

Activated Carbon: Fundamentals and New Applications

Activated carbon sorbents are important tools in water purification and air-pollution control. This article provides information on the fundamentals of this diverse sorbent and on new applications for which it is being employed

Ken Koehlert
Cabot Corp.

IN BRIEF

ACTIVATED CARBON
BASICS

RAW MATERIALS

ACTIVATION PROCESSES

POST-PROCESSING

ADSORPTION
FUNDAMENTALS

FACTORS AFFECTING
PERFORMANCE

APPLICATION TYPES

BIOGAS PURIFICATION

SEDIMENT REMEDIATION

Global sustainability trends are creating increased demand for purification of air and water, as well as more environmentally friendly process alternatives. Activated carbon (AC) sorbents play important roles in applications throughout the chemical process industries (CPI). These range from traditional applications, such as municipal water purification and fluegas treatment, to cutting-edge applications, such as adsorbed natural gas storage and double-layer capacitors.

In this article we review the basics of activated carbon, as well as the link between activated carbon properties and adsorption performance. In addition, the article provides an overview of two emerging applications for activated carbon sorbents — biogas purification and sediment remediation.

Activated carbon basics

Activated carbon is a highly porous, high-surface-area adsorptive material with a largely amorphous structure. It is composed primarily of aromatic configurations of carbon atoms joined by random cross-linkages. Activated carbon differs from another form of carbon — graphite — in that activated carbon has sheets or groups of atoms that are stacked unevenly in a disorganized man-

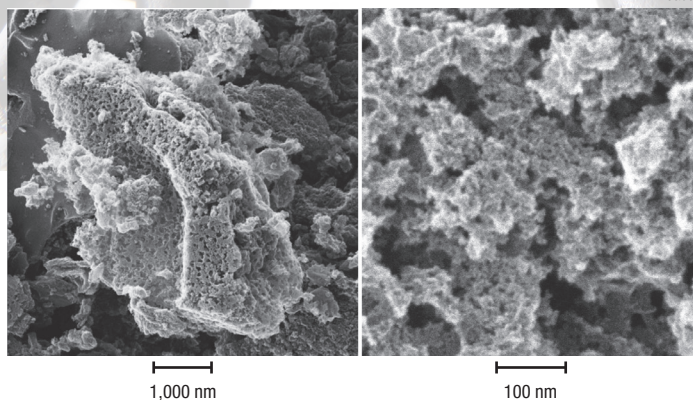


FIGURE 1. These images from a helium-ion microscope show the pore structure of lignite-based activated carbon

ner. The degree of order varies based on the starting raw material and thermal history. Graphitic platelets in steam-activated coal are somewhat ordered, while more amorphous aromatic structures are found in chemically activated wood.

Randomized bonding creates a highly porous structure with numerous cracks, crevices and voids between the carbon layers. Activated carbon's molecular size porosity and the resulting enormous internal surface area make this material extremely effective for adsorbing a wide range of impurities from liquids and gases. To provide some perspective for the internal surface area of activated carbon, the annual activated carbon production of the author's employer has a surface area nearly equal to the total land area on Earth (148 million km²). Figure 1 shows two micrographs of the internal structure of steam-activated lignite.

Activated carbon sorbents are tailored for specific applications mainly based on pore size and pore volume requirements. Porosity and other parameters are controlled by the following: 1) raw material selection; 2) activation process conditions; and 3) post-processing steps. Depending on the application, activated carbon may be in the form of powder (PAC), granule (GAC) or extrudate (EAC). All three forms are available in a range of particle sizes.

Raw materials

Almost any carbon-containing material can be used to produce activated carbon. In practice, economics and target product properties are the determining factors in the selection of raw materials. The base raw material has a significant impact on the final product properties, including pore size distribution and volume, hardness and purity. Most commercial activated carbons are manufactured from the following raw materials:

- Coal (anthracite, bituminous, sub-bituminous, lignite)
- Coconut shell
- Wood

Some types of activated carbon are produced from less conventional raw materials, such as peat, olive stones, fruit pits, petroleum coke, pitch, synthetic polymers, scrap tires and waste cellulose materials.

Raw materials may undergo pre-processing steps to control size, form and other properties. They may be crushed, milled, briquetted or mixed with binders and extruded prior to activation.

Activation processes

Activated carbons are manufactured via one of two processes: steam activation at high temperature or chemical activation using a strong dehydrating agent.

Steam activation is the most commonly used method for activated carbon production. It is performed in rotary kilns, shaft kilns, multi-hearth furnaces or fluidized beds, and proceeds through the following steps:

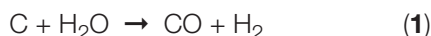
Drying. Activated carbon raw materials in commercial use contain residual moisture that must be removed before activation can take place.

Devolatilization. Volatile organic compounds (VOCs) are formed by cracking

reactions in the raw material at temperatures between 100 and 400°C.

Charring. Higher-molecular-weight organic materials are converted to a carbonaceous char residue at temperatures of 400–600°C. At this point, incipient porosity and increased internal surface area begin to form.

Activation. Activation is generally conducted in a steam atmosphere at temperatures between 700 and 1,050°C, depending on the pore structure of the carbon being produced. The desired reaction is shown in Equation (1).



This reaction gasifies portions of the solid carbon to create pore volume. Typically, about half of the carbonaceous char material entering the activation step will be reacted away to create the desired internal pore structure. The diagrams in Figure 2 depict the development of porosity during steam activation.

Chemical activation is used to produce carbons with pore structures and compositions that are somewhat different from those in steam-activated carbons. For example, chemically activated wood has higher mesoporosity and higher oxygen content than a steam-activated carbon. The chemical activation process consists of mixing raw biomass with a strong dehydrating agent and heating to about 400 to 700°C. The dehydrating agent (typically phosphoric acid or zinc chloride) extracts the moisture from the raw material and fixes the volatile component of the biomass while the activation occurs. The degree of activation is determined by the ratio of raw material to dehydrating agent and by the heating time and temperature. After activation, the product is extracted to yield a highly porous activated carbon product and the dehydrating agent is recovered.

Chemical activation with potassium hydroxide is of great recent interest because it can produce highly microporous carbons with specific surface areas at or beyond the theoretical value for graphene (about 2,600 m²/g).

Post-processing

Following activation, activated carbon sorbents may undergo a series of post-processing steps, including the following:

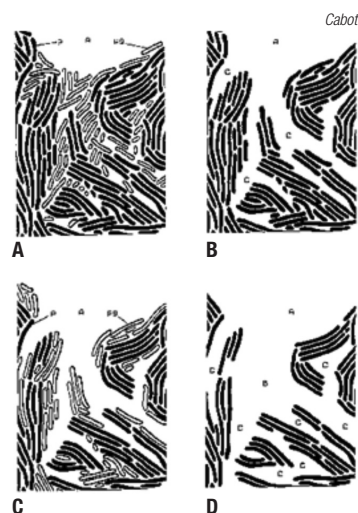


FIGURE 2. This series of diagrams illustrates pore development during steam activation

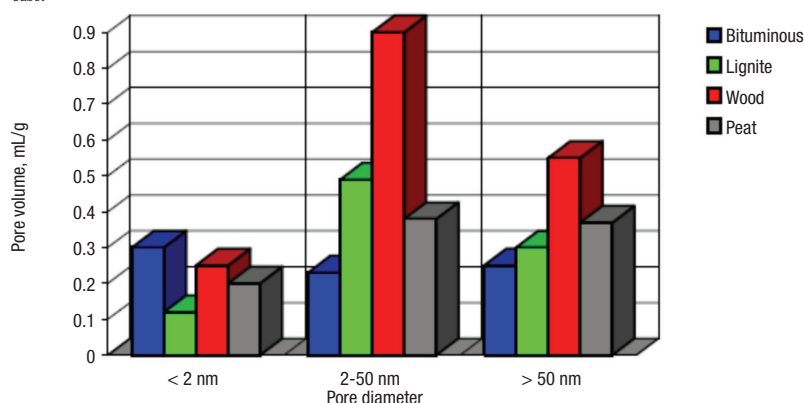


FIGURE 3. The distribution of pore volumes differs depending on the starting material for the activated carbon

Washing. Activated carbon may be acid-washed to reduce ash content and remove soluble impurities, such as iron. Varying levels of increased purity are required for some applications, including double-layer capacitors, pharmaceuticals and food and beverages.

Sizing. Granular products may be sieved to specific particle size ranges. Common mesh-size specifications range from 20 x 40 to 4 x 8 mesh (approximately 0.4 mm x 0.8 mm to 2 mm x 5 mm). Extrudates are produced with diameters ranging from 0.8 to 5 mm and length-to-diameter ratios between about 1:1 to 4:1. Granule and extrudate sizes are specified to balance mass transfer and pressure drop. Powder products are often ground in roller, hammer or jet mills to achieve a target particle-size distribution (PSD), often specified by the terms d5, d50 and d90, which are measures of particle diameters. D50 (median particle size) can range from 5 to about 20 micrometers (μm). Smaller particles improve mass transport, but can lead to filterability challenges. Tight control of PSD can optimize the balance.

Shaping. Powdered activated carbons may be formulated with binders and shaped into cylinders, tubes, honeycombs and other extruded forms to optimize surface-to-volume ratio and pressure drop for various applications. Granules and extrudates may also be formed into filter blocks and plates using polymeric binders.

Impregnation. Some contaminants, such as formaldehyde, elemental mercury and hydrogen sulfide are not adsorbed on activated carbon. Chemical impregnation can add functionality to the carbon sorbent to catalyze a reaction or promote chemisorption. Activated carbon manufacturers add functionality for a

range of applications. Silver is commonly used to disinfect water. A more specialized example is impregnation with metal salts and amines for military gas masks. On a larger scale, impregnation is used to promote the oxidation of mercury in coal-fired utility fluegas applications. Products for enhanced sulfur removal are impregnated with potassium iodide or sodium hydroxide. Another example of impregnation by end-users is the deposition of precious metals on activated carbon to form heterogeneous catalysts.

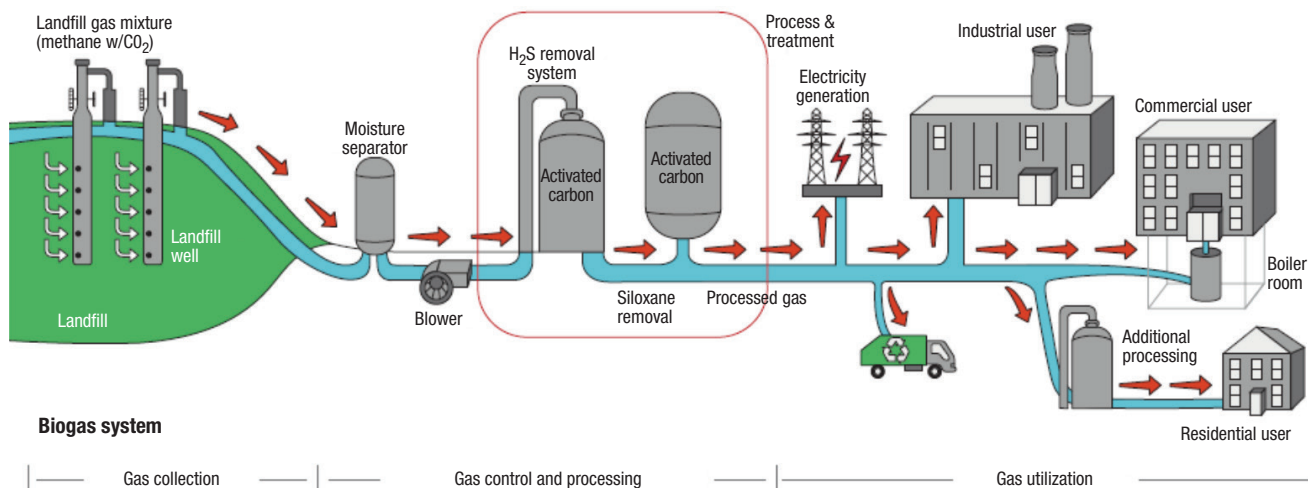
Re-activation. Some granular and extruded products can be re-activated and recycled after use to minimize cost and environmental impact. In this process, spent carbon loaded with organic contaminants is thermally treated in a process similar to steam activation. Re-activation desorbs and destroys volatile contaminants and restores much of the original pore volume and adsorptive capacity. Typical product loss during re-activation is 5–15%, requiring makeup with virgin material.

Adsorption fundamentals

Activated carbon sorbents remove low concentrations of chemicals (adsorbates) from a fluid (liquid or gas) by adsorption, the process of accumulation of materials onto a solid surface. Adsorption occurs within the activated carbon pore structure by two distinct mechanisms: physical and chemical adsorption.

Physical adsorption. Molecules are attached to the carbon surface by van der Waals attractive forces. These intermolecular forces are very weak and diminish with increasing distance between the carbon surface and the adsorbate molecule. Because the weak attractive forces are greatly dependent on distance, physical adsorption occurs primarily within pores that have a radius only a few times greater than the molecular diameter of the adsorbed molecule. Pores that are smaller than the size of the impurity molecule are inaccessible and do not participate in the adsorption process. Pores that are significantly larger than the adsorbate molecule are not as effective at adsorption because the attractive force diminishes as the distance between the pore surface and the adsorbate is increased.

Adsorption occurs after the impurity molecule has diffused into the carbon



pore structure to an adsorption site. The process is diffusion-rate-limited and the large pores play a role in transporting adsorbate to the adsorption sites. Physical adsorption is an equilibrium process and is very dependent on the concentration of the adsorbate in the solution.

The relationship between the amount of adsorbate on the surface versus that in the solution is described by the adsorp-

tion isotherm. The Freundlich isotherm is commonly used to empirically define this relationship. The Freundlich adsorption isotherm equation is shown here:

$$C_{\text{carbon}} = k_f C_{\text{water}}^{1/n} \quad (2)$$

Where:

C_{carbon} = concentration of adsorbate adsorbed on carbon

FIGURE 4. This schematic diagram shows the collection, purification and use of biogas from a landfill site

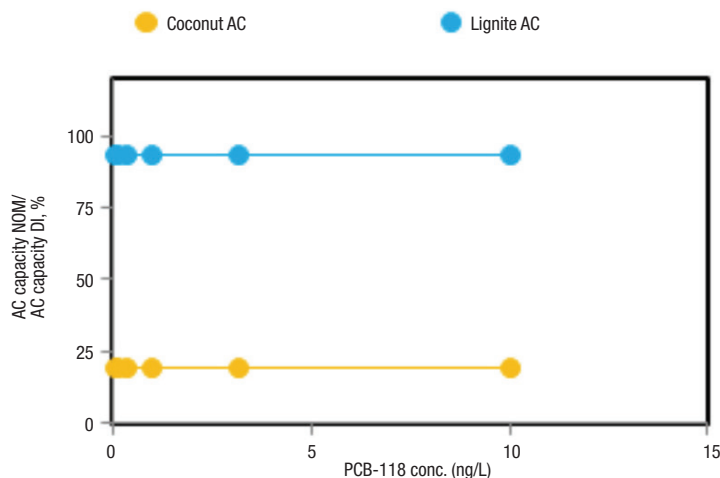


FIGURE 5. This diagram shows a comparison of lignite- and coconut-based activated carbon performance with 50 mg/L natural organic material (NOM)

C_{water} = equilibrium concentration of adsorbate in solution
 K_f and n are constants for a given HOC and carbon at room temperature

The partition coefficient (C_{carbon} / C_{water}) can be calculated from Freundlich equation at a given equilibrium concentration. If a single compound is being adsorbed by activated carbon, all pores of a suitable size are available for adsorption and the amount of material adsorbed is the maximum achievable by the particular carbon.

If several adsorbate molecules are present, there can be competition for the adsorption sites. In that situation, the larger impurity molecules will block some of the smaller pores. This may reduce the carbon's ability to adsorb the smaller-sized adsorbates.

Chemical adsorption. Chemical adsorption refers to the direct reaction of the adsorbed molecule with an active site on the carbon surface. As a result of the reaction, a chemical bond is formed between the adsorbate and the carbon surface. The active sites on the carbon surface involved in chemisorption are mainly functional groups that contain oxygen and alter the electron balance of the carbon surface. If the molecule being adsorbed is chemically bound to the carbon surface (shared electrons), the process is termed chemisorption.

If the adsorbed molecule resides only temporarily on the carbon surface, picks up an electron, and then leaves the carbon surface, the process is described as catalytic conversion. This is the mechanism responsible for the dechlorination reaction used by bottlers to convert free chlorine in water to chlorides.

Factors affecting performance

Factors that affect the performance of activated carbons can come from the specifics of the application, or from the activated carbon itself.

Application-related factors. Several factors can aid or hinder adsorption. The principal factor is the molecular size of the compound being adsorbed. Activated carbon adsorption increases as the size of the molecule being adsorbed increases. Certain types of functional groups on the impurity molecule can also affect its adsorbability.

Because the physical adsorption process is an equilibrium reaction, the concentration of the molecule to be adsorbed strongly affects the amount adsorbed, as described by the adsorption isotherm. The solubility of the adsorbed compound is also important, with lower solubility resulting in greater adsorption.

Adsorption rate increases with temperature. However, desorption rate also increases with temperature and it is not possible to predict the net effect in liquid-phase applications. The principal reason for adsorbing at elevated temperatures in the liquid phase is to lower viscosity and increase diffusion rate. In gas-phase applications, adsorption always decreases with higher temperature.

Activated-carbon-related factors. In adsorption applications, the most critical performance parameter is the distribution of pore size and volume. Since adsorption occurs almost exclusively in pores just a few times larger than the adsorbate molecule, it is the pore volume within this size range that determines adsorption capacity. The highly porous nature of activated carbon gives rise to surface areas as large as 3,000 m²/g.

Pore sizes are classified as micro-, meso- or macropores, according to the conventions of the International Union of Pure and Applied Chemistry (IUPAC; iupac.org). Micropores with widths less than 2 nm are useful for adsorbing small molecules, especially in vapor applications. Mesopores, ranging in width from 2 to 50 nm, are in the right size range to adsorb many contaminant materials. Macropores greater than 50 nm in width have minimal adsorption capacity, but are critical in determining adsorption kinetics within the particle. The larger pores provide transport paths for molecules to diffuse into the mesopores

and micropores, where adsorption takes place. Figure 3 compares the pore distribution of four different activated carbons from a variety of raw materials and activation processes.

Surface area can be determined by nitrogen adsorption using the BET (Brunauer, Emmet, Teller) method. Pore size distribution can be quantified by examining the adsorption and desorption of nitrogen, carbon dioxide and other adsorbates. Mercury porosimetry is well suited to measure macropore and large mesopore volume. However, it is more common and convenient to measure and rank activated carbon performance using specific adsorbates that mimic the application. Examples include iodine adsorption to assess small pore capacity and dye molecule adsorption (methylene blue, bromophenol blue, and so on) to assess medium-sized pores. In some cases, the characterization test is directly related to the final application, as in the case of molasses decolorizing efficiency as a predictor of performance in sugar applications, and butane working capacity as a performance metric for carbons used to control automobile gasoline vapor emissions.

Particle size and distribution impact performance in both PAC and GAC applications. For PAC, size and size distribution correlate to mass-transfer resistance and filterability. In batch applications, a fine particle size provides rapid adsorption, but also a high pressure drop and slow filtration when removing the sorbent. The best balance of performance is often found by narrowing the size distribution. In GAC and extrudate packed-bed applications, size is again related to mass-transfer resistance and pressure drop.

Durability is of particular concern for GAC and EAC forms. Particles must be able to resist damage and fines formation during transport, column loading and use — especially if the application involves column backwashing. Activated carbons for gold extraction have some of the most stringent durability requirements. Durable particles are also required to minimize losses during re-activation.

High purity is critical in some applications. Food, beverage and potable water applications require low levels of extractables. Pharmaceutical activated carbons must have ultra-high purity and full traceability. Emerging uses in double-layer capacitors and other electrochemical applications depend on high purity for extended cycle life.

Application types

Activated carbon sorbents are used in two broad application classes: vapor and liquid purification. Within each class are examples of two types of fluid-sorbent contacting. These are PAC dosing and GAC/EAC packed columns. Beyond purification, activated carbons are used in a number of specialized applications.

In PAC dosing systems, activated carbon particles are injected into the contaminated fluid, dispersed within the fluid for an appropriate contact time, and then removed by sedimentation or filtration. PAC dosing may be used in batch or continuous injection systems. PAC contact times range from 0.05 to 2 seconds in gas-phase systems and 1 to 60 minutes in liquid-phase batch applications. In municipal water treatment, PAC may be added continuously as a slurry or powder and then can be removed by flocculation, sedimentation and filtration. In coal-fired utility mercury removal, PAC is injected into the fluegas through a distribution lance and removed in the electrostatic precipitator or fabric filter.

In packed-bed systems, fluid flows through a static bed of GAC or EAC. As the contaminant concentration in the fluid decreases, the loading on the carbon increases, creating a concentration gradient along the column. The mass-transfer zone is defined by the gradient between the inlet concentration existing in the fully loaded bed and the outlet concentration. Breakthrough occurs when the mass-transfer zone travels to the exit of the column. Packed-bed systems are sized based on either calculated or experimentally determined isotherms, contact time based on estimated or measured kinetics and mass transfer, and pres-

sure drop requirements.

Vapor-phase purification applications cover a wide range of contaminant molecules from mercury to volatile organic materials. Some specific examples include gasoline vapor in automobile evaporative-loss-control devices, mercury in coal-fired utility fluegas and dioxin in incinerator offgas. Another vapor-phase application is pressure- or temperature-swung adsorption for solvent recovery and hydrogen purification. Impregnated carbons are used in military gas masks and industrial respirators to protect personnel from toxic gases. An emerging

One of the most effective technologies for high-performance impurity removal in biogas is a two-step treatment with activated carbon

application in this area — removal of hydrogen sulfide and siloxanes from biogas — is highlighted below.

Activated carbon sorbents are used to purify a wide range of liquid systems, including potable water, wastewater, industrial process water, chemicals, pharmaceuticals, foods and beverages. Removal of taste and odor contaminants and harmful pollutants from potable water is one of the main purification applications. Activated carbon is used to remove precious metal catalysts after synthesis of pharmaceutical active ingredients. Liquid sugar decolorization is one of the earliest activated carbon applications and remains important today. Activated carbon is used to remove undesirable taste compounds and color precursors from processed fruit juices. Color removal from natural-gas liquids is a more recent application. Activated carbon application in sediment remediation is covered in more detail below.

Non-purification applications of activated carbon include gold recovery from cyanide leaching solutions, storage of gases, such as hydrogen and methane, and electrodes for double-layer capacitors and catalysts.

Biogas purification

Biogas is an environmentally friendly and sustainable fuel derived from the breakdown of organic matter. It is typically produced at landfills, wastewater treatment facilities, or through anaero-

bic digestion using animal manure or vegetation. The main constituents of biogas are methane and carbon dioxide, however, it also contains undesirable impurities like hydrogen sulfide (H_2S), siloxanes and VOCs. These unwanted impurities are present in low concentrations, but must be removed to reduce combustion equipment damage and downtime, to ensure emission targets are met, and to meet gas-purity specifications. After purification, the biogas can either be sent to an engine to generate power, sold into the natural gas grid or sold as a transportation fuel in the form of biomethane. Figure 4 shows where activated carbon adsorption is used in a typical biogas system.

One of the most effective technologies for high-performance impurity removal in biogas is a two-step treatment with activated carbon. For optimal performance, an operator will first direct a humid gas through an activated carbon bed where H_2S is reduced to elemental sulfur by a catalytic process. After H_2S removal, the gas is dried and sent to a separate activated carbon bed, where siloxane and VOC impurities are removed by physical adsorption.

H_2S purification. H_2S is a hazardous chemical compound present in biogas. Biogas producers need to remove H_2S because it is poisonous, corrosive, flammable and malodorous. Traditionally, biological scrubbers, iron-oxide-based media, or impregnated activated carbons have been used for H_2S removal in biogas. All technologies are capable of removing H_2S ; however, none of these technologies has been optimized specifically for biogas. Biological scrubbers are very effective at removing high concentrations of H_2S , but can be difficult to operate and capital-intensive to install. Iron oxide media are low-priced, but generally demonstrate very low removal efficiency. Iron oxide media are also notorious for bricking (bridging between particles, forming lumps), which leads to costly and time-intensive removal efforts. Chemically impregnated activated carbon has a higher loading efficiency, but can be quite expensive. Impregnated carbons can also pose safety challenges, as they may cause bed fires due to an exothermic reaction with H_2S .

Many operators today are focusing on total cost of ownership and are choos-

ing a media or engineered solution that offers the lowest cost per mass of H_2S removed. In making this calculation, the operator considers capital investment for each technology, followed by analysis of long-term operating costs. For media-based solutions, they must consider the amount of media needed to fill the vessel, the operating time until media saturation, the cost and time associated with media changeouts, and ultimately, how the downtime impacts the ability to process gas. It is important to consider total lifecycle cost in developing activated carbons for biogas H_2S removal.

Siloxanes and VOC purification. Siloxanes are a group of synthetic compounds used in the manufacture of personal hygiene, healthcare and industrial products. Disposal of these products creates the risk of siloxane impurities in biogas, posing significant risks depending on the final application. In combustion engines, boilers, turbines and fuel cells, siloxanes can form silica that causes damage, destruction and reduced operating efficiency. Siloxane damage leads to higher operational costs and can seriously impact biogas upgrading and even prevent sales of contaminated biogas.

VOCs are impurities often found in biogas derived from agriculture, landfills and wastewater-treatment facilities. Depending on the application, VOCs can be viewed either as beneficial or detrimental to the quality of the gas. If the biogas is sent for combustion, the VOCs are often considered a beneficial high-Btu additive. When biogas is further upgraded to biomethane, VOCs must be removed to prevent significant damage to membranes and to limit emissions of sulfur oxides and nitrogen oxides. Pipeline gas has strict limits on VOC concentration.

Activated carbon has traditionally been used for siloxane and VOC removal, as it is effective at physically removing both compounds. For dedicated siloxane removal, users often opt for temperature-swing adsorption (TSA) using an activated-carbon bed as a polishing step. The decision to use activated carbon versus TSA typically comes down to operating conditions and costs. TSA systems have relatively high upfront capital costs and also use significant amounts of gas for regeneration. If an operator is pulling from a

gas-limited source, they will likely prefer using activated carbon only. TSA units are also known to struggle with removing some lower-molecular-weight siloxanes, which means that they often require activated carbon polishing vessels to remove all siloxane compounds. High concentrations of siloxane in a biogas can lead to high operational costs to replace a standard activated carbon because much of the carbon pore volume is spent removing different families of compounds from the gas. Specifically designed surface modifications to standard activated carbon can allow the preferential adsorption of siloxanes over VOCs. This results in significantly better siloxane loading capacity versus standard activated carbon products. Since this type of modified product does not require a TSA unit to achieve high performance, it is a way that processors could avoid the need to invest in an expensive system upfront, but still realize long-term savings.

Biogas is one of the more challenging gas-purification applications. Depending on the source, the amount and the speciation of impurities is constantly variable. When deciding which adsorption technology to deploy, an operator must consider many factors to determine the highest-performance and most cost-effective solution for their site.

Sediment remediation

Sediments accumulated on the bottom of waterbodies are sinks for toxic, bio-accumulative chemicals that can be transferred to invertebrates and fish via food webs. Increasingly, remediation practitioners are turning to in-situ treatment of contaminated sediments to reduce the ecological and human-health risks posed by contaminants. This is mainly because conventional technologies (such as dredging and conventional sand capping) have not always demonstrated risk reduction. A new approach of in-situ sediment treatment via contaminant sequestration involves placing activated carbon amendments on contaminated sediments. In this application, activated carbon is used to adsorb HOCs, such as polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyl (PCBs) from sediment pore water. One challenge in this application is interference

from natural organic matter (NOM). Large organic molecules present in the water matrix, such as humic and fulvic acids, can cause blockage of the activated carbon pore structure, leading to reduced adsorption capacity for target contaminants. Highly microporous carbons are particularly prone to blockage. Activated carbon with a tailored blend of mesoporosity and microporosity is required for resistance to NOM and removal of target contaminants.

Increasingly, remediation practitioners are turning to in-situ treatment of contaminated sediments to reduce human health and ecological risks

Lignite-derived, activated carbon grades now exist specifically for removing PCBs, PAHs, dioxins and furans in contaminated sediments. Activated carbons developed for this application have an optimal pore size distribution that is designed to be highly effective for the removal of these compounds in the presence of NOM concentrations typical in sediment pore water. This broad pore-size distribution is critical for high performance, as NOM can partially or completely block the adsorptive capacity of more microporous carbons. Figure 5 compares microporous coconut AC and lignite AC with tailored porosity in removal of PCB-118. The chart shows the ratio of PCB removal in water with 50 mg/L NOM to removal in distilled water and clearly demonstrates lignite's resistance to pore blockage.

Activated carbon amendments are applied to the sediment either by direct mixing, as a component in a geotextile mat, or by incorporating it into a cap that creates a physical and adsorptive barrier between the contaminated sediment and water. The cap consists of sand or aggregate and carbon can be added as GAC or as a PAC coating applied to the surface of the aggregate.

In order to design reactive caps using activated carbon, engineering firms frequently use the CAPSIM model, developed by professor Danny Reible of Texas Tech University (Lubbock, Tex.; www.ttu.edu). To assess and approve a specific activated carbon grade in a reactive cap, engineering firms require specific activated-carbon performance data, namely the partition coefficient,

which can be calculated from a Freundlich adsorption isotherm equation at a given equilibrium concentration of the contaminant in pore water.

The author's employer has generated partition coefficients for a wide range of PAH and PCB contaminants for activated carbon products in this area. These data, combined with knowledge of site conditions, enables the design of reactive caps using the CAPSIM model. Using the right activated carbon amendment and cap design can provide in-situ sediment remediation solutions that prevent breakthrough from contaminated sediments for 100 years or more.

Summary remarks

Activated carbon is a sorbent with wide-ranging uses in the purification of vapor and liquid systems, as well as specialized uses in fuel storage, catalysis and electrochemistry. Activated carbon can be tailored for specific applications by a combination of raw material selection, activation process conditions and post-processing, including shaping and chemical impregnation. Adsorption performance is driven by pore size and volume distribution, and other factors, such as durability and particle size, influence the choice of activated carbon for a specific application. Activated carbon can be used in liquid or vapor applications in either PAC or GAC/EAC form. Biogas purification and sediment remediation are two recent applications that highlight the versatility of activated carbon sorbents for purification applications. ■

Edited by Scott Jenkins

Author



Ken Koehlert is the product line and technology director for Cabot Norit Activated Carbon (157 Concord Road, Billerica, MA 01821; Phone: 1-978-663-3455; Email: ken.koehlert@cabotcorp.com). Koehlert has spent more than 30 years at Cabot, and has held positions in process and product R&D and manufacturing across several of the company's businesses. He received B.S.Ch.E. and M.S.Ch.E. degrees from the Massachusetts Institute of Technology. Koehlert's team develops and supports a wide range of products, including two unique activated carbons for biogas purification. DARCO BG1 material optimizes the cost of H₂S removed while limiting the concern for exothermic reactions associated with impregnated activated carbons. Cabot's recently launched Norit Silpure product has a specifically designed surface to preferentially adsorb siloxanes over VOCs. The team also works with Norit SedimentPure activated carbons with tailored porosity to remove target contaminants in the presence of natural organic matter.

