GRANULAR ACTIVATED CARBON (GAC) FACT SHEET

The use of granular activated carbon (GAC) for water purification became common around the start of the 20th century (1906) when the "activation" process was applied to charcoal (which had been used for centuries). Thermal activation of charcoal greatly improves its pore volume, surface area and structure making it a superb workhorse for water treatment.

The Adsorption Concept

A clean carbon surface is oleophilic, meaning "oil loving" and the opposite of hydrophilic or "water loving". It has a strong attraction for organic compounds and other non-polar contaminants and adsorbs them onto the carbon surface where they are held by van der Waals forces. Adsorption is the primary mechanism by which GAC works and the primary reason it is widely used to reduce undesirable taste, odor and color and to improve the safety of drinking water by also effectively removing common disinfection byproducts (THMs), organic contaminants like chlorinated solvents and other industrial pollutants, pesticides, and select heavy metals such as lead and mercury. , Modern GAC products are made from coconut shell, coal, wood, lignite and/or petroleum products.   The selection of carbon source is often driven by the contaminant reduction performance targeted by the manufacturer.

GAC Structure

Each carbon source produces a GAC with a unique pore structure consisting of micro-pores, meso-pores and macro-pores. Micro-pores are very small—often smaller than a typical molecule (5-1000 Angstroms). An Angstrom (Å) is 1/10,000,000 of a millimeter. As an illustration, the period at the end of this sentence is about 5,000,000 Å.

Coconut shell carbons tend to have a higher percentage of micro-pores making it a good choice for small organics and disinfection byproducts. Wood carbons have more macro-pores making them better for de-colorization and removal of larger organics. Coal bases give an intermediate pore structure making them a good choice for general purpose organic reduction.

GAC's capacity for organic removal is derived from its very high surface area. A single gram of GAC can have a surface area exceeding 1000 m^2. A pound of carbon has more than 35 acres of surface—almost 100 football fields. It is not possible to utilize the complete surface area of GAC nor is it necessary. If you were to load a one molecule thick, filmed layer of an organic onto the entire surface of GAC, you would have only loaded about 6.25 ml of liquid~~ about 1/4 teaspoon per pound. But since the organic is soluble in itself, the film thickens and the adsorbed weight increases. With systems in

series and running to saturation (outlet contaminant level equals inlet level) it is possible to load as much as 0.1 lbs or 45 ml on a volumetric basis per pound of GAC.

GAC Properties

Accessibility to the adsorption sites within the GAC pore structure and surface area available is key. This is a function of (1) the degree of activation of the carbon base for providing the pathways. The degree of activation is measured by its carbon tetrachloride number (CTC). A value of 50 or more is considered good for water treatment. And (2) the relative surface area of the carbon measured by Iodine Number (Io N) which for potable water treatment should be in the range of 900-1050.

An important consideration in selecting a GAC product is its Abrasion Number. (AN) This is a relative measure of the media's ability to withstand abrasion (or size reduction) when physically tumbled (such as during backwashing). Shell carbons have the highest abrasion resistance at about 90 AN. Coal bases are average at about 70 AN. Ratings below 70 may not hold up well to vigorous backwashing.

The mesh size of a particular GAC may not affect its ultimate adsorptive performance but it does affect hydraulic performance (pressure drop or □P) and kinetics (rate of reaction). An 8x30 mesh carbon is approximately 2mm in diameter. A 12x40 measures about 1mm and a 20x50 mesh is about 0.5mm. The □P is much higher with the finer mesh products but the higher kinetics may allow one to use shallower beds. The rate of reaction of a 12x40 mesh is twice that of an 8x30 mesh of the same product and a 20x50 mesh is twice as fast as the 12x40. Deep beds (6-10 ft deep) might choose the 8x30 product. Cartridges would use a 20x50 and most general purpose applications should consider the 12x40 mesh.

Water is an excellent solvent for small amounts of just about everything including organic solvents. The forces by which water holds an organic in solution are quite strong. In order for GAC to pull an organic from solution, the forces of attraction must be stronger than the forces of solubilization. Factors that enhance organic adsorption onto GAC are: lower pH (organics are more soluble at higher pH), slower flow-measured in minutes of empty bed contact time (EBCT), relative molecular weight (MW) and solubility of the organic. Low MW alcohols such as methanol and ethanol for instance are very soluble in water and not removed by GAC. Although organics are generally less soluble in colder water, temperature also impacts mobility (transport) of the contaminant into the pores. Therefore, cold water may actually inhibit the removal of that contaminant. Furthermore, some organics are volatile and can be desorbed (released) from the GAC in hot water. For those instances, using a hot water source to backwash the GAC will actually do a partial regeneration on it.

Color bodies such as tannins are high MW organics that can be removed by GAC. However, a proper product must be selected to have the right pore structure for the task at hand. Wood based GAC products have a long history of use for de-colorization.

Flow Considerations

Empty Bed Contact Time (EBCT), represents the hydraulic flow rate through a GAC bed and is usually reported in "minutes". Simply put, it is the volume of media (in gallons, m^3, ft^3) divided by the flow volume (in gallons, m3, ft^3) per unit of time (minutes, hours). A one cubic ft GAC filter is 7.5 gallons of GAC. A flow of water through that filter at 2.5 gpm has an EBCT of (7.5/2.5) = 3 minutes. Just make sure you use the same volume units to do the calculation. A GAC filter must have sufficient EBCT to do the job plus enough safety margin to cover variations in the quality of the water being treated. Organics such as pesticides and THM's require long EBCTs because of the safety margin needed. Think of the "consequences of failure" when sizing your design.

A second concept in retention time is that of "Half Lengths". This tells us that if it takes x number of seconds (or minutes) to reduce a particular contaminant by 50%, it will take x number of seconds to reduce the residual level of contaminant by an addition 50% (of the remaining). So if one half length removes 50%, two half lengths will remove 75% and three will remove 87.5About seven half lengths are required to remove 99% and ten to reach 99.9%. This is why many municipal GAC systems used for reducing the level of THMs to single digit ppb levels will have EBCTs of 25 minutes or more.

In addition to the contact time, there are hydraulic flow considerations for GAC. Filters can be neither too large nor too small. Large filters are prone to channeling when run too slowly. Small filters will suffer from high ⯐P and particle fracture (abrasion) when pushed too hard. A proper design should have a superficial (surface) flow of 4-10 gpm/ft^2 (minimum to maximum) with temporary peaks not exceeding 12-15 gpm/ft^2. Volumetric flows can be 1-10 gpm/ft^3 for (minimum to maximum). Note, the EBCT range for that volumetric flow is 7.5 minutes down to about 45 seconds.

De-chlorination

A second very important property of GAC is its ability to catalytically reduce chlorine from an oxidizer (NaOCl) to a salt (NaCl) by taking away the reactive oxygen. This is a very fast reaction requiring an EBCT of only 30-40 seconds. A 10 inch cartridge with a flow of 0.5 gpm is about 25 seconds EBCT and can remove 95% of incoming chlorine for 2500 gallons. A cubic foot of the same GAC flowing at 5 gpm (EBCT = 1.5 minutes) can do the same job for 1,000,000 gallons. A cubic foot of GAC can make about 40 cartridges (with an implied capacity of 40x2500 = 100,000 gallons). The difference is in the longer EBCT allows the GAC to work better for a longer time because the longer EBCT allows more of the GAC to take part in the process.

More communities are switching from chlorine to chloramine (usually NH_2Cl, the mono-chloramine) as a means of reducing the tendency for chlorine to form THMs when used as the primary disinfectant. The deactivation of chloramine can be accomplished with GAC but the filter has to be sized about four times the size of a regular GAC filter used for chlorine. To increase the EBCT, filter units can be strung in series. Catalytic carbon, which has an oxidizing capability is more effective for chloramine reduction with EBCTs of about 5 minutes.

Activated Carbon for Radon Removal

Radon (Symbol Rn) is a radioactive gas that does not impart taste or odor to water. It stems from the natural decay of uranium to radium and radium to radon (radon is known to increase the risk of lung cancer when inhaled). Radon is the second leading cause of lung cancer in the US today. To a lesser extent, ingestion of radon contaminated water can lead to an increased risk of stomach cancer. Radon in drinking water is not federally regulated, although EPA has a longstanding proposal for an MCL of 300 pCi/L, or an alternative MCL of 4000 pCi/L. However, limits in drinking water vary by state and range from 300 to 20,000 pCi/L.

GACs radon reduction performance will be dependent on carbon source, bed design, radon loading, and to some extent water chemistry. Radon performance is driven by the establishment of a steady state rate constant (Kss) where the adsorption and subsequent decay to radon daughters comes into equilibrium with the radon being loaded from the influent water. GAC has been shown to achieve greater than 90% reduction of radon from treated drinking water. However, for POE, or small system applications the EPA suggests using this technique only when the radon content is < < 5000 pCi/L to ensure that there is no excessive gamma emissions from the carbon and to limit the buildup of long-rived radionuclides (ie. [210]lead) which can create handling and disposal concerns. It is recommended that media should be replaced at least on an annual basis. The US EPA Carb dose program can be used to calculate anticipated radon progeny activity at end of media life. Ion exchange pretreatment, or backwashing can be used to prevent fouling of the media.

At low influent radon activities (< 5000 pCi/L), EPA considers GAC to be a preferred treatment technology for POE, provided that the water being treated does not contain long-lived radionuclides. At higher influent levels (> 5000 pCi/L) aeration techniques are preferred.

NSF/ANSI Standard 53 includes a test protocol for evaluating radon reduction for POU devices. The protocol limits use to influent levels of radon below 4000 pCi/L and requires a minimum 90 % reduction of radon in the treated water. The Standard also limits filter life to one year.

Disposal

At some point, GAC becomes exhausted and you would need to re-bed the media. Depending upon how the GAC was used, it may be considered non-hazardous and can be removed by the user or a service company. If the GAC was used for potable water and is deemed non-hazardous, there are no concerns regarding sending it to an industrial landfill. If the use was industrial waste of known hazardous contaminants, the spent carbon must be tested to determine if it would be classified as hazardous or non-hazardous (this may depend upon the concentration of contaminants contained). Hazardous media may be classified as such due to toxicity, ignitability, corrosivity or reactivity. Guidelines can be found on the EPA website under: EPA Hazardous Waste Generators, Title 40, Part 261.

Waste Generator Defined

The US EPA classifies "waste generators" by size. For quantities of "haz" waste under 100 Kg/month (220 lbs), generators may be classified as "Conditionally Exempt Small Quantity Generators" **(CESQG).** No permit is required and they may accumulate up to 1000 Kg (2200 lbs) at any time. They MUST, however, turn over such waste to someone authorized to manage it (more than likely involving a fee). Larger generators have higher limits but require permits and inspections.

An alternate to landfill disposal is returning the spent GAC to the manufacturer for re-activation. This is usually reserved for large scale carbon users with a substantial quantity of media. Reactivation uses a special high temperature furnace to vaporize most contaminants and restores the clean pore structure of the original carbon. Please note, re-activated carbon cannot be used for potable water applications unless it is the **same** GAC previously used in the process by the **same** user. Reactivated GAC may still contain toxic inorganics that may be altered in their degree of solubility by the reactivation process. Re-activation should be considered **only as a means of disposal**.

Another disposal technique is using the spent carbon as fuel in a cement kiln. The spent carbon has a high recoverable fuel value and is destroyed in the process. Again, this option is best reserved for larger quantities of hazardous media.

As part of treatment system installation procedures, system performance characteristics should be verified by tests conducted under established test procedures and water analysis. Thereafter, the resulting water should be monitored periodically to verify continued performance. The application of the water treatment equipment must be controlled diligently to ensure that acceptable feed water conditions and equipment capacity are not exceeded. Consumers should contact a water treatment professional as described above, or follow the equipment manufacturer's installation instructions and contact the manufacturer to confirm usage and capacity. To ensure the manufacturer can provide the most accurate recommendations, have test results for lead and iron on hand for review.

ACKNOWLEDGEMENT

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This reference document is published by:

Water Quality® ASSOCIATION

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