What is Activated Carbon?

By John Sherbondy

Activated carbon is used to purify liquids and gases in a variety of applications, including municipal drinking water, food and beverage processing, odor removal, industrial pollution control, and point-of-use filters in the home. Public awareness and the concern about safe drinking water have driven consumers to install point-of-use carbon systems in their homes, further purifying the water that they drink.

Many of these home water filters use activated carbon to reliably remove dissolved impurities and disinfection byproducts that can make water taste bad. But what is activated carbon and how does it work?

What Is Activated Carbon?

Activated carbon is a material that is produced from carbonaceous source materials, such as coal, coconuts, nutshells, peat, wood, and lignite.

The primary raw material used for activated carbon is any organic material with a high carbon content. The carbon-based material is converted to activated carbon through physical modification and thermal decomposition in a furnace, under a controlled atmosphere and temperature.

The finished product has a large surface area per unit volume and a network of submicroscopic pores where adsorption takes place.

Activated carbon has an incredibly large surface area per unit volume, and a network of submicroscopic pores where adsorption takes place.

What are the Properties of Activated Carbon?

An activated carbon product can be characterized by its activity and physical properties. Activity properties include pore size distribution that defines the available pore volume of a carbon over three pore size regions: the micropore, mesopore, and macropore regions:

- Micropore region - less than 100 Angstroms
- Mesopore region - between 100 and 1,000 Angstrom
- Macropore region - greater than 1,000 Angstroms

Pore size distribution properties are key indicators of a carbon's potential performance for removing contaminants (adsorbates) from water. The molecules encountered in the gas phase are generally smaller than those in the liquid phase applications; therefore, a gas phase carbon has the majority of its pores concentrated in the micropore region.

A broad range of pore sizes must be available, both for ease of movement of adsorbates through the carbon pores and for the adsorption of particular molecular sizes. Liquid phase carbons often contain a broader pore size distribution to remove color bodies and larger organic materials, while maintaining some microporosity for the removal of taste and odor compounds.

Physical properties include surface area, product density, mesh size, abrasion resistance, and ash content.

Typical measured carbon properties include:

Iodine Number - standard testing done to estimate the surface area of the activated carbon by measuring iodine adsorption at a given set of standard testing conditions, reported in mg I2 adsorbed per gram carbon

Surface Area - amount of surface available for adsorption for a given mass of carbon, measured using techniques such as BET nitrogen adsorption; reported in units of m2/g

Product Density - several properties available, including apparent density which is the density of the carbon at maximum packing efficiency, reported in g/cc or lbs/cf

Mesh Size - measure of particle range of the granular product, usually reported as a range of sieve openings, such as 12 x 40 for a carbon that passes a 12 mesh screen, but is retained on a 40 mesh screen with a specification on the amount that can be retained on the larger opening screen or passing the smaller opening screen; basis is US sieve sizes Abrasion Number - measure of the ability of the carbon product to resist attrition; this important property permits one to understand how durable the activated carbon is in applications where backwashing is required, carbon will be transferred, or treatment velocities are above average

Ash Level - a measure of the non-carbon content of the activated carbon; all base materials have a certain ash constituency, with the content varying from base material to base material; for example, coconut shell carbon tends to have more alkali earth metals, while coal-based carbons have more heavy metals

How Does Activated Carbon Work?

Physical adsorption is the primary means by which activated carbon works to remove contaminants from liquid or vapor streams. Carbon's large surface area per unit weight allows for contaminants to adhere to the activated carbon media.

The large internal surface area of carbon has several attractive forces that work to attract other molecules. These forces manifest in a similar manner as gravitational force; therefore, contaminants in water are adsorbed (or adhered) to the surface of carbon from a solution as a result of differences in adsorbate concentration in the solution and in the carbon pores.

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 to adhere to other molecules.

The dissolved adsorbate migrates from the solution through the pore channels to reach the area where the strongest attractive forces are located. 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 exhibit this preference to adsorb are able to do so when there is enough energy on the surface of the carbon to overcome the energy needed to adsorb the contaminant.

Contaminants that are organic, have high molecular weights, and are neutral, or non-polar, in their chemical nature are readily adsorbed on activated carbon. For water adsorbates to become physically adsorbed onto activated carbon, they must both be dissolved in water so that they are smaller than the size of the carbon pore openings and can pass through 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.

Why are Activated Carbons Different?

Activated carbons are different because of the starting material and manufacturing methods. These raw materials establish the general characterizes, and differences will exist in the finished product.

Domestically, most carbons are manufactured from coals. 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 more suited than others for specific applications.

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 dechlorination and the removal of a wider variety of organic chemical contaminants from water, including the larger color bodies. Coconut-based carbon tends to exhibit greater microporosity, which is more suited for removal of low concentrations of organics such as in drinking water applications. This property can be deduced when comparing iodine numbers on the activated carbons. Carbons with higher iodine numbers will tend to have larger surface area; therefore, they will have higher capacity for comparatively weakly adsorbed organics. On the other hand, carbons with lower iodine numbers may still have wider pores, which could be favored for removal of large organic molecules. There are some applications where color removal will be better facilitated by a reactivated carbon as opposed to a high iodine carbon.

Another comparative factor is the hardness of the carbon. For instance, the abrasion resistance of activated carbons can be important if the carbon is to be used in an application where frequent back-washing will be required. As mentioned above, coconut carbons have a higher abrasion number than bituminous coal-based carbons and would be expected to experience less attrition over time in this type of an application.

Density can also be a major consideration for specific applications. As the table below shows, the densities of activated carbons 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.

Table 1 Typical Properties of Activated Carbons Produced from Different Raw Materials			
	Coconut	**Bituminous**	**Lignite**
Iodine Number	1,100	950	600
Abrasion Number	85	75	60
Bulk Density as packed in column lbs/ft^3	25	25	23
% Ash	3	6.7	20.1

Ash content can play an important role in applications for water treatment. The water soluble ash fraction may be liberated on contact with the activated carbon; this may lead to undesirable effects, such as imparting cloudiness to the water. Some applications with water having low pH can also liberate acid soluble ash and can actually impart color, such as when coal-based carbons are exposed to low pH water and iron is eluted from the carbon, imparting a yellowish-orange color to the effluent water. The table above summarizes these comparative properties.

While activated carbon is very useful for applications such as municipal water treatment, it is important for the user to solicit the product information and pricing from the activated carbon provider, ensuring that the best possible choice is made for the application. In this way, although a number of carbons may be good candidates for the application, the one that may offer the best cost-effective solution is the one that is used.