Water Treatment NOTES

Cornell Cooperative Extension, College of Human Ecology

Activated Carbon Treatment of Drinking Water

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Activated carbon filtration (AC) is effective in reducing certain organic chemicals and chlorine in water. It can also reduce the quantity of lead in water although most lead-reducing systems use another filter medium in addition to carbon. Water is passed through granular or block carbon material to reduce toxic compounds as well as harmless taste- and odor-producing chemicals. This fact sheet discusses the principles and processes of typical activated carbon filtration systems.

People are increasingly concerned about contaminants in their drinking water that cannot be removed by water softeners or physical filtration. Solvents, pesticides, industrial wastes, and leaking underground storage tanks are some sources of this contamination. Undesirable compounds such as methylene chloride, trichloroethylene, benzene, chlorobenzenes, carbon tetrachloride, and vinyl chloride pose health risks in drinking water. Lead from water pipes and joints may show up in water at the tap. The reaction of chlorine with organic matter during the chlorination of drinking water can produce other compounds such as trihalomethanes as by-products, which may increase the risk of certain cancers. Radon, a radioactive decay product of natural uranium, can be found in groundwater as well as in the air of buildings and has been related to lung cancer. Those considering the addition of an activated carbon filter to reduce toxic chemicals should first determine whether their water contains problem compounds. Public water systems are routinely monitored for contamination, and results of these tests must be made available on request. These water supplies must conform to the requirements established in each state under the federal Safe Drinking Water Act. If the level of any contaminant exceeds the maximum, treatment must be undertaken or new sources of potable (drinkable) water provided. Private water systems must be tested at the owner's initiative to determine whether treatment is needed. Decisions to do costly testing should be made based on knowledge of contamination incidents that can affect the private water supply.

Principles of activated carbon filtration

There are two basic types of water filters: particulate filters and adsorptive/reactive filters. Particulate filters exclude particles by size, and adsorptive/reactive filters contain a material (medium) that either adsorbs or reacts with a contaminant in water. The principles of activated carbon filtration are the same as those of any other adsorption material. The contaminant is attracted to and held (adsorbed) on the surface of the carbon particles. The characteristics of the carbon material (particle and pore size, surface area, surface chemistry, density, and hardness) influence the efficiency of adsorption.

The characteristics of the chemical contaminant such as the tendency of the chemical to leave water are also important. Compounds that are less water soluble (hydrophobic) are more likely to be adsorbed to a solid. A second characteristic is the attraction of the contaminant to the carbon surface. If several compounds are present in the water, strong adsorbers will attach to the carbon in greater quantity than those with weak adsorbing ability. These combined factors enable the activated carbon material to draw the molecule out of the water. The effectiveness of activated carbon for removing certain contaminants is shown in Table 1.

Table 1. Effectiveness of Activated Carbon in the Removal of certain contaminants

Contaminant	Comments
Bacteria, viruses	Preferred disinfection methods are chlorination or ultraviolet treatment. Use activated carbon only on microbiologically safe (coliform negative) water.
Cysts (*Cryptosporidium*,*Giardia lamblia*)	Look for NSF certification mark.
Chlorine and chlorination by-products	Leaves no residual chlorine for further disinfection.
Color/odor	Use faucet-mounted device when treatment is only for aesthetic reasons.
Lead	Look for NSF certification mark.
Organic chemicals	Use only point-of-entry units. Use petroleum, lignite, coconut shell, or coal-based carbon; do not backwash carbon. Look for NSF certification mark
Petroleum/gasoline by-products	Use only point-of-entry units. Use petroleum, lignite, coconut shell, or coal-based carbon; do not backwash carbon.
Radon	Radon held in carbon until it decays; use POE unit; do not backwash carbon. Investigate aeration as an alternative.
Volatile organic chemicals (VOCs)	Use point-of-entry devices. Investigate aeration as an alternative. Look for NSF certification mark.

The length of contact time between the water and the carbon material, governed by the rate of water flow, has a significant effect on adsorption of contaminants. More contact time results in greater adsorption. The amount of carbon present in a cartridge or filter affects the amount and type of contaminant removed. Less carbon is required to remove taste- and odor-producing chemicals than to remove trihalomethanes. The overall water quality (turbidity or presence of other contaminants) also affects the capacity of activated carbon to adsorb a specific contaminant.

When the activated carbon becomes saturated (all adsorption sites filled), contaminants can flow from the carbon back into solution.

Tips for Using Activated Carbon Filtration Devices

- The carbon cartridge should have rigid sides to maximize contact between the water and the carbon.
- A newly installed device should be flushed with water, following the manufacturer's instructions. For pour-through models, water should flow slowly through the unit to assure adequate contact with the carbon.
- Filters should be changed on schedule to avoid contaminant breakthrough.
- Only cold, microbiologically safe water should be used.
- Hazardous levels of organic chemicals are treated with a point-of-entry device.

To prevent this breakthrough from occurring, some activated carbon devices will shut off the water supply after a specified number of gallons have been treated. Using two activated carbon cartridges in series is another safeguard against breakthrough. One cannot assume that flow of water through the activated carbon unit will decrease as the filter becomes saturated with contaminant.

Materials used in activated carbon filtration

The solid material used in an activated carbon filter is typically petroleum coke, bituminous coal, lignite, wood products, coconut shell, or peanut shells, all of which are sources of carbon. The material is activated by subjecting it to high temperature (2300 °F) and steam in the absence of oxygen. This process produces a carbon substance with many small pores and thus a very large surface area, which is then crushed to yield a granular or pulverized product (see Figure 1).

Granular activated carbon (GAC) is more commonly used in private water systems than pulverized activated carbon (PAC). GAC units are canisters holding coarse carbon in a column through which water passes. Depending on the characteristics (particle size, pore size, surface area) of the granular carbon used, these units are effective for removing organic chemicals in industrial waste and trace organics, lead, and taste and odors in drinking water.

PAC cartridges use a finer mesh carbon. They may be paper-wound (carbon particles loaded on the paper) or wet-molded (carbon particles mixed with

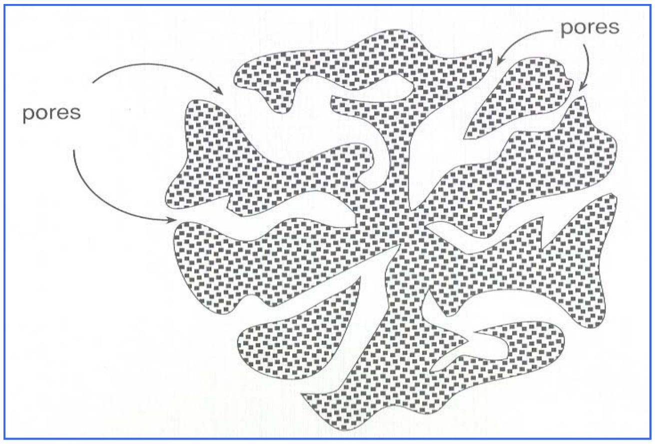

Figure 1. A typical carbon particle has numerous pores that provide a large surface area for water treatment. Adapted from Lykins, R W, Jr., Clark, R. M, Goodrich, j A., 38, Point-of-use/Point-of-entry for Drinking Water Treatment, *Lewis Publishers, an imprint of CRC Press, Boca Raton, Florida, 1992. With permission.*

fibers). PAC can also be fused or pressed into a block form, which is more frequently used in activated carbon filter systems. Block carbon can clog easily if the feed water is cloudy or turbid, resulting in a significant drop in water pressure. A pre-filtration sediment filter is often recommended with a block carbon device.

Synthetic resins, not often used in home treatment devices, are also available as filtering media. Although activated carbon is efficient in removing a variety of organic chemicals, a specially formulated synthetic resin may be a better adsorber for a specific contaminant. Resin filters are somewhat easier to restore (clean for reuse) than activated carbon units.

Bacterial growth

The material in an activated carbon cartridge provides a growth surface for bacteria. If the filter has not been used for at least five days or if large quantities of water have been treated, the bacterial population can increase. Although research studies so far show that only nonpathogenic bacteria (those that do not cause disease in humans) have been found on the carbon, bacterial growth on activated carbon may be a potential health hazard.

Some manufacturers claim that the infusion of compounds such as silver can prevent bacterial growth on the carbon surface or that a specific type of carbon will screen harmful bacteria from the water. The Environmental Protection Agency has not endorsed these methods for reducing bacteria in the filter or in the water. If a carbon treatment device has not been used for five days or longer, running the water for 10 to 30 seconds, or until 1 to 2 quarts have passed through, reduces bacterial count in the treated water. As a precaution, activated carbon filters are recommended for use only on microbiologically safe (coliform negative) water.

Structure of activated carbon units

A typical activated carbon cartridge is a cylinder holding various amounts of carbon, depending on the size of the unit. The sides of the cartridge should be rigid (hard plastic or stainless steel) to force water through the length of the column bed. Cartridges with sides of mesh or wound string allow water to pass by without sufficient contact with the activated carbon. This is not a problem with block carbon.

Where the treatment unit is located in the home depends on its intended function. Users may choose from point-of-entry (POE) or from four point-of-use (POU) models: in-line, line-bypass, faucet-mounted, or pour-through.

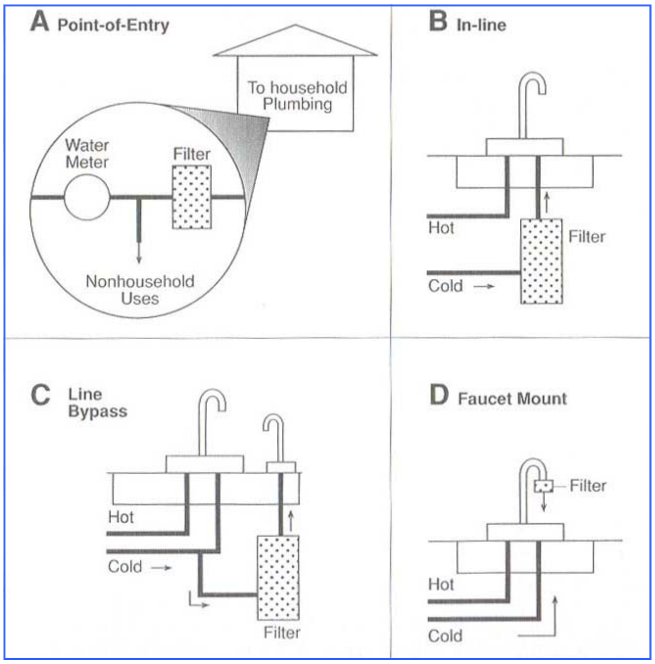

Figure 2 Activated carbon filtering devices are designed for point-of-entry or point-of-use treatment. Adapted from Journal American Water Works Association, Vol. 75, No. 1 (January 1995), by permission. Copyright © 1995, American Water Works Association.

A POE device treats all water coming into the residence (Figure 2A). The water line can be tapped before filtration for outdoor uses. The POE device is recommended for treatment of radon and volatile organic compounds (VOCs). Because VOCs easily vaporize from water into the air, POE treatment prevents inhalation of hazardous vapors from the shower, dishwasher, or washing machine or exposure through skin contact. This device should meet certain guidelines concerning contact time between the water and the carbon, the type and amount of carbon used, and the wastewater discharge. Specific recommendations should be obtained from the local health department.

POU devices treat water at specific points within the house and are particularly useful for removal of lead and chlorine. POU activated carbon filters should not be relied on to treat individual water supplies that have been contaminated with organic chemicals. The in-line device is installed beneath the kitchen sink in the cold water supply line (Figure 2B). If both hot and cold water come from a single spigot, the treated (cold) water can mix with the untreated (hot) water. Only the cold water can be considered to be treated.

The line-bypass unit is also attached to the cold water pipe, but a separate faucet installed at the sink provides treated water for cooking and drinking (Figure 2C). The regular tap delivers untreated water for washing or other non-consumptive uses. This design increases the life of the carbon by allowing a choice of treated or untreated water, depending on the intended use.

Faucet-mounted units are attached to the faucet (usually in the kitchen) or placed on the counter with connections to the faucet (Figure 2D). There are two basic designs. The bypass option has a valve to send water used for cooking and drinking through the filter or to send water used for washing directly to the faucet. Again, this option prolongs the life of the carbon cartridge. The non-bypass option filters all water passing through the faucet.

The pour-through model, similar in design to a drip coffee maker, is the simplest type of activated carbon filter. A quantity of untreated water is poured through the carbon, and the treated water is collected in a receptacle. These units are not connected to the water supply and usually sit on the counter. They are portable, require no installation, and are convenient for camping or picnicking.

Pour-through and faucet-mounted units are inexpensive but will treat only small quantities of water at a time and are not as effective as larger, automatic units.

Because the quantity of carbon contained in a pour-through or faucet-mounted unit is not large enough to provide extensive contact with the water, these devices are not recommended for removal of toxic organic chemicals.

Maintenance

Carbon cartridges must be replaced at regular intervals, according to manufacturer's instructions. Replacement intervals should be calculated based on the average daily water use through the filter and the amount of contaminant being removed. Cartridge disposal depends on usage. A carbon cartridge (POE only) can be backwashed (flushed) or discarded if non-toxics have been adsorbed. To remove taste- and odor-producing chemicals, the POE unit can be backwashed manually or automatically depending on the device's capabilities. Used carbon cartridges add to household waste, but disposal of saturated carbon cartridges does not significantly increase the load on a landfill. Federal law allows homeowners to dispose of GAC units as household waste.

Removing Radon from Water by Activated Carbon Filtration

- Radon, which is a cause of lung cancer, is a radioactive decay product of natural uranium that moves through soil and rock into groundwater or enters a building through cracks or openings in the foundation.
- The major source of radon is indoor air. If you are concerned about radon in your water, have your water tested.
- People inhale radon that vaporizes from water used in the bath or shower, dishwasher, washing machine, or in cooking. Skin contact is possible.
- Radon is removed from water by granular activated carbon. The carbon, which is effective for many years, holds the radon until it decays into non-radioactive compounds. Point of entry without backwashing must be used.
- In radon removal, the activated carbon unit becomes a source of low-level radioactivity. The unit should be located in a remote comer of the home or outside in a pump house directly over the well.
- An aeration system set up outside the home is another alternative for radon removal.

If an activated carbon POE unit is placed on a home water supply because of known toxic or hazardous chemicals, the carbon cartridges may have to be disposed of in accordance with local regulatory or health agency recommendations. Carbon cartridges that have been used for removal of toxic chemicals can be sent to an appropriate facility to be regenerated (contaminants burned off and carbon reactivated). Treatment of hazardous chemicals requires carbon regeneration by commercial water treatment firms. The procedure is similar to the original activation process. Research shows that regenerated carbon adsorbs as well as newly activated carbon and that gases released to the atmosphere during reactivation do not contain high levels of hazardous chemicals.

Choosing an activated carbon unit

When purchasing an activated carbon filtration device, the consumer should first consider the current quality of the drinking water. An activated carbon unit to get rid of simple taste and odor problems is quite different from one designed to remove low levels of toxic contaminants. Private water supplies should be tested for particular contaminants.

Public water suppliers must provide results of regular testing upon request. The best unit for a given situation depends on the amount and type of carbon contained in the unit, what contaminants it is certified to reduce, initial and replacement cost of filters, frequency of filter change, and operating convenience. Other important considerations are the potential drop in water pressure in the home system after installation of a unit and the daily quantity of treated water supplied by the device.

Activated carbon treatment has limitations. It does not soften water or remove bacteria, viruses, most dissolved metals, hydrogen sulfide, fluoride, or nitrate. It removes limited quantities of rust, but particulate matter or high iron levels clog the unit. Activated carbon is not a recognized method of bacteria removal.

Many point-of-use products on the market today are combination filters. Particulate filters, combined with carbon filters, can filter sediment present in the water. Very fine particulate filters are sometimes combined with GAC cartridges so that the filter system can be certified for cyst reduction. Cyst reduction has become an important concern to consumers because some water supply sources (particularly surface water and groundwater connected to surface water) contain disease-causing protozoan cysts *(e.g., Giardia and Cryptosporidium)* that are difficult to detect and that are not destroyed in the chlorination process. Many public water supplies have a filtration process that removes these cysts, but if consumers want to buy a filter that assures 99.95% cyst reduction, they should look for this certification by NSF, International. Some block activated carbon devices are also certified for cyst reduction because of the filtering action of the block carbon itself. Because protozoan (e.g., *Giardia and Cryptosporidium)* cysts are very small in size (less than 5 microns) and are present in very low concentrations, they do not rapidly clog activated carbon or combination filters.

NSF International certifies water treatment units for reduction of health-related contaminants as well as for aesthetic (taste and odor) problems. Activated carbon units and combination units containing activated carbon should be checked for NSF certification for total trihalomethane reduction, volatile organic carbon reduction, lead reduction, and cyst reduction. Look for the NSF certification mark to assure that contaminant reduction claims are true, the system is not adding anything harmful to the water, and the system is structurally sound. New activated carbon technology is becoming available every day. Check with your local Cooperative Extension office or water treatment professional for the latest information and NSF certification for activated carbon units.

Summary

- Activated carbon adsorption is an effective means for reducing organic chemicals, chlorine, lead, and unpleasant tastes and odors in water.
- This treatment can produce water of more desirable quality than that from some public or private supplies. Units ranging from simple, manually operated devices to complex, automatic ones are designed to ensure the reduction of specific contaminants.
- Not all carbon units reduce lead. Look for the NSF certification mark for specific contaminant reduction claims.

References

Bellen, G., M. Anderson, and R. Gottler. *Management of Point-of-Use Drinking Water Treatment Systems, Final Report. U.S.* Environmental Protection Agency: Water Engineering Research Laboratory, Office of Research and Development. Cincinnati, 1984.

Hasbrouck, S. Removing Radon from Water Using Granular Activated Carbon Adsorption. *Information Digest,* University of Maine at Orono. June 1986.

References *continued*

Lalezary, S., M. Pirbazari, and M. McGuire. Evaluating Activated Carbons for Removing Low Concentrations of Taste and Odor-Producing *Organics.journal of American Water Works Association.* Nov. 1986. Pp. 76-82.

Lykins, B. W., E. E. Geldreich, J. Q. Adams, J. C. Ireland, and R. M. Clark. *Granular Activated Carbon for Removing Nontrihalomethane Organics from Drinking Water, Project Summary.* U.S. Environmental Protection Agency, No. EPA600/S2-84-165. Dec. 1984.

Matchett, B. What to Expect from Carbon Cartridges. *Water Technology* 16(11):76-79,1993.

Michaud, C. F. Baffled by Multi-Media Cartridges? *Water Technology* 17(9): 50-54, 1994.

Michaud, C F. Get Specific with Cartridges. *Water Technology* 18(4):90-92,1995.

Outman, C. S., V. L. Snoeyink, J. T. O'Connor, and M. J. Taras. *Removing Trace Organics from Drinking Water Using Activated Carbon and Polymeric Adsorbents.* U.S. Environmental Protection Agency Project Summary. EPA-600/S2-81077,078,079. July 198 1. Cincinnati.

Snoeyinck, V. L. Principles of Adsorption by Activated Carbon. Paper presented at the Fourth Domestic Water Quality Symposium, Chicago, Dec. 16-17, 1985.

Wagenet, L., K. Mancl, and M. Sailus. *Home Water Treatment.* Northeast Regional Agricultural Engineering Service, Ithaca, N.Y., 1995.

Water Filters. *Consumer Reports* 48:68-73, 102. Feb. 1983.

Water Treatment Handbook: A Homeowners Guide to Safer Drinking Water. Emmaus, Pa.: Rodale Press Product Testing Department, Rodale Press, 1985.

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