Calgon Carbon Corporation AB-1056-05/93

Application Bulletin

CAPITALIZE ON CARBON'S ABILITIES

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It can improve water's taste, remove odors and reduce toxins.

Summary

Activated carbon products comprise 13 percent of the $ 1.4 billion domestic water treatment market, analysts say. Point-of-use products use various forms of the material, but all share an affinity for contaminants including trihalomethanes and organochlorides. The medium, however, isn't a panacea.

Over the past three decades, homeowners hoping to improve their drinking water have turned to point-of-entry (POE) and point-of-use (POU) water treatment systems. Often the products they use contain activated carbon, a medium that can improve water's taste and odor while reducing levels of health-threatening substances.

Quenching U.S. homeowners' thirst for water treatment is a $1.4 billion industry that grew more than five percent each of the last three years, according to Baytel Associates, a water treatment industry market research firm. That trend is expected to continue, with activated carbon system sales comprising approximately 13 percent of the overall market, the company says.

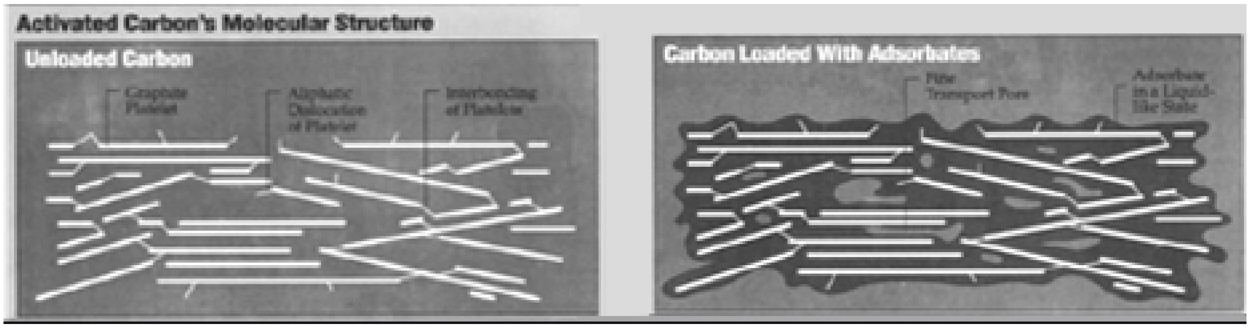
Activated carbon is similar to crude graphite, the material used in pencils. Activated carbon, diamonds and graphite are the few pure forms of carbon and contain almost no nitrogen, hydrogen, halogens, sulfur or oxygen.

From a chemist's perspective, activated carbon is an imperfect form of graphite. This imperfect structure results in a high degree of porosity and more than a million-fold range of pore sizes, from visible cracks and crevices to gaps and voids of molecular dimensions. Porosity is what distinguishes activated carbon from graphite or diamonds and makes it "activated."

Intermolecular attractions in the smallest pores result in adsorption forces. Carbon adsorption forces are analogous to gravity, but operate on a molecular, not astronomical, scale. They cause a reaction similar to precipitation, where adsorbates are removed from solution.

To develop a strong adsorption force, the distance between the carbon and adsorbate must be decreased by decreasing its pore size, or the number of carbon atoms in the structure must be increased by increasing the density of the carbon

Chemical reactions and chemical bonding can also occur between the adsorbing molecules and the carbon surface or its inorganic ash impurities. This is referred to as chemical adsorption or chemisorption.



Three Carbon Types

Activated carbon comes in three basic forms: powder, granular and bonded blocks.

Powdered carbon is used in batches by municipalities to treat potable water. It’s less expensive but labor-intensive and sometimes troublesome to use, in part because it must be physically separated from water.

Granular carbon is simpler to handle. In most situations, the carbon granules are packed into a vessel called an “adsorber column” or carbon column. Dimensions and shapes of carbon columns vary, but their width is generally less than their length.

The water to be treated flows between the granules, and adsorption occurs as contaminants diffuse from outside the particle to the adsorbing pore structures distributed within it. The contaminant must be in solution to diffuse, then enter the pore structure and adsorb.

Flow through the carbon column can be up, down or annular. In all cases, the granules should be immersed in water for best results.

Carbon blocks are also used for water treatment. Using molds, carbon is either extruded or bonded to form shapes. These shapes are generally placed in some type of filter housing to direct water flow.

Bonded blocks enable manufacturers to assemble carbon filters easily. They provide a simple way to handle dusty, small-mesh granular carbons. They can also physically filter water to lower particulate levels. Because bonded blocks typically are composed of fine mesh carbon, adsorption is usually faster than with granular units.

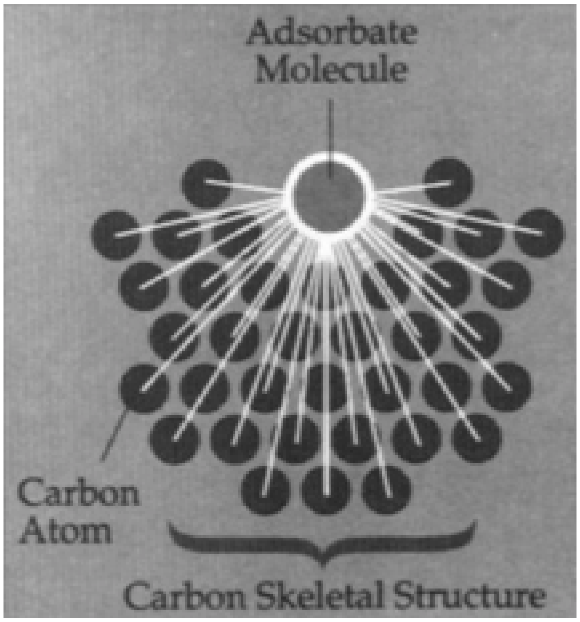
What It Can Do

Physical adsorption is what activated carbon does best. In POU and POE applications, physical adsorption removes taste and odor, volatile organic compounds (VOCs), tri-halomethanes (THMs) and other halocarbons from drinking water.

The physical adsorption process takes time, however, because adsorbates must move from the particle's exterior to the adsorption sites within it. Required contact time depends on the amount of carbon used and flow rated through it. Typical POU devices provide 20 to 40 seconds of contact time.

Taste and odor removal is an important ability of activated carbon. Molecules with carbon-sulfur bonds often smell and taste bad, but these are often preferentially adsorbed on carbon. The same is true of molecules with aromatic rings.

Carbon treatment helps very little, however, in cases where tastes and odor arise from small, highly-soluble molecules like ammonia or methanol.



Each carbon molecule attracts adsorbates into adsorption sites

Calgon Carbon Corporation
P.O. Box 717
Pittsburgh, Pa 15230

Chemviron Carbon
Zoning Industriel C
B-7181 Feluy, Belgium

AB-1056-05/93

Adsorption Forces

VOC removal is another of carbon's abilities. Chemical analyses show that as many as 1000 compounds can be present in water, but because adsorption is non-specific, all organic compounds adsorb on carbon.

> Activated carbon, however, differentiates among these contaminants. The most strongly adsorbed materials have the highest capacity on the carbon and are efficiently removed. Weakly-adsorbed components have lower carbon capacities and are the first to exhaust the carbon column.
>
> THMs and halocarbons are among a special group of VOCs that are favorably adsorbed. The more chlorine substituted on a molecule, the more strongly it is adsorbed on carbon, so carbon-chlorine or carbon-bromine compounds are better adsorbed than carbon-hydrogen compounds.
>
> THMs and halocarbon vary from weakly- to strongly-adsorbing. Carbon requirements can therefore vary according to the concentration of common THM and halocarbon contaminants.

While these carbon requirements relate to removal of a single component, they show the relative adsorbability of the different species. For multiple components, carbon requirements can be approximated by adding the carbon requirement for each individual component.

Activated carbon is also used for more than physical adsorption. Like graphite, carbon is a reducing agent that reacts with strong oxidizing agents such as chlorine dioxide, hypochlorous acid and ozone. It removes free chlorine from potable water using the following chemical reaction:

$$HOCl = C \text{ (skeleton) } fl \ CO^* + HCl$$

The CO* represents oxidation of the carbon skeleton by the formation of a carbon-oxygen bond. It may or may not result in the formation of free carbon monoxide (CO) or carbon dioxide (CO_2).
Chlorine removal is slow when HOCl is in the part per million (ppm) concentration range, so the carbon pore structure must physically adsorb free chlorine to increase its concentration to the point where the reaction is accelerated. That's why spent carbon with physically-adsorbed organics won't concentrate HOCl or induce the rapid reaction rates required.

Carbon's de-chlorination capacity is generally determined by its capacity for high molecular weight organics. Small granules adsorb and react faster than large granules, so some differences in de-chlorination performance are primarily due to the mesh size of the particles.

Granular carbon adsorbers can also remove contaminants through physical filtration. Since physical filtering doesn't involve adsorption, carbon spent with organics will continue to be an effective physical filter. A 12x40 mesh carbon column will remove most suspended solids greater than 10 microns in diameter. The smaller the carbon mesh size, the more efficient its physical filtration.

Physical filtration is sensitive to the packing of the carbon granules in the column. The denser the packing, the more effective it is. Filtered solids may be removed by backwashing the carbon bed at high flows. Because bonded blocks of carbon are generally composed of densely-packed fine particles, it's possible to extend their physical filtering limits to less than one micron. This can be important for cyst removal.

What It Can't Do

Activated carbon may be the ultimate physical adsorbent, but it has limitations in POU and POE applications. Carbon adsorption isn't the technology of choice for:

Water Softening. Activated carbon has less than one-tenth the ion exchange capacity of good commercial resins. Activated carbon is ineffective at softening water or removing high levels of iron.

Desalinating. Everything adsorbs on carbon to some extent, but highly water-soluble inorganic salts aren't effectively adsorbed. Cations like potassium, sodium, calcium and magnesium are seldom adsorbable because of their high solubility in water. Anions like nitrate, fluoride, sulfate and chloride are also seldom adsorbable because their salts are highly soluble.

Bactericidal Treatment. Bacteria and algae are much too large to enter the pore structure of activated carbon. The only means of removing bacteria, algae, or viruses with activated carbon is by physical filtration. Through some carbon blocks can be used for physical filtration of larger cysts in water, no carbon can be used reliably to achieve desinfection.

Heavy Metals Removal. Carbon's ability to remove heavy metals like lead, arsenic and mercury depends on their form. In some cases carbon's physical adsorption properties make it the best choice for removing heavy metals in the part per billion (ppb) concentration range, but no recommendation can be made for activated carbon without a thorough understanding of the forms of heavy metals present.

Activated carbon shouldn't be used for nitrate and fluoride removal. While it also can't soften or disinfect water, it enhances water's aestetics through dechlorination and mechanical filtration. It also enhances health protection by adsorbing synthetic and natural organic contaminants.

by Dr.Mick Greenbank

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