CARBON:

An Evaluation

of Carbon Composition

and Appropriate Applications

Summary: *How effective your carbon filtration system is often depends on what type of carbon you use forthe particularapplication. Varying carbon materialsrom bone char to anthracite coal to coconut shell and beyond—offer different properties for adsorbing or removing different contaminants. Here is a practical discussion ofboth materials and processing directed toward water treatment equipment dealers.*

Amazingly, more than 700 specific organic contaminants have been identified in drinking water supplies in the United States alone.' There are a variety of techniques available to remove these organic pollutants but the most prominent among these techniques is granular activated carbon (GAC) adsorption. Adsorption by granular activated carbon is regarded as the most effective water treatment process in removing many types df soluble organic materials found in drinking water. Not only are GACs important in the adsorption of organic chemicals, they also improve the aesthetics in producing high quality water—taste, color and odor. Although GAC filters aren't designed to kill or remove bacteria or viruses, knowing the importance these filters have on adsorbing other contaminants and particles from water is important for your customers. These organics are of great concern in water treatment because they react with many disinfectants, especiallychlorine, and cause the formation of disinfection by-products (DBPs), which include trihalomethanes (THMs). These DBPs can add to poor taste and are often carcinogenic and, therefore, highly undesirable.[2]

When addressing the significance of GACs and their applications, it's imperative that key issues are addressed . These issues to be considered include:

1. The raw materials used in the manufacture of GACs and how they're activated;
2. The relationship between the adsorbent and adsorbate, and
3. The different adsorbent properties of varying activated carbons.

Raw materials in making GACs

Activated carbon is manufactured by selective oxidation of a carbonaceous—carbon containing—material to produce a highly porous structure. Almost any carbonaceous material can be used.[3] In the United States, GAC is generally derived from some form of bituminous coal, lignite, wood, peat, bone char or coconut shell. Depending on the application applied, some carbons perform better than others. Other raw materials are used to manufacturelow-value, agricultural by-products such as rice and soybean hulls, sugarcane bagasse (spent cane pulp), and shells of peanuts, pecans and walnuts are becoming more popular, and are just as effective as the traditional materials.[4]

Carbonaceous materials are activated by either high-temperature steam or chemical dehydration. High-temperature steam activation is more common, and water-grade GAC is typically manufactured by this process. It involves heating the raw material to high temperatures (800-to-l,000”C) under very carefully controlled oxidizing conditions in the presence of steam, which acts as an oxidizing gas.

Chemical activation consists of heating the raw material to a lower temperature (400-to-500°C) in the presence of a strong dehydrating agent. The most common agentis phosphoric acid, although zinc chloride and others are used in different countries.

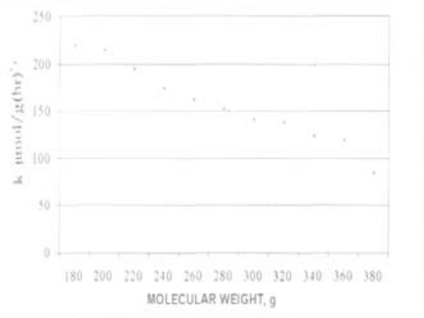
Once carbons are activated, manv undergo a process known as acid washing. Acid washing reduces trace metals from carbons, ash and other water-soluble contaminants (such as silica) that can leach out of a new carbon when first placed into service.

The choice of raw materials, the activation method and the manufac turing conditions control many properties of the actaited ca rbon and thus, the adsorbent characteristics.the adsorbent play in filtering your customer's drinng water.

The adsorbate

In layman's terms, the adsorbate is generally the substance being adsorbed—the contaminant to be

Figure 1.
The effect of molecular size on rate of adsorption



removed; while the adsorbent is the material doing the adsorbing. For a number of reasons, the chemical characteristics of the adsorbate are important. These characteristics determine the size and configuration of the particular molecule to be adsorbed." Molecule size is important for three reasons. First, as size increases, solubility decreases. Secondly, the adsorbate's molecular size is relevant because all adsorbents rely heavily on internal surface areas for full use of their adsorption capabilities. Figure 1 shows the effect of molecular size on the reaction of adsorption. Therefore, it's important to know that if the molecule is too large, adsorption will be hindered. This hindrance is a direct result of the large molecule blocking or not being able to penetrate pores or

The adsorbate and adsorbent

Upon contact with water containging soluble organic materials, GAC selectively removes these materials by ad sorption. Ad sorption is the phenomenon whereby molecules adhere to a surface with which thev come into contact due to forces of attraction at the surface. The use of surface energy to attract and hold molecules is a physical process, not a chemical one.

Even though adsorption is a rather uncomplicated process to understand, it's important to stress to you r customers the dynamics of the relationship that the adsorbate and

Figure 2.
Schematic representation of a constituent region of an activated carbon particle.

pathways within the adsorbent. Lastly, larger molecules tend to diffuse slower and require more time for full equilibrium. Even though the size and configuration of the adsorbate molecule are of great significance, molecular form is also of great. meaningfulness. Whether the molecule is in an ionic or neutral state, or is a branched isomer or a straight chain (see Glossary) will have an impact on removal of the adsorbate because of how varying configurations relate to that of the carbon, or adsorbent. The size, configuration and form of a molecule affect the rate of diffusion ofanadsorbate in any given solution. The adsorbentLikewise, the adsorbent's chemical and physical properties are rather vital. It's s these properties that successfully remove materials from a solution. The chemical properties include the degree of ionization of the adsorbent's surface, the types of functional groups on the adsorbent and the degree to which these properties can be altered by contact with a solution." [1] Ionized or active function groups on the adsorbent's surface allow chemical interactions of "chemisorption," which usually produce effects different from and less reversible than physical adsorption. Also, the capability of the chemical nature of the adsorbate to be treated can also have either beneficial or adverse effects on the adsorption process.

Not only do the chemical properties play a significant part in an adsorbcnt'sabilitytoadsorb,butphysi-cal properties are of equal weight. Granules, particles or powders are basic physical properties of an adsorbent. Surface area, size and distribution of pores also directly impact adsorption performance.

Adsorbent application of CAC

In any activated carbon particle, pores of different sizes are found. The activation of differentmaterials results in different pore size distributions. Therefore, when raw materials are activated, their applications for adsorption differ. Activated carbons are usually applied to adsorb molecules, and are thus best compared by their ad-sorptive properties. As discussed earlier, bituminous coal, lignite, wood, peat, bone char and coconut shells are common raw materials used in activation of carbon and a

comparison of theiradsorptive properties will be discussed. Various uncommon raw materials used in the activation of carbon also will be discussed.

Bituminous coal

Bituminous coal has both micro-and mesopores. Figure 2 shows the difference between a micropore, mesopore and macropore. In terms of adsorptive characteristics, bituminous-based coal carbons have a good capacity for smaller molecules. Containing a broad-spectrum pore size, coal is a good general-purpose carbon. Because of its pore size distribution, bituminous coal adsorbs more iodine, phenol and atrazine than any other activated raw materials.[6]

Lignite

Lignite on the other hand, contains a large percentage of macropores and is very light in density. Lignite realtive

There are a number of substances that can be and are used to make activated carbon—bone char; rice and soybean hulls; peanut, pecan and walnut shells; apricot and peach pits; spent sugarcane, and even lobster husks. But only a tew are most relevant to the water treatment industry. Here is a basic review of those and how effective they likely are at removing certain waterborne contaminants.

GAC properties:	**Coconut Shell**	**Coal**	**Wood**	**Lignite**
Hardness	++	+	0	•
Ash	++	+		-
Micropores	++	+	--	-
Mesopores	+	+	+	+
Macropores	-	+	++	+
Contaminant:				
Chlorine	++	++	++	++
Chloramtne	+	+	0	0
Chlorinated solvents	++	++	+	+
VOCs	++	+	0	0
Suspended organics (oils)	-	-	0	-
Natural organics (tannins/et< s.)	0	+	++	++
Grease & oil	--	--		--
Metals	+	0	-	-
Sediment	-	-	-	-
Odor	+	++	++	++
Salts	--	--	--	
TDS	--	--	--	--

++ — very effective + — effective 0 — fair - — poor - - not applicable

mesoporous, featuring not only pores in the 1-to-4 nanometer (nm) radius range, but also larger macropores which provide excellent accessibility of the adsorbate, Since lignite carbons have a higher capacity for larger molecules, they can effectively adsorb the higher molecular weight disinfection by-products (DBPs) discussed earlier. Aside from its effectiveness on the adsorption of DBPs, lignite-based carbons adsorb more humic acid, tannic acid and molasses color than any other raw material.[7] The lignite-based activated carbon used for removing arsenic is derived from the burning of peat moss or other related compounds such as sub-bituminous coal.

Wood

Wood-based carbons carry the highest percent of macropores of all carbons and as such have one of the highest molasses number of GACs. Wood-based carbons are mostly used for de-coloration in the wine industry. Most wood carbons, which all have the same basic chemical properties, come from by-products of the lumber and paper industries.

Peat

Peat carbons, like bituminous carbons, have a multi-purpose character: both micro- and mesopores. Peat carbons are effective and cheap. They are effective in the treatment of color, organic compounds and some metals in filtration systems.[9]

Bone Char

[8]Bone char is manufactured by using the bones of animals. Primarily a Scottish product, it has a rather large percentage of macropores and is used primarily in the sugar industry for decoloration. It also demonstrates a fair capacity for the reduction of aluminum, flouride, silver and lead.

Coconut shells

Coconut shell-based carbons are predominately microporous. They are suitable when only low molecular weight materials are removed. The presence of higher molecular weight materials readily leads to plugging of the entrances of micropores, severely reducing the practical performance. Coconut is the hardest and least dusty of all the base materials and has the highest iodine number. The coconut shell carbon is believed to createsweeter tasting water. Because of the unique pore structure of the carbon, it's well suited for chemical adsorption, including volatile organic chemicals (VOCs), while reducing chlorine and chemicals that contribute to taste and odor."

Uncommon carbons

Low value, agricultural byproducts like rice straw, soybean hulls, shells of peanuts, pecans and walnuts are being made into GACs. Many of these by-products have produced GACs having excellent physica 1 properties for commercial usage. The carbons made from pecan and walnut shells have a greater adsorption of several organic priority pollutants than other GACs tested. These are pollutants identified by the USEPA that municipal public *water systems must monitor on a periodic basis. Research also shows exceptional metal adsorbing properties with activated carbons made from soybean hulls, peanut shells and rice straws. The metals tested were lead, cadmium, nickel, copper and zinc*

Conclusion

When choosing the correct filter carbon, it's important your customers are aware of the raw materials used in activating carbon, the relationship the adsorbate and adsorbent play in theadsorption process and the properties of various carbons in eliminating organics and other contaminants. Thus, dealers can effectively employ the right carbon to improve the taste, odor and color of their customers' drinking water.□

References

1. Coyle, J.T.; I.H. Suffet and T.L. Yohe, "Monitoring and Analysis of Aqueous Chlorine Effects on Granular Activated Carbon Pilot Contractors," *Activated Carbon Adsorption of Organics from the Aqueous Phase,* Ann Arbor Science Publishers Inc., Ann Arbor, Mich., 1980.

Kvech, S., and E. Tull, Activated Carbon, 1996, pp. 1-2; http://www.ce.vt.edu/ enviro2/wtprimer/carbon

Bryant, E.A., G.P. Fulton and G.C. Budd, *Disinfection Alternatives for Safe Drinking Water,* Van Nostrand Reinhold, New York, 1992.

4. Johns, M.M., W.E. Marshall and C.A. Toles, *Granular Activated Carbons Made From Agricultural By-Products for Adsorbing Dissolved Metals and Organics,* 1997, p. 1-2, (http://www.nal.usda.gov/ttic/tektran/ data).

5. Slejko, F.L., *Adsorption Technology,* Marcel Dekker, New York, p. 34-90.

"What is Activated Carbon," http:// www.norit.com/carbon/l-0.htm

"Choosing the Correct Filter Carbon," http:/ /www.r skem.com/accessories/ carbon.html

Yehaskel, A., *Activated Carbon,* Noyes Data Corporation, New Jersey, 1978, p. 260.

McKay, G., "Peat—An Adsorbent/Filtration Medium for Water Treatment," *Water Services,* Vol. 84, June 1980, pp. 357-359.

10. "Activated Carbon," http:// www.gsi.thomasregister.com/olc/gsi/ active.htm

Glossary of terms

active function(al) group: site where ionic pairing, or bonding, takes place; where absorbate is "plated" onto the carbon; in the case of silver-impregnated carbon, this is where the silver is attached to the carbon

adsorbate: material to be removed from solution

adsorbent: material on which adsorption will occur

bagasse: in the case of sugarcane, this is the substance left over when sugar has been removed from the cane; the ash form of this substance is used as a carbon adsorbent

branched isomer: a central straight chain in molecular form with groups attached; the group on the straight chain are called side chains

carbonaceous: a carbon containing material

GAC: granular activated carbon

iodine number: the weight of iodine in milligrams which can be adsorbed by a gram of carbon; the iodine number is a measure of carbon's ability to adsorb low molecular weight organics, which is based on the capability to adsorb iodine from a standard solution; thus, the iodine number is a measure of micropores and indicative of surface area

ionic state: a charged subatomic particle

isomer: any of two or more chemical compounds having the same constituent elements in the same proportion by weight but differing in physical or chemical properties because of differences in the structure of their molecules

macropore: a pore with a radius (or half width) larger than 25 nanometers (nm)

mesopore: a pore with a radius between 1 nm and 25 nm

micropore: a pore with a radius below 1 nm

molecular weight: the relative average weight of a molecule of a substance, expressed by a number equal to the sum of the atomic weights of all atoms in the molecule; determines the hierarchy of elements and selectivity

molasses number: characterizes the availability of large pore diameters; this number is appropriate for characterizing an activated carbon for removing the higher molecular weight precursor compounds; the molasses number is a measure of the transitional pores

neutral state: a subatomic particle that is not electrically charged

straight chain: see *branched isomer*

surface area: the surface of a material available for adsorption to take place per square meter per gram

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