OxyVAC™

IN-SITU OXIDATION SYSTEM

1.0 OXY VAC™ PROCESS DESCRIPTION

The process of injecting concentrated oxidants (including hydrogen peroxide) has been used to treat soil and wastewater for many years. Terra Vac developed and patented the process of combining in-situ oxidant injection with vacuum extraction, Dual Phase Extraction, or air sparging (Oxy VAC™) to enhance the distribution of oxidant in the subsurface as well as capture off gasses that are created as a result of the exothermic reaction. This process is especially effective for the remediation of MTBE and its degradation products. The process has been used for source area treatment as well as large full-scale area treatment and as a barrier for off-site migration.

Some advantages of this technology are that it:

- Minimizes the need for groundwater extraction;
- Increase the effectiveness of DVE, and Air Sparging;
- Enhances down-gradient biodegradation; and is a
- Rapid low cost remedial solution.

The Oxy VAC™ process has been approved for use by the California Regional Water Quality Control Board (CRWQCB), the United States Environmental Protection Agency (USEPA) and many other state and local regulatory agencies. The USEPA recently issued a guidance document that strongly suggests that this approach be used when using Fenton's chemistry for in-situ remediation. Terra Vac has safely applied this technology at over 40 sites since 1990.

When properly injected into the subsurface, concentrated hydrogen peroxide (>3%) reacts with naturally occurring iron (Fe^{2+}) to produce the hydroxyl radical (OH•), commonly known as Fenton's reagent. The hydroxyl radical is a very strong oxidizer and will break down hydrocarbons to carbon dioxide and water, usually within a few minutes of injection. The reaction is exothermic (produces heat) and must be monitored

to prevent excess heat build-up in the subsurface. The chemical reaction that produces the hydroxyl radical is:

$$2H_2O_2 + 2Fe^{2+} = 2OH\bullet + 2OH^- + 2Fe^{3+}$$

A description of the chemical reactions that take place for hydrocarbon oxidation is included in Appendix A.

The approach for treatment using Oxy VAC™ will involve using a center extraction point (Dual-Phase Extraction or groundwater pumping) to establish a subsurface air and groundwater gradient. Oxidant is then injected into the subsurface inside the DVE radius of influence of the extraction well. This approach will aid the subsurface distribution of oxidant as well as capture off gasses that are created.

The Oxy VAC™ process is non-selective in the carbon sources that react with the oxidant. Not only will hydrocarbons react, but also native soil microbes and other organic carbon sources will be consumed along with the hydrocarbons. However, studies at other sites have indicated that the native microbes are able to re-populate the subsurface after treatment. Terra Vac has observed that the water quality of a typical site continues to improve for several weeks or months following in-situ oxidation. Based on this effect, it appears that the residual dissolved oxygen concentrations and heat generated by the Oxy VAC™ process are beneficial to the overall soil and groundwater microbe population.

Degradation of MTBE does create the formation of byproducts. The byproducts formed during OxyVAC™ would also be formed during natural biodegradation. The advantage of using OxyVAC™ is that the byproducts are also removed by application of the process.

Terra Vac has applied in-situ oxidation in numerous pilot studies, including refineries in California and service station sites, as well as full-scale site remediation at a Superfund site in Pennsylvania.

2.0 SAFETY CONSIDERATIONS

With our years of experience using this technology Terra Vac has developed many safety processes that segregate us from others applying similar approaches. Due to the reactivity and volatile nature of hydrogen peroxide, several safety measures are instituted to ensure the safety of the site and personnel. Terra Vac has successfully and safely applied this technology across a wide range of hydrocarbon and MTBE concentrations. The below safety measures have proven to be effective and just an example of some of the precautions taken.

- Low concentrations of oxidant will be used during injections.
- Temperature probes will be placed in each well to monitor subsurface temperatures during oxidant injection.
- DVE will be utilized to capture off-gasses produced during subsurface reactions.

- Controlled, manual additions will take place over several days to minimize temperature increases (full scale systems can use automatic injection).
- Natural iron will initially be used to ensure a slow reaction.
- Vapor samples will be collected and analyzed for increases in oxygen and carbon dioxide content.

3.0 PROJECT SUMMARIES

In the enclosed appendix are summaries of several OxyVAC™ projects that demonstrate the effectiveness of this patented technology for MTBE remediation.

1) San Diego facility – At this facility Terra Vac conducted testing for in-situ remediation of MTBE. The results showed an average of greater than 90% in-situ removal of MTBE. In addition, groundwater samples collect more than one year after application of the process showed little rebound of MTBE concentrations.
2) Bakersfield facility – Terra Vac performed "hot spot" remediation of MTBE. With MTBE concentrations as high as 90,000 ppb in groundwater, Terra Vac's approach resulted in greater than 80% reduction in groundwater concentrations.
3) Bench Scale Testing - Terra Vac has conducted numerous bench scale tests for site specific applications of the technology. Included are results for evaluation of the approach to remove not only MTBE but also successfully remove byproducts.