Activated Carbon: The Next Generation

Innovations in surface-modified activated carbon reveal waves of the future

By Dr. Vivek Gaur, Dennis Roberts & Dr. P.A. Shankar

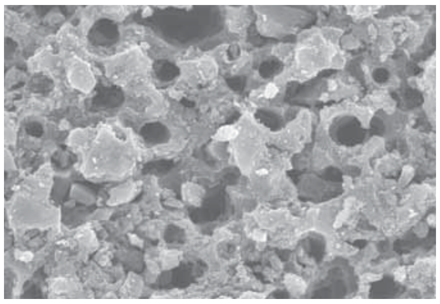


Figure 1. The microporous structure of activated carbon.

Activated carbon is used on an enormous scale in gas and water purification, metal extraction, medicine and many other applications. It is prepared from a variety of carbonaceous precursors, including coal, peat and coconut shells which are carbonized and then "activated," either by oxidization with CO_2 or steam, or by treatment with acids, bases or other chemicals.

Activated carbon is a well-known commercial material that is effectively used as an adsorbent for the removal of a wide variety of organic and inorganic pollutants dissolved in water or from gaseous emissions. In addition to wastewater treatment, activated carbon is widely used as an adsorbent in the purification of drinking water because of its ability to remove contaminants such as chlorine, chloramines, volatile organic compounds (VOC) and disinfection byproducts. Activated carbon is well suited to this task because of its exceptionally high surface area ranging from 800 to 1,500 m^2/g, well-developed internal microporous structure as well as the presence of a wide spectrum of surface functional groups (Figure 2).

As an inert porous carrier material, it is capable of distributing chemicals, particles or charged species on its large hydrophobic internal surface, thus making them accessible to distinct pollutants present in water. The principle of adsorption of the pollutant species on the activated carbon surface is well known to have bonding with van der Waals forces in association with London dispersion forces.

There has been an essential need for enhancing the adsorption capacity of activated carbon due to:

- The increase in contaminants such as VOCs caused by higher levels of industrial/agricultural pollutants;
- Higher regulatory standards for contaminant reduction; and
- Desire for increased claims capacity in ever smaller footprints.

While the effectiveness of activated carbon to act as an adsorbent for a variety of contaminants is well noted, advanced research on activated carbon modification is gaining prominence due to the need to enhance activated carbon's ability to remove certain contaminants from drinking water. It is essential to understand the various factors that influence the adsorption capacity of activated carbon so their specific physical and chemical attributes can be tailored to increase their affinities toward metal, inorganic or organic species present in water. These factors include not only the specific surface area and pore size distribution, but also its surface chemistry.

Surface Modification Technology

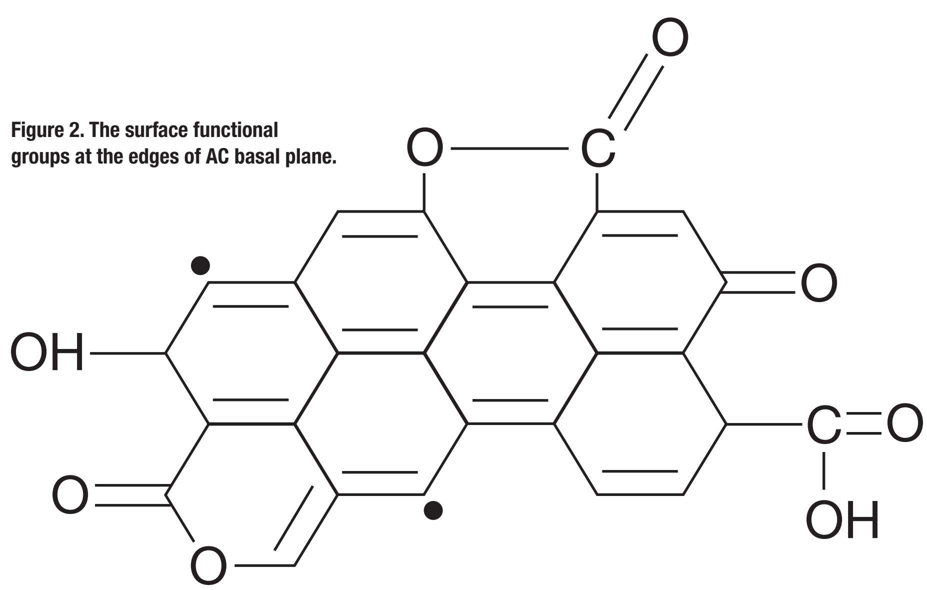
The surface chemistry of activated carbon is basically determined by the acidic and basic character of their surface, and can be changed by treating or impregnating them with oxidizing agents either in gas phase or in aqueous solution. Activated carbons containing several types of inorganic impregnates such as silver, and cations such as Al, Mn, Zn, Fe, Li and Ca, have been prepared for specific application in air and water pollution control. These treatments result in loading of a certain amount of either anionic charges (e.g., O_2^-) or the cationic charges (e.g., N^+ and NH_2^+) to the activated carbon surface, which makes the carbon materials more effective, hydrophilic and acidic or basic, depending on the nature of the charge(s). For example, more acidic surface charge density results in higher capacity for the reduction of heavy metals such as lead, cadmium and mercury. Similarly, one can control the surface basicity to enhance the affinity towards organic species like BTX and phenol. Similarly, treatments that create more positive charges such as N+ and NH_2^+ on activated carbon surface are favorable for enhancing the organic contaminant reduction. Furthermore, the thermal treatment of activated carbon also is favorable for enhancing adsorption of organic compounds from water since the basic characteristic of activated carbon is amplified at high-temperature conditions.

The Next Generation Is Now

While there continues to be substantial research and development investments in this field, there have been several important breakthroughs that are ready to leave the lab and be incorporated into drinking water treatment devices for enhanced reduction of lead and VOC contamination.

In July 2007, NSF implemented new testing protocols for lead reduction, making it very difficult for certain products, especially inexpensive pour-through pitchers, to maintain their lead reduction claims using traditional granular filtration media because it was unable to pass the new particulate lead standard—until now. The performance of surface-modified carbon obtained by oxidizing the activated carbon or by doping with oxygen is far superior for heavy metals reduction. The reduction of heavy metals, in particular, lead, is easier in acidic pH (less than 7.0) conditions as compared to basic pH (7.5 to 9.0) because in the later stage, the metals are present in the particulate form while it is in the dissolved form at lower pH. It is difficult to trap heavy metals in particulate form by the GAC filter media. Utilizing the enormous internal surface area of activated carbon, the charged ions are distributed uniformly, resulting in significantly higher reduction of both particulate as well as dissolved metals in a wide range of pH. At the same time, higher volume claims can easily be obtained by using highly charged GAC filters. These modified carbon granules can be used in pour-through pitcher applications to successfully reduce lead to the new NSF Standard 53 protocols as well as cartridge and carbon block applications for the reduction of soluble and particulate lead without the need for additional lead scavenger media.

Figure 2. The surface functional groups at the edges of AC basal plane.



In addition to a first-of-its-kind modified GAC for heavy metal reduction, surface modification techniques have been developed for enhanced VOC reduction and capacity, allowing claims that were previously unavailable using traditional activated carbon. Similarly, these surface-modified carbons loaded with appropriate amounts of cationic charged particles show enhanced affinity toward the VOC reduction from water. It is observed that the filter media using such a surface-modified activated carbon results in approximately 3.5 times higher volume claims for VOC reduction.

This specialty modified GAC for VOC reduction allows water treatment systems designers to reduce the overall size of their device while maintaining their existing claims or significantly increase their capacities using the same size filter media. This media is available in granules, powders and block formats providing the system engineer tremendous flexibility in product design.

Future Technologies

New technologies, such as plasma processing, also are being investigated to modify the surface of activated carbon. The plasma technique is a very efficient method to create the desired charge on the activated carbon surface, making it more effective for the removal of any species. Plasma oxidation is a process wherein activated carbon is exposed to plasma under vacuum or atmospheric pressure in atmospheric oxygen. During this process, the textural properties of activated carbon are completely retained; only the surface chemistry of activated carbon is modified in accordance with the nature and density of the plasma atmosphere. Based on the required mitigation of species, the gaseous environment for plasma may be varied. During plasma oxidation, there would be an increase in the surface acidity due to chemical addition of oxygen to carbon surfaces as oxygen free radicals and ions are attached to the carbon atoms located at the peripheral surface of the graphitic platelets. In the future, plasma-treated carbons could be a source of specialty carbons to remove specific contaminants or pollutants present in air or water. Research should focus on ways and means of exploiting the potential of plasma treatment for removing targeted chemicals/metals/microbes.

Conclusion

For almost 150 years, activated carbon has been one of the most effective solutions to water purification issues. As novel and promising modification techniques like plasma treatment are further developed, enhancements to the chemical characteristics of activated carbon that do not compromise their physical characteristics will open up new opportunities to custom-tailor activated carbon to remove all kinds of contaminants from water. *wqp*

Dr. Vivek Gaur is general manager of technology and Dr. P.A. Shankar is head of technology, Filtrex Group Singapore. Dennis Roberts is director, North American operations, Filtrex Technologies USA. Roberts can be reached at 760.992.9112 x707 or by e-mail at droberts@filtrexusa.com.

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