ACCELERATED BIOREMEDIATION WITH OXYGEN RELEASE COMPOUND-ADVANCED (ORC-ADVANCED™): EVOLUTION OF TIME-RELEASE ELECTRON ACCEPTORS

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REGENESIS

INTRODUCTION

ORC-Advanced™ is a unique, patented formulation of calcium oxyhydroxide that releases oxygen slowly upon hydration and forms simple calcium hydroxide and water.

$$CaO(OH)_2 + H_2O \longrightarrow \tfrac{1}{2} O_2 + Ca(OH)_2 + H_2O$$

ORC-Advanced is a new and improved time-release electron acceptor. ORC-Advanced releases a minimum of 17% oxygen by weight into the groundwater, as compared with 10% oxygen provided by the original Oxygen Release Compound (ORC®).

The oxygen released by ORC-Advanced facilitates the aerobic bioremediation of a wide range of environmental contaminants. Oxygen is typically the limiting substrate for microbes capable of aerobically biodegrading contaminants, such as petroleum hydrocarbons and fuel oxygenates such as MTBE. Without adequate oxygen, contaminant degradation will either cease or proceed at a much slower rate.

ORC-Advanced is the newest product in Regenesis' line of slow release compounds and offers many of the same benefits as the well established ORC. ORC and ORC-Advanced are both "low intensity" approaches to site remediation, providing a simple, passive, low-cost and long-term acceleration of aerobic natural attenuation. Remediation experts, looking for a long-lasting oxygen source without incurring the cost of installing mechanical oxygen injection systems or multiple reinjections of other oxidizing chemicals, turn to ORC-Advanced. ORC-Advanced has now been applied at over 200 sites.

TREATABLE CONTAMINANTS

ORC-Advanced can be used for bioremediation of any aerobically biodegradable contaminant. Examples of contaminants treated by ORC-Advanced:

- Benzene, toluene, ethylbenzene, and xylenes (BTEX) and other light petroleum hydrocarbons
- Heating oil, diesel, jet fuel, and polycyclic aromatic hydrocarbons (PAHs)
- Petroleum oxygenates and additives like metyl *tert*-butyl ether (MTBE) and ethanol
- Chlorinated aromatics like chlorobenzene and chloroanaline
- Chlorinated ethenes and ethanes like dichloroethene (DCE), vinyl chloride (VC), dichloroethane (DCA) and chloroethane (CA)
- Chlorinated methanes like methylene chloride and chloromethane
- Herbicides like atrazine, alachlor, metolachlor and acetochlor

CONTROLLED RELEASE TECHNOLOGY (CRT™)

In calcium peroxide compounds, often sold as "slow release," the rate of oxygen formation is simply dependent upon the rate of hydration. When placed into water, this results in a rapid, uncontrolled formation and release of oxygen from the crystalline matrix. Then, as hydroxides form, a significant portion of the oxygen deeper in the crystal is made unavailable or becomes "locked up," as shown in Figure 1.

ORC-Advanced is not simply calcium peroxide, but rather a patented formulation of calcium oxyhydroxide intercalated with food-grade phosphate (Figure 2). The term intercalation refers to the permeation of phosphate ions through the calcium oxyhydroxide crystal, partially inhibiting the transmission of water into the structure. Controlling the rate of hydration of the crystal produces a "timed" oxygen release. Intercalation also increases shelf life stability; ORC-Advanced can be stored for several years without risking significant product degradation.

The patented intercalation process, also known as Controlled Release Technology (CRT™), provides "balance" – it slows down the rate of oxygen release white at the same time preventing "lock-up".

Figure 1.
Intercalated vs. Unintercalated Peroxygens

- Unintercalated peroxygen is subject to "oxygen lock-up:"

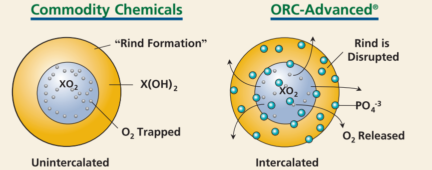
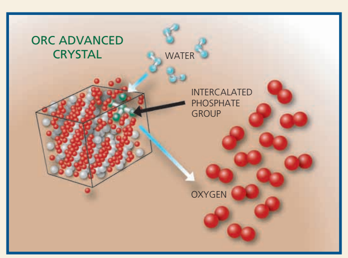


Figure 2.
Intercalated phosphate ions



CRT Specifics

Uniformly embedded within the crystalline structure of the peroxygen are phosphate ions. These ions do two important things:

1. They slow the rate of hydration that liberates oxygen thereby creating the CRT effect and
2. They form exit pathways for the oxygen in an otherwise tightly packed crystal that can become even more "locked-up" when hydroxides begin to form as a reaction by-product following oxygen liberation.

OXYGEN RELEASE CHARACTERISTICS TO OPTIMIZE BIOREMEDIATION

In the stimulation of aerobic bioremediation, the rate of oxygen release is a critical factor. If oxygen is released in excess of saturation, the oxygen will be simply wasted as it bubbles out of solution. By controlling the rate of oxygen release with CRT technology, the rapid release rates observed with calcium peroxide are avoided.

Figure 3a depicts oxygen release rate data for both ORC-Advanced and a calcium peroxide-type product often sold as being "slow release." Note the excessive oxygen released by the calcium peroxide product in the first 60 day period compared to the controlled oxygen release by ORC Advanced. In most contaminated groundwater settings, this excessive amount of oxygen would exceed the "physical holding capacity" and "microbial demand" of the aquifer and would be wasted.

Additionally, calcium peroxide compounds become exhausted in their release rates in the very period of highest aerobic microbial oxygen demand-when the microbial population is optimized and efficiently degrading contaminants. This is clearly seen in the data in Figure 3a, where the calcium peroxide compound drops off in its rate of oxygen release after about 180 days. ORC-Advanced continuously releases oxygen for approximately one year in the field.

Figure 3a
ORC Advanced vs. Commodity Calcium Peroxide

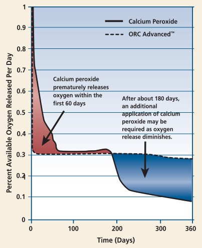
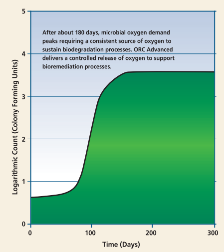


Figure 3b
Generalized Aerobic Microbial Growth Curve for Contaminated Aquifer Settings



ORC-Advanced validates its patented CRT profile optimizing the long-term, steady concentration of available oxygen at amounts between 0.3 and 0.4 percent per day. Calcium peroxide exhibits a quick initial oxygen overload in the early months following injection, losing a significant portion of its available oxygen. After 180 days calcium peroxide exhibits a sub-optimal oxygen release profile (just when microbial oxygen demand typically reaches its upper limits - Figure 3b) and is diminished in its ability to stimulate bioremediation.

BENEFITS OF ORC-ADVANCED

"Rapid" Site Closure

- Accelerates natural attenuation by 10X to 1,000X — reducing time to site closure

Cost-Effective

- No capital costs for systems
- No operation & maintenance costs
- Reduced installation costs
- Typically 30 – 50% less expensive than mechanical systems

ORC-ADVANCED APPLICATION STRATEGIES

Combined ORC-Advanced application strategies are shown in the diagram below (Figure 4). ORC-Advanced can be applied in a variety of ways, with some or all of the methods being appropriate at a given site.

Figure 4.
Methods of ORC Application

ORC-Advanced powder can be made into a slurry that is backfilled or injected into the saturated zone, or it can be dispersed as the dry powder into the contaminated area. Applications of ORC-Advanced, by slurry or powder, provide oxygen at a timed rate that is generally consistent with demand. This allows the site to be passively managed.

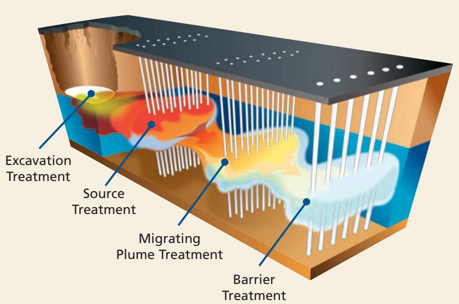
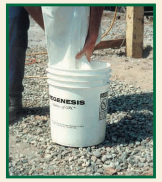


Figure 5.
ORC-Advanced Slurry Injection



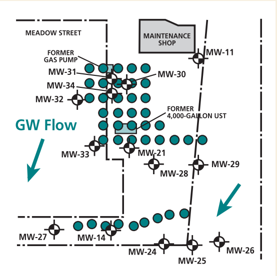
ORC powder is mixed with water to form a slurry

ORC slurry is poured into the hopper of a slurry injection pump

Direct-push injection of slurry

Figure 6.
ORC-Advanced Excavation Application

CASE HISTORY 1 – ORC-ADVANCED APPLICATION IN CONNECTICUT



Application Details

Soil type: silty sand
1,000 lbs ORC-Advanced applied in March 2004
Two areas of application:
1) source area
2) downgradient edge of plume
Source area: 32 injection points in a grid formation
Downgradient cut-off barrier: 9 injection points
Treatment thickness: 10 ft (from 8 to 18 ft bgs)

Results

TREATED WELLS

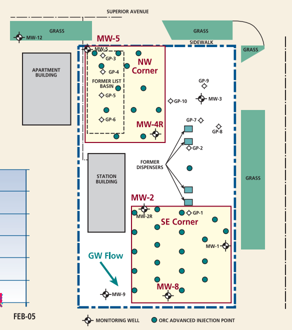
Location	% Change	Initial Conc. BTEX (mg/L)	Conc. BTEX (mg/L) after 3 months
In grid	53% ▼ decrease	20.4	9.5
Downgradient edge	47% ▼ decrease	1.9	1.0
Downgradient barrier	30% ▼ decrease	1.0	0.7

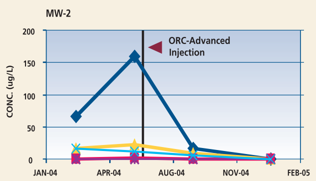
UNTREATED WELLS

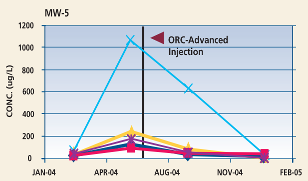
Location	% Change	Initial Conc. BTEX (mg/L)	Conc. BTEX (mg/L) after 3 months
20-25 ft Downgradient	67% ▲ increase	.03	.05
Wells lateral to grid	54% ▲ increase	1.3	2.0

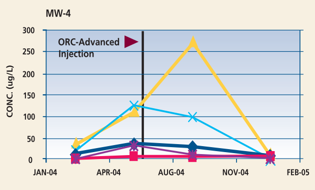
CASE HISTORY 2 – SERVICE STATION IN SHEBOYGAN, WI

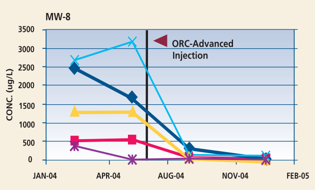
Elevated levels of petroleum hydrocarbons were discovered near the former dispenser island at a service station in Sheboygan, WI. After soil excavation, residual contamination continued to affect the groundwater. *In situ* bioremediation using ORC-Advanced was chosen to reduce BTEX and naphthalene. In the northwest corner of the site, the location of the former UST basin, a total of 480 pounds of ORC-Advanced was injected. In the southeast corner, the area of highest contamination, a total of 2,370 pounds of ORC-Advanced was injected.

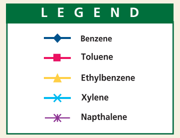












On average, concentrations continued to increase up until the ORC-Advanced application and significant decreases of all contaminants were seen shortly after ORC-Advanced injection. In well MW-2, total BTEX was reduced to non-detect. Total BTEX concentrations were reduced to 8 and 18 ug/L in wells MW-4 and MW-5, respectively. In well MW-8, total BTEX was reduced from 1745 ug/L to 42.2 ug/L, a 97% reduction. Monitoring is on-going as concentrations continue to decrease toward MCLs.

ORC ADVANCED™
OXYGEN RELEASE COMPOUND