WHAT'S NEW WITH Granular Activated Carbon

A Review of GAC

by C.F. "Chubb" Michaud

About the time you think you've heard everything about granular activated carbon (GAC), something new comes up. *Water Conditioning & Purification Magazine (WC&P)* published a comprehensive summary of GAC information in a 1988 series entitled, "GAC—The Workhorse of the Water Treatment Industry". GAC is, indeed, a workhorse that is unlikely to be put out to pasture anytime soon. No other media does so much for the aesthetic improvement of the color, taste and odor of water as GAC —a workhorse of many different colors.

The purpose of this article is to serve as a review and hopefully provide the correct impression and understanding. In addition, a complete list of references for GAC articles published by WC&P in the past 10 years can be found at the end of this article. For more information on these articles, contact *WC&P*.

The magic of GAC

A clean carbon surface, free from salt and organics, is hydrophobic (water hating) and oleophilic (oil loving). Couple this with a tremendous surface area (over 4 million square feet per pound) and a network of pathways (pore structure) that provide easy access to that surface area and you have the makings of a great filter media that can remove dissolved organics from water. This process (mechanism) for which GAC is best known is called adsorption.

GAC functions by several mechanisms:

1. Adsorption
2. Catalytic Reduction
3. Particulate Filtration
4. Molecular Sieve
5. Ionic Bonding
6. Catalytic Oxidation (new)

And, there may be others, yet undiscovered. Numbers 1 and 2 are the most important for residential and commercial applications. Numbers 3, 4 and 5 also occur, and, unless properly addressed, can become problematic. Particulates and debris can plug the bed or cause channeling. Trapped colloids, such as iron or organics, can bleed taste. Adsorbed metals can desorb (come back off) with changes in the water conditions. Industrial applications which include precious metal recovery, solvent separation and various product fractionations include all five. Number 6 is a new category, but not a new function.

Knowing how GAC functions gives us an understanding of its limitations and how to avoid misapplication. Since water is a universal solvent, it has a voracious appetite for dissolving a little bit of everything it touches. In order for GAC to act as an adsorbent, the attraction forces between the GAC and the contaminant must be stronger than the forces of the water which are holding that contaminant in solution. Any condition such as an increase in pH or temperature which increases the solubility of a particular organic contaminate will have a detrimental effect on adsorption. If the attraction forces are too weak, adsorption occurs too slowly, and breakthrough results. If the conditions change so that solubility becomes more favorable, a shift in equilibrium occurs and, not only can one have breakthrough, one can actually desorb the contaminants back off the GAC and into the water. The contaminant level can actually go up!

The mere fact that a contaminant (in water) is exposed to GAC guarantees nothing. Just as passing one's hand quickly (do not try this at home) over an open flame does not produce a burn, passing water through a bed of GAC does not always result in the removal of dissolved contaminants. Several factors must be considered.

The single most important consideration is the empty bed contact time (EBCT). Removing organics to parts per billion (ppb) or parts per trillion (ppt) levels is asking for perfection. Perfection takes time—lots of time. EBCTs of 20 to 30 minutes are fairly common. Other factors that establish and upset GAC equilibrium are pH and temperature.

Organics tend to be more soluble in higher pH water. The alkaline "booster" in washing detergents enhances solubility of oily "soils" and grease and, thus, facilitates removal. Therefore, lower pHs would improve the operation of a GAC adsorber because the lower pH generally tends to make the organics less soluble. Likewise, higher temperatures improve the solubility of organics as may an increased salt content. Cooler, lower TDS water is therefore easier to treat with GAC.

While elevated temperatures do increase the "mobility" of organic molecules in water which can enhance adsorption initially, extreme swings will generally be detrimental. Using GAC for volatile organic adsorption on any system that sees major shifts (25°F or more) in water temperature will always spell trouble. Seasonal shifts can also be troublesome. It's a good idea to rebed GAC before the warmer months on annual changeouts. This way, the bed is at its peak when the contaminants are toughest to remove due to higher water temperatures.

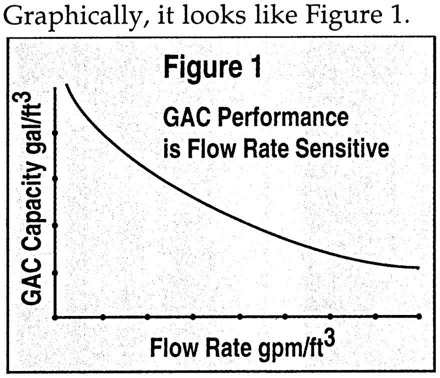
GAC works best at temperatures between 60° and 105°F (15 and 40°C) and should be increased in size for applications in cold water. At feed temperatures below 70°F, the size of the bed should double for every 20°F of temperature drop. Below 35°F, even chlorine removal may be nearly impossible. Higher temperatures are beneficial for chlorine removal because of the increased activity of the free chlorine, making it more reactive with the GAC. However, elevated temperatures make volatile organics (VOCs) even more volatile. Avoid hot (above 105°F) water unless the application is for chlorine removal.

Not all organics are the same. Some, such as tannins and other "natural" organics, are more of a nuisance because of taste, color, odor, and staining. They may also support microbial growth. However, they generally do not cause illness. On the other hand, halogenated solvents can be very toxic and will cause problems over time.

As a boxer in college, I was taught to size up my opponent before planning my ring strategy. It would be defensive (avoiding my opponent's strengths) or offensive (attacking my opponents weaknesses). This, of course, assumed that my strengths were solid and my weaknesses were non-existent. In some cases, my opponent's weaknesses were still stronger than my strengths. This, perhaps explains why I pursued a career in engineering rather than boxing.

This process of sizing up the opponent is known as "risk assessment". One utilizes a different strategy if the results of failure are more likely to cause harm than if they simply cause discontent. With GAC filters, the best strategy is to be generous if the problem is real.

The EBCT established for a given GAC filter will determine the life/performance (degradation profile) curve. In other words, for any given application, the shorter the EBCT, the steeper the loss of performance. All GAC beds start out at near 100 percent removal regardless of flow rate. However, the faster the flow per unit volume of GAC, the sooner one sees breakthrough. This drop off is not in direct proportion to flow. Doubling the flow rate reduces the capacity by about 30 percent. Increasing the flow by a factor of 4x will reduce capacity by 50 percent. For any given grade of GAC, you will get fewer gallons of performance at higher flow per unit volume. Graphically, it looks like Figure 1.

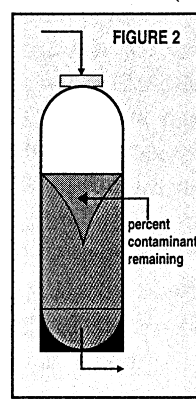


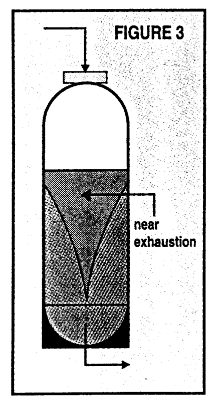
The removal rates with respect to EBCT are based on the "half length" concept. If a retention time of x minutes results in the removal of 50 percent, then a retention time of 2x minutes results in 75 percent and 3x equals 87.5 percent. Assuming 95 percent as breakthrough for a particular application, one must theoretically provide the equivalent of five half lengths. If half length is determined to be 60 seconds, an EBCT of five minutes will give 95-plus percent adsorption (*see Table 1*).

Table 1

Half Lengths	Percent Adsorption
1	50.0%
2	75.0%
3	87.5%
4	93.8%
5	96.9%
6	98.4%
7	99.2%
8	99.6%
9	99.8%
10	99.9%

Graphically, we can show the percent removal as water advances down the column (*Figure 2*). As time advances, the exhaustion wave moves down (*Figure 3*).





Doubling the flow rate does not, by itself, decrease capacity. The GAC will still adsorb the same amount of contaminant at saturation. However, since we never run GAC to saturation, we do observe a drop in its ability to treat the same number of gallons. This volume of treatment is referred to as "column capacity" or "operating capacity". GAC capacity is generally defined in terms of the

GAC's ability to reduce a certain contaminant to some particular level for a certain number of gallons. Increasing the flow rate moves the exhaustion front further down the column which causes breakthrough to occur more rapidly (*see Figures 4 and 5*).

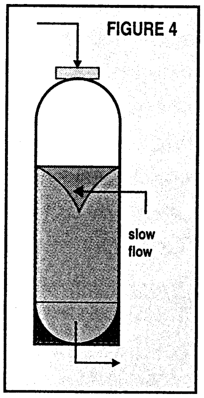


FIGURE 4

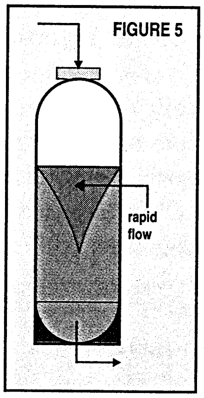


FIGURE 5

We can conclude from this that the slower the flow, the flatter the wave front. Therefore, longer EBCT not only provides higher efficiency (percent removal,) but longer life (higher operating capacity). Overrunning the bed results in almost immediate breakthrough (*See Figure 6*).

There are different half lengths for each compound and complex formulas for calculating ultimate capacities.

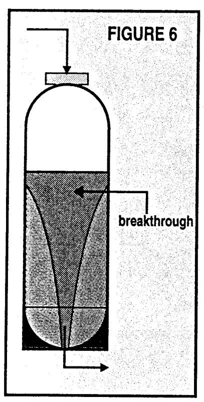


FIGURE 6

Total capacities for organic adsorption are as high as 20 to 25 percent by weight for most GAC's used for water treatment. This means a liter of GAC (weight of about 500 grams) should adsorb about 125 grams of organics. At 1 ppm (1 mg/L), this amount of GAC should treat about 125,000 liters of water. This is equivalent to about 800,000 gallons per cubic foot.

Experience tells us that if you are short of that 20 to 30 minute EBCT and not using multiple vessels in rotation, these figures are not achieved. At five minutes EBCT, operating capacity may be reached in as little as 50,000 gallons per cubic foot or five to six percent by weight. The reason is that the exhaustion profile resembles Figure 5 more so than Figure 4.

A look at the certification achievements for 10-inch cartridges run at flows of 0.5 gpm (equivalent to 20 gpm/ft^3) with EBCT of only 20 seconds or so, shows satisfactory volatile organic carbon (VOC) removal of 1,000 gallons or less. Since cartridges contain 0.025 to 0.035 cubic feet of GAC, this translates to a performance of 30,000 to 40,000 gallons per cubic foot of GAC. This is far from the 150,000 gallons expected from a whole house unit run at five gpm/ft^3 (EBCT=90 seconds) or the 1,000,000 gallons per unit that might be achieved with a cubic foot of GAC in a municipal treatment system with EBCT of 20 to 30 minutes. Keep in mind that these cartridges are generally challenged with only 0.15 ppm of VOCs. In actuality, they are only absorbing about 0.5 grams of VOCs which equates to only 0.125 percent by weight. Again, the reason is too short an EBCT.

Installing GAC in multiple vessels linked in a series, allows for the removal of spent GAC (Tank #1) and the addition of fresh GAC (Tank #4). The result is a higher percentage of capacity utilization (*see Figure 7*). Tank #2 still has usable capacity when Tank #3 breaks through. By rotating forward, this capacity can be used.

To calculate the EBCT for any system, divide the volume of GAC by the flow rate per minute. The answer is in minutes of retention. Be sure to use similar units. If the GAC volume is in cubic feet (volume), convert it to gallons (volume) by multiplying by 7.5 gal/cubic foot. Then, divide by gpm. If the volume is in cubic inches, convert the flow to cubic inches per minute by multiplying gpm flow by 231 cubic inches per gallon. If you are advanced enough to be using the metric system, you don't need any help. But, for purposes of being complete, divide the liters of GAC by the flow in liters per minute.

The following chart illustrates the EBCT for various flow rates:

Table 2

Flow Rate gpm/ft^3	EBCT
0.35	22 min
0.5	15 min
1	7 min 30 sec
2	3 min 45 sec
3	2 min 30 sec
4	1 min 53 sec
5	1 min 30 sec
10	45 sec
15	30 sec
20	23 sec
30	15 sec
40	11 sec
50	9 sec

The primary reason for early GAC filter failure is that the systems were designed with too short an EBCT. The GAC simply cannot maintain the 90 to 95 percent removal rate

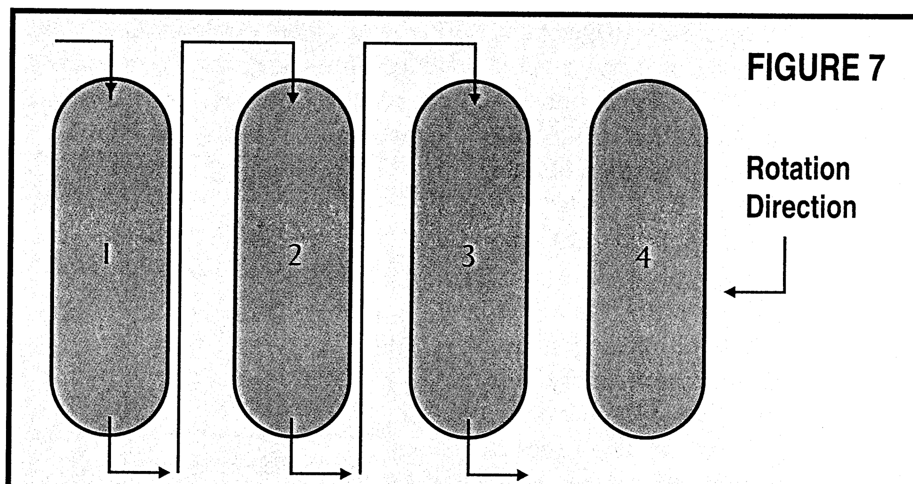


FIGURE 7

required for acceptability testing.

Reducing the mesh size of a GAC improves the kinetics, thus, it flattens the exhaustion profile. This improves both the efficiency and the capacity of the GAC system. Smaller systems such as cartridges and counter-top filters should utilize 20 x 50 mesh or 30 x 100 mesh cuts. Whole house and commercial units will use 12 x 40 mesh and larger, deep bed municipal and industrial systems can use 8 x 30 mesh to reduce pressure drop.

Cutting the mean particle diameter by 50 percent allows you to run at twice the flow rate per unit volume with the same capacity. In other words, a 12 x 40 mesh can be run at twice the flow of 8 x 30 mesh, and a 20 x 50 mesh can handle four times the flow (*See Table 3*). Pressure drop at high flow through 20 x 50 mesh can exceed 15 psi. Nonetheless, one can utilize 20 x 50 mesh GAC for whole house systems with very good results.

Table 3

Mesh Size	Approximate Mean Particle Diameter
8X30 mesh	2.0 mm
12X40 mesh	1.0 mm
20X50 mesh	0.5 mm
30X100 mesh	0.25 mm

The removal of chlorine through catalytic reduction follows a similar capacity curve to that of VOC reduction by adsorption. However, the EBCTs required for effective dechlorination are much shorter. EBCTs of 75 to 90 seconds will handle one to two ppm of chlorine for 500,000 to 1,000,000 gallons per cubic foot of 12 x 40 mesh GAC (depending on pH and temperature). Whole house systems intended for natural organics should be designed at EBCTs of 2.5 to five minutes depending upon the severity of the problem. Systems on toxic organics (VOCs and pesticides) should be sized with minimum EBCTs of five minutes and tested every six months. For five gpm, you will need at least 3.3 cubic feet of 12x40 GAC. Anticipate annual changeouts on the latter.

Catalytic carbons have modified surface properties that enhance the catalytic functionality of the GAC - thus converting the oxidation state of various elements - notably, hydrogen sulfide (H_2S). The S^- is adsorbed and then converted to S^0 (elemental sulphur) and SO_4^{--} (sulfate ion). Once the sulfide is adsorbed and converted, it is desorbed and the site is restored. For these reactions to occur, excess dissolved oxygen is required and a minimum EBCT of five minutes built into the design. These carbons are also good oxygen scavengers.

Conclusion

GAC filters are excellent crud collectors. The accumulation of organics and debris on GAC provides sufficient nutrient to support the growth of bacteria and algae. Periodic backwashing will help rid of this build up. Weekly backwashing should suffice for most systems, but daily may be required if the feed water has high turbidity. Use a prefilter if suspended solids exceed one ppm. Small POU GAC filters that cannot be backwashed should be flushed for 30 seconds prior to use.

The use of GAC to remove radon is no longer recommended. The accumulation of radioactivity can become a problem in the GAC tank and disposal is also a concern. Instead, aeration is the treatment of choice.

The use of GAC as an all purpose filter to rid well water of metals, red water iron and dirt is not recommended. This is not an application for GAC. However, using GAC on well water for the removal of taste from organics is fine. Use adequate prefiltration for suspended solids such as dirt or red water iron (rust).

We do not advise the combination of GAC and softening resin in the same tank unless provisions have been made for regular (every two years or so) changeouts of the complete media. Spent GAC deteriorates with time in the presence of chlorine and eventually will dissolve back into the water, carrying with it everything that it picked up. Use a separate tank or a "piggy-back" double tank adaptor to keep the media separate.

Time your rebedding of household GAC systems to spring or before the water warms up. This gives maximum protection during the time when desorption is at its highest potential.

We advise against non-backwashing systems for whole house applications. Backwash weekly or couple with a softener in "piggy-back" fashion to allow regular flushing of the GAC bed.❑

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Listing of GAC Articles Published by *WC&P* Magazine, 1988-present

- "GAC to Become Workhorse of Water Purification Industry", by C.F. "Chubb" Michaud, June 1988.
- "Granular Activated Carbon", by C.F. "Chubb" Michaud, July 1988.
- "Granular Activated Carbon: Putting it All Together", by C.F. "Chubb" Michaud, August 1988.
- "Granular Re-Activated Carbon", by C.F. "Chubb" Michaud, February 1991.
- "Cocunut Shells: Activated Carbon Source", by Mohammed A. Bayati, March 1991.
- "Granular Re-Activated Carbon: Part II", by C.F. "Chubb" Michaud, March 1991.
- "An Activated Carbon Primer", by David Wycherley & Mohammed Bayati, June 1991.
- "Standard Definitions of Terms Relating to Activated Carbon", by David Wycherley & Mohammed Bayati, June 1991.
- "British Establishing Carbon Standards" British Water Quality Association, July 1991.
- "Extruded Activated Carbon Filters", by Dr. Evan E. Koslow, Richard Kendrick, & Bruce Saaski, October 1991.
- "Using Activated Carbon", by Mohammed A. Bayati & Elwood V. Reinhart, January 1993.
- "Carbon Filters", by Tom Holler & Tom Schinner, February 1993.
- "Cocunut Shell Carbon", by David E. Wycherley, August 1993.
- "Understanding Activated Carbon", by Dean Jarog, May 1994.
- "Catalytic Oxidation Process One Answer to Carwash Woes", by Ronald G. Fink.
- "GAC Kinetics: Finer Mesh Carbons Represent the Better Value", by C.F. "Chubb" Michaud, January 1995.
- "Catalytic/Adsorptive Carbon Creates a Media Breakthrough", by Steve Spotts and Andy McClure, June 1995.
- "Sizing Whole House Softeners and GAC Filters", by C.F. "Chubb" Michaud, November 1995.