Klozur® KP Application Guidelines

Klozur® KP is a high purity extended release grade of potassium persulfate. Klozur KP will persist in the subsurface for an extended period of time when applied at concentrations greater than its theoretical solubility. Klozur KP can be activated using PeroxyChem's patented technologies[1] to form powerful oxidative and reductive radicals that aggressively treat a wide array of targeted contaminants. PeroxyChem's persulfate activation technology is well established having been successfully applied in thousands of field applications and scientifically validated in hundreds of independent peer-reviewed journal articles and conference presentations.

Klozur KP is part of PeroxyChem's portfolio of persulfate-based oxidants includes Klozur SP, Klozur One, and Klozur CR. Klozur products are typically applied using an injection, soil mixing, or backfill strategies to establish contact between the activated persulfate and the contaminants of concern. This document will provide general application guidelines for Klozur KP. For more information on Klozur KP or other products in PeroxyChem's Klozur Portfolio, please visit www.klozur.com.

FIELD APPLICATIONS

Klozur KP is typically injected into the target zone as a solid-slurry mixture or applied directly as a solid amendment to an excavation, trench or with backfill. Klozur KP in the solid state will slowly dissolve maintaining a concentration of persulfate in groundwater over time. The solid state extended release Klozur KP is typically paired with a solid state extended release activator such as hydrated lime [$Ca(OH)_2$] or zero valent iron (ZVI). Hydrated lime can be added either directly with the Klozur KP or placed close by, but downgradient. ZVI must be placed downgradient from Klozur KP as it cannot be safely mixed with the Klozur KP. In applications where aqueous phase activators are not expected to migrate with groundwater flow, other activators can be used. For more information on each activation chemistry, please visit www.klozur.com or consult with your regional PeroxyChem technical representative.

SLURRY PREPARATION

Klozur KP is a fine granular product with a low solubility at typical injection temperatures (Table 1). In most applications it will not be fully soluble in water and it will need to be prepared as a water-solid slurry. The slurry should be stirred until the entire product is suspended in solution and the uniform suspension maintained for injection. When batching any Klozur product, it is important to ensure that the tank, water, mixing equipment and any other parts that will contact the reagent solution are clean and devoid of impurities that might react with the oxidant. Klozur KP should be batched in systems where all wetted parts or parts that could become wetted are chemically compatible. Please refer to PeroxyChem's Technical Bulletin: *Corrosion and Material Compatibility with Klozur Persulfate*, which can be found at peroxychem.com/remediation, for a list of chemically compatible materials. A chemically compatible secondary containment is also recommended beneath the batching system.

Klozur KP slurries are typically prepared in small batches the day of the injection event for immediate use. PeroxyChem does not recommend making a Klozur KP slurry prior to the day of use or storing a Klozur KP slurry overnight (*See Tank and Pump Safety Note below). Mixing should take place in a chemically compatible tank, such as high-density polyethylene (HDPE), with a chemically compatible mechanical mixer composed of a material such as 304 or 316 stainless steel. Klozur KP will begin to decompose and generate acid if impurities such as metals are present in the make-up water or at elevated temperatures. PeroxyChem recommends that Klozur KP slurries be held no longer than 8 hours at cool temperatures (typically less than 20°C) and not exceed 30°C. Higher temperatures will result in decomposition.

Temperature	Klozur® KP	
(◦C)	(wt%)	(g/L)
0	1.6	17
10	2.6	29
20	4.5	47
25	5.7	59

Table 1: Solubility of Klozur KP in Water at Various Temperatures

TANK AND PUMP RECOMMENDATIONS

A Klozur KP slurry is typically prepared in a chemically compatible, vented tank. A tank with a conical bottom and bottom drain can aide in the removal of the slurry. The slurry within the tank should be under constant agitation until emptied. In addition to the main line to the injection network, a small recycle loop from the pump back into the tank will help prevent the accumulation of slurry contents that may be too high in solids or if the slurry begins to settle out at levels below the mechanical mixer. Near the very end of the tank cycle, the pump recycle line should be shut-off entirely to allow full flow forward via the pump to the injection point. All wetted parts in the injection system, including the tank, valves, flanges, gaskets, check valves, pumps, pipes, and gauges should be chemically compatible with Klozur KP and, as necessary, the activation chemistry.

Air-operated, positive displacement, self-priming double diaphragm pumps have been successfully used for the injection of 10 to 35 wt% Klozur KP. It is recommended that the double diaphragm pump with a minimum of 1 ½ inch inlet and outlet be used. A variety of these types of pumps are manufactured by Wilden® and Sandpiper®. All wetted parts of the pump and all parts in contact with Klozur KP must be constructed of or coated with materials compatible with oxidizers such as 304L or 316L stainless steel, polyethylene, polyvinylidene fluoride (PVDF) or polytetrafluoroethylene (PTFE or Teflon®).

TANK AND PUMP SAFETY NOTE*

Klozur KP may undergo decomposition if stored or handled improperly or if it comes into contact with impurities. Please refer to the Klozur KP Safety Data Sheet (SDS) and the Klozur Persulfate Safety and Handling Technical Bulletin available on PeroxyChem's website. Klozur persulfate slurries/solutions decompose auto-catalytically. Decomposition is a function of temperature, time, the presence of activators including transition metals, and exposure to incompatible materials. The duration slurries and solutions are under pressure should be limited as they can increase in temperature and decompose more rapidly. Excessive strictures or friction points in the conveyance system should be eliminated for the same reason.

All equipment, such as pumps, tanks, and hoses, MUST be cleaned out with a water flush at the end of every work day. This is to avoid potential pressure buildup due to decomposition and to reduce potential corrosion on equipment.

INJECTION OF KLOZUR KP

Klozur KP needs to be applied or injected in a manner that will allow for transport and distribution of the solid material into the subsurface. Klozur KP is injected at depth through rods are typically solid (blank) until reaching the intended depth where the reagents can flow through large orifices and out into the targeted interval of the subsurface. The reagents are then distributed into the subsurface for a certain radius of influence (ROI) depending upon the site characteristics and injection volume. As a solid-slurry, Klozur KP is typically applied through large orifice tooling at pressures sufficient to create fractures that aide distribution. Several contractors utilize specialized tooling for the injection of solid-slurries. The most common method used are based on Direct Push Technology (DPT).

If using DPT tooling, at each injection point the rods are initially advanced to the top (or bottom) of the targeted depth interval and a specified volume of slurry is injected before proceeding to the next depth. Using DPT tooling allows for targeting vertical injection intervals of approximately 1 to 3 ft (0.3 to 1.0 m). The preferred approach for the injections is often in the top-down direction using an injection tip that directs the slurry horizontally. However, different contractors may prefer to start at the bottom of the target interval (bottom-up approach) based on their specific tooling or an evaluation of site conditions.

Since carbon steel is the common material for DPT rods, most practitioners prefer to use alkaline activated Klozur persulfate to help minimize possible corrosion. Other steps to mitigate corrosion that are commonly taken include taping or otherwise protecting the rod threads with materials compatible with Klozur KP, and rinsing the rods after use and prior to storage. The rinse solution often includes a pH buffer, such as sodium bicarbonate, and a reactant such as a dilute alcohol or sodium ascorbate. PeroxyChem recommends coordinating with your DPT contractor to make sure they are using a chemically compatible system to inject Klozur KP.

Depending on the injection objectives, other common components that may be necessary in an injection system include flow meters, pressure gauges, pressure relief valves, temperature gauges, valves to open and close portions of the system (i.e. ball valves or equivalent), and valves to help moderate injection rates (i.e. gate valves or equivalent). If injecting into multiple locations simultaneously, multiple injection lines can be split off down gradient of the injection pump with each line typically having its own set of valves, gauges, and flow meters. All components of the injection system must be chemically compatible with Klozur KP and the activator chemistry.

Injection Spacing

Activated Klozur KP needs to be adequately distributed within the subsurface in order to establish sufficient contact with the contamination. The volume of reagents injected can be critical in terms of the distance from each injection point the reagents are distributed. This distance is commonly referred to as the radius of influence, or ROI.

There are typically three ROIs:

- Design ROI. The design ROI is the radius intended to be treated by each injection point. This can include the injection ROI, as well as additional distribution of the reagent due to diffusion and advection with groundwater flow after the injection event. Injection point spacing is often set so that the design ROIs overlap, typically by 15 to 20 percent, which minimizes untreated areas and results in additional treatment of soils the furthest away from the injection points.

- Injection ROI. The injection ROI is a design parameter estimating the distance the injection volume will distribute the reagents from the injection point. For injection of solid-slurries, the injection ROI is often a result of injection pressure, flowrate, and the formation.

- Observed ROI. This is the actual ROI from an injection point confirmed in field optimization studies or field pilot tests. The observed ROI may vary vertically with different soil types and preferential flow paths even from the same injection point.

It is recommended that these parameters be evaluated during a pilot-scale test injection and that a flexible approach be used during a field installation as site conditions can vary. Based on experience from a range of sites for DPT, a design ROI of approximately 5 ft (1.5 m) to 6 ft (1.8 m) for each injection location and spacing injection locations 8 ft (2.4 m) to 12 ft (3.7 m) apart (on center) are typical. Specialized injection tooling has been observed to have ROIs of up to 20 ft (6 m), which would include spacing each injection location 30 (9 m) to 36 ft (11 m) apart (on center). Injection locations tend to be located in staggered rows with overlapping ROIs. PeroxyChem recommends discussing injection spacing with your selected contractor and confirming the observed ROI during a field application.

Soil acceptance may also vary greatly depending on the Klozur KP slurry concentration, site lithology and heterogeneity, ability to fracture the soil, and injection depth. As a general guideline the amount of Klozur KP accepted by soils in more permeable formations is approximately 100 lbs solids per vertical foot (150 kg/m). For less permeable formations, soil acceptance is approximately 50 lbs per vertical foot (75 kg/m). Another general rule that is often applied to estimating the mass of solids that can be added to a subsurface is to fill 10 percent of the pore volume with solids (v/v). The actual soil acceptance can be tested and confirmed in field pilot scale tests. If greater amounts of Klozur KP are required, a closer spacing of the injection locations, or smaller ROI, may need to be used or the slurry concentration can be increased, if possible.

Note: Significantly greater ROIs have been observed with certain fracturing techniques. Please contact PeroxyChem for further information regarding ROI monitoring and site observations.

Soil Mixing

Soil mixing is a common method of establishing contact between activated Klozur KP and contamination in the subsurface. A soil mixing strategy typically involves the mechanical agitation of subsurface soils blending in both Klozur KP and the necessary activator reagents. The mechanical agitation breaks apart the natural soil structure and helps to establish contact between activated Klozur persulfate and the contamination found in the soils. Since good

contact is key for successful remediation and soil mixing can be particularly useful in treating source zones and lower permeable soils such as silts or clays. Klozur KP is typically applied at 1% to 5% w/w with the soil.

Soil mixing has been used to target:

- Source areas as the primary method of treatment
- To treat residual contamination after excavation as a secondary method of treatment
- Combined with *in situ* stabilization (ISS) and other technologies

Soil mixing equipment often contains carbon steel. Klozur KP, by itself, is corrosive to carbon steel. Most practitioners prefer alkaline activated persulfate for soil mixing as it helps protect the carbon steel mixing equipment. If interested in a soil mixing application, please contact your PeroxyChem technical representative or email remediation@peroxychem.com to discuss how to decrease the potential corrosion of the mixing equipment.

For more information, please refer to the *Klozur Persulfate Soil Mixing Recommendations and Applications Guidelines* document, which can be found at peroxychem.com/remediation.

Trench Application

Klozur KP can also be applied to a site in a trench. This method would be used to create a permeable reactive barrier and treat aqueous phase contamination. Trenches can be constructed using excavator tools or specialized trench tools that insert the reagent mixture into the subsurface as the trench is being created. The depth of a trench is limited by the tool used to create the trench. To maintain permeability, Klozur KP is typically blended with a highly conductive material such as sand. If the activator is added to the same trench as Klozur KP, the activator must be compatible. In the event that the activator and Klozur KP are not compatible, such as ZVI, then it is recommended that the Klozur KP be installed in a trench up gradient of a second trench containing the activator. In this case, the Klozur KP will dissolve and flow down gradient to be activated in the second trench.

Backfill Application

Absent any specific site information, a range of 1 to 4 lbs Klozur KP per square foot of the pit surface area, or approximately 5 to 20 Kg per square meter, is recommended during mixing as a polishing treatment for residual contamination. If the Klozur KP is to be blended with soil in the bottom of the excavation, 1 to 4 lbs Klozur KP per cubic foot or approximately 16 to 64 Kg per cubic meter, is recommended and should be combined with appropriate amounts of activator (see activation guides at www.klozur.com). Higher dosage rates are typically applied at sites with more extensive contaminant impacts, to offset uncertainty or variability in contaminant distribution, with higher groundwater flow velocities, or as otherwise desired. Lower dosage rates tend to be used for less contaminated sites.

Klozur KP can be applied as a backfill amendment in a variety of modes, including: 1) Directly applying the dry reagents to the base of the excavation and backfilling on top; 2) Applying directly to the base of the excavation and then using a device such as a mixing tool or excavator to blend the Klozur KP with the soil or soil slurry; or, 3) Blending Klozur KP and activator with additional backfill material and applying the combined material to the bottom of the excavation. When applying dry phase reagents, it is recommended that Klozur KP and activator be applied very close

to or directly on the base of the excavation to minimize dusting and that all personnel be wearing proper personal protective equipment (PPE) as specified in the Klozur KP and selected activator SDS(s).

Klozur KP and activator are intended to be in hydrated conditions they rely on a sufficient amount of water to facilitate the treatment mechanism. Because of this, Klozur KP is intended to be applied as a backfill amendment in the saturated zone or in zones that will be saturated with water very shortly after the application. If Klozur KP is applied as a dry reagent it should be wetted down and the area should be saturated with water so that the conditions will remain saturated for a sustained period of time.

OPTIMIZATION STUDIES: BENCH AND PILOT SCALE TESTS

Projects often include a series of tests to help develop and confirm a variety of design parameters and assumptions prior to the full-scale application of Klozur KP. PeroxyChem recommends performing bench scale tests to estimate the non-target demand associated with the soil and, if desired, to confirm the treatment effectiveness of different concentrations of Klozur KP with contaminated site soils and groundwater. The non-target demand test is a critical design element for Klozur KP. PeroxyChem refers to our non-target demand, or soil oxidant demand (SOD), test as the Klozur Demand Test (KDT). PeroxyChem has a full-service treatability laboratory to conduct bench scale studies using Klozur KP. More information on these lab tests is available from your PeroxyChem technical representative or by emailing remediation@peroxychem.com.

Field optimization studies or field pilot tests can be used to further assess the application of Klozur KP prior to a full-scale application. In addition to confirming treatment effectiveness, common objectives of these field evaluations include assessing injection pressures, flow rates, reagent distribution, and using the observed ROI to confirm the assumptions made in determining both the design and injection ROI.

STORAGE AND HANDLING

Klozur KP is a UN Class 5.1 oxidizer. It should be stored in a secure, cool and dry location. The temperature of Klozur KP should not exceed 45°C (113°F). PeroxyChem does not recommend storing Klozur KP in field conditions for extended periods of time. Do not store liquid solutions of Klozur KP. For more information on storage and handling, please see guidelines for persulfate at www.peroxychem.com/chemistries/persulfates/safe-storage-handling.

MATERIALS OF COMPATIBILITY

As specified by the safety data sheet (SDS), Klozur KP is a DOT class 5.1 oxidizer and a corrosive material. All materials contacting Klozur KP should be chemically compatible including tanks, pumps, injection rods, seals, gaskets, tubing, hoses, and mixing equipment.

Compatible materials include: stainless steel (304L and 316L), polyethylene (PE), polyvinylchloride (PVC), polytetrafluoroethylene (PTFE), Viton®, polyvinylidene fluoride (PVDF), and butyl rubber. Materials NOT compatible include, nitrile rubber, carbon steel, aluminum, brass, galvanized steel, or any other metal susceptible to corrosion. Compatibility may change based upon the combination of Klozur KP with its activator solution. Please refer to

PeroxyChem's Corrosion and Material Compatibility of Klozur Persulfate Technical Bulletin for more detailed information, available at www.peroxychem.com/remediation.

HEALTH AND SAFETY

Klozur persulfate has been applied safely and effectively at thousands of sites. However, as with any chemical, proper procedures should be followed and recommended equipment used. When working with Klozur persulfate, ensure adequate ventilation and use the appropriate personal protective equipment, including safety glasses, suitable protective clothing, boots (steel toed or equivalent), chemical resistant gloves, hard hat, and hearing protection. For dust, splash, mist, or spray exposures wear a filtering dust mask and chemical protective goggles. A face shield can also be used in addition to goggles.

Please consult the appropriate safety data sheets (SDS) for guidelines regarding proper handling procedures. Klozur persulfate SDS's can be found at www.peroxychem.com/remediation. Additional safety equipment may be required for mechanical and site operations.

Please contact PeroxyChem for additional guidance.

Notes

1. A limited use license is included with the purchase of Klozur® Persulfate for PeroxyChem's suite of national and international patents for the activation of persulfate to remediate environmental contaminants of concern including but not limited to US 6474908, US 7473372, US 9821353, US 7524141, US 7576254B2, US 7785038, and US 9375768B2.