BOS 200® versus Colloidal Activated Carbon

Powdered – vs – Colloidal

Choosing the Right Activated Carbon Can Be a Challenge

RPI
Remediation Products, Inc.

BOS 200® versus Colloidal Activated Carbon (CAC)

Technical Bulletin

Executive Summary

Key differences exist between activated carbon based in situ remediation technologies such as BOS 200® and colloidal activated carbon (CAC). These differences include remedial efficiency, applicable groundwater and soil concentration ranges, application technique, particle size, bacterial and nutrient co-injection, and selection of terminal electron acceptors.

BOS 200® and BOS 200+® are complete in situ remediation systems that incorporate powdered activated carbon, electron acceptors, micro- and macronutrients, and a blend of facultative bacteria. CACs typically lack key nutrients and beneficial bacteria, although specific deficiencies vary by product.

This Technical Bulletin outlines the differences between CAC and BOS 200, enabling environmental practitioners to select the appropriate technology that meets project objectives and client expectations.

Technology Comparison Summary

Characteristic	**BOS 200®**	**CAC**
Applicable for Low Concentration Plumes	✓	✓
Applicable for High Concentration Source Areas	✓	✗
Applicable in High K Zones	✓	✓
Applicable in Low K Zones	✓	✗
May Coat Sand Filter Pack	✗	✓
Requires High Salt "Parking Agent"	✗	✓

Characteristic	**BOS 200®**	**CAC**
Hydrocarbon Degrading Bacteria Added	✓	✗
Electron Acceptor Co-injected	✓	Variable
Nutrients Added	✓	✗
AC Surface Features Support Microbial Life	✓	✗
Blocks Existing Organic Soil Porosity	✗	✓
Uses "Primed" Activated Carbon	✓	✗

Detailed Technical Comparison

1. Applicable Concentration Ranges

Significant differences exist between CAC and BOS 200 technologies regarding treatable contaminant concentrations.

CAC Limitations

The CAC approach is limited by the amount of activated carbon that can exist in solution. Aggregation of particles in colloidal systems has been studied extensively across various industries. Determining particle concentration requires trade-offs:

- **Low loading** fails to support sufficient adsorption
- **High loading** results in particle aggregation

When significant particle aggregation occurs, the average particle size exceeds the intended colloidal range, negating the value of colloidal-sized particles.

To facilitate activated carbon loading and reduce particle aggregation, all colloidal activated carbon products use dispersants. The dispersant influences loading, distribution, formation interactions, bioremediation rate, and sustainability. Project managers should carefully consider dispersant characteristics when evaluating colloidal products.

The rate at which colloidal carbon agglomerates and affixes to the formation depends on the dispersant employed (Haupt, 2019) and installation technique. Therefore, CAC technologies are limited to polishing and/or dissolved-phase treatment due to the incompatibility of colloidal suspensions and high carbon loading.

BOS 200 Advantages

In contrast, BOS 200 successfully treats across the concentration spectrum from polishing to LNAPL treatment. Case studies for BOS 200 source area applications can be found at:

- https://www.trapandtreat.com/portfolio_page/marshall-iron-and-metal-bos-200/
- https://astenvironmental.com/portfolio/bos-200-application-earns-no-further-action-status/
- https://ejlskov.com/bioremediation-reduces-costs-for-groundwater-clean-up-at-shell-refinery/

2. Carbon Sources

The choice of material from which activated carbon is made significantly affects its adsorption characteristics (Zango et al., 2020). Despite being rich in binding pores (micropores), coconut-based AC exhibits slower kinetic adsorption due to relatively fewer transport pores or mesopores (McNamara et al., 2018).

Key Differences:

- **BOS 200**: Uses food-grade, coal-based activated carbon
- **CAC**: Typically made from coconut shell carbon

Coconut shell carbons are less expensive and easier to mill to colloidal size, but coconut carbon does not bioregenerate as well as wood-based (Piai et al., 2019) or coal-based activated carbons (Zhang et al., 2013). Based on bioregeneration alone, coconut carbon requires a 20-30% increase in loading relative to coal-based carbon.

Additionally, coconut carbon has lower adsorption capacity for petroleum hydrocarbons across molecular weights compared to coal-based activated carbons, although it performs slightly better at adsorbing low molecular weight aromatics.

3. Application Techniques

CAC and BOS 200 are applied to the subsurface using significantly different methods.

CAC Application

An advertised strength of CAC is that it can be applied using low flow rates and low-pressure conditions without specialized equipment. However:

- **Low-flow, low-pressure injection** works only in high hydraulic conductivity aquifers (sands, gravels)
- **Low-flow, low-pressure injection cannot penetrate lower-permeability zones** where most contaminant mass typically resides
- **Relies strictly on diffusion** from lower to higher permeability zones, making it limited and inefficient outside high-conductivity geological settings

After numerous failures to distribute CAC using low pressure, CAC installers have begun employing high-pressure injection. However, this negates the core selling point that high-pressure equipment is unnecessary. If high-pressure equipment is required, there is no added value to grinding activated carbon to 1-2 µm. The small particle size becomes incompatible with high mass activated carbon loading, and the dispersant facilitates uncontrolled dispersion, potentially requiring salt solution injection to address dispersion issues.

BOS 200 Application

BOS 200 is installed using high-energy emplacement methods tuned to lithology:

Coarse-grained aquifers:

- High emplacement velocities overcome natural filtering effects
- Create radial mixing within treatment zone
- Injection pressure signature is typically linear

Fine-grained aquifers:

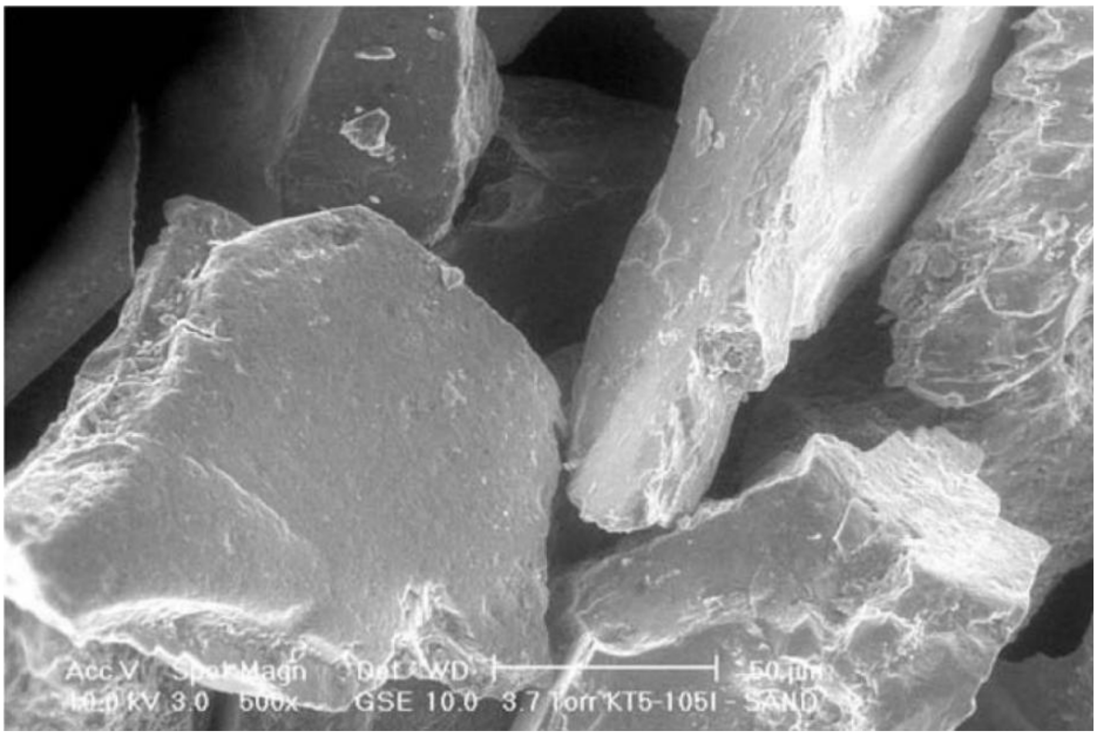
- Sufficient pressure applied to cause soil structure to yield along preexisting low-resistance paths
- BOS 200 is applied at lower, sustained injection pressure (propagation/maintenance pressure)
- Tight grid spacing (typically 5-10 ft) with vertically offset injection intervals

BOS 200 is installed as a slurry. When active injection ceases, product movement stops as pressure bleeds off, and BOS 200 remains emplaced in the stratigraphy. BOS 200 does not move once emplaced.

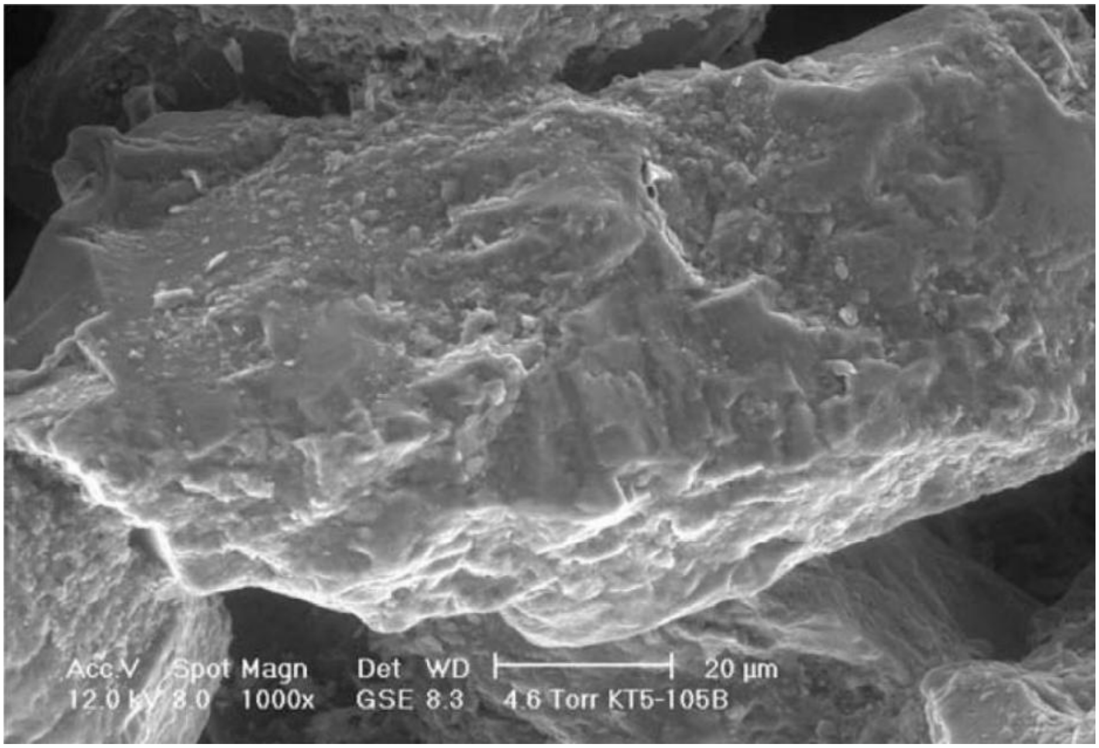
4. Monitoring Well Impact

CAC Issues

CAC coats sand particles in monitoring well filter packs (see Images 1A and 1B below). Once CAC coats the filter pack, monitoring wells fail to accurately characterize groundwater contaminant concentrations, as contaminants are lost to the CAC-coated filter pack. Additionally, colloidal particles pass through pore spaces and enter monitoring wells. Given the small size of CAC particles, monitoring wells cannot be rehabilitated solely by cleaning.



Scanning electron microscope (SEM) image of sand particles without CAC coating.



Scanning electron microscope (SEM) image of sand particles with CAC coating. The coating appears as particles in the sub-micron to 3 µm range. Compare the sand grains in Image 1A to Image 1B and note the rough surface from colloidal carbon attachment. Sand grains in a fine 20/40 mesh sand pack have an effective pore diameter of 85-170 µm. Colloidal particles can pass through the pore space (images from Haupt 2019).

Laboratory Testing Results

One CAC company's literature claims that groundwater samples can be sent to the laboratory for contaminant analysis when you can see through a 40-mL VOA vial. They write that when you can see through the vial that corresponding to approximately 100 mg/L or less suspended CAC (Regenesis 2022).

The RPI Laboratory tested this claim by adding CAC to vials containing 50 ppb of p-Bromo fluorobenzene. The relative percent change between the blank without CAC and the 100 ppm CAC sample was 53.8%. Being approximately 50% wrong is not trivial for analytical results. See Table 1. You may be able to see through a vial containing CAC, but that does not mean your analytical results are accurate.

The data demonstrate the interference effect of colloidal activated carbon (CAC) on the GC/MS analysis of p-Bromofluorobenzene. There is a clear inverse correlation between CAC concentration and analyte recovery, with recovery decreasing from 64.72% in the blank to 29.92% at a CAC concentration of 100 ppm.

Experimental Data

CAC (ppm)	Recovered (ppb)	Recovery (%)
0	32.36	64.7
10	30.25	60.5
50	20.84	41.7
100	14.96	29.9

All samples spiked with 50 ppb p-Bromofluorobenzene

Table 1. This data demonstrates that CAC particles adsorb the benzene compound, reducing the amount available for detection and leading to underestimation of contaminant concentrations in environmental samples containing CAC.

BOS 200 Advantage

Using methods developed within the RPI Group, BOS 200 can be cleaned out of monitoring wells in most cases.

5. Activated Carbon Particle Size

CAC lacks significant surface fractures and macropores because they are removed by the milling process used to make particles "colloidal" sized. BOS 200 particles average 24 µm in diameter, while CAC particles average 2 µm in diameter. This size difference impacts both biodegradation and adsorption.

Microbial Habitat Differences

Activated carbon installed in the subsurface becomes a habitat for microorganisms. Bacteria range in size from approximately 1 to 5µm—meaning microbes are on average larger than individual CAC particles. Bacteria are simply too large to inhabit CAC particles. In contrast, bacteria can and do inhabit the macropores and surface features of BOS 200, making it an efficient platform for biological treatment.

Performance Implications

- **CAC has higher rollover rate**: Milling to 1-2 µm slightly increases initial adsorption rate but results in faster desorption than powdered or granular activated carbon
- **Loss of macropores and mesopores** increases desorption rate significantly, directly resulting in higher contaminant rollover (McNamara 2018) (Liang 2007)
- **Lower biodegradation rates**: Decreasing particle size leads to lower biodegradation rates (Rattier 2012)

- **Reduced substrate diffusion**: While biofilm develops on activated carbon post-emplacement, increasing particle size lowers substrate diffusion within biofilm while increasing biodegradation (Liang 2007) (Rattier 2012) (El Gamal 2018)
- **Porosity blockage**: Particles ≤2μm block soil porosity, limiting connectivity and hindering biodegradation (Fredrickson 1997) (Santamarina 2006) (Wang 2010)

Permeable Reactive Barrier Incompatibility

CAC is inappropriate for permeable reactive barriers. While marketed as able to move into permeable zones, this mobility is undesirable for PRB installations where activated carbon must remain embedded in the desired zone to reduce mass flux. The inability of colloidal-sized particles to remain suspended without dispersants affects PRBs because colloidal carbon moves. Various salts (parking solutions) are injected to drive CAC out of solution, but the impact of these salts on remedial efficiency has not been studied.

6. Bioaugmentation

CAC Limitations

CAC technologies do not generally prime activated carbon or co-inject microbes. This approach may subject CAC to rollover due to failure to provide a consistent treatment mechanism. Without a degradation mechanism, other contaminants or organic carbon can desorb the sorbed contaminants, as chemicals with higher heats of adsorption displace those with lower heats of adsorption.

BOS 200 Advantages

BOS 200 is applied as a complete remediation system including a blend of facultative bacteria. Bacteria are added to the mix tank prior to application to prime the activated carbon. Priming activated carbon is fundamental to forming biologically active carbon and stimulates bioremediation processes from day zero. Waiting for indigenous bacteria to inhabit carbon delays degradation, and degradation may not proceed efficiently if formation bacteria cannot degrade the full range of hydrocarbons.

7. Electron Acceptors and Nutrient Addition

Robust microbial degradation occurs only when microbes are provided with an environment favorable to growth and reproduction. Just as humans need oxygen as an electron acceptor in metabolic processes, microbes need electron acceptors to sustain their metabolic processes.

CAC Approaches

CAC products, depending on the specific product, may be combined with:

- **Oxygenates** (such as calcium oxyhydroxide)
- **Electron acceptors** (including nitrate, sulfate, and iron)

Oxygenates are only cost-effective when contamination levels are trivial enough for microbial destruction of the contamination to occur before the oxygenate is depleted, or when aquifers can maintain sufficient oxygenation after supplied oxygenate is exhausted. Most oxygen-releasing compounds are active for about six months in high-seepage velocity aquifers.

Most petroleum-contaminated aquifers are anaerobic because microbial metabolic activities consume available oxygen early in hydrocarbon releases. Therefore, some CAC products provide electron acceptors such as sulfate, recognizing that changing an aquifer's oxygen status is challenging.

BOS 200 Approach

BOS 200 provides appropriate electron acceptors, nutrients, and facultative bacteria to establish an optimal environment supporting both aerobic and anaerobic degradation. Recognizing that most hydrocarbon contamination is likely degraded anaerobically, BOS 200 is designed to provide long-term electron acceptors. Electron acceptors are not just another add on, with BOS 200 electron acceptors are included.

8. Cost Analysis

RPI employs activated carbon as a platform and catalyst for remediation as part of a comprehensive approach. Activated carbon constitutes a significant portion of all carbon-based product costs, making cost comparison relevant.

Product Composition Comparison

- **Popular CAC product**: 68% water, 25% activated carbon, 7% other components
- **BOS 200+**: 61.5% activated carbon, 38.5% other components (electron acceptors and nutrients)

One pound of CAC contains roughly: 454 gms x 0.25 = 113.5 gms carbon.
One pound of BOS 200+ contains 454 gms x 0.615 = 279.2 gms carbon.
BOS 200+ contains (279.2/113.5)x 100 = 246% more activated carbon.

Cost Analysis Example

A popular CAC product costs approximately $4.25 per pound but contains 68% water. If CAC sells for $4.25 per pound and contains only 32% dry ingredients, then the cost of dry ingredients is $4.25 ÷ 0.32 = approximately $13.28 per pound.

In contrast, BOS 200 and 200+ are dry products requiring no mathematical calculations—they remain $4.25 per pound.

On a dry weight basis, CAC costs over three times that of BOS 200+!

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