



1. What is RemOx® SR+ ISCO reagent?

RemOx SR+ consists of solid potassium permanganate and solid sodium persulfate particles dispersed within a solid paraffin wax matrix. The finished product is formed into the shape of a cylinder. Each cylinder is loaded with approximately 38% (w/w) of potassium permanganate, 38% (w/w) of solid sodium persulfate, and 24% (w/w) paraffin wax.

2. What are the weights/dimensions of the cylinders?

RemOx SR+ cylinders are 2.5" (6.35 cm) in diameter and 18" (45.72 cm) long. The cylinders weigh approximately 5.7 pounds (2.6 kg) each.

3. Is the paraffin wax non-toxic? Is the wax biodegradable?

Paraffin wax is a benign material that is biodegradable and considered environmentally green (testing by Western Michigan University concluded that although the wax is biodegradable, it is not likely in a form the microbes can access, therefore is not likely to significantly degrade over time).

4. What is the oxidant release mechanism from the paraffin wax?

The oxidant dissolves and diffuses steadily from the paraffin matrix into groundwater and is transported with ambient groundwater flow. The release continues at a steady rate until no additional oxidant remains in the cylinder and the benign paraffin wax shell remains.

5. What are the parameters necessary to design a RemOx SR+ treatment system for a site?

Key site characteristics that are important to understand for successful design include:

1. The rate of oxidant demand due to interaction with natural subsurface constituents,
2. Site groundwater seepage velocity
 - i. Hydraulic conductivity
 - ii. Hydraulic gradient
 - iii. Soil porosity

Ideally one should know the 2nd order natural oxidant demand (NOD) rate (L/mmol-day), although if not available this can be estimated from 1st order values.

The 2nd order rate can be derived by measuring oxidant concentrations in the aqueous phase resulting from reactions of a soil/water slurry (1:1 ratio by volume is typical) over time at three different oxidant concentrations (common values are 100, 1,000, and 10,000 mg/L of oxidant, however the rate can be determined from any three initial oxidant concentrations with a recommended range of at least an order of magnitude). Common data points to collect are 2-4 time points within the first day, then daily up to 1-2 weeks or when the change in concentration cannot be differentiated from replicate variability. For each concentration, a constant (1/day) for the 1st order rate of decay is assessed. The slope of the line from a plot of concentration (L/mmol) vs 1st order rate constant 1/day) provides the 2nd order rate constant (L/mmol-day).

The amount and rate of oxidants consumed by the aquifer material, or the NOD expressed as g-oxidant/kg-media, depends on the concentration of oxidants present. When present at higher concentration more oxidant is nonproductively consumed by NOD than when present at lower concentration. Because the rate of groundwater flow influences the concentrations of oxidants that will be available to interact with the subsurface, a more accurate, site-specific estimation of oxidant distribution with space and time can be made using a 2nd order rate constant. As the oxidants concentrations decrease with time, its rate of depletion can be adjusted accordingly.





5. (Continued)

Estimates can be made using 1st order values by dividing the 1st order rate constant (1/day) by the concentration (mmol/L); however this may not actually be representative of the system (Figure 1). This approach assumes the linear trend passes through the origin with no y-intercept, but that is not always the case. The error in this approach is greater at higher concentration (i.e., slower groundwater velocities).

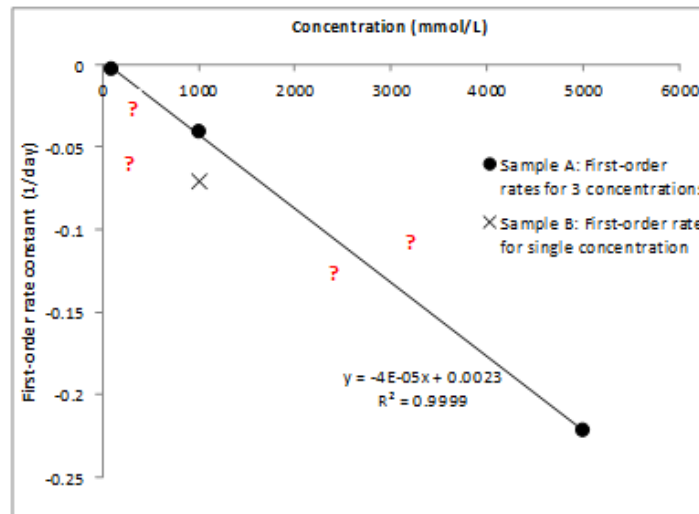


Figure 1. 1st order rate constants collected for three concentrations of persulfate for a sample (solid circles) vs. one concentration of persulfate for a sample (X). Question marks point out the uncertainty associated with the rate constants that may result from reaction with different concentrations of persulfate.

6. What effect does the natural oxidant demand have on the sustained release technology?

Because the persulfate in the cylinders is unactivated, most site conditions would not be anticipated to cause fast depletion. A high NOD (rate and extent) will result in oxidant consumption in very close proximity to the cylinders and limited transport downgradient from the cylinders. The available oxidant concentration for contaminant treatment may be too low for treatment of contaminant. To overcome high demand, cylinders can be placed close together in the direction of groundwater flow or even within the same well.

7. How long will the cylinders persist?

Based on the rate of oxidant released from the cylinder, it is estimated to persist between 4 and 6 months but is very dependent on site specific parameters.

8. How does seepage velocity affect cylinder site design?

There is an optimum site-specific seepage velocity that will depend on the site's NOD and the contaminant type present. In general, if the seepage velocity is too low, there will be a localized high concentration of oxidant that will eventually diffuse throughout the soil matrix over long time frames, but will require very close cylinder spacing that may not be practical. On the other hand, if the groundwater velocity is significantly greater than the rate at which oxidant is released from the cylinders, then a dilute concentration will result, which may not be high enough for effective contaminant destruction.





8. (Continued)

For example, if a design goal is to achieve approximately 1,000 mg/L of oxidant for 6 months, seepage velocities need to be less than 30 cm/d (approx. 1 ft/d) for a low oxidant demand setting using 2.5" (6.35 cm) cylinders. If higher than this velocity, concentrations will be less than the 1,000 mg/L target. If velocities are low (e.g., ≤ 0.5 cm/d), resulting concentrations are high for a longer duration, however it will take longer than 6 months for relevant concentrations to reach a short distance (e.g., 1 ft (0.3 m)) from the cylinders. Because the release rate of the SR+ cylinders is relatively steady, it is expected for the oxidant concentration to be relatively constant throughout its lifetime, although there will be a "ramp up" and "ramp down" period at the beginning and end of the cylinder lifetime, respectively, when concentrations are lower than the longer-term steady-state concentration.

9. What is the recommended spacing for the cylinders? Does it vary with soil type, seepage velocity?

Cylinders should be spaced laterally (side-by-side) as close as technically and economically feasible. Oxidant released from the cylinders will not likely undergo significant lateral dispersion under the range of site conditions for which they are most viable. A general rule of thumb is that lateral dispersion can be expected to be approximately 1/100th of the distance a dissolved species would be expected to travel with groundwater in a given period of time. With a fast velocity of 1 ft/d (50 cm/d), if the oxidant were completely nonreactive, we may expect it to travel 365 ft (111.25 m) down gradient in a year, but less than 4 ft (1.21 m) from side-to-side. With reaction (NOD), we can reasonably expect these values to be significantly less. An efficient approach is using off-set rows in a grid configuration.

Longitudinal spacing (down gradient with flow of groundwater) will depend on NOD and seepage velocity. In general, under low NOD and high velocity conditions, the cylinders can be spaced up to 5-10 ft (1.52-3.04 m) apart in rows while maintaining a consistent and sufficient concentration over time. Under high NOD and low velocity conditions, cylinder spacing of 1 ft (0.3 m) or even less may be necessary.

Cylinder spacing will also depend on treatment performance objectives. For simple mass flux reduction down gradient from treatment, it is less critical to maintain a consistent zone of oxidant. Fluctuations of oxidant concentration over space and time can occur while still achieving significant mass flux reduction. However, if the goal is to achieve a specific low concentration goal such as a maximum contaminant level (MCL), maintaining a consistent concentration through appropriate spacing and change-out frequency will be essential.

10. What are the recommended installation methods for RemOx SR+ cylinders?

The cylinders can be installed using traditional direct push technologies (DPT) or within existing or new wells. If wells are spaced far apart, it is recommended to install cylinders between wells via DPT due to limited dispersion.

11. Can the RemOx SR+ cylinders offer a cost savings over traditional ISCO?

Where applicable, RemOx SR+ can decrease active time on site, number of mobilizations to a site, and energy costs relative to traditional ISCO. The cylinders can also assist with potential rebound and with mitigating potential offsite migration (barrier applications), passively and at low cost.

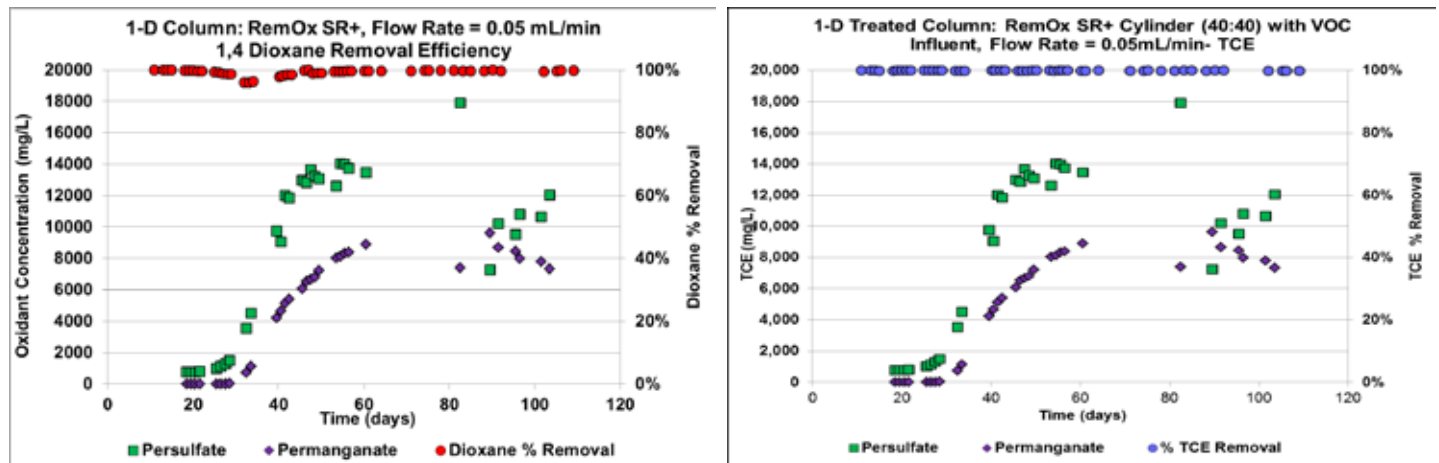
12. What contaminants of concern (COCs) can RemOx SR+ effectively treat?

RemOx SR+ is effective at removing a variety of COCs such as chlorinated solvents, 1,4-dioxane, BTEX, phenols, and PAHs to list a few.





12. (Continued)



Figures 2 and 3. Laboratory column studies data showing >99% removal of 1,4-dioxane and TCE.

13. Why does Carus recommend RemOx SR+ cylinders over RemOx SR or Persulfate SR cylinders?

RemOx[®] SR ISCO reagent (potassium permanganate only cylinders) form manganese dioxide coating on the cylinders at some sites without coupled use of sodium hexametaphosphate (SHMP). The deposition impacts the oxidant release and distribution. The manganese dioxide coating concern is not present with RemOx SR+ cylinders based on the chemistries of the two oxidants combined in one cylinder.

Laboratory results have indicated enhanced reaction rates occur with RemOx SR+ compared to Persulfate SR cylinders. This is due to the presence of manganese generated from permanganate oxidation.

An additional benefit of RemOx SR+ over other cylinder options include readily available manganese. Researchers indicate naturally occurring solids can activate persulfate, however freshly precipitated manganese is readily available to react with persulfate also enhancing the reaction rate of contaminants of concern.

RemOx SR+ also has the benefit of permanganate longevity with the reactivity of persulfate.

1,4-Dioxane Reaction Rate Constants (k)		
1,4-Dioxane Concentration (mg/L)	RemOx [®] S ISCO Reagent	Persulfate SR ISCO Reagent
100	6.76E-07 L mol ⁻¹ s ⁻¹	5.88E-04 L mol ⁻¹ s ⁻¹
14	8.80E-07 L mol ⁻¹ s ⁻¹	3.05E-04 L mol ⁻¹ s ⁻¹
RemOx [®] SR+ ISCO Reagent	Permanganate	Unactivated Persulfate
100	1.16E-03 L mol ⁻¹ s ⁻¹	1.96E-04 L mol ⁻¹ s ⁻¹
14	1.47E-03 L mol ⁻¹ s ⁻¹	2.49E-04 L mol ⁻¹ s ⁻¹

Figure 4. RemOx SR+ enhanced reaction rate constants (k) for 1,4-dioxane.





14. What is the best method to analyze RemOx SR+ present at a site?

Field kits are available for both permanganate and persulfate. However, interferences occur in the presence of both oxidants. It is recommended to collect samples and ship to a laboratory to analyze for permanganate concentrations using ultraviolet-visible spectroscopy and persulfate concentrations using ion chromatography (IC).

15. What field parameters provide meaningful data to understand if the cylinders are “working”?

The best indicators of whether the cylinders are effectively and predictably releasing oxidant are the persulfate concentration nearby and downgradient from where the cylinders are emplaced. Sulfate is a byproduct of persulfate reactions and could also serve as an indicator. The most accurate indicator of treatment success is the measurement of contaminant itself and contaminant oxidation byproducts (e.g., chloride for oxidation of chlorinated ethenes if generated in sufficient quantity for detection).

16. Discuss the effect of pH and if this can be an indicator of no persulfate reactivity or enhanced persulfate reactivity.

Acidity is a byproduct of persulfate reactions. Many aquifers have significant buffer capacity and a drop in pH may not be detected. Effective oxidation can occur without any corresponding change in pH. However, if the buffer capacity is low, the pH may drop and contaminant reaction rates would increase as a result.

17. What is the proper way to dispose of the spent cylinders?

Spent RemOx SR+ cylinders should be disposed as hazardous waste unless the material has been tested to be non-hazardous.

