

Application Bulletin

The Biological Activated Carbon Process for Water Purification

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Granular activated carbon (GAC) has been used extensively for the removal of dissolved organics from drinking water. In the early seventies, it was reported that bacteria with proliferate in GAC filters may be responsible for a fraction of the net removal of organics in the filter. Following this discovery, pre-ozonation was found to significantly enhance the biological activity on GAC. The combination of ozonation and GAC is commonly referred to as the *biological activated carbon (BAC)* process, or *biologically enhanced activated carbon* process.

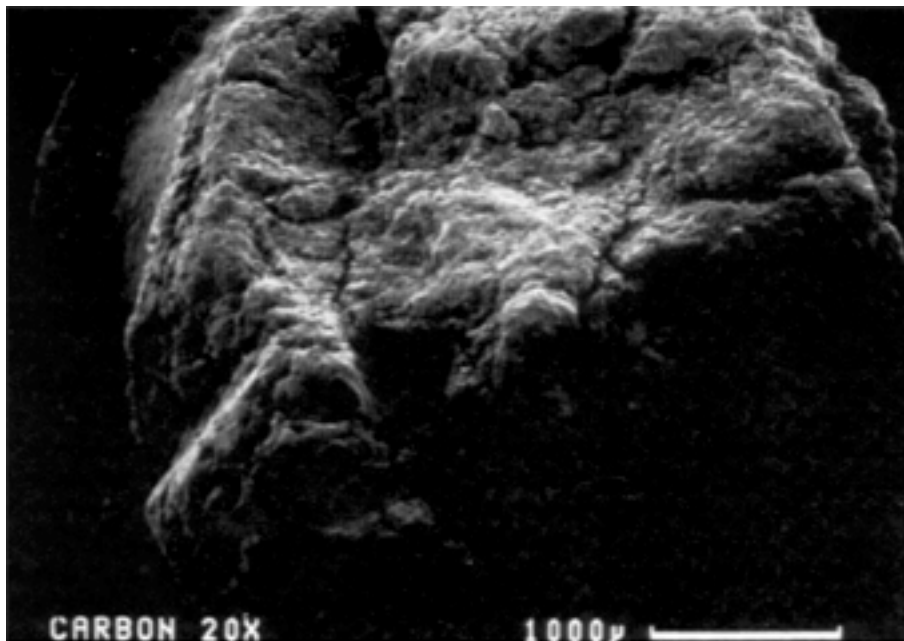
In Europe, the BAC process was implemented in many large water treatment plants in the '80s.

Reasons for its widespread use include:

- ◆ The generally poorer quality of surface waters, when compared to North America
- ◆ The concern for chlorination by-products. For instance, under the European Community drinking water directives, the guide level for organochlorine compounds is 1 µg/L
- ◆ The strict aesthetic demands of European consumers

The European way of thinking for production of high quality drinking water is spreading rapidly in other industrialized countries such as Japan, Canada, and Australia.

The US water industry has been reluctant to use microorganisms for drinking water treatment. However, biological treatment is expected to become more common over the next decade. Driving forces behind this change will be the increased use of ozone in response to the disinfectants-disinfection by-product (D-DP) rule, and the increased concern over biological re-growth in the distribution system.



The extent of the surface area of a particle of granular activated carbon, which looks like it might be the moon, is apparent on this microscopic photograph.



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Benefits of Biological Activity

Biological elimination of dissolved organic compounds within GAC filters offers several finished water quality benefits. For instance, biological activity removes a significant fraction of *dissolved organic carbon* (DOC). A theoretical representation of DOC removed by adsorption and biological activity is shown in the figure. Initially, most of the removal occurs through physical adsorption (Period A), while the bacteria are in the acclimation phase. During this period, DOC removal ranges from 40 to 90 percent. A 10 to 20 percent fraction is non-adsorbable on GAC.

During period B, adsorption and biological degradation processes operate in parallel. The bacteria are now acclimated, and the removal by adsorption is gradually decreasing due to the saturation of adsorption sites. Period C is referred to as the steady-state period. Biological oxidation is the predominant process responsible for DOC removal. Most of the adsorption capacity is exhausted. Under steady-state conditions, DOC removal efficiencies range from 15 to 40 percent. If the removal efficiency obtained under steady-state conditions meets treatment objectives, the service life of GAC can be significantly increased.

Naturally occurring compounds comprising the DOC of surface waters are known to be precursors of *disinfection* (chlorination) *byproducts* (DBPs) such as *trihalomethanes* (THMs) and *haloacetic acids* (HAAs). THMs and HAAs are the major compounds targeted under the D-DBP rule. The removal of these DBP precursors correlates with the removal of DOC. However, greater removal efficiencies have been reported for precursors of *total organic halogen* (TOX), THM and HAA than for DOC, showing the selectivity of biological treatment for these chlorine-reactive compounds. Under steady-state conditions, removal efficiencies of THM and HAA precursors reportedly range from 20 to 70 percent. Removal efficiencies are much greater in the initial stages of the process (Period A), in which 75 to 90 percent of precursors are removed through physical adsorption.

Biological oxidation within GAC filters also can be efficient for the removal of inorganics such as ammonia. Ammonia is a toxic chemical which promotes bio-growth and reacts with chlorine. The combined removal of DOC and ammonia leads to a significant reduction of the chlorine demand of the finished water. A reduced chlorine demand lowers the amount of DBPs and improves the aesthetic quality of the water.

Pre-ozonation provides many benefits to the water treatment process (e.g., excellent disinfection without the formation of THMs or HAAs, micro-flocculation, color removal, iron and manganese removal, reduction of taste and odor, enhanced biological activity, etc.). However, ozonation byproducts are generally readily biodegradable and can lead to bio-growth in the distribution system. The removal of these biodegradable compounds within BAC filters leads to the control of biological re-growth and an increased stability of the residual chlorine. Under steady-state conditions, removal efficiencies of *assimilable organic carbon* (AOC) and *biodegradable organic carbon* (BDOC) have been reported to range from 50 to 100 percent. In addition, the process can lead to the complete removal of ozonation by-products that are of health concern and may be targeted for future regulations. These include some short-chain aldehydes.

Biologically active GAC also can be effective for eliminating synthetic organic chemicals such as benzene, toluene, and pesticides like atrazine which present health concerns. The process also can reduce the concentrations of taste- and odor-causing compounds such as short-chain aldehydes (fruity), amines and aliphatic aldehydes (fishy), and phenols and chlorinated phenols (antiseptic/medicinal).

Finally, biological activity can enhance the adsorption capacity of GAC for non- or slowly biodegradable compounds by eliminating substances that would otherwise compete for adsorption sites. This is sometimes referred to as the bio-regeneration effect.

Major BAC Process Variables

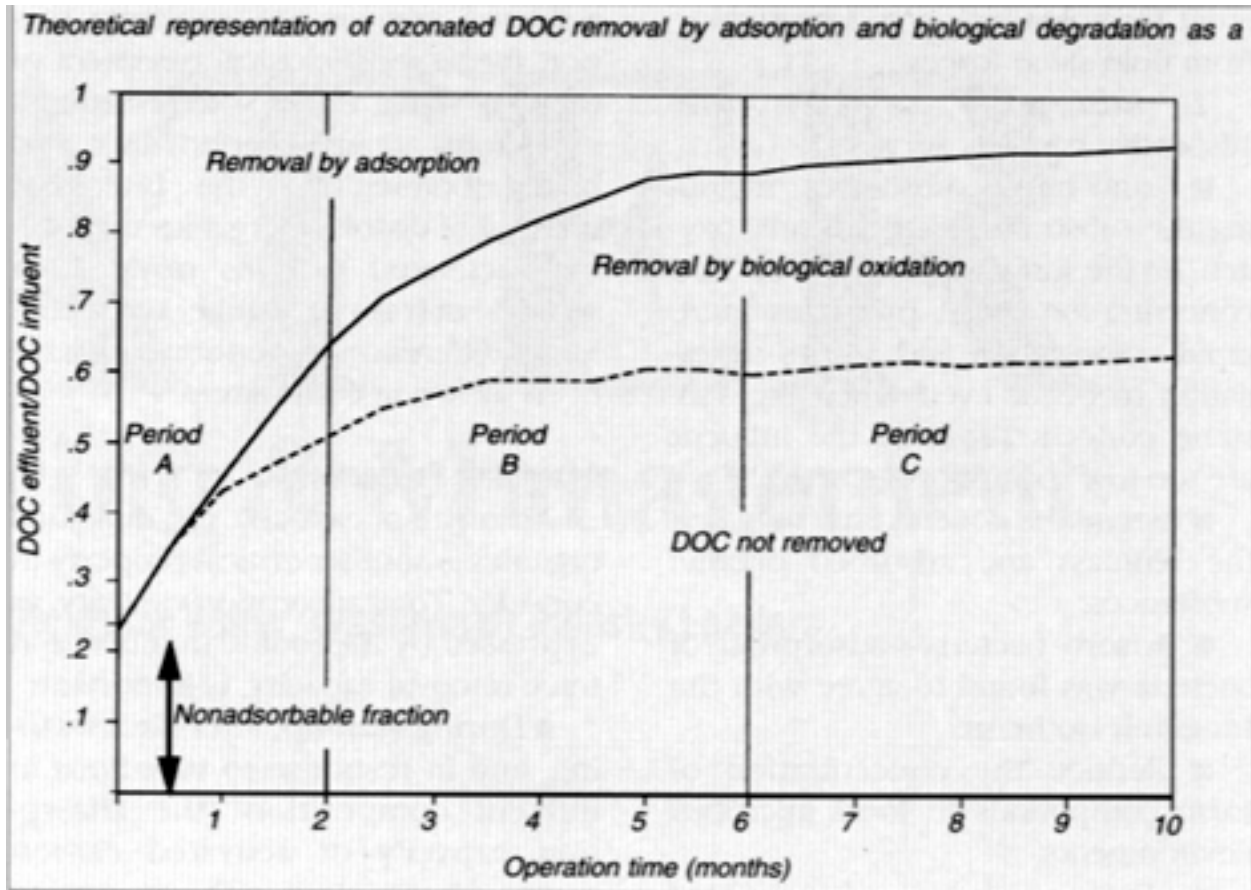
The empty bed contact time is the most important parameter for the removal of biodegradable organic matter. The contact time to be selected is dependent on the treatment objective, the support media type (discussed later), and the water temperature. Contact times reported in major French waterworks range from 10 to 15 minutes. Efficient AOC removal can be obtained with a contact time less than five minutes.



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The presence of microorganisms and higher forms of life in BAC filters leads to more rapid pressure buildups and requires more frequent and efficient backwashing procedures. The effect is more drastic in warm water than in cold water. BAC filters must be backwashed on a regular basis to prevent the proliferation of higher organisms in the media and maintain a low trophic level. A fraction of the bacterial biomass fixed on GAC is eliminated during backwashing. In cold water, the removal efficiency of biodegradable matter is significantly reduced after backwashing, but winter operation requires less frequent backwashing. This reduction is even more significant if filters are backwashed with chlorinated water. Additionally, the efficiency of biological treatment is lowered if the influent has been pre-disinfected with chlorine, chloramines, or chlorine dioxide.

Recent Canadian and US studies have demonstrated that first stage BAC filters achieved similar performance to post-filter GAC adsorbers, drastically reducing the capital cost involved. Consequently, given an adequate contact time, BAC filters can be retrofitted into existing sand or dual media filters.

The risk of exportation of bacterial biomass into the effluent must be assessed when considering the BAC process. Bacteria exiting the BAC filters are easily eliminated by post-disinfection. Activated carbon particles have been shown to provide a habitat for organisms and to protect them from inactivation during post-disinfection. Additional filtration through sand is recommended to prevent escape of activated carbon fines in the product water. This can be accomplished by having a layer of sand media (6 to 9 in.) as a support for the granulated activated carbon media.



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Biological Activity on Filtration Media

The efficiency of activated carbon for biological treatment of drinking water is significantly greater than the efficiency of conventional filtration media such as sand or anthracite.

Granular activated carbon has the ability to support a denser bacterial population than sand or anthracite. Under drinking water conditions and with pre-ozonated water, fixed bacterial biomass reported in the literature ranges from 1.0×10^6 to 1.0×10^7 bacteria/gram of sand or anthracite versus 1.0×10^8 to 1.0×10^9 bacteria/gram of activated carbon.

Three major properties of GAC have been suggested to explain the differences.

1. Porosity, Surface Area, and Surface Roughness The average diameters of single-cell bacteria found in water supplies range from 0.3 to 10 μm . Activated carbon is characterized by the presence of man-made and inherent crevices, ridges, macropores, and other surface irregularities which provide a sheltered environment for colonization and protection from fluid shear forces.

2. Adsorption Capacity The adsorptive capacity serves to:

- ◆ Concentrate substances, including the substrates, nutrients and oxygen, on the surface of the carbon. This concentration effect promotes more rapid colonization and allows degradation to occur even when the substrate concentrations in the influent are too low to support growth
- ◆ Extend the contact time between the biomass and adsorbed organic substances
- ◆ Adsorb bacteria - adsorption of bacteria was found to agree with the Langmuir isotherm
- ◆ Reduce the concentration of toxic compounds in local microbial environments

3. Surface Charge of Activated Carbon The presence of a variety of functional groups on the carbon surface has been shown to enhance microbial attachment. Greater biological activity within and faster colonization on GAC lead to the following benefits over conventional filtration media:

- ◆ Greater efficiency for the removal of biodegradable compounds. A similar performance will require a significantly longer time with sand and anthracite
- ◆ Shorter acclimation time. This has a major impact during start-up and after backwashing
- ◆ Faster response to variations in the influent water quality, such as concentration in bio-degradable compounds, concentration in toxic organics, and temperature. Benefits are more pronounced in cold water
- ◆ Finally, physical adsorption on GAC provides additional benefits over conventional filtration media

Selection of GAC for Biological Treatment

Factors to be considered when selecting activated carbon for the treatment of drinking water are:

- ◆ Biological support properties
- ◆ Adsorption capacity properties
- ◆ Physical properties such as density, abrasion resistance, and hardness, and their effect on a reactivated product

Biological Support Properties

Due to their inherent and/or manmade macroporous structure, adsorption capacity, and surface chemistry, most commercially available granular activated carbons are excellent support media for biological treatment of drinking water. Under water treatment conditions, similar performance has been obtained for the biological removal of dissolved organics with various activated carbons made from sources such as coal, lignite, and wood. Minor differences in performance have been shown in cold water.

Adsorption Properties

Adsorption capacity for dissolved organics is another critical property to consider. Total adsorption capacity, as expressed by the iodine number, and trace removal capacity, is important:

- ◆ During start-up, after backwashing, and in response to variations in influent composition (the adsorption capacity of activated carbon serves to maintain effluent quality until the biological activity of the system is established)
- ◆ For the removal of non- or slowly biodegradable organics of concern (taste and odor compounds, micro-pollutants such as synthetic organic chemicals, pesticides, etc.)
- ◆ For additional removal of natural organic matter



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Physical Properties

Additional properties to consider when selecting an activated carbon product include the *apparent bed density* (AD), hardness and abrasion resistance, chemical reactivity, ash level and ash constituents. These properties are characteristic limitations of the starting material (e.g., bituminous coal, lignite, wood, etc.)

The AD of activated carbon influences the backwashing efficiency, the thermal reactivation yield, and the quantity of product, on a weight basis, per volume of GAC contactor. Carbon characterized by a greater AD hold up to higher backwashing water velocities; they allow more flexibility for thermal reactivation; they represent a greater amount of product, on a weight basis, per bed volume (consequently, a longer on-stream time for a similar adsorption capacity). Finally, they hold up better to the removal of carbon atoms when contacted with oxidants such as chlorine or ozone.

Carbons with high hardness and abrasion resistance lead to low carbon losses (e.g. carbon fines) during treatment, backwashing, transfer, and thermal reactivation (high reactivation yields).

Low chemical reactivity products are critical for high thermal reactivation yields, and consequently lower make-up requirements and costs.

Finally, the ash content and ash constituents determine the leaching characteristics of the product.

Service Life

Several factors must be assessed when considering carbon change-out or reactivation. The most critical is the remaining adsorption capacity of the carbon. Significant capacity is required if an important fraction of DOC, and consequently of DBP precursors, must be removed. Under these conditions, the GAC service life ranges from six to 12 months.

Adsorption capacity also may be required for the control of taste and odor. For this purpose, service lives of two to five years can be expected.

Finally, the adsorption capacity will be required if the water contains the continuous or episodic presence of micro-pollutants such as synthetic organic chemicals, pesticides, etc. Carbon service lives of one two years are common under these conditions. However, monitoring breakthrough of the contaminants may be needed for better predictions.

For high quality raw water, for which small reductions in DOC and DBP precursors are sufficient to meet the treatment objectives, and that do not contain micro-pollutants of concern or taste- and odor-causing compounds, biological activity on GAC may suffice and significant physical adsorption may not be required. Under these conditions, the service life of the carbon may be limited by the buildup of metals and refractory organics on the carbon that would significantly reduce biological activity. Finally, metals buildup and high organic loadings will have a negative effect on the quality of the carbon and subsequent reactivated product if reactivation is used. For all these reasons, service lives of two to five years are recommended.

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