Extended Release Low Solubility Potassium Persulfate Laboratory and Field Applications

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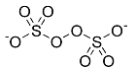
Persulfates

- Klozur SP
  - Environmental grade sodium persulfate
- Klozur KP
  - Environmental grade potassium persulfate



Key Persulfate Characteristics:

- A strong oxidant
- Applicable across a broad range of organic contaminants
- Extended subsurface lifetime (weeks to months)
- Little to no heat or gas evolution
- Activation results in the formation of radicals

Klozur KP vs Klozur SP

- Different characteristics equals different opportunities

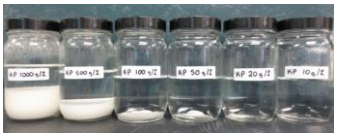
Temperature (°C)	Klozur SP wt%	Klozur SP g/L	Klozur KP wt%	Klozur KP g/L
0	36.5	480	1.6	17
10	40.1	540	2.6	29
20	41.8	570	4.5	47
25	42.3	580	5.7	59

- Primary differences to sodium persulfate
  - Solubility
  - K^+ vs. Na^+

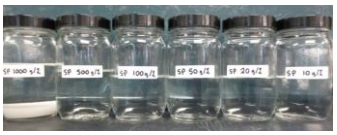
Characteristic	SP	KP
Formula	$Na_2S_2O_8$	$K_2S_2O_8$
Molecular Weight	238.1	270.3
Crystal density (g/cc)	2.59	2.48
Color	White	White
Odor	None	None
Loose bulk density (g/cc)	1.12	1.30

Solubility Limited Release Static System

Reactors at ~20°C
Klozur KP Solubility = 47 g/L



Reactors at ~20°C
Klozur SP Solubility = 570 g/L



Conceptual Permeable Reactive Barrier

- Permeable Reactive Barrier (PRB)
- Conceptual Design of Gate
  - 50 ft wide, 10 ft high, and 3 ft deep
  - 60,000 lbs of Klozur KP
  - 15% ePorosity

Groundwater Flow

KP PRB

Conceptual Persistence of the Extended Release KP

Conceptual Klozur KP Persistence (years)						
	Temp (°C)	5	10	15	20	25
	Solubility (g/L)	22	29	37	47	59
Groundwater Seepage Velocity (ft/yr)	10	58	44	35	27	22
	25	23	18	14	11	9
	50	12	8.8	6.9	5.5	4.3
	75	7.8	5.9	4.6	3.6	2.9
	100	5.8	4.4	3.5	2.7	2.2
	500	1.2	0.9	0.7	0.5	0.4

*Does not consider potential "site" factors

Activation of Persulfate

Sodium Persulfate:

- Aqueous phase oxidant – aqueous phase activators
  - NaOH (alkaline)
  - Fe:Chelate
  - Hydrogen peroxide
  - Heat

Potassium Persulfate:

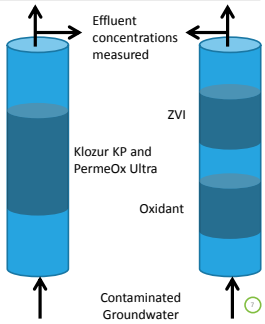
- Solid/extended release oxidant – **Solid/extended release activators**
  - **Hydrated lime-$Ca(OH)_2$ (alkaline)**
  - Zero Valent Iron (ZVI)
    - Separate trench (down gradient)
  - PermeOx Ultra (alkaline)

Purchase of Klozur persulfate includes with it the grant of a limited license under PeroxyChem's patents covering the use of Klozur persulfate for environmental applications at no additional cost to the buyer

Treatability Column

Site:
- Former drum storage facility
- Superfund site
- Contaminanted with chlorinated ethenes, ethanes, and 1,4-dioxane

Column Study:
- 12 inch columns
  - 50:50 blend of sand and either Klozur KP or Klozur SP. Sand above and below
- Four columns (20 °C)
  - Control (sand only)
  - Klozur SP
    - ZVI
  - Klozur KP
    - ZVI
    - PermeOx® Ultra
    - Hydrated Lime



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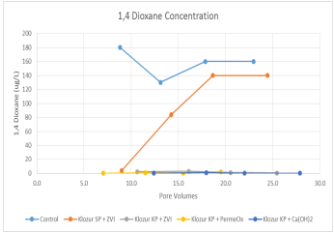
Treatment of 1,4-Dioxane



- All systems with KP treated 1,4-Dioxane to ND
- SP had breakthrough
- ZVI and hydrated lime lasted the longest

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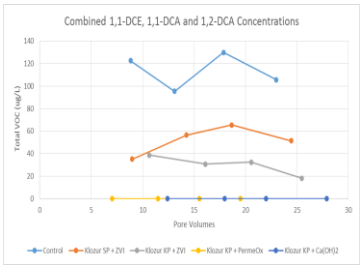
Treatment of CVOCs

- Alkaline activated KP treat cVOCs to ND
- ZVI activated KP-~75% treatment
- SP with ZVI-~50% treatment



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Potential Applications

K^+ vs. Na^+	Benefit from Extended Release
• Certain sites have limits on sodium	• Permeable reactive barriers – Funnel and Gate
• Potassium persulfate would be alternative – Higher solubility at higher temperatures	• Low permeable soils – Low groundwater flux
	• In situ soil mixing

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Field Applications of KP

- Mostly emplacement
- Activated:
  - Iron-chelate
  - Alkaline
- Rationale
  - Easy of emplacement
  - Potassium residual
  - Longevity over SP
- Aquifer materials
  - Clay
  - Sand
  - Bedrock

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Conceptual Implementation Approaches

- Constructed Permeable Reactive Barrier
  - Ditch/trench tool
  - Excavator
- In Situ Soil Mixing
  - KP, SP or blend
  - Slaked lime or NaOH activator

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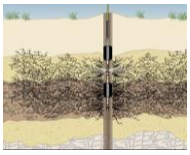
Conceptual Implementation Approaches

- Expected loadings through emplacement/ fracturing technologies
  - Hydraulic
    - 50-100 lbs per linear foot
  - Specialized Hydraulic
    - 1,000-4,000+ lbs per fracture
  - Pneumatic
    - ~300-500 lbs per vertical foot



Case Study

Courtesy of Riskcom and Toterra

- Former industrial sites in Germany
- Former drum area
- Contaminants: cVOCs, Naphthalene and BTEX
- Contaminants mainly in low permeable sandstone up to 12 m bgs
- Pump & treat not practical and not possible for excavation
- Preferred approach was hydraulically placed ISCO technology

Case Study

- Pilot Project:
  - Targeted 7 to 11 m bgs
  - Heavy GW impacts
  - Emplaced KP:
    - 3 injection location
    - 5 lifts per location
  - Total of 1,350 kg KP with 200 kg of ferrous lactate

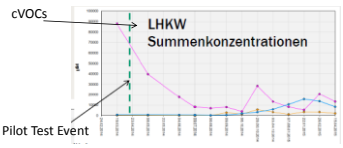
Courtesy of Riskcom and Toterra

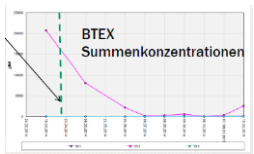
Tiltmeter Data

- Area of influence of the fractures
  - IBr-1
    - 125 m2 (1,350 ft2)
    - 9.1 x 13.7 m (30 x 45 ft)
  - IBr-2
    - 111 m2 (1,200 ft2)
    - 9.1 x 12.2 m (30 x 40 ft)
  - IBr-3
    - 127 m2 (1,375 ft2)
    - 7.6 x 15.2 m (25 x 55 ft)
- If circular: 6.2 m ROI (~20 ft)
  - Observed to be more rectangular

Analysis by Gord Guest/Geotactical

Long Term Monitoring Results





Courtesy of Riskcom

Results and Conclusions

- 1 Year Post Application Monitoring
- Successful distribution of KP and activator over a 200 m^2 area (2,152 ft^2) with 3 injection locations
- Activated Klozur KP resulted in up to 99% treatment of Target COCs

Date	Contaminant (mg/L)				
	PCE	TCE	cDCE	BTEX	PAH
3/19/2014	13,000	22,000	52,000	20,713	98
10/7/2014	8	23	3,800	47	5
Percent Reduction	99.9%	99.9%	92.7%	99.8%	94.5%
4/15/2015	4	6	13,000	2,570	104
Percent Reduction	99.97%	99.97%	75.0%	87.6%	-5.3%

Courtesy of Riskcom

Klozur KP Summary

- Extended Release Oxidant
  - Groundwater plumes
  - Low permeable soils
  - Potassium residual
- Critical Information:
  - Groundwater flux
    - Hydraulic conductivity
    - Hydraulic gradient
  - Aquifer temperature
  - Aqueous phase demand
    - Target
    - Non-target (COD, etc)
  - Depth to target interval

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Klozur KP Summary: Compounds Degraded

Example Contaminants Treated by Klozur Persulfate with proper activation

Chlorinated Solvents
PCE, TCE, DCE
TCA, DCA
Vinyl chloride
Carbon tetrachloride
Chloroform
Chloroethane
Chloromethane
Dichloropropane
Trichloropropane
Methylene chloride

Others
Carbon disulfide
Aniline
1,4-Dioxane

TPH
BTEX
GRO
DRO
ORO
creosote

Oxygenates
MTBE
TBA

Fluorinated
Freon
PFCAs (PFOA)
Fluorotelomers

Chlorobenzenes
Chlorobenzene
Dichlorobenzene
Trichlorobenzene

Phenols
Phenol
Chlorophenols
Nitrophenols

PAHs
Anthracene
Benzopyrene
Styrene
Naphthalene
Pyrene
Chrysene
Trimethylbenzene

Pesticides
DDT
Chlordane
Heptachlor
Lindane
Toxaphene
MCPA
Bromoxynil

Energetics
Trinitrotoluene (TNT)
Dinitrotoluene (DNT)
RDX

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Klozur® Portfolio

KLOZUR® SP
– Sodium persulfate

KLOZUR® ONE
– "All-in-One" product where activator (5%) and Klozur SP (95%) are in the same product

KLOZUR® KP
– Potassium persulfate

KLOZUR® CR
– "Combined Remedy" with ISCO and ISB from a blend of Klozur SP and PermeOx® Ultra

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Each product has it's place

- KLOZUR® SP
  - Source zone treatment
  - Oxidative and reductive pathways
  - Alkaline activation best for DPT rods/soil mixing
- KLOZUR® ONE
  - Source zone treatment
    - Highly soluble
  - Primarily oxidative pathway
  - Ease of Use
- KLOZUR® KP
  - Permeable Reactive Barriers
  - Low permeable soil treatment
  - Soil Mixing
  - Oxidative and reductive pathways
- KLOZUR® CR
  - Combined remedy of ISCO followed by bioremediation

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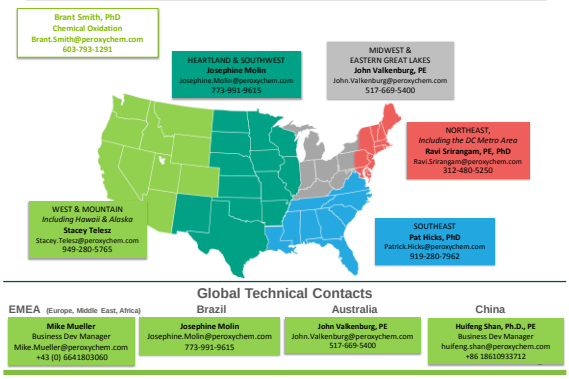
PeroxyChem Environmental Solutions Team



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