University of Waterloo

In-Situ Enhanced Bioremediation of MTBE and BTEX at a California gas station site…..Oxygen Diffusion technology case study:

A new in-situ enhanced bioremediation treatment approach was recently utilized to remediate BTEX and MTBE groundwater contamination caused by leaking underground storage tanks (USTs) at a former gas station site located in California. After 15 years of UST leakage, the dissolved hydrocarbon plume had migrated across the gas station property boundary and had subsequently contaminated a neighboring commercial property with MTBE being detected at approximately 480 ug/l at the furthest monitoring well located 180 feet downgradient from the USTs. The Waterloo Emitter™ oxygen diffusive remediation system was successful in elevating dissolved oxygen (DO) concentrations towards maximum solubility levels in the 25-30 ppm range within the oxygen diffusion wells which served to create enhanced bioremediation conditions that resulted in an approximate 95% decrease in MTBE and benzene contamination concentrations measured over a 15 month test period.

Site Conditions

Based on a series of soil borings, the lithology of the site may be characterized as having sandy clay to clayed sand from grade to approximately 10 to 15 feet below ground surface (bgs) and is underlain with coarse-grained mixtures of gravel and bedrock to the total depth explored (25 feet). Groundwater beneath the site appears to be located at or above the alluvium/volcanic bedrock interface. The local regional groundwater gradient is towards the northwest with a hydraulic gradient of approximately 0.04 feet/foot, however this gradient is suspected of being locally affected by fracture systems within the bedrock. Historical groundwater levels have ranged from 6 ft to 21 ft. bgs. Past aquifer testing at the site indicated that maximum sustainable well yields from the formation ranged from 0.2 to 0.6 gpm with no noticeable drawdown measured in nearby adjacent monitoring wells. In previous years several other alternative treatment technologies, such as air-sparging, soil vapor extraction, and dual phase extraction were all considered for application at this site; however based upon preliminary testing it was determined that the lithology at the site was not suitable to achieve any meaningful remediation performance using these conventional treatment techniques.

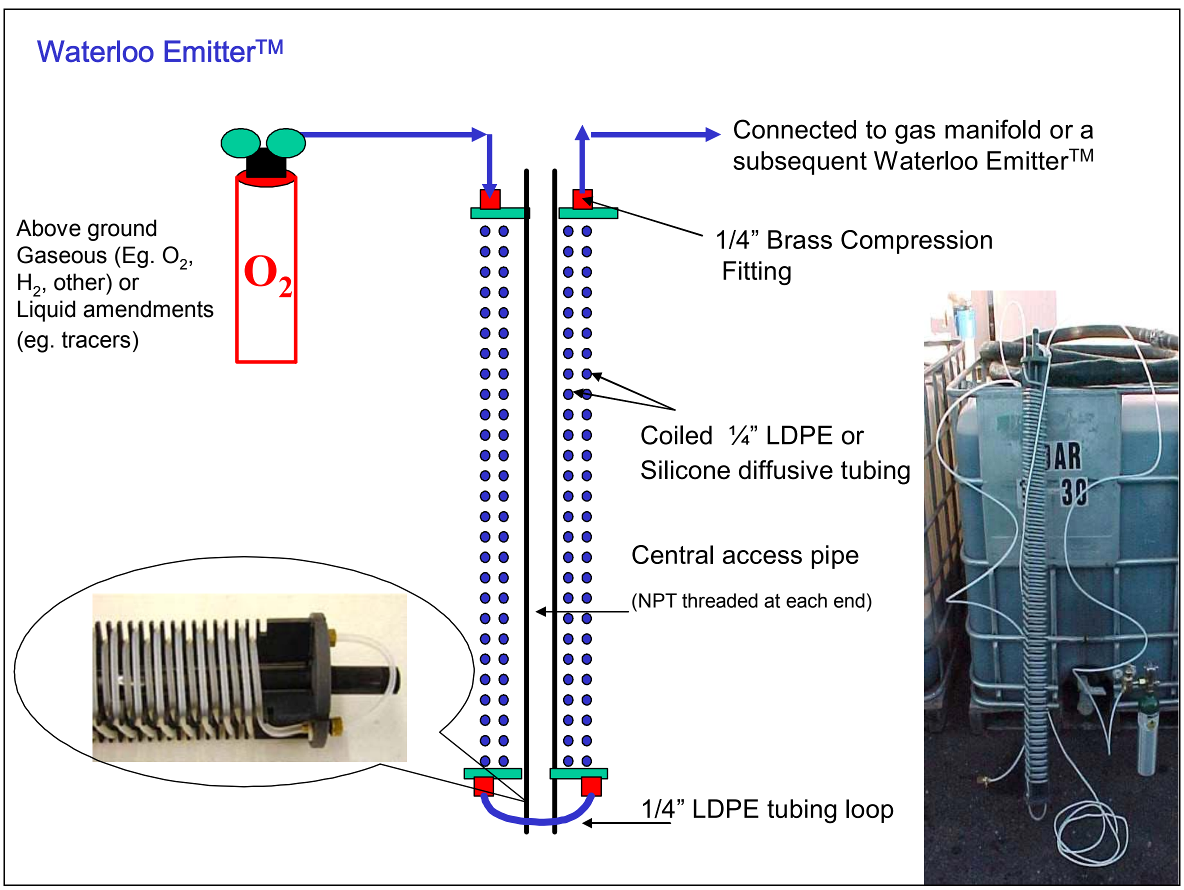
The site is contaminated with typical gasoline petroleum hydrocarbons (ie. BTEX) and gasoline oxygenate (ie. methyl tertiary butyl ether (MTBE)) that exceeds local regulatory maximum concentration levels. The entire downgradient extent of the dissolved hydrocarbon plume is currently not defined by the existing monitoring well network, however the plume is estimated to be at least 140-160 feet downgradient and 60 feet wide crossgradient of the gas station UST's. The furthest downgradient portion of the plume extends into an adjacent property where MTBE had been detected as high as 1.2 mg/L in 1999 and more recently at 480 ug/L. Based on historical and current data, residual soil contamination is estimated to include 323 pounds of total petroleum hydrocardon (TPH), 12 pounds of benzene, and 0.136 pounds of MTBE and residual groundwater contamination is estimated to include 64.4 pounds of TPH, 6.5 pounds of benzene, and 51.85 pounds of MTBE beneath and in the vicinity of the gas station site.

Waterloo Emitter™ technology

The Waterloo Emitter™ technology was selected for a performance test to determine whether an in-situ enhanced bioremediation technique might be suitable for the treatment of BTEX and

MTBE under the variable and low permeable site conditions. The Waterloo Emitter™ utilizes a patent-protected engineered device that provides controlled and uniform diffusive release of a wide range of liquid or gaseous bio-enhancing amendment materials, in this case oxygen gas. The standard Waterloo Emitter™ is comprised of a 5 foot cylindrical PVC frame around which ¼" diameter diffusive tubing is coiled (Figure 1). A central access pipe runs down the center of the PVC frame that easily accommodates the insertion of down-well instrumentation to monitor groundwater conditions and remediation performance. For this particular test application, oxygen gas was selected as the amendment material to be diffused into the groundwater to stimulate the aerobic bioremediation of MTBE and BTEX. The Waterloo Emitter™ was connected directly to an oxygen gas cylinder and molecular oxygen was directly diffused into the soil and groundwater without any intermediary bubble-gas or solids dissolution phase transfer that is associated with conventional air sparging, micro bubbler, or oxygen release compound techniques. The immediate availability of molecular oxygen from the Waterloo Emitter™ means the highest possible dissolved oxygen (DO) concentrations can be attained for any given site conditions The technique is extremely versatile and can be used in shallow or deep installations and does not require any minimum hydraulic head pressure or pressure balancing (as required by competitive micro-bubbler technologies) and is amenable to well installations where the device may only be partially immersed in groundwater as may occur with seasonal changes in groundwater levels. The Waterloo Emitter™ is uniquely differentiated from other enhanced bioremediation techniques as it provides a passive, controlled, and uniform dosing of enhancement materials (eg. O_2) which is important to sustain a constant and active bioremediating micro-organism population.

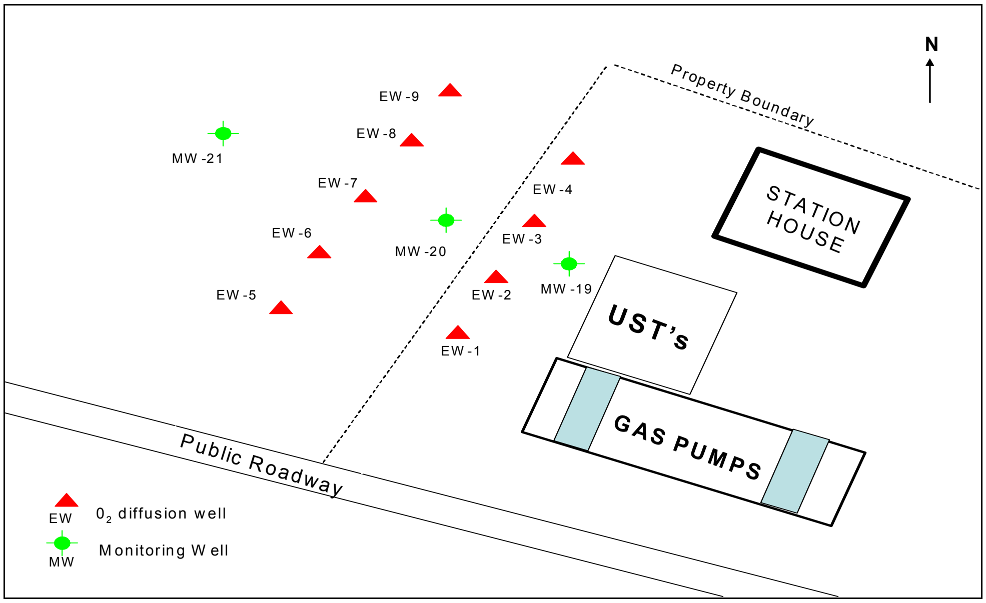
Figure 1



Installation and Operating Conditions

This technology performance validation project utilized 9 Waterloo Emitters™ installed in two parallel rows of 4 inch diameter emitter wells (EW) positioned as follows: i) 4 EWs installed approximately 17 ft. downgradient of the UST and ii) 5 EWs installed approximately 26 ft. downgradient from the first row of EWs. The EWs were installed on 12 foot centers with the second row of EWs being centred on a 6 foot parallel offset from the first row of EWs (refer to Figure 2) which served to create a virtual barrier wall with an overall effective spacing of 6 feet between diffusive oxygen release zones. Monitoring wells (MW) were installed in a straight line transecting the virtual oxygenated zone as follows: i) MW-19 installed 5 ft. from the UST and 12 ft. in front of the first row of EWs, ii) MW-20 installed 12 ft. from the first row of EWs and 16 ft. in front of the second row of EWs, and iii) MW-21 installed 24 ft. downgradient of the second row of EWs.

Figure 2



The wells were installed at depths ranging between 23 to 26.5 ft. bgs and the depth to groundwater within the wells ranged from 9 to 16 ft. bgs. Each of the 4" diameter EWs were screened 20 ft. from the bottom of each well. For this test project, a 3.25" diameter "Scotty" tank (2.3 lb. oxygen capacity) was installed at the top of each EW and connected directly to the Waterloo Emitters™ (installations typically utilize a single source of O_2 with a transfer manifold line running to the EWs). A Waterloo Emitter™ equipped with silicone diffusion tubing was selected for this performance test (although they are also available in a less diffusive low density polyethylene tubing model) and the emitters were operated at 20 psi (rated to a maximum of 25 psi). Based on the diffusion coefficient for silicone, it is theoretically estimated that at 20 psi each Waterloo Emitter™ shall diffuse molecular oxygen at approximately 12.9 L/day which was estimated to be more than sufficient to achieve a dissolved oxygen (DO) concentration of 30 mg/L in each of the EWs given the specific site conditions (Refer to Table 1 for comparison to other oxygen gas utilization rates under different diffusion tubing types and operating conditions).

Table 1

Oxygen Gas emitted from Waterloo Emitters™ at different cylinder pressures

Equipped with LDPE Diffusive Tubing

Regulator Pressure (psi)	Oxygen gas emitted (L/day/emitter)
60	0.23
70	0.26
80	0.29
90	0.32
100	0.35
110	0.39

Equipped with Silicone Diffusive Tubing

Regulator Pressure (psi)	Oxygen gas emitted (L/day/emitter)
5	2.34
10	2.94
15	3.53
20	4.13

Results and Performance

At the beginning of this technology performance validation project, the groundwater contamination concentrations found in the EWs and associated monitoring wells (MW-19, MW-20, and MW-21) ranged from 6,700 ppb to 25,000 ppb for MTBE and from 130 ppb to 17,100 ppb for benzene. For the same wells, the starting DO levels were below detection limits thus confirming that the site conditions were anaerobic and not conducive for supporting an aerobic natural attenuation approach to remediating MTBE.

Over the 15 month test period, three of the EWs (EW-3, EW-6, and EW-7) were sampled on a bi-annual basis while the related three MWs (MW-19, MW-20, and MW-21) were sampled quarterly for selected hydrocarbon and DO testing. Based on the data collected to date, oxygen diffused enhanced bioremediation of petroleum hydrocarbons, such as benzene, and the fuel oxygenate MTBE is occurring at the site. There has been approximately a 95% decrease in MTBE and benzene contamination in EW-6, EW-7 and MW-21 observed over the test period. Additionally, DO concentrations in the EWs towards the end of the testing period were observed to be consistently in the range of 20-30 ppm range while the MW concentrations were observed to be in the 0.5- 2 ppm range at distances ranging from 12 – 24 feet from the EWs (Refer to Figures 3-5).

Figure 3

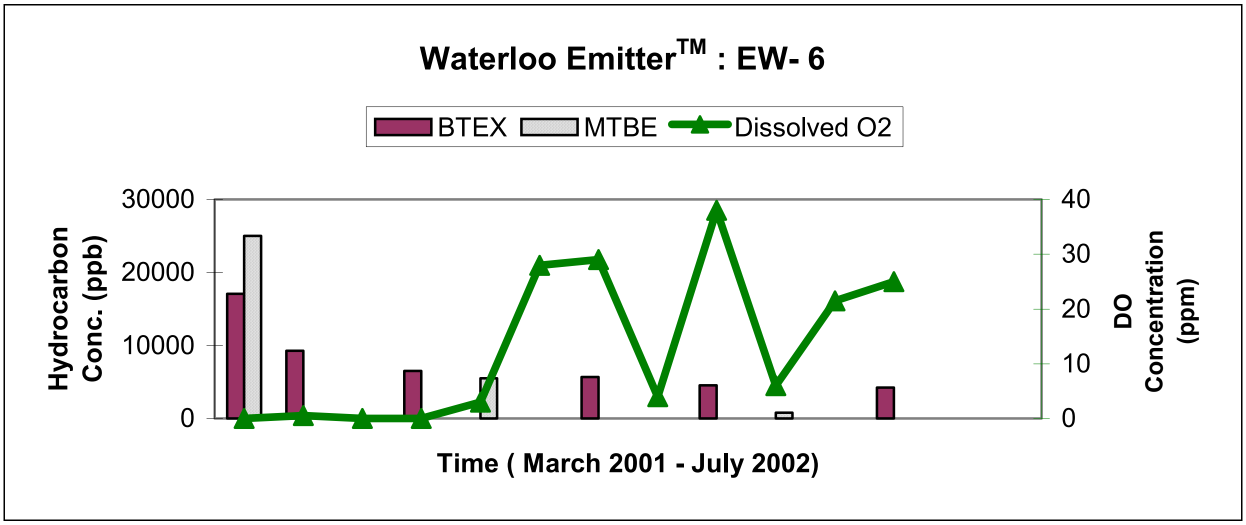


Figure 4:

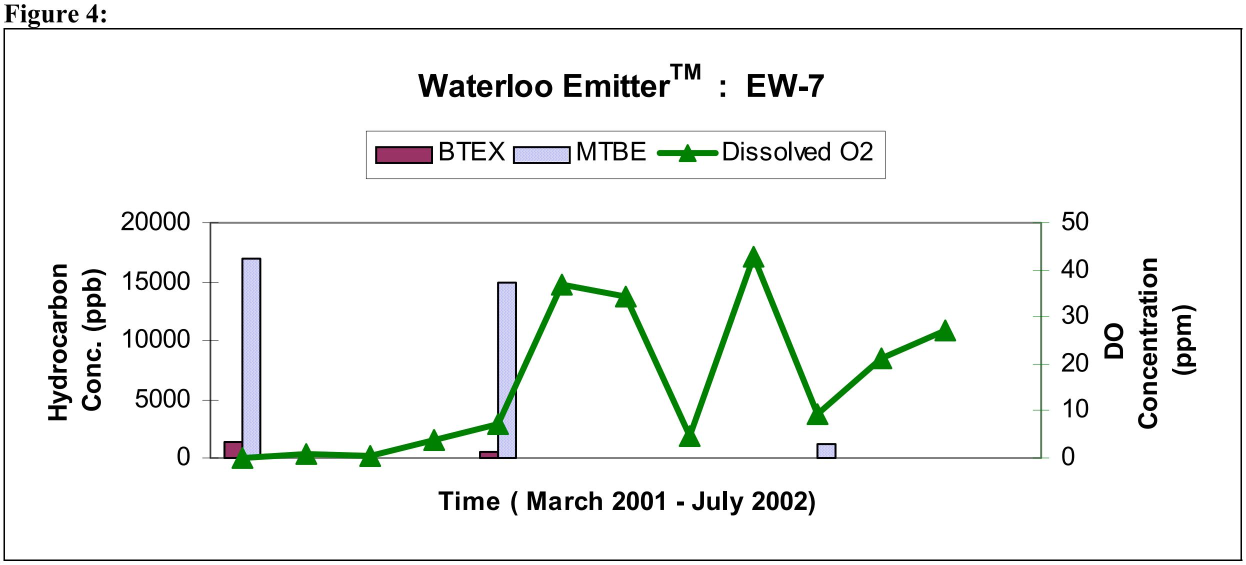
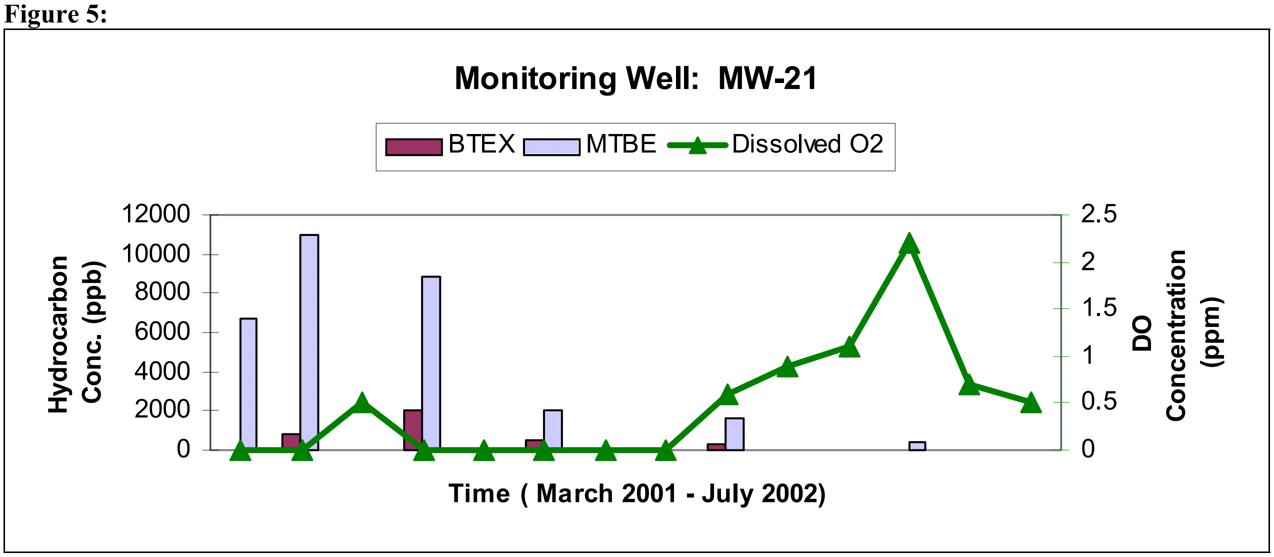


Figure 5:



Ongoing oxygen diffusion and monitoring continues at the site and the test has been expanded to use the Waterloo Emitters™ to assist defining the site flow paths and velocity of the contaminated plume. Two of the Waterloo Emitters™ (EW-2 and EW-3) were connected to oxygen cylinders containing approximately 7% of SF_6 (a compound known to be non-sorbing and non-degrading in groundwater) in order to concurrently diffuse oxygen and SF_6 to achieve the dual purpose of remediation and groundwater flow tracing. The groundwater tracing data is being collected to better define the contaminated plume in order to help determine whether additional Waterloo Emitters™ should be installed to further enhance the current rate of bioremediation occurring at the site. The groundwater tracing data will also be used to define the lateral influence on the flow of groundwater into and out of the 4" diameter EWs. Depending on the ongoing assessment of monitoring and groundwater flow data, it may be possible to further optimize the bioremediation performance by adding a second emitter device to each EW thereby doubling the volume of molecular O_2 diffused into the groundwater to maintain higher DO levels at maximum solubility limits. Another optimization approach might also include the introduction of re-circulation pumping across adjacent EW well pairs in order to laterally expand the overall treatment zone.

Numerous projects utilizing the Waterloo Emitter™ for the bio-enhanced remediation of groundwater contaminated from leaking underground gasoline storage tanks, particularly MTBE, have demonstrated the ability of the Waterloo Emitter™ to release elevated and sustainable concentrations of the desired bio-amendment material to the target treatment zone. The Waterloo Emitter™ is particularly desirable for use in UST remediation applications which are typically located on small gas station sites that require a minimum technology foot print, low maintenance, and high effectiveness (gas stations are often located in light commercial and residential areas which may be close to sensitive receptor water supplies). The comparatively low cost of a Waterloo Emitter™ remediation application is also financially compelling for typical gas station UST remediation projects where the projects are often publicly co-funded by federal and State remediation funding programs.

This case study was prepared by the University of Waterloo with editorial input provided by both the gas station owner and the site consultant.