RegenOx™

Advanced Chemical Oxidation

Comparison of RegenOx™ to Persulfate

Activation

RegenOx™ is a two part product composed of an oxidizer/catalyst complex (Part A) and an activator complex (Part B). The activation of RegenOx is carried out by simply mixing Part A and Part B together in an on-site tank prior to injection. This is a very safe and easy operation.

Conversely, the activation of persulfate involves complex and often very hazardous operations. Persulfate activation is often accomplished by injecting concentrated hydrogen peroxide or sodium hydroxide solutions under high pressure resulting in a dangerous exothermic reaction. These activities present a significant safety concern for those applying persulfate solutions. Also, the serial application of activator solutions into pre-injected persulfate solutions often can result in displacement of un-activated persulfate away from the treatment area.

Relative Oxidizing Capacities of RegenOx™ and Persulfate

RegenOx oxidizer (Part A) contains sodium percarbonate and a surface catalyst (patent pending), as the principal ingredients by mass. Sodium percarbonate has more than two times the oxidizing capacity of sodium persulfate on a per unit weight basis. The direct comparison is based on the formula weights and number of oxidation-electrons per formula unit:

Sodium percarbonate	$(Na_2CO_3)_2(H_2O_2)_3$	Formula Weight 314,	**(6-electron oxidant)**
Sodium persulfate	$Na_2S_2O_8$	Formula Weight 238,	**(2-electron oxidant)**

On a per-unit-mass basis:

> (2/238)/(6/314) = 44% = (Oxidizing capacity of sodium persulfate)/(Oxidizing capacity of sodium percarbonate)

When the comparison is done for activated versions of these oxidants, we find that RegenOx is still favored on a per-pound basis. How much depends directly on the amount of activator used for each. Consider a common case where RegenOx is used in a 1:1 ratio of Part A to Part B, and sodium persulfate activator is used in a ratio of 1:0.2 (persulfate to activator). This gives an adjusted ratio of oxidizing capacities on a per-unit-mass basis:

(44%)(2/1.2) = 73% = (oxidizing capacity of **activated** persulfate)/(oxidizing capacity of RegenOx @1:1).

If this math is confusing, think about dilution: As applied, the total weight of RegenOx is 2x that of just part A. As applied, activated persulfate weight is 1.2x that of just persulfate. Hence the ratio of 2/1.2.

Note that we use a large quantity of RegenOx activator in typical designs, and the oxidizing capacity of RegenOx on a per-pound basis could be increased further by cutting down on the amount of Part B for designs where this makes sense.

In summary, the stoichiometric quantity of activated sodium persulfate required to treat a contaminant mass is about 1/3 more (by weight) than the quantity of RegenOx required to treat that same mass.

RegenOx™ Pricing Relative to Klozur® Sodium Persulfate per Application

A realistic cost comparison can be derived by employing a hypothetical "typical" site with a volume of 16,000 cubic yards with an average perchloroethene contamination (PCE) concentration of 50 ppm and 30% porosity. Under this typical scenario RegenOx offers a cost savings of $13K over sodium persulfate or $0.82 less per cubic yard.

Table 1: Cost Comparison Between RegenOx™ Oxidation System and Klozur® Sodium Persulfate

Cost	Sodium Persulfate*					RegenOx™			
Direct Capital Costs	No.	Units	Unit Cost	Cost		No.	Units	Unit Cost	Cost
Direct-Push Mob	1	ea.	$5,000	$5,000		1	ea.	$5,000	$5,000
Direct-Push Contractor	25	days	$2,500	$62,500		20	days	$2,500	$50,000
Oxidant Costs	48,137	lbs	$1.20	$57,764		16,020	lbs	$2.00	$32,040
Activator Costs	10,697	lbs	$0.65	$6,953		16,020	lbs	$2.00	$32,040
	58,834			$132,217		32,040			$119,080

* P. Block and W. Cutler, "Klozur® Activated Persulfate for Site Remediation: Comparative Evaluation of Treatment Efficacy and Implementation Costs.", Presented at 4th International Conf. on Oxidation and Reduction technologies for In-Situ Treatment of Soil and Groundwater, October 23-27, 2005.

Most chemical oxidation sites require product re-application to minimize rebound. Because RegenOx™ uses a true catalyst (i.e in both Part A and Part B) which will remain active in the subsurface for years, re-application costs will be significantly less on subsequent injections. For re-application, the use of RegenOx in the scenario described above offers a cost savings of $29K over sodium persulfate or $1.82 less per cubic yard (Table 2).

Table 2: Re-application Cost Comparison Between RegenOx™ Oxidation System and Klozur® Sodium Persulfate

Cost	Sodium Persulfate					RegenOx™			
Direct Capital Costs	No.	Units	Unit Cost	Cost		No.	Units	Unit Cost	Cost
Direct-Push Mob	1	ea.	$5,000	$5,000		1	ea.	$5,000	$5,000
Direct-Push Contractor	25	days	$2,500	$62,500		20	days	$2,500	$50,000
Oxidant Costs	48,137	lbs	$1.20	$57,764		16,020	lbs	$2.00	$32,040
Activator Costs	10,697	lbs	$0.65	$6,953		8,010	lbs	$2.00	$16,020
	58,834			$132,217		24,030			$103,060

* P. Block and W. Cutler, "Klozur® Activated Persulfate for Site Remediation: Comparative Evaluation of Treatment Efficacy and Implementation Costs.", Presented at 4th International Conf. on Oxidation and Reduction technologies for In-Situ Treatment of Soil and Groundwater, October 23-27, 2005.

Safety/ Material Compatibility

RegenOx is engineered for ease of handling in the field and is safely mixed without the safety risks and hazards attendant to other chemical oxidant such as persulfate-type products. The activation of persulfate poses significant safety risks as this process usually entails the use of concentrated hazardous fluids injected under high pressure.

The use of persulfate and the attendant activator solutions also raises significant materials compatibility issues. The use of activated persulfate can lead to corrosion and damage of underground structures as well as the tooling used to apply the material (figure 1).

Figure 1. (Left) a corroded pump fitting that required replacement after one day of operation using sodium persulfate. (Right) a new fitting for sake of comparison.

Longevity

RegenOx remains effective in the subsurface for a period of time lasting from about 15 days to one month. The length of time it lasts is adjustable by adding more or less of the Part B Activator. In comparison, activated persulfate has a longevity range of only several days time.