



INDIANA DEPARTMENT OF ENVIRONMENTAL MANAGEMENT

In-Situ Chemical Oxidation

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Notice

The Technology Evaluation Work Group completed this evaluation of In-Situ Chemical Oxidation remediation systems based on professional expertise and review of items listed in the “References” section of this document. The criteria for performing the evaluation are generally described in the IDEM OLQ technical memorandum, *Submittal Guidance for Evaluation of Innovative Remediation Technologies*.

This evaluation does not approve this technology nor does it verify its effectiveness in conditions not identified here. Mention of trade names or commercial products does not constitute endorsement or recommendation by the IDEM for use.

Background

There are numerous types of in-situ chemical oxidation (ISCO) systems. IDEM OLQ Geological Services Section has evaluated the remediation applications of various ISCO systems (see descriptions below), with or without special catalysts, pH adjustment compounds, and iron supplements. All of these are intended to chemically break down contamination in soil and groundwater. Some of these have oxygen as an end product, which may stimulate aerobic microbes (those not killed by the peroxides and toxic secondary chemicals).

Note: These chemical oxidants should not be confused with Oxygen Release Compound (ORC)[™] sold by Regenesis, which is a magnesium peroxide with phosphate added to form time-release crystals. ORC is used to provide oxygen to stimulate microbial action, rather than for chemical oxidation (see Geological Services technical memo on ORC[™] applications).

The types of in-situ chemical oxidation systems discussed in this guide include:

1. Hydrogen Peroxide, or Fenton’s Reaction/Reagent

The reaction of iron catalyzed peroxide oxidation at pH 2.5–3.5 is called a “Fenton’s reaction,” and the iron/peroxide mixture is known as “Fenton’s reagent.” Attempts have been made to use hydrogen peroxide for in-situ remediation for at least thirty years.

Due to the almost instantaneous reaction of hydrogen peroxide, only an immediate and extremely localized “flash” effect has normally been achieved. The chemicals usually attenuate before they can reach the contamination.

Fenton’s Reaction also requires acidic conditions (pH between 2.5 and 3.5), which are difficult to create in-situ, particularly in Indiana limestone areas. The USEPA (2004, page XIII-5) states, “*Because of the low pH requirement, Fenton’s Reagent treatment may not be efficient or effective in limestone geology or sediments with elevated pH levels, or with significant capacity to buffer these reactions.*” With the above problems, “*A classical Fenton’s system cannot be readily created in situ as it is generally too difficult to maintain a well-mixed, low-peroxide concentration in the subsurface*” (ITRC 2005, page 11).

Under ideal conditions, peroxides can degrade TCA, PCE, TCE, DCE, VC, BTEX, phenols, MTBE, and explosives. It works poorly on DCA, PAHs, and PCBs; and almost not at all on pesticides. There are major safety problems with use of peroxides (see below).

2. “Modified”, or “Non-pH-Dependant” Fenton’s Reaction

These systems do not actually produce Fenton’s Reaction, but like to capitalize on the name. There are two general types of “modified Fenton’s” systems:

- One uses hydrogen peroxide and a chelating agent or “special formula” to keep the iron catalyst available without acidic conditions.
- The other type of “modified Fenton’s” uses calcium or magnesium peroxide to provide a slower-release hydrogen peroxide.

“*This type of system is significantly more complicated than traditional Fenton’s*” (ITRC 2005, page 11), and can be even more difficult to sustain. The solid peroxide compounds (magnesium peroxide and calcium peroxide, which are mixed with water for application) produce similar effects to liquid hydrogen peroxide, but at a slower rate, taking up to several weeks to attenuate. This provides a slower and safer exothermic reaction than the liquid hydrogen peroxide, but the same precautions are still needed for their use. The slower reaction would also hopefully allow for more time for the compound to be distributed in the subsurface. Laboratory tests have shown that solid peroxides may produce little better results than cheaper, safer, bio-nutrients.

3. Permanganates

These systems typically use potassium permanganate or sodium permanganate. Both degrade far slower than the peroxides, and can be emplaced easier. Permanganates can be used under a wide range of pH conditions, and do not produce the heat, steam, and vapors often produced by the peroxides. There are still some significant safety/explosive issues (see below).

Permanganates can work well with PCE, TCE, DCE, VC, PAHs, phenols, and explosives. It is a poor degrader of benzene, pesticides, TCA, and PCBs.

4. Ozone

Since ozone is a gas, it can be emplaced by injection into the vadose zone, by ozone sparging, or by injection of ozonated water. Ozone is highly reactive, but has a short half life and needs to be generated close to the treatment area. Injection wells or sparge points need to be placed closely together.

Ozone is capable of degrading PCE, TCE, DCE, VC, BTEX, phenols, MTBE, TBA, and explosives. It reacts poorly with DCA, PAHs, TCA, PCBs, and pesticides.

5. Persulfates

The persulfates used are ammonium persulfate, sodium persulfate, and potassium persulfate. The oxidative strength of persulfates changes drastically with variations in pH, temperature, and the presence of ferrous ions. Persulfates usually require the presence of an activator, usually chelated iron, which must be emplaced along with the persulfate, not mixed before injection. The possible variations and chemical complexities are large, and the various chemical reactions can help or hinder remediation.

Under ideal conditions, activated persulfates can degrade PCE, TCE, DCE, VC, BTEX, phenols, MTBE, and TBA. They are a poor degrader of PAHs, explosives, pesticides, and PCBs.

Note: Several of the above oxidative materials are often combined, such as ozone and peroxides. These combinations may work better than one compound alone, but most have the same advantages and disadvantages of the original compounds. Combinations of varied proportions of the above components are often issued under a trade name. Mixtures of peroxides and sodium percarbonate, and mixtures of persulfates (without activators) and peroxides are being sold by vendors. Some of these ISCO mixes may be a problem in that the amount of any one compound delivered may be too dilute to have much effect, particularly in low permeable soils.

Advantages

In-Situ Chemical Oxidation is usually much faster (weeks or months) than most other remediation methods. It also (with the exception of off-gassing from hydrogen peroxide use) does not leave wastes to treat or transport. Some ISCO applications are less invasive and cause less site disruption than other remediation methods. Some oxidants produce oxygen, which will help aerobic microbial decomposition of some hydrocarbons. Chemical oxidation may be cost-effective.

Limitations

There are numerous possible disadvantages to in-situ chemical oxidation. Some are inherent to the chemistry, others to site conditions, or both. The disadvantages include:

Safety Concerns

Safety issues are described in a separate section below.

Potential for Increased Contaminant Mobilization

Even if the oxidants are effective on the contaminants, there may be other effects. The ITRC (2005, page 18) notes *“However, because of the reactivity of the oxidants, there is the potential to cause a significant change in both the concentration and distribution of contamination, potentially resulting in large changes in a site’s established equilibrium of contaminants between the vapor, liquid, and sorbed phases.”* In other words, the contaminants may be mobilized. There may be an increase in vapors, or redistribution of contamination from the sorbed phase into groundwater.

The results of trial applications of solid and liquid peroxides at different sites in Indiana have all shown an increase in hydrocarbon concentrations in groundwater after application, due to the desorption effect from the oxidants, that tends to mobilize adsorbed hydrocarbons rather than chemically break them down.

A major consideration in all liquid ISCO applications is the amount of fluid introduced during the oxidant emplacement, particularly in the source area. The same volume of fluid will be displaced as is introduced. This can spread contamination further. Also it can cause a misleading impression that the oxidant is reducing contamination, when only dilution or dispersion is taking place. An extensive monitoring system is needed to warn against an expansion of the contaminant plume.

A poorly planned ISCO system may lead to a much larger contaminant plume than existed before application. Because of this, additional monitoring wells, and monitoring, is needed to detect any adverse mobilization. A contingency plan must be in place which details the response to any adverse contaminant mobilization.

Need for Detailed Site Characterization

Because of the above safety and mobilization problems, a much more detailed site characterization is needed. It should include not only the need to find free product, utility lines, piping and possible migration pathways, but also:

- subsurface heterogeneities,
- the nature and mass of contaminants,
- groundwater depth/elevation and direction/gradient of groundwater flow,
- site topography,
- aquifer geochemistry (reduced mineral content, organic content, mineral demand for ferrous iron, sulfite, nitrite, dissolved oxygen, etc.),
- potential receptors,
- detailed lithology, hydraulic parameters (conductivity, transmissivity, storativity, effective porosity, etc.), particle size distribution, and soil porosity,

- metals analyses (including hexavalent chromium), plus TDS, major anions, major cations, and natural oxidant demand.

Permanganate treatment also calls for the manganese concentration in groundwater to be determined. Persulfate treatment also needs sulfate levels and the baseline iron content. Peroxide treatment calls for the baseline iron content, and alkalinity. Ozone treatment in the vadose zone adds moisture content to the large list above.

Additional Monitoring Needed

Both the USEPA (2004, page XIII-45), and the ITRC (2005, page 60), call for monitoring of oxidant remediation sites for a minimum of one year after injection, to guard against rebound. There is also additional monitoring needed during the remediation process, as mentioned above. Metals concentrations are particularly important for permanganate treatments. Sulfate concentrations are needed for persulfate injections. Peroxide use calls for continuous temperature measurements, and both peroxide and ozone injection call for continuous measurements of oxygen gas, carbon dioxide, and the Lower Explosive Limit (LEL).

Increased Potential for Metals Mobilization

“In all ISCO projects it is important to know what metals are present in the soil and groundwater because this treatment technology can oxidize some metals, including iron, chromium, and selenium, to a more soluble form, thereby increasing their migration potential...Knowing which metals are present will aid in the selection of metals that should be monitored throughout the injection ...The initial investigation should include the following metals at a minimum: arsenic, barium, cadmium, copper, iron, lead, and selenium” (ITRC 2005, page 24).

Costs

Because of the necessary monitoring and safety precautions, chemical oxidation may have *“potentially higher initial and overall costs relative to other source area solutions”* (USEPA 2004, page XIII-3). Most of the safety precautions and monitoring that the USEPA states are needed, and the ITRC advises, have not been included on Indiana sites. For public safety, they need to be considered.

Problems with Oxidant Distribution

The most serious problem in using ISCO in Indiana is getting enough oxidant in contact with the contamination. This problem and related concerns are described in a separate section below.

Need for Contingency Planning

The USEPA states that chemical oxidation *“may not be technically or economically able to reduce contaminants to background or very low concentrations”* (USEPA 2004, page XIII-3). Because chemical oxidation applications are often not successful the first time,

“In many cases, multiple application events or extended system operation are required” (ITRC 2005, page 46). Because of the uncertainty of success in using chemical oxidation, the USEPA states that “Contingency plans should also be prepared as part of the remedial design” (USEPA 2004, page XIII-33). These plans should “include response actions to take if performance monitoring data indicate any of the following:

- # Inadequate oxidant distribution*
- # Inadequate permeation of low permeability soil zones*
- # Low petroleum mass reduction rates*
- # Excessive contaminant migration*
- # Recalcitrance of constituents*
- # Production of excessive fugitive emissions*
- # Rebound in contaminant levels measured during long term post-application monitoring*
- # Evidence of oxidant moving in wrong direction” (USEPA 2004, page XIII-33)*

These are all problems that can and do occur with chemical oxidation applications. No corrective action plan (CAP) should be accepted unless each of these items is completely covered.

Problems Encountered

Problems with Oxidant Distribution

The most serious problem in using ISCO in Indiana is getting enough oxidant in contact with the contamination. *“Chemical oxidants may not be able to penetrate low permeability homogeneous soils or horizons in heterogeneous soils that contain the bulk of petroleum contaminant mass” (USEPA 2004, page XIII-2). Most tills are too tight for effective oxidant emplacement. Inhomogeneous layers are also difficult, as the injected oxidants will follow the most permeable layer, and little will penetrate the tighter material. “In addition, the tendency for the development or enhancement of preferential flow paths may be increased by the addition of Fenton’s reagent or the use of ozone sparging” (USEPA 2004, page XIII-22). “Typical ROIs (radius of influence) for injections range from 2.5 feet for tight clays to 25 feet in permeable saturated soils” (ITRC 2005, page 48).*

Also to be noted when attempting to determine the ROI for planning injection spacing is that *“Oxidant transport can be reaction limited because the oxidants are being depleted as they move through the subsurface. Therefore, the effective radius of oxidation treatment may be substantially less than the hydraulic (or pneumatic in the case of ozone gas) ROI” (ITRC 2005, page 46). The depletion of oxidants is due to the presence of compounds that raise the natural oxidant demand (NOD). These compounds are naturally occurring organic or inorganic substances that have a greater oxidant demand than most contaminants, so will react with the oxidants first, leaving less for remediation. Organic matter or humic acids have very large oxidant demands. Peat layers generally prohibit use of oxidants. Inorganic oxidant demands come from*

nitrification and the oxidation of sulfide, iron, iron sulfide, chromium, selenium, manganese, etc.

“NOD almost always exceeds contaminant oxygen demand” (USEPA 2004, page XIII-19). In many cases, the amount of oxidants injected is too small to overcome the NOD and attack the contamination. Too much oxidant can cause excessive mineralization, death of local microbial populations, and reduced efficiency. Therefore, the NOD must be known before a corrective action plan (CAP) using oxidants can be prepared. *“The results of laboratory-scale testing of an ISCO technology may or may not be directly (linearly) applied to the design of a corresponding pilot-scale study...Nonetheless, laboratory-scale tests are essential for estimating site-specific oxidant demand due to the soil matrix”* (ITRC 2005, pages 40-41).

Precipitate Formation

In addition to the difficulty of penetrating low permeable formations, oxidants often form metal precipitates (usually iron or manganese oxides) that can further clog pore spaces, and reduce the ROI. *“An important side reaction also occurs resulting in the formation of precipitates---it involves the reaction of two end products of this chain reaction, hydroxide ions and FE(III)”* to form an *“amorphous iron oxide (precipitate). This side reaction consumes available iron and is favored by a basic pH”* (ITRC 2005, page 11). Manganese oxide is particularly deposited by permanganate injections.

Dilution Problems

Solid compounds used for ISCO are usually mixed into a slurry and injected. Some of the injection methods require the compounds to be diluted to 10% or less, which greatly reduces effectiveness (see Geological Services technical memo on the Direct Injection Device (DID) system). At that dilution, it is difficult to inject enough of the active ingredients into low permeable soils to produce the desired cleanup. Also, all oxidants will react with water, and the act of producing a slurry will start oxidant depletion, the rate of which depends on the oxidant compound and amount of water.

Another point to consider is that the injection of large amounts of water into a contaminated area will dilute the amount of contamination present. *“An issue that must be resolved when assessing treatment effectiveness is the role of displacement of contaminated water away from the injection points. Depending on sampling locations observed, post-injection declines might reflect the displacement of contaminated water rather than actual contaminant mass destruction”* (ITRC 2005, page 56). Many of the papers submitted to this office to ‘prove’ that chemical oxidation works, show the signs of dilution, or have no monitoring wells sited to detect dilution/contaminant mobilizing. Any area where oxidants are injected needs to have a comprehensive monitoring well system in place. Monitoring should start before oxidant injection, and continue at least a year after (see above). Transducers are the best way to monitor water levels over time.

Application Problems

“ISCO is an aqueous-phase technology, so except for ozone, the oxidant must be applied to a saturated or near saturated conditions” (ITRC 2005, page 21). Some consultants have applied chemical oxidants to soil contamination, resulting in a much larger contaminated area than before injection, (see below). By their nature, chemical oxidation treatments are applicable to the saturated zone only.

Examples of Unsafe Conditions due to ISCO

- Injections of liquid hydrogen peroxide under pressure have resulted in explosions, one of which destroyed a house, killed a resident, and sent a manhole cover through the roof of a neighboring daycare center.
- Applications of peroxides at an Indiana site resulted in a steam and pressure buildup and a flaming eruption that caused injuries, and burn marks on an industrial plant’s 20-foot high ceiling.
- Use of a proprietary mix of peroxides and other compounds on a chlorinated pesticide spill in Indiana resulted in the “*minor*” release of chlorine gas (Holish et al, 2000).
- One Indiana site had only soil contamination before two treatments with a magnesium/calcium peroxide blend, after which the groundwater was twenty times the MCL for benzene, off-site.

Safety Issues

The following are the main safety concerns when using ISCO.

- Both liquid and solid peroxides have the same limitations, in that they can not be safely applied to free product, or around piping, tanks, or utility lines. The injections can produce a violently exothermic reaction - particularly in the presence of hydrocarbon free product; producing steam, pressure, and/or an explosive off-gas. Several companies claim that they can prevent the more violent exothermic reactions by slow injection, a thermocouple on the injection device, or by watching the amount of foam jetted to the surface. These claims are specious, as the indicator they are watching does not trigger until after the peroxide is already emplaced. Peroxide use calls for continuous temperature measurements, and both peroxide and ozone injection call for continuous measurements of oxygen gas, carbon dioxide, and the Lower Explosive Limit (LEL).
- The heat produced by even dilute hydrogen peroxide can also produce significant hydrocarbon vapors in the subsurface, with attendant dangers to nearby structures or utility corridors. To prevent problems with off-gassing, the USEPA states, “*Special precautions (i.e., SVE [soil vapor extraction] system) are required for appropriate implementation of remedial action involving Fenton’s Reagent/hydrogen peroxide*” (USEPA 2004, page XIII-3). Although contractors and vendors may insist differently, this statement by the USEPA, and problems at sites in Indiana, show that

basic safety issues should make an SVE system a requirement for any remediation using liquid hydrogen peroxide. Some states currently require an SVE system with peroxide injections.

- Applications of peroxides in particular can result in a steam and pressure buildup that can erupt to the surface. This may be limited to bubbles and foam, but applications on Indiana sites (even with thermocouples and low pressure injection) have resulted in small geysers bursting out of the surface. The buildup of subsurface pressure can also cause damage to surface structures.
- Sodium permanganate often comes in a liquid solution, at 40% strength. This poses a “*significant handling and explosion risk*” (USEPA 2004, page XIII-5).

Indiana Case Studies (or use in similar environment)

Hydrogen Peroxide/Fenton’s

A major application of hydrogen peroxide was performed in late 2001, at a large industrial site. Low to moderate levels of hydrocarbon contamination were restricted to a small (160 X 100 feet) area near the tank pit. Contamination was also mostly above 10 feet bgs. With this small and fairly isolated area to deal with, IDEM suggested excavation or RISC closure. Instead, the responsible party (RP) elected to use hydrogen peroxide/Fenton’s Reagent. The RP addressed most of the safety concerns in a meeting with IDEM, and was given a conditional approval for a trial remediation.

Thirty-six stainless steel injection wells were installed, on 20-foot centers. Each well was 15-feet deep, and screened from 5 to 15-feet. A 3-foot by 3-foot and ½ foot thick concrete pad was built around each well to help prevent breakthrough of the exothermic reaction to the surface. Each well was topped by a wellhead assembly which included intake and exhaust check valves, a pressure gauge, a 14-foot long stringer to extend into the well, and supply piping. The supply hoses were connected to one of the five secondary distribution manifolds, which were connected to the main manifold.

An environmental company, who has extensive experience in hydrogen peroxide applications, performed the injections. First, each well was “conditioned” by the injection of 100 pounds of ferrous sulfate, 2 gallons of hydrochloric acid, and 53 gallons of water. This was intended to produce the iron-rich and acidic conditions needed for Fenton’s Reaction to succeed.

Injections were made very slowly, over nearly a month, to help keep pressures down and prevent explosions or breakthrough to the surface. In spite of this, high-pressure breakthroughs near the concrete pads or under the pavement were common, with the chemicals bubbling through to the surface, or even erupting in small (generally less than 2-foot high) geysers. A total of 8,651 gallons of 17.5% hydrogen peroxide solution was injected, along with 162 gallons of conditioner, 159 gallons of acid, and about 1900 gallons of water. This totals 10,872 gallons, for an average of about 300 gallons of liquids for each of the 36 wells.

The site aspects and restricted area of contamination provided optimal conditions for a test of hydrogen peroxide injections for hydrocarbon remediation. The amount of product injected, and the closely spaced injection points, should have been more than adequate for remediation, if this technique is capable of working effectively in-situ. Although analyses for an in-depth comparison were not provided, the hydrogen peroxide treatments have produced, at best, significantly less than 50% soil cleanup, and a 43% increase in groundwater contamination. The levels of contaminants found in the groundwater have greatly increased, probably due to contaminant mobilization. The groundwater contamination is also spreading, probably due to the more than 10,000 gallons of added liquids.

The injection of hydrogen peroxide was not successful. Although a cost/benefit analysis was not provided, the man-hours and material costs have obviously been high, to obtain worse site conditions than were present before injection. A possible minor soil cleanup is more than offset by a dramatic increase and expansion of groundwater contamination. In all probability, much better results could have been obtained, at less expense, from conventional remediation or RISC closure. The hydrogen peroxide injections have demonstrated a definite lack of remediation effectiveness at this site. Hydrogen peroxide works well in the laboratory and for ex-situ soil or water treatment cells where chemistry can be controlled, but in-situ applications present problems.

Ozone

There are currently several pilot and full-scale ozone systems in Indiana. All are in sandy soil. Results are very promising. More will be added here as the projects advance.

Calcium & Magnesium Peroxide

IDEM has a fairly extensive file on use of these solid peroxides, and of proprietary blends mostly of peroxides. There have been some applications in sandy soils that have been fairly successful. To date (April 6, 2005), Geological Services has not received validated data showing that site cleanup objectives have been achieved using the solid peroxides in-situ in low-permeable soils. All sites have shown contaminant mobilization, but no cleanup.

Companies claim that they have special catalysts or amendments that allow for successful “non-pH-dependent Fenton’s Reaction,” or they have a patented delivery system that allows their process to be used even in Indiana’s normally low-permeable zones. These claims have yet to be validated. The actual data from numerous applications has not shown a successful remediation in-situ, in low-permeable soils.

Permanganate

This has been applied at three sites in Indiana that Geological Services knows of. One site was in Indiana clay till. It failed because it could not be distributed (even under high-pressure injection) in the clay. Another was in sand, on low concentrations of

chlorinated compounds. It failed as well, probably because the injections could not overcome the NOD of the soil, which was not tested beforehand. Contaminant concentrations did increase, showing some desorption, but no cleanup. The third site failed as well. It contained high levels of TCE, which were treated with large amounts of permanganate. It failed to produce significant remediation, but the reason why was not determined.

Conclusion

In-Situ Chemical Oxidation is becoming a widely-used remedial option. However, there are special concerns due to the safety issues, and limitations of this form of remediation.

Corrective Action Plan (CAP) Requirements

Before a CAP using in-situ chemical oxidation can be approved, it needs to contain:

1. A very detailed **site characterization**. See item #3 under “Limitations” above for a list of some of the items that must be included in the site characterization.
2. Laboratory results showing the **natural oxygen demand (NOD)** of the site soils.
3. Results of an on-site **pilot study**, which establishes the oxidant concentrations, injection rates and volumes, temperature, pressures, time of treatment, and radius of influence.
4. An **SVE system** for hydrogen peroxide applications.
5. A detailed **contingency plan** which incorporates the information above.
6. A site **safety plan**, which covers the special problems presented by handling and use of oxidants.
7. Plans for **site monitoring**, with quarterly sampling in the ISCO treatment area, and immediate surroundings, for a **minimum** of one year.

Viability

The USEPA (2005, page XIII-15), in their section titled ‘*Overall Viability*,’ states that there are three *“limits of chemical oxidation viability at a site. If review of the corrective action plan indicates that any of the following conditions exist, chemical oxidation is not likely to be a feasible or appropriate remedial solution for the site.”* These conditions are: the presence of free product, underground utility lines, or low permeable soils.

None of the chemical oxidants can economically remediate free product, and the peroxides can be extremely dangerous if they contact it. Underground utilities can be adversely affected by the heat, VOC vapors, elevated oxygen levels, and potential

corrosion that can occur with chemical oxidation treatments. The problems of low permeable soils may be helped by soil fracturing, using the less reactive oxidants, or repeated treatments. However, none of these are guaranteed to work, and all this adds to the expense and time needed.

In sum, if low permeable soil is encountered, chemical oxidation should not be a first choice for remediation. If a contractor or site owner is insistent upon using oxidants in a silty or clay zone, the preceding CAP requirements are needed, plus a contingency for alternative remediation if ISCO fails.

Recommendations

The information available at this time does not support using chemical oxidants for most in-situ applications in low permeable soil. The solid peroxides may be useful in sandy soil, on low levels of contamination. Ozone treatment seems to be useful, on some sites. Geological Services recommends disapproval of any corrective action plan using liquid hydrogen peroxides in-situ, because of the safety issues and the lack of success using these chemicals in Indiana.

Due to the extreme variability in results from ISCO systems, and the long list of things the USEPA states can go wrong with ISCO treatments (above), all chemical oxidation treatments should be on a pay-for-performance basis with the Excess Liability Trust Fund or any other State funded cleanup.

Further Information

If you have any additional information regarding this technology or any questions about the evaluation, please contact Mr. Steve Poe of IDEM OLQ Geological Services Section at (317) 234-0992 or by e-mail at SPOE@idem.IN.gov. This technical guidance document will be updated periodically or if new information is acquired.

References

ITRC 2005. Technical and Regulatory Guidance for In Situ Chemical Oxidation of Contaminated Soil and Groundwater, Second Edition. Prepared by the Interstate Technology & Regulatory Council, In Situ Chemical Oxidation Team. 140 pp.

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