NebGuide
University of Nebraska–Lincoln Extension, Institute of Agriculture and Natural Resources
Know how. Know now.

G1489
(Revised September 2008)

Drinking Water Treatment: Activated Carbon Filtration

Bruce I. Dvorak, Extension Environmental Engineering Specialist
Sharon O. Skipton, Extension Water Quality Educator

Activated carbon filtration can effectively reduce certain organic compounds and chlorine in drinking water. It can also reduce the quantity of lead, dissolved radon, and harmless taste- and odor-causing compounds. This guide discusses the principles, processes and requirements of activated carbon filtration systems for the domestic (household) user.

Contaminants Removed From Water by Activated Carbon Filtration

Homeowners are increasingly concerned about contaminants in their water supply that may affect health or cause taste and odor problems. Sources of these contaminants might include solvents, pesticides, industrial wastes, or contaminants from leaking underground storage tanks. Contaminants such as benzene, chlorobenzenes, trichloroethylene, carbon tetrachloride, methylene chloride, and vinyl chloride in drinking water may pose health risks if they are present in quantities above the EPA Health Advisory Level (HAL). Activated carbon (AC) filtration can effectively reduce some of these organic chemicals as well as certain harmless taste- and odor-producing compounds.

Some drinking water may be disinfected with chlorine or chloramines. During disinfection the reaction of chlorine with organic matter during drinking water chlorination can produce compounds such as trihalomethanes (THMs) as byproducts. These disinfection byproducts may increase the risk of certain cancers. The EPA mandates that public systems have less than 80 parts per billion (ppb) of THMs in their treated water. AC filtration can be effective in removing chlorine, chloramines, and some disinfection byproducts.

In addition, lead from water pipes and joints may be present in water from the tap. AC filtration can reduce lead in drinking water, though another filter medium is commonly used in addition to AC for this purpose. Only very specialized AC filters effectively adsorb heavy metals. Radon, a radioactive decay product of natural uranium that has been related to lung cancer, can be found in some groundwater. Radon gas also can be removed by AC filtration, though removal rates for different types of AC equipment have not been established.

Contaminants Not Removed by Activated Carbon Filtration

No one piece of treatment equipment manages all contaminants. All treatment methods have limitations and often a combination of treatment processes is required to effectively treat the water. Different types of carbon and carbon filters remove different contaminants and no one type of carbon removes all contaminants at maximum efficiency. AC filters will not remove microbial contaminants (such as bacteria and viruses), calcium and magnesium (hard water minerals), fluoride, nitrate, and many other compounds. Refer to Extension Circular 703, *Drinking Water Treatment: An Overview* for a discussion of possible water quality problems and appropriate treatments for these contaminants. Further information can be obtained from the appropriate treatment guide in the Drinking Water Treatment series (listed as part of this publication's Web resources).

Water Testing

Regardless of which water treatment system is considered, test the water first to determine what substances are present. Public water systems routinely test for contaminants. Water utilities are required to publish Consumer Confidence Reports (CCRs), which inform consumers on the source of the water, contaminants that are present, potential health effects of those contaminants and methods of treatment used by the utility. Depending on the population served by the utility, CCRs may be mailed, published in newspapers or posted on the Internet, but copies can be obtained from the local water utility. Public supplies must conform to federal standards established by the Safe Drinking Water Act. If contaminants exceed the Maximum Contaminant Level (MCL), the water must be treated to correct the problem and/or another source of water suitable for drinking must be provided.

In contrast, monitoring of private water systems is the homeowner's responsibility. Therefore, contamination is more likely to go undetected in a private water supply. Knowing what contaminants may be present in the water should guide the testing, since it's not economically feasible to test for all possible contaminants. It is essential to know what contaminants are present, their quantities, and reasons for removal (i.e., to reduce contaminants posing health risks, to remove tastes or odors, etc.) prior to selecting water treatment methods or equipment. Refer to NebGuide 907 *Drinking Water: Testing for Quality*.

Treatment Principles

There are two basic types of water filters: (1) sediment (or mechanical) filters which filter particles by size and (2) adsorptive or reactive filters which contain a medium that adsorbs or reacts with a water contaminant. Activated carbon filtration is an adsorptive process in which the contaminant is attracted to and held (adsorbed) onto the surface of the carbon particles. The efficiency of the adsorption process is influenced by carbon characteristics (particle and pore size, surface area, density and hardness) and the contaminant characteristics (concentration, tendency of chemical to leave the water, solubility of the contaminant, and contaminant attraction to the carbon surface).

The medium for an activated carbon filter is typically petroleum coke, bituminous coal, lignite, wood products, coconut shell or peanut shells, which are all sources of carbon. The carbon medium is "activated" by subjecting it to steam and high temperature (2300^{o}F) without oxygen. In some cases, the carbon also may be processed by an acid wash or coated with a compound to enhance the removal of specific contaminants. This activation produces carbon with many small pores and, therefore, a very high surface area. It is then crushed to produce a granular or pulverized carbon product. This creates small particles with more outside surface area available for compounds to enter the AC, which results in greater contaminant removal. The source of the carbon and the activation method determine the effectiveness of removal for specific contaminants. For instance, the carbon that most effectively removes lead is obtained from a different source and activation method than the carbon that most effectively removes chlorine. *Figure 1* is a schematic of an activated carbon particle.

If more than one contaminant is present in the water, those contaminants easily and strongly adsorbed to the carbon will adsorb in greater quantity than less well-adsorbed contaminants. This is called competitive adsorption and can significantly affect the dynamics of carbon adsorption. Competitive adsorption can result in a less well-adsorbed compound leaving the filter while a better-adsorbed compound is still being removed.

The length of contact time between the water and the carbon — which is determined by the rate of water flow — also affects contaminant adsorption. Greater contact time can allow for greater adsorption of contaminant. Also, the amount of carbon in the filter affects contaminant removal. For instance, less carbon is generally required to remove taste and odor-producing compounds than to remove trihalomethane (THM). The amount of carbon also can affect how quickly the carbon becomes full (saturated).

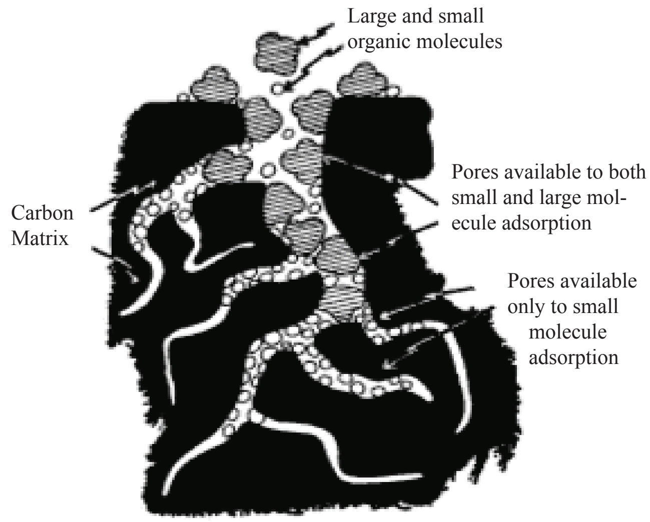

Figure 1. Activated carbon particle. Adapted from Culp, G.L., and R.L. Culp. 1974. *New Concepts in Water Purification.* Van Nostrand Reinhold Co., New York.

When all adsorption sites on the activated carbon become full of contaminants, the filter is saturated and has reached its capacity. At this point, some contaminants may not be adsorbed, or some may move from the carbon back into the water. This is called breakthrough since the contaminant "breaks through" the filter and is in the "treated" water. When this occurs, it is possible that the contaminant concentration in the "treated" water may actually be higher than in the untreated water. In order to prevent breakthrough, some AC filtration units will shut off the water supply after a specified number of gallons have been treated; most units, however, do not have this feature. Using two AC filters or cartridges in series can help safeguard against breakthrough.

Equipment

Activated carbon filtration units can be either point-of-use (POU) or point-of-entry (POE) treatment. A POE device treats all water coming into the house. This type of setup is recommended for treatment of some nuisance compounds, radon and volatile organic compounds (VOCs). VOCs can easily vaporize from water in showers, washing machines and dishwashers and come in contact with skin. A POE device that reduces the contaminant at the point of entry is appropriate for such a situation. POE devices should meet guidelines for contact time, the type and amount of carbon used and the wastewater discharge.

POU devices treat water at a point or points of use within the house and are useful for removal of lead and chlorine. Point-of-use models can be either in-line, line-bypass, faucet-mounted or pour-through. An in-line device is installed beneath the kitchen sink in the cold water supply line. In this situation, if hot and cold water come through one spigot, the treated cold water mixes with the untreated hot water; then only the cold

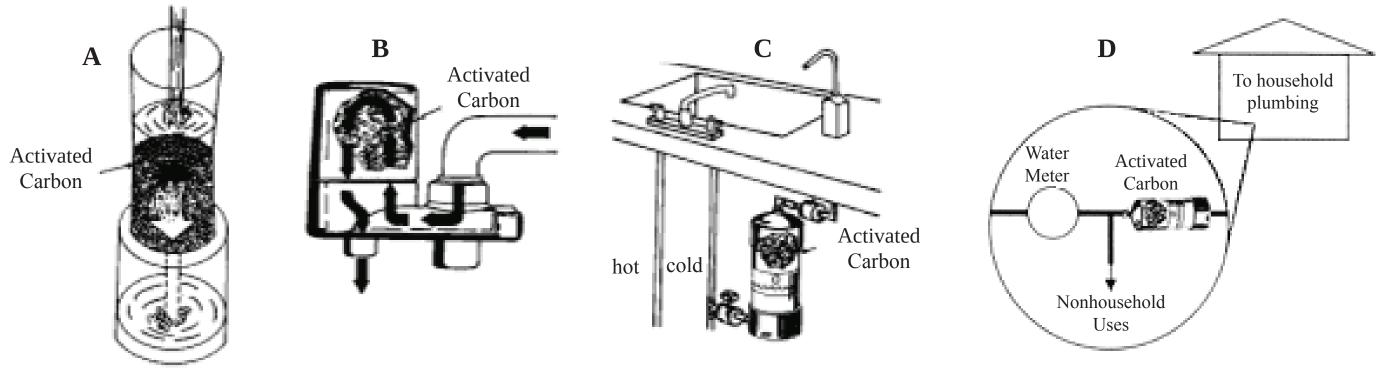

Figure 2. Types of activated carbon filtration units are: A) pour-through; B) faucet-mounted; C) line-bypass and D) point-of-entry. Adapted from *"Treatment Systems for Household Water Supplies: Activated Carbon Filtration,"* North Dakota State University Extension Service.

can be considered to be treated. In the line-bypass system, a separate faucet is installed at the sink. The unit is attached to the cold water pipe and provides drinking and cooking water, with the regular tap providing untreated water for non-consumptive use. This arrangement increases the life of the carbon by allowing a choice of treated or untreated water, depending on use.

Faucet-mounted devices are attached to the faucet or sit on the counter with connections to the faucet. These can have bypass valves that allow selective filtering if water is going to be used for cooking or drinking, which prolongs the life of the carbon. Pour-through models (such as pitchers with a filter) are the simplest type of AC filter. Water is simply poured through the carbon and collected in a container. These units aren't connected to the water supply. Both pour-through and faucet-mounted units are inexpensive and simple, but will treat only limited quantities of water at a time and are not as effective as other devices because contact time is limited due to the small amounts of carbon contained in the units. *Figure 2* shows the different types of AC filters.

One measure of the AC's capacity to remove organic compounds is its iodine number. This is the amount of iodine (in milligrams) adsorbed by one gram of AC under set conditions. A higher iodine number generally indicates greater adsorptive capacity.

Carbon cartridges must be replaced regularly. Replacement intervals should be determined based on daily water flow through the filter and the contaminant being removed. Some manufacturers state a recommended water treatment capacity in gallons, beyond which the AC should be replaced. Most devices on the market do not indicate how much water has passed through the filter, so a consumer must estimate the number of days the filter will last before needing replacement. To do this, assume that one person uses 1 gallon per day for drinking. Assume 1 to 3 gallons per day for cooking per household.

For example, a household with four people would use 4 gallons per day for drinking and possibly 1 gallon for cooking, for a total of 5 gallons of water use per day. A 200-gallon capacity filter would last 40 days under these conditions (200 gallons/5 gallons a day = 40 days).

These estimates, however, do not take into consideration the contaminant being removed and its concentration. Tests done by Rodale Press Product Testing Department indicated that filter performance was reduced significantly after 75 percent of the manufacturer's recommended lifetime. Therefore, it may be safer to replace the filter more often than recommended by the manufacturer. Retailers can help you determine replacement intervals as well. However, the only way to be certain if a filter is successfully removing contaminants is by repeated testing of the filtered water for the contaminants to be removed.

Some systems claim to alert the user when the cartridge should be changed. This may be determined by a pressure drop across the filter. However, a pressure drop may or may not result from the filter reaching adsorption capacity, as saturation and breakthrough can occur long before a pressure change occurs. When a change in water pressure occurs, or a change in taste, odor, or sediment is noticed, malfunction is indicated and the filter should be replaced.

AC filters which have been idle for a number of days or which are saturated with organic matter provide an excellent environment for bacterial growth. There is little risk to healthy people consuming harmless (non-pathogenic) bacteria found on most AC filters. However, there may be some concern for the very young, the very old, and those with weakened immune systems. When a filter has sat idle for several hours (such as in the morning) the amount of bacteria on the filter may be limited by running water through the filter for 30 seconds.

Some filters are impregnated with silver to try to prevent bacterial growth, but studies indicate that this practice makes little difference in reducing bacteria. Any advantage seen from the silver is only apparent in the first month of use. The best practice is to replace the filter as often or more often than the manufacturer recommends. Although AC filtration products with silver in them are *registered* with the EPA, realize that is no guarantee that the device is effective or has been tested or *endorsed* by the EPA. It is required that water treatment equipment with an active ingredient intended to prohibit growth of microorganisms be registered with the EPA.

A sediment or particulate filter installed ahead of any AC filter will prolong the life of the AC unit. Sediment can easily and quickly clog the pores of an AC filter and a good sediment filter can be obtained for a fraction of the price of most high volume AC filters.

Cost of AC equipment varies with the type of filter installed. Pour-through and faucet-mounted filters for taste and odor removal are generally less costly than high volume units used for reducing health risks from specific trace contaminants.

Selection Requirements

Federal, state, or local laws do not regulate activated carbon filtration POU and POE home systems. The industry is self-regulated. The NSF (formerly known as the National Sanitation Foundation) and the Water Quality Association (WQA) evaluate performance, construction, advertising and operation manual information. The NSF program establishes performance standards that must be met for endorsement and certification. The WQA program uses the same NSF standards and provides equivalent American National Standards Institute (ANSI) accredited product certifications. WQA-certified products carry the Water Quality Association Gold Seal. Though these certifications and validations should not be the only criteria for choosing an AC system, they are helpful to ensure effectiveness of the system.

Other important guidelines for consumers purchasing drinking water treatment equipment are discussed in NebGuide 1488 *Drinking Water Treatment: What You Need to Know When Selecting Water Treatment Equipment.* Drinking water treatment NebGuides and guides on specific contaminants may be found at *ianrpubs.unl.edu*. The NebGuide series on drinking water treatment focuses on contaminants most likely to be encountered in Nebraska drinking water supplies.

Summary

Drinking water treatment using activated carbon (AC) filtration is one option for a homeowner to treat drinking water problems. AC is an effective method for treating certain organic compounds, unpleasant tastes and odors, and chlorine, though its not effective for metals, nitrate, microbial contaminants and other inorganic contaminants. Select an AC system based on water analysis and assessment of individual homeowner's needs and situation. Regular replacement of the filter/cartridge is critical to maintain effectiveness and reduce bacterial contamination of the filter. The NSF and the WQA test and certify products. This certification can help guide selection.

Acknowledgment

The authors wish to acknowledge the contribution of former UNL extension engineer Jodi Kocher, who collaborated with them in the previous version of this NebGuide.

This publication has been peer reviewed.

UNL offers several NebGuides relating to water quality. To find out more, check with your local extension office of go online at *http://extension.unl.edu/publications*.

Index: Water Resource Management
Drinking Water
2003, Revised September 2008