when a number of major drinking water supply wells were impacted by MTBE above action levels, which are as low as 5 ug/L in some states. Since MTBE's use as a gasoline additive was relatively new, beginning in 1979 and seeing widespread use with the promulgation of the Clean Air Act Amendments of 1990, its behavior in the subsurface was not nearly as well understood as BTEX constituents. In particular, little was known about MTBE's biological degradation capacity. The U.S. Environmental Protection Agency (EPA) stated that "MTBE is more resistant to biodegradation than benzene" and "MTBE can complicate remedial activities because of its greater water solubility and resistance to natural biodegradation."¹

Due to the lack of understanding of MTBE's biodegradation potential, initial remedial activities typically employed conventional physical remedial technologies such as air stripping and

granular activated carbon (GAC). While these methods can effectively remove MTBE from water, their effectiveness on MTBE compared to BTEX compounds is limited by MTBE's high aqueous solubility (45,000 mg/L vs. 25 mg/L for benzene). As a result of the high solubility, as well as the low Henry's Law Constant (0.000587 atm-m³/mole, vs. 0.0055 atm-m³/mole for benzene), and low Organic Carbon Partitioning Coefficient (12, vs. 58 for benzene), the effectiveness of conventional technologies becomes reduced, resulting in higher construction and operating costs when these technologies are employed.

In the late 1990s, laboratory bench studies began to identify specific strains of bacteria that were good degraders of MTBEⁱⁱ. Field studies confirmed that these bacteria strains were found commonly at gasoline contaminated sites. At the same time, bioreactor technology began to emerge, primarily in Europe, as an effective method of MTBE remediation. However, as late as 2001, physical separation methods were still commonly considered by many in the United States to be the state-of-the-art for MTBE remediation.

Biodegradation studies performed for MTBE and other oxygenates have identified 16 MTBE-degrading cultures of bacteria. Laboratory and field studies have identified both aerobic and anaerobic degradation of MTBE can occur, under both primarily metabolism and cometabolism scenarios.ⁱⁱⁱ

Although the low organic carbon partition coefficient (K_{oc}) of MTBE makes removal of MTBE from water difficult by adsorption methods, it works in the remediator's favor when removing the contaminant from the aquifer. BTEX remediation through pump-and-treat methods can be troublesome due to the sorbed fraction of the contaminants in the soil matrix. These sorbed contaminants act as a secondary source of groundwater contamination, and cause the rebound effect that has become common at so many groundwater remediation sites. Since the K_{oc} value is relatively low, pump-and-treat methods are applied with greater effectiveness when remediating MTBE, achieving remedial goals with greater ease than for BTEX constituents, which have higher K_{oc} values.

Project Background

The site that is the subject of this paper is a convenience store with active retail gasoline distribution located in Southeastern Pennsylvania. MTBE was detected in groundwater above the Pennsylvania Department of Environmental Protection (DEP) action level of 20 ug/L on the adjoining downgradient property. The ensuing site characterization revealed that the source was a failed vapor recovery connection on the store's tank system. Shallow (<6 feet deep) groundwater was heavily impacted at the tank field. While BTEX concentrations were minimal, MTBE was detected in the source area at concentration as high as 980,000 ug/L.

The subject site is located approximately 60 feet from a tributary to the Brandywine Creek. Pennsylvania lists the Brandywine Creek as a High Quality (HQ) special protection water body. Stringent "no degradation" standards apply to special protection waters in Pennsylvania. Due to the proximity of the plume to the tributary (<100 feet), and the Brandywine Creek's HQ classification, an active remedial method was determined to be most appropriate.

Site Data

The eastern 2/3 of the subject site is developed. The western 1/3 is grass and woodland. A vacant wooded property adjoins the site to the west. The tributary to Brandywine Creek is located along the west side of this property, approximately 60 feet west of the subject site. Groundwater depth is between 3 and 9 feet below grade. During the remedial feasibility study phase, it was discovered that a very low recharge rate would render conventional recovery wells impractical. Thus, two interceptor trenches were employed, along with a source area recovery well, to intercept the contaminant plume.

Based on interceptor trench pilot test results, groundwater recovery pilot testing conservatively predicted a starting MTBE concentration of 5,000 ug/L from the combined flow of the two interceptor trenches and recovery well, and a combined recovery rate of 22.5 gallons per minute (gpm). The actual MTBE concentration at system start-up and the sustained pumping rate were 2,000 ug/L and 11 gpm.

System Design

The treatment train applied at the site consisted of a TFB followed by dual 1,000-pound GAC units for polishing. Preliminary design calculations for the TFB were performed by Water & Soil Remediation s.r.l. (WSR) of Mantova, Italy. WSR had previously completed 15 TFB applications with great success, achieving MTBE removal efficiencies of up to 99%. The TFB design consisted of a 3,000-gallon conical tank filled with 300 cubic feet of packing media. The packing media are one-inch long pieces of one-inch diameter corrugated plastic tubing. This material has a high specific surface ratio of $250 \text{ m}^2/\text{m}^3$, which is the primary factor in media selection for a bioreactor, where water contact to the accumulated biomass on the media surface is critical. (Unlike media selection for a packed tower air stripper, pressure drop across the tower is not an applicable design parameter.) A system schematic is presented in Figure 1 below.

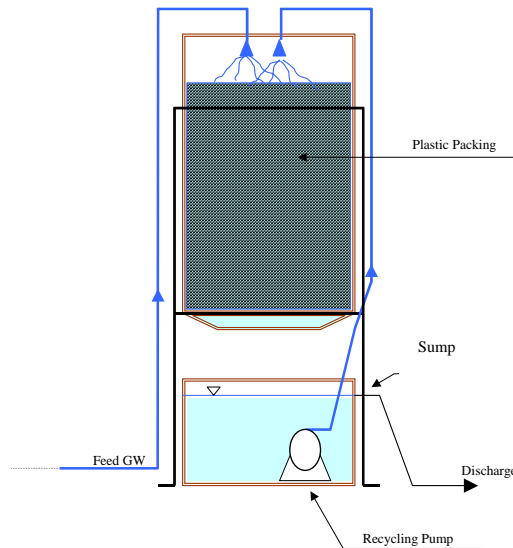


Figure 1: Trickling Filter Bioreactor Schematic
Courtesy Water & Soil Remediation s.r.l.

The required reactor volume was determined empirically, with the primary variables affecting the bioreactor's removal efficiency being the mass input rate ($\text{g}_{\text{MTBE}}/\text{m}^3_{\text{reactor}}\cdot\text{h}$) and residence time. From field applications, WSR established an acceptable mass input rate of 3 to 5 $\text{g}_{\text{MTBE}}/\text{m}^3_{\text{reactor}}\cdot\text{h}$. Also, residence times between 0.1 and 0.2 h were proven to provide high removal efficiencies. The resulting reactor vessel design was a 3,000-gallon conical-bottom plastic tank with dimensions of 10.5 feet high and 90" diameter.

Recovered water is manifolded into a single supply pipe and introduced to the top of the reactor via a single spray nozzle. Oxygenation of the water takes place by natural air convection through the reactor. After passing through the reactor, water is collected in a 500-gallon sump. Water is constantly recirculated at a rate approximately equal to the system's untreated water inflow rate. Due to the stringent discharge limits to the Brandywine Creek, treated water from the TFB must be pumped to dual GAC units for polishing prior to stream discharge.

Biodegradation rates of bacteria begin to become reduced below a temperature of 14°C. Therefore, it was necessary to control the system's temperature during winter months by installing heat tracing and insulation on various system components, particularly the reactor vessel.

Cost Analysis

System start-up occurred in June of 2003. After seeding the system with contaminated water and running in recycle-only mode for two weeks, normal operation began. The initial MTBE removal efficiency was approximately 65%. Following approximately three months of operation, MTBE removal efficiency improved to 85%. Various new spray nozzle configurations are being considered to improve the delivery of supply water to the top of the reactor and hopefully increase removal efficiency to above 95%. After approximately one year of operation, MTBE concentrations have decreased to non-detectable levels in two point-of-compliance wells, and have been reduced by 92% in the third point-of-compliance well. The MTBE removal efficiency and groundwater concentrations during the first year of operation are depicted in Figures 2 and 3, respectively.

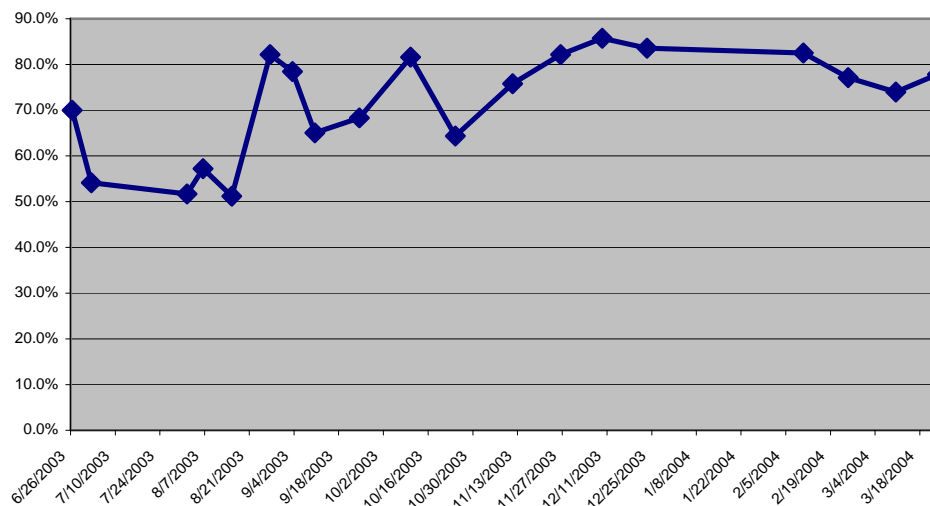


Figure 2: MTBE Removal Efficiency vs. Time

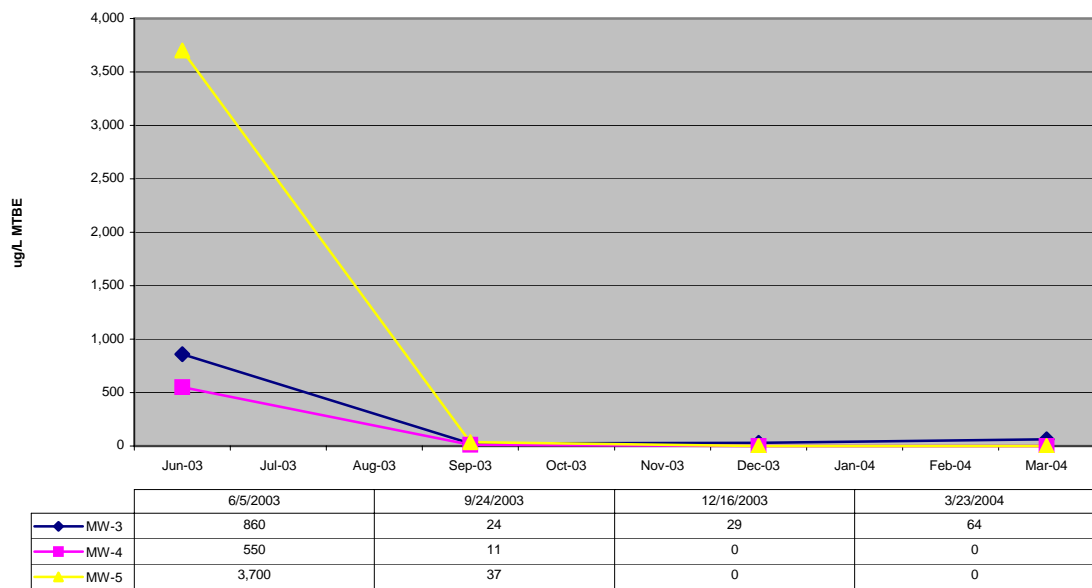


Figure 3: MTBE Concentrations in Monitoring Wells

A remedial cost analysis was performed using site data, comparing capital and operating costs of a TFB with other common technologies. Cost comparisons included TFB, Shallow Tray Air Stripper with Thermal Oxidation for Off-Gas Treatment, and Granular Activated Carbon. The cost comparison considered the installation costs of the three technologies (excluding common costs such as recovery wells), and two years of remediation system operation. In the first cost comparison, MTBE influent concentrations similar to those observed at the subject site were used. These were 2,000 ug/L for Year 1 and 1,000 ug/L for Year 2. For the second comparison, slightly higher values of 5,000 ug/L for Year 1 and 2,000 ug/L for Year 2 were used.

The installation cost is the greatest for the air stripper with off-gas treatment, at \$150,000. Since the system includes the blower stripper and oxidizer fan, the electric cost of \$24,000 per year is significantly higher than the two competing technologies. Also, propane to fire the oxidizer adds an even more significant operating cost of \$57,000 per year. The least costly hardware installation is the GAC system at \$50,000, which includes a flow equalizing tank and transfer pump, and two 3,000-pound GAC vessels. However, carbon replacement is a significant operating cost for this technology, due to the low carbon adsorption coefficient of MTBE. Costs for coconut-shell activated carbon (the best type for MTBE applications) are \$1.36/pound for supply and reactivation of carbon. The bioreactor installation cost is \$70,000.

The installation cost of the bioreactor is slightly more than GAC, but significantly less than air stripping since no off-gas emission treatment is necessary. (VOC emission calculations using AP-42 formulas indicated minimal loss of VOCs from the bioreactor.) The key benefit to bioreactor technology is the low operating costs. Since it does not require forced air or emission controls and does not generate waste, the only operating cost (other than routine maintenance) is electric usage to power the recirculation pump, transfer pump and heaters, which equals approximately \$1,500/year. The side-by-side comparisons graphically represented in Figures 4 and 5 below, demonstrate the significance of the low operating costs in the overall attractiveness of treatment technologies. After a break-even period of two years, the additional installation cost of the bioreactor is recovered by the savings in system operation over the activated carbon

system under the first scenario. This comparison is based on actual data for the subject site, where the starting influent MTBE concentrations was approximately 2,000 ug/L. Cost savings become significantly greater when MTBE concentrations are higher, as depicted in Figure 5, where the starting MTBE influent concentration is 5,000 ug/L. In this scenario, the breakeven period is 12 months, with a \$17,000 cost savings after two years of operation compared to an activated carbon system.

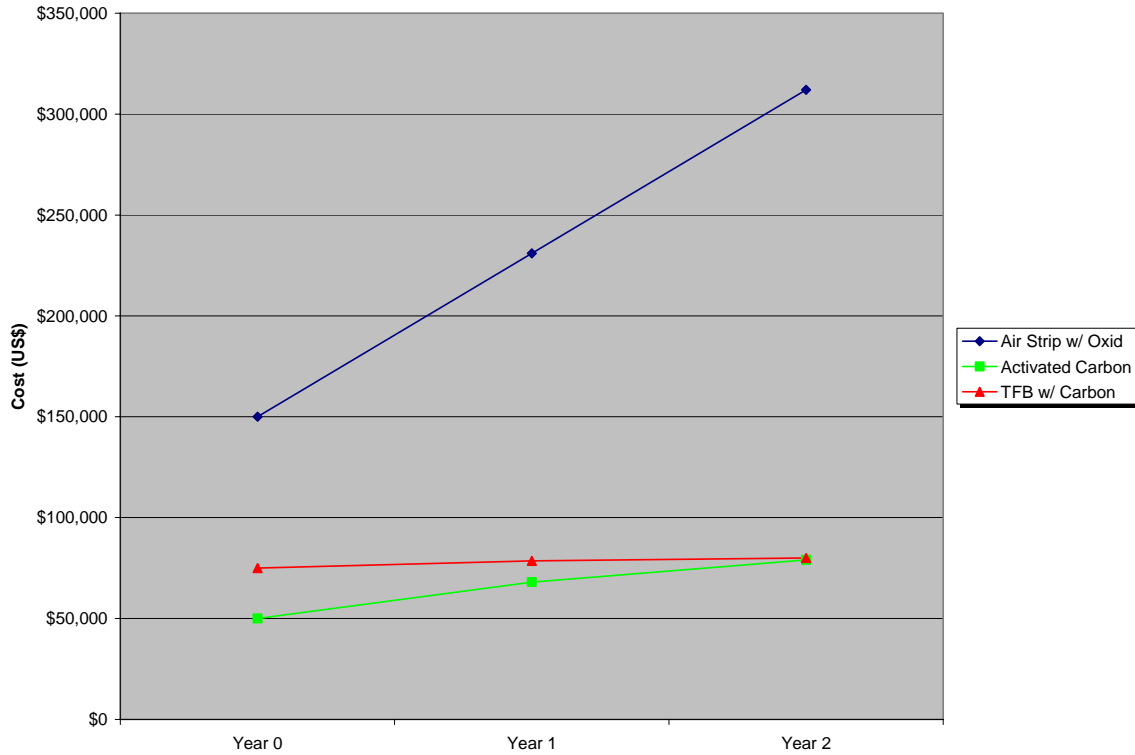


Figure 4: 2-Year Cumulative Costs at 2,000 ug/L MTBE

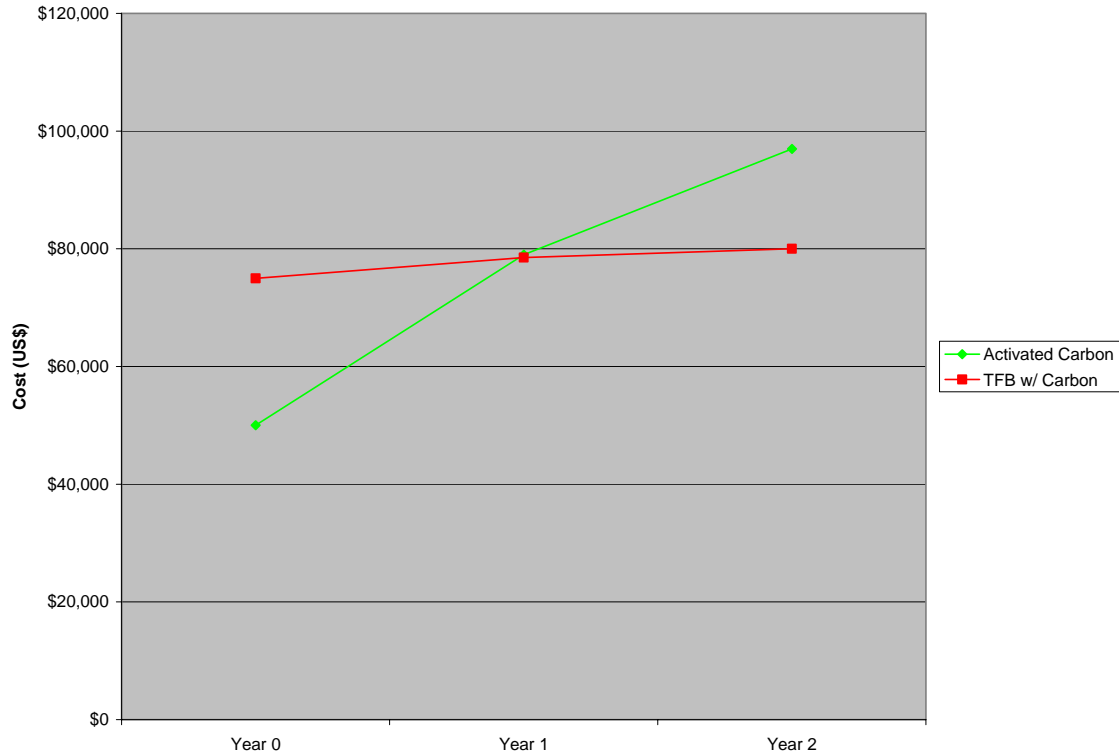


Figure 5: 2-Year Cumulative Costs at 5,000 ug/L MTBE

Conclusion

TFB technology can be very cost-effective compared to alternative ex-situ treatment methods. Energy consumption is very low and the lack of significant air emissions eliminates the need for expensive emissions controls. A site-specific comparison of TFB operating costs to other conventional technologies predict a large and almost immediate savings over air stripping with thermal oxidation, and a savings over liquid phase activated carbon between one and two years of operation. The removal efficiency and cost-effectiveness establish Trickling Filter Bioreactor technology as the Best Available Technology for ex-situ groundwater remediation at many gasoline-contaminated sites.

ⁱ U.S. EPA, MTBE Fact Sheet #2, Jan 1998.

ⁱⁱ Deeb, et al (2000) Aerobic MTBE Biodegradation: An Examination of Past Studies, Current Challenges and Future Research Directions. *Biodegradation* **11**, 171.

ⁱⁱⁱ Stocking, et al (2001) Bioremediation of MTBE: A Review from a Practical Perspective. *Biodegradation* **11**, 187.