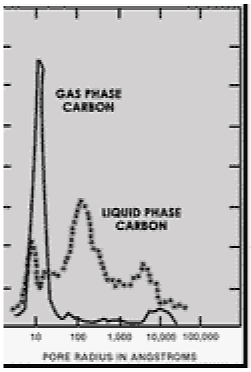

Activated Carbon | What is it, How Does It Work?

By Robert T. Deithorn and Anthony F. Mazzoni

In the last decade public awareness and concern over the quality of drinking water has resulted in more and more consumers turning to point-of-use devices for treating water to their own desired level of quality. This is reflected in the market for home water filters, designed to remove objectionable tastes and odors and organic contaminants from water, which has experienced substantial growth. The material in these filters, activated carbon, is recognized as effective and reliable in removing impurities. Activated carbon has a tremendous adsorptive capacity, an affinity for a wide variety of dissolved organics and chlorine and an ability to be custom-tailored to suit specific applications.

But what is activated carbon, and how does it work? How do carbon products differ? How do products and operating conditions affect the efficiency of a POU treatment system?

What Is Activated Carbon?

The primary raw material used for activated carbon is any organic material with a high carbon content (coal, wood, peat, coconut shells). ***Granular activated carbon*** is most commonly produced by grinding the raw material, adding a suitable binder to give it hardness, re-compacting and crushing to the correct size. The carbon-based material is converted to activated carbon by thermal decomposition in a furnace using a controlled atmosphere and heat.

The resultant product has an incredibly large surface area per unit volume, and a network of submicroscopic pores where adsorption takes place. The walls of the pores provide the surface layer molecules essential for adsorption. Amazingly, one pound of carbon (a quart container) provides a surface area equivalent to six football fields.

How Does Activated Carbon Work?

Physical adsorption is the primary means by which activated carbon works to remove contaminants from water. Carbon's highly porous nature provides a large surface area for contaminants (adsorbates) to collect. In simple terms, physical adsorption occurs because all molecules exert attractive forces, especially molecules at the surface of a solid (pore walls of carbon), and these surface molecules seek other molecules to adhere to. The large internal surface area of carbon has many attractive forces that work to attract other molecules. Thus, contaminants in water are adsorbed (or held) to the surface of carbon by surface attractive forces similar to gravitational forces. Adsorption from solution occurs as a result of differences in adsorbate concentration in the solution and in the carbon pores. The adsorbate migrates from the solution through the pore channels to reach the area where the strongest attractive forces are.

With this understanding of how the adsorption process works, we must then understand why it works, or why water contaminants become adsorbates.

Water contaminants adsorb because the attraction of the carbon surface for them is stronger than the attractive forces that keep them dissolved in solution. Those compounds that are more adsorbable onto activated carbon generally have a lower water solubility, are organic (made up of carbon atoms), have a higher molecular weight and a neutral or non-polar chemical nature. It should be pointed out that for water adsorbates to become physically adsorbed onto activated carbon, they must be both dissolved in water and smaller than the size of the carbon pore openings so that they can pass into the carbon pores and accumulate.

Besides physical adsorption, chemical reactions can occur on a carbon surface. One such reaction is chlorine removal from water involving the chemical reaction of chlorine with carbon to form chloride ions. This reaction is important to POU treatment because this conversion of chlorine to chloride is the basis for the removal of some common objectionable tastes and odors from drinking water.

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What are the Properties of Activated Carbon?

Activated carbon products can be characterized by physical properties and activity properties. Both physical and activity properties become important factors in the specification of commercial carbons for POU applications

Important physical properties are surface area, product density; mesh size, abrasion resistance and ash content. In water treatment applications, carbon density is expressed as backwashed and drained (BWD) or bulk density. This establishes the number of pounds of carbon required to fill a backwashable filter, and is expressed in terms of pounds per cubic foot.

Mesh size (8x30, 12x40, 20x50, etc.) establishes the range of particle sizes and thus, the effective particle size that will be used in a filter. Particle size is an important parameter in specifying carbons for specific applications, affecting such operating conditions as pressure drop, filtration capabilities, backwash rate requirements and the rate of adsorption of contaminants. While a smaller particle size effects more pressure drop across a carbon bed, the rate of diffusion of an organic into the pore and its subsequent adsorption is significantly increased.

Another important characteristic that distinguishes different types of ***liquid phase carbons*** is abrasion resistance. Abrasion resistance refers to a carbon's ability to withstand degradation during handling and is expressed in terms of abrasion number. The higher the abrasion number, the more resistant the carbon is to abrasion.

The final important physical property of activated carbon is ash level, which reflects the purity of the carbon. It is the inorganic residue left after heating of the raw material. Common ash constituents of coal-based carbons are silica, alumina, iron, calcium and magnesium.

Activity characterizations are key indicators of a carbon's potential performance for removing contaminants from water. An important characterization tool used in determining the ability of a carbon to adsorb a particular adsorbent is the pore size distribution, which is usually depicted in the form of a curve (Figure 1). The pore size distribution is produced through adsorption of gases and liquids under pressure. It defines the avail- able pore volume of a carbon over three pore size regions: The micropore region (less than 100 Angstroms. in size), mesopore region (between 100 and 1,000 Angstroms), and macropore region (greater than 1,000 Angstroms).

Figure 1 shows the difference in pore size distribution between a carbon used for a gas phase application and that used for a liquid phase application. The molecules encountered in gas phase are generally smaller and more mobile than those in liquid phase applications. There- fore, a gas phase carbon has the majority of its pores concentrated in the micropore region. There is a wider range of molecular sizes in liquid phase work (taste and odor, color bodies, organics, pesticides), and adsorbates are less mobile in water. This means a broader range of pore sizes must be available, both for ease of movement of adsorbates through the carbon pores and for adsorption of particular molecular sizes. Inexpensive tests have traditionally been used to approximate the distribution of pores available for a carbon as just described. These tests include the adsorption of a single standard reference adsorbate, and give the ability to distinguish activity characteristics of different carbons.

Iodine is the most common standard adsorbate and is often used as a general measurement of carbon capacity. However, because of its small molecular size, Iodine more accurately defines the small pore or micropore volume of a carbon and thus reflects its ability to adsorb low molecular weight, small substances. Iodine number is defined as the milligrams of Iodine adsorbed by one gram of carbon, and it approximates the internal surface area (square meters per gram).

Molasses number is a measure of the degree of de-colorization of a standard molasses solution. Because color pigments are large and cannot penetrate into small pores, the mo- lasses number defines the large pore or macropore volume of a carbon. It is used as a relative guideline for measuring the capacity of a carbon for larger adsorbate molecules.

Why are Activated Carbons Different?

As mentioned earlier, because activated carbons can be made from any carbonaceous raw material, differences will exist in the finished product as shown in Table 1. Domestically, most carbons are manufactured from coals. These include, in order of decreasing quality, metallurgical-grade bituminous coal, a lower ranked sub-bituminous coal and lignite. The base raw material and pretreatment steps prior to activation can affect many of the physical and activity characteristics of activated carbon. These different properties make some carbons better suited than others for specific applications.

Carbons made from lignite tend to have a large pore diameter (higher molasses number) that makes them better suited for the removal of large color body molecules from liquids. Bituminous coal activated carbons have a broad range of pore diameters. Since these carbons have both a fine and wide pore diameter, they are well suited for general de-chlorination and the removal of a wider variety of organic chemical contaminants from water, including the larger color bodies.

Some physical properties can be important in determining which carbon is best suited for a specific application. For instance, the abrasion resistance of activated carbons can be important if the carbon is to be used in an application where frequent backwashing will be required.

Generally, coal-based activated carbons show an increase in the abrasion number (therefore. increased abrasion resistance) when going from the softer lignite carbons to the bituminous coal carbons (Table 1).

Table 1

Typical Properties of Activated Carbons Produced from Different Raw Materials

	Bituminous	Sub-Bituminous	Lignite
Iodine Number	1,000	1,000	600
Molasses Number	235	230	300
Abrasion Number	80	75	60
Bulk Density as packed in column pounds / ft^3	26	25	23
Volume Activity	26,000	25,000	13,800
% Ash	6.7	12.3	20.1
* % Phosphorus On Carbon	<.05%	1-5%	<.05%

* Part of ash that can form a precipitate in hard water areas.

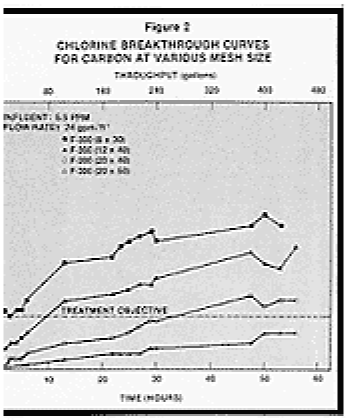
Density can also be a major consideration for specific applications. As Table 1 shows the densities of activated carbons also vary with the raw material. Fewer pounds of carbon with a low density will fit into a given container as compared to a carbon with a high density. This is significant because, while a container may require less carbon weight of a low-density carbon to make a volume fill. Its contaminant removal performance may be severely reduced as compared to a higher density carbon.

The concept of volume activity then becomes important when evaluating carbons. A simple calculation for determining the volume activity of carbons is to multiply the bulk density by the Iodine number. Thus, two containers having the same volume with carbons having the same Iodine activity (measured in milligrams Iodine per gram carbon) but different densities will have significantly different total surface areas (volume activity) available for adsorption.

Table 1 presents volume activity data for carbons made from three different raw materials. These volume activities have been calculated for a standard volume of one cubic foot. Differences in volume activity are evident when Iodine activities are the same but bulk densities are different (bituminous vs. sub-bituminous), and even more dramatic when both Iodine activities and bulk densities are different (bituminous vs. lignite).

Ash content can play an important role in home water filter applications. Activated carbons made from high ash content coals, such as sub-bituminous or lignite generally have some sort of chemical acid treatment step to reduce the inorganic constituents that cannot be activated. Although rinsed acid residuals can remain with the activated carbon after treatment. Table 1 shows the high phosphorus level on sub-bituminous-based activated carbon as a result of phosphoric acid pre-treatment. These residuals can some times be released during use and combined with metal ions in water to form magnesium or calcium precipitates (e.g., magnesium phosphate, calcium phosphate). When this happens, cloudy water can be produced.

Major Considerations for POU Treatment Design



Now that we understand the properties of activated carbon, how it works and how activated carbons are different, let's look at how activated carbon selection and operating conditions affect the performance of a treatment device.

The particle size of activated carbon affects how any POU treatment system will perform. The smaller the particle size of the activated carbon, the faster the rate of removal, whether by adsorption or chemical reaction, because the contaminant has less distance to go to reach the pores in the center of the activated carbon particle. The faster the rate of adsorption, the better the POU system will perform. To illustrate the particle size effect on performance, let's look at how an 8x30 mesh ***activated carbon*** resized to a 12x40, 20x40 and 20x50 mesh performs in a de-chlorination study.

An influent chlorine concentration of approximately 5 ppm and a surface-loading rate in 1-inch columns of 24 gpm/ft2 was used (Figure 2) in the study. This gave an empty bed contact time of 10 seconds. Four columns were run in a parallel mode using the same feed water and the same amount of activated carbon packed in 1-inch columns. In Figure 2 the data shows that the column with the smallest particle size, the 20x50 mesh, was able to maintain the treatment objective of 1 ppm through the entire 60-hour experiment, whereas the 8x30 mesh product broke through the treatment objective after 5 hours. Although the smaller particle size activated carbon performed better at the high flow rate, the potential for pressure drop problems must be considered.

Another major operating variable that impacts adsorption is the concentration of the adsorbate relative to its solubility. Adsorption capacity increases at higher concentrations of the adsorbate. Still, even at the lower contaminant concentrations found in drinking water, a significant activated carbon capacity remains to provide effective removal of these compounds.

Other operating factors that can influence activated carbon performance are temperature and pH. While adsorption capacity can increase with de- creasing stream temperatures, the temperature effect is minimal. How- ever, practical operation of POU treatment systems is recommended at ambient or colder temperatures. The pH of the water is important from the standpoint of its effect on solubility of the particular contaminant. Some organic compounds can exist in a more disassociated, polar form due to a pH shift, and would be less amenable to adsorption because of their increased solubility.

In summation, the two most important operating conditions for water treatment systems are flow rate of the water stream and concentration of the adsorbate relative to its solubility in water. As a general rule, lower flow rates allow a greater contact time with a unit volume of activated carbon, thereby improving the ability of the available activated carbon pore surfaces to attract and adsorb molecules. High flow rates can result in inefficient use of a carbon's capacity by not allowing the time for an adsorbate to migrate through the activated carbon pore to adsorption surfaces; however, it may be possible to compensate for high flow rates with a smaller particle size.

Conclusion: There are several considerations involved in the selection of an activated carbon for POU treatment.

A typical laundry list of items for evaluation includes the type of contaminant to be removed (chlorine, general taste and odor, color bodies, specific organics, or all of these). The treatment objective, handling requirements and purity of the effluent water.

Treatment devices with short contact times require the smallest particle size activated carbon practical for efficient use in contaminant removal. Also, activated carbons with a higher density and a high Iodine number allow more pounds of activated carbon to be placed in a given volume unit and provide more total surface area (volume activity) in any given container. If the system is to be backwashable, the use of a high abrasion number activated carbon is recommended so that the activated carbon will not break up during backwashing. Finally: it is important to know how your activated carbon is produced, the raw materials used and whether or not the raw material has been chemically treated which might affect the quality of the water coming out of the treatment unit.

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