by Elwood V. Rinehart

Activated Carbon Basics

Basics

Activated carbon is like a radio: everyone knows it works, but few people know exactly how. This article is a brief summary of the sources of carbons, the activation process, the principle of adsorption, and the range of current applications.

The wide world of carbon

Carbon can exist in a number of forms with either crystalline or amorphous structures. The most well known crystalline forms are diamonds and graphite, the uses of which are widespread and well documented. The amorphous forms include carbon black, carbon fibers, and porous carbons, all of which are obtained by heating or burning under controlled conditions such carbonaceous materials as coal, coconut shells, wood, peat, lignite, and petroleum. The carbonaceous material is usually solid and naturally occurring.

Porous carbons are obtained as a residue after the volatile components of the carbonaceous material are removed by a thermal process in the absence of air. The most important products are cokes and charcoals, which are used in very large quantities in the iron and steel industry. Charcoal is the product that provides the raw material for activated carbon.

Charcoal has to be treated further in order to develop the extensive internal pore structure that categorizes activated carbon. Adsorption capacity is determined to a great extent by the degree of development of this internal pore structure, and also by the nature of the carbon's surface chemistry (acidic or alkaline).

How carbon is "activated"

The most common method is the steam activation process, which is accomplished in two stages. The material is first carbonized to an intermediate product, the pores of which are either too small or too constricted for it to be a useful adsorbent. Enlarging the pore structure to produce a more accessible internal surface area is then achieved by chemically reacting the carbonized product with steam at a temperature between 800°C and 1,000°C.

The reaction takes place on all of the internal surfaces of the carbons, removing carbon from the pore walls and thereby enlarging them. Control of temperature is critical. If the temperature is below 800°C, the rate of reaction is too slow to be economical (the energy cost to open up the pore structure increases while the yield decreases). Above 1,000°C, the reaction becomes erosive, concentrating on the outer layer of the carbon particles, reducing each particle is size, and leaving the interior unactivated.

Careful control of the steam activation process, therefore, allows the pore size to be readily altered to suit a wide range of specific applications. For the adsorption of smaller molecules from solution, i.e., water purification, the pore structure

Pore structure

Three groups of pores can be distinguished in an activated carbon

1. Micropores (0-20 Angstrom*)
2. Transitional pores (20-500 Angstrom*)
3. Macropores (> 500 Angstrom*)

*One angstrom = 0.0000001 mm, or one tenth the size of a sugar granule.

The major portion of the surface area is derived from the small diameter micropore and the medium diameter transitional pore regions. Micropores have been found to be the most effective in trapping small molecules in gas and liquid phase applications. The transitional pore region is most suitable for adsorbing large molecular species such as color molecules.

The raw material for an activated carbon plays a major part in determining the ability of the final product to adsorb certain molecular species. Activated carbons produced from coconut shells exhibit a predominance of micropores, while coal based carbons have a wider range of transitional pores. The development of an extensive macropore structure is found when either peat or wood is used as the raw material.

For carbons with a predominance of micropores, the internal surface area is incredibly large. Many activated carbons have internal areas in the region of 500 to 1,500 square meters per gram, and it is this enormous area which makes them effective adsorbents. Viewed another way, just one pound of activated carbon at 950 m2/g has the equivalent surface area of 100 football fields. All organic compounds will be selectively adsorbed in the activated carbon pores dependent on their size. •

obviously does not have to be opened up to the same extent as for the adsorption of larger molecules.

Activated carbon can be manufactured in powder, granular, pellet, spherical and block forms. Rotary, vertical, and multiple hearth kilns are all used, depending on the individual preferences of each manufacturer. Activated carbon that has been determined through laboratory testing to be spent may often be reactivated in a kiln and reused.

Adsorption

Adsorption is the process by which fluid molecules become attached to a surface by physical or chemical forces (or a combination of both). In physical adsorption the impurities are held on the surface of the carbon by low level van der Waals forces, while in chemisorption the forces are relatively strong and occur at active sites on the surface. Physical adsorption is predominant when using activated carbon in water purification, and the efficiency of the carbon will depend upon its accessible surface. The activated carbon actually removes the impurity in bleaching operations where a colored impurity is chemically changed to a colorless material.

A number of factors can affect adsorption such as pore size distribution, molecular size of the impurity, particle size of the carbon, temperature of the carbon treatment, and the pH of the solution. The following relationships, however, generally apply when other variables are held constant

- Adsorption efficiency increases as the particle size of the impurity decreases.

- Adsorption efficiency increases as the temperature decreases.

- Adsorption efficiency increases as the contaminant solubility decreases.

- Adsorption efficiency increases as contact time is increased.

Impregnated carbons

Activated carbons which have been chemically coated or treated are referred to as impregnated carbons. These specialized adsorbents are available in both granular and pelletized forms, and provide advanced treatment technology for many commercial applications. Impregnated activated carbon adsorbs and retains specific gases long enough for the chemical impregnant to react with the contaminant and form a stable or fixed compound within the carbon, thus eliminating the contaminant from the stream.

Impregnated carbons have been specifically formulated for many chemical compounds which have proven to be difficult to control with standard activated carbons. Examples of these compounds include ammonia, mercury, sulfur dioxide, hydrogen sulfide, ethylene, hydrogen chloride, chlorine, methyl iodide, formaldehyde, and hydrogen cyanide.

Potable water carbons

Many specialty carbons have been developed specifically as filter media for the POU/POE industry. For example, Barnebey & Sutcliffe offers more than 30 NSF-approved grades of activated carbon for the removal of taste and odor, chlorine, chloramines, THMs, and other contaminants. Silver impregnated carbons are also available for the control of bacteria growth within the filter.

Purification with carbon is a centuries-old technique which in recent decades has become much more effective and economical through advanced production processes and chemical technology. Today, millions of tons of activated carbons are sold annually for uses ranging from air and water filtration to recovery of precious metals and industrial solvents. •

About the Author:
Elwood V. Rinehart is Product Manager for Potable/Process Water Treatment Carbons for Barnebey & Sutcliffe Corporation, Columbus, Ohio. “Woody” has been in the water treatment industry for more than 35 years, with over 12 years of specific experience with both gas and liquid adsorption applications for activated carbon.

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