Chapter 20
Vapor-Phase Carbon Adsorption

20-1. General

This chapter is organized into two main sections. The first describes the process and application of vapor-phase carbon adsorption and the second contains a hazard analysis with controls and control points listed.

20-2. Technology Description

a. Process.

Activated carbon, contained in a reaction vessel, can be used to adsorb organic compounds from an air stream. The volatile organic compounds (VOCs) dissolved in the air stream are adsorbed from the stream and the effluent discharged to the atmosphere. In general, based on mass of activated charcoal used, vapor-phase canister systems adsorb more hydrocarbon mass than liquid based systems (see Chapter 19). Therefore, vapor systems are often used in conjunction with air stripping processes to treat VOC-contaminated water. Vapor-phase carbon adsorption is also used in conjunction with air stripping and soil vapor extraction (SVE) to remove compounds of concern from the vapor stream prior to its release to the atmosphere. See Figure 20-1.

In these systems, adsorbed chemicals are not altered chemically, only concentrated in the carbon media, which may require additional post-treatment destruction to meet final disposal requirements.

b. Applications.

This technology is applicable to the removal of VOCs and some semi-volatile organic compounds (SVOCs) from vapor streams. It is not suitable for removing compounds that cannot be readily volatilized. Each chemical has a different affinity for the activated carbon, depending on that chemical’s properties and configuration; thus, each chemical is adsorbed to different degrees (and mass ratio).

Adsorption isotherms for many organic chemicals are available from the activated charcoal manufacturers. These isotherms predict the weight of chemical adsorbed at standard equilibrium conditions per unit weight of carbon.

The effectiveness of treatment is a function of the chemicals being treated, chemical mixture (including water), residence time, temperature, and other factors. Activated carbon treatment is more effective for non-polar molecules and aromatic hydrocarbons than chlorinated analogues. Multi-ring compounds are strongly adsorbed so this method is particularly effective for polyaromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). Treatment of short alkanes and alkenes, oxygenated solvents, and other small organic molecules (e.g., acetone, methyl ethyl ketone (MEK) and vinyl chloride) is significantly less effective.

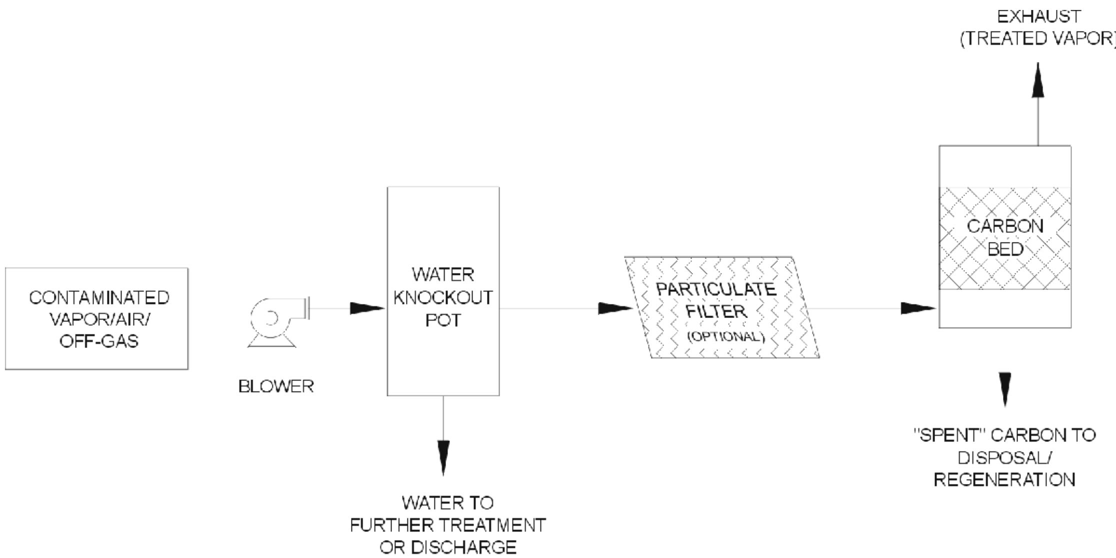

FIGURE 20-1. VAPOR PHASE CARBON ADSORPTION

Air streams that contain compounds that may form peroxides or otherwise auto-ignite are of particular concern when using vapor-phase activated carbon adsorption. Other compounds, such as hydrogen sulfide, which are adsorbed exothermically, may generate enough heat to ignite the activated carbon beds.

20-3. Hazard Analysis

Principal unique hazards associated with vapor-phase carbon adsorption, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Fire (Waste Components).*
Description. Fires may result when the treatment stream contains reactive compounds or chemicals that adsorb exothermally to the carbon, e.g., hydrogen sulfide or peroxides that may auto-ignite. Activated carbon fires occur when it is adsorbing any easily oxidizable organic solvents, especially carbonyls such as ketones. Activated carbon is especially prone to fires when 1) carbon with a high activity or ash content is used, 2) the moisture content of the carbon is critically reduced (e.g., 50%) throughout the operational cycles of adsorption, desorption, and cooling, 3) the carbon bed contains air flow restrictions or obstructions creating exothermic hot spots, or 4) the type of solvents being adsorbed are highly oxidizable and are exothermically adsorbed. (See "Preventing

Bed Fires in Carbon Adsorption Systems,", Miller K.J., C. R. Noddings, R. C. Nattkemper, 3M, St. Paul MN, For Presentation: 80th Annual Meeting of APCA NY, NY 21-26 June 1987.)

Control. Controls for fire include:

- Use experienced operators and supervisors trained in the flammability/reactivity characteristics of the vapor waste stream when adsorbed on the carbon, the exposure hazards of the waste vapor stream, and the design operating parameters of the carbon beds.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct deficiencies found.
- Audit and apply proper quality assurance/quality control (QA/QC) to assure the pretreatment units and the carbon bed systems are operated as designed.
- Properly ground all carbon treatment systems. See EM 385-1-1, Section 11, and NFPA 70.
- Operate the system and waste vapor stream system within design parameters.
- Do not allow the waste vapor stream flow to exceed the capacity of the system.
- Select proper activated carbon and start-up procedures for new carbon compatible with the contaminant being adsorbed.
- Control the activated carbon moisture by controlling the solvent-laden air temperature and percent relative humidity, using superheated steam for desorption, and optimizing cooling and drying cycle time and conditions.
- Design and maintain even airflow distribution throughout the activated carbon.
- Establish operating procedures for easily oxidizable solvents.
- Use an inert gas such as nitrogen during shutdowns. Flood the bed with water to make it inert and remove excess heat from hot spots.
- Monitor hot spots by monitoring off-gases such as CO or CO_2 above and below the beds.
- Continuously monitor and control the carbon bed operating temperatures.
- Select an alternate technology during design if the known or anticipated contaminants pose an unacceptable risk of fire.
- Thoroughly train the operators in emergency procedures, in life saving first aid procedures including extracting, extinguishing, decontaminating and stabilizing victims, and in emergency system isolation, shutdown and extinguishing procedures.
- Locate fire fighting equipment and emergency eyewashes and showers at critical points throughout the system. (See American National Standards Institute ANSI Z358.1 – 1998.)

CONTROL POINT: Design

(2) *Confined Spaces*.
Description. Entering carbon bed tanks to inspect, repair, or maintain them may constitute a permit-required confined-space entry. Hazards associated with confined space include asphyxiation, exposure to toxic wastes or poisonous gases (such as PAHs, PCBs, or VOCs), and oxygen deficiency owing to an oxygen demand phenomenon associated with wet activated carbon in both liquid or vapor systems and the catalytic properties of activated carbon that may generate process off-gas by enhancing normal decomposition or oxidation (e.g., CO_2, ethanol, methane) in the confined activated carbon tank space, inhalation of carbon particles or microbes, and engulfment/entrapment in the carbon bed.

Control. Controls for confined-space entry include:

- Train operators and workers in confined space hazards and permit-required confined space entry procedures.
- Design carbon bed vessels to maximize ease of and maintenance activities and minimize the frequency, duration, and extent of maintenance required.
- Develop a confined space permit to include hazard assessment (see 29 CFR 1910.146), including atmosphere testing inside the vessels prior to and throughout the entry.
- Ventilate or purge the air space prior to and during the entry to eliminate risk of encountering an oxygen-deficient or toxic atmosphere. Activated carbon can exhibit a measurable oxygen demand, which can create the oxygen-deficient atmosphere.
- Complete carbon bed vessel manufacturer's shutdown procedures and lockout/tag-out of associated pumping or electrically energized systems prior to entry. Eliminate possible buildup of static electricity.
- Use air-supplied respirators to control inhalation exposures to toxic chemicals and prevent asphyxiation.

CONTROL POINT: Operations, Maintenance

(3) *Fire or Explosion (Gas Transfer).*
Description. In some situations the waste stream or the carbon bed can contain concentrations of VOC above the lower explosive limit (LEL). A fire or explosion may occur if equipment is not approved for flammable locations or if static electricity is discharged during vapor treatment or during removal of carbon from the vessel.

Control. Controls for fire during gas transfer include:

- Train the system operators on fire or explosion hazards during transfer and carbon replacement activities. Include the identification of potential ignition sources such as the creation of static electricity.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct deficiencies found.
- Verify that drawings include hazardous area classifications, as defined in NFPA 70-500-1 through 500-10.

- Use controls, wiring, and equipment on and near the beds that meet the requirements of EM 385-1-1, Section 11, and NFPA 70.
- Bond and ground transfer systems properly to prevent static discharge as required by EM 385-1-1, Section 11, or NFPA 70.
- Permit only trained, experienced personnel to work around the beds.
- Thoroughly train operators in emergency procedures in response to a catastrophic failure and in life saving first aid procedures. This should include halting fire reactions, extracting, extinguishing, decontaminating and stabilizing victims, and in emergency system isolation and shutdown and extinguishing procedures.
- Locate fire fighting equipment and emergency eyewashes and showers at critical points throughout the system. (See ANSI Z358.1 – 1998.)

CONTROL POINT: Design, Construction, Operations, Maintenance

(4) *Carbon Holding Tanks/Drums.*
Description. Carbon holding tanks or drums containing VOC-saturated carbon may leak or spill over into the surrounding areas during operations or loading and unloading of carbon. The resulting spill may be easily ignited. Conditions during which the carbon may be heated may increase this risk.

Control. Controls for carbon holding tanks/drums include:

- Train operators in hazards associated with holding saturated carbon, including the unique hazardous physical properties of the adsorbed chemical being handled and potential for static electricity buildup during handling. Permit only trained and experienced workers in tank/drum areas.
- Equip carbon holding tanks or drums with adequate spill containment.
- Install spill or leak detection monitors and alarms when appropriate.
- Verify that drawings indicate the hazardous area classifications as defined in NFPA 70, Chapter 5, 500.1 through 500.10.
- Use controls, wiring, and equipment on or near the tanks or drums that meet the requirements of EM 385-1-1, Section 11, and NFPA 70.
- Mark all electrical systems properly for potential hazards.
- Ventilate storage areas adequately to help prevent the accumulation of VOCs.

CONTROL POINT: Design, Construction, Operations, Maintenance

(5) *Vapor Transfer Equipment Design*.
Description. Vapor transfer equipment (pumps, fans, blowers, piping, pipe fittings, valves, and instruments) that contact contaminated vapors can corrode or dissolve and damage or destroy facilities and result in worker exposures to chemical and physical hazards.

Control. Controls for vapor transfer equipment include:

- Use vapor transfer equipment (pumps, fan, blowers, piping, pipe fittings, valves, and instruments) fabricated from materials that are chemically inert to contaminants in the system.
- Utilize electrical interlock systems to control vacuum pumps and blowers at critical temperatures within the system.
- Consult EM 1110-1-4008, "Liquid Process Piping," and UFGS 15200A, "Liquid Process Piping," for appropriate pumping materials. Require operator training in potential exposures to chemicals being transferred in the waste vapor stream and in the potential incompatibilities within the transfer system that could lead to a catastrophic release.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct all deficiencies found.
- Train the operators in emergency procedures in the event of a catastrophic failure, in life saving first aid procedures including halting reactions, extracting, extinguishing, decontaminating and stabilizing victims, and in emergency system isolation and shutdown and extinguishing procedures.
- Locate fire fighting equipment and emergency eyewashes and showers at critical points throughout the system. (See ANSI Z358.1 – 1998.)

CONTROL POINT: Design, Construction, Maintenance

(6) *Fires or Explosion (Carbon).*
Description. Carbon beds can be operated under pressure or vacuum. Systems designed to operate under pressure (e.g., fans, pumps, or blowers upstream from the carbon bed) have a potential risk of flammable vapor leakage that may explode if ignited. Carbon dust can also be ignited and cause explosions. Reactions of chemicals, such as ketones, with activated carbon can be exothermic and cause fires or explosions.

Control. Controls for fire or explosion include:

- Use experienced operators and supervisors trained in the design operating parameters of the carbon beds, waste vapor stream transfer systems, and in the operating incompatibilities that could lead to a catastrophic reaction.
- Perform a Process Hazard Analysis prior to startup and correct all deficiencies found.
- Use containment drip pans or receivers where leaks may occur.
- Install spill or leak detection instruments.
- Design tanks and piping around pressurized carbon beds to handle the maximum operating pressures plus an appropriate safety factor.
- Install over-pressure instrumentation to decrease the possibility of uncontrolled or fugitive vapor releases. Instruments can be set to shut down fans, blowers, or pumps.
- Assess the reactive compatibility of contaminants and carbon beds and evaluate risk of exothermic reactions.
- Minimize the generation of explosive dust or fines during carbon handling.

- Ground all carbon transfer equipment including vacuum trucks or vacuum drums to prevent static electricity from igniting the fine carbon dust. Vacuum trucks exert a tremendous vacuum and only trained, authorized personnel must be allowed to operate the systems.
- Ground and bond system components and include other design elements to minimize potential ignition sources, such as static electricity, electrical spark or open flame, particularly during change out of carbon.
- Thoroughly train the operators in emergency procedures in the event of catastrophic failure, in life saving first aid procedures including halting chemical reactions, extracting, extinguishing, decontaminating and stabilizing victims, and in emergency system isolation, shutdown, and extinguishing procedures.
- Locate emergency eyewashes and showers at critical points throughout the system. (See ANSI Z358.1 – 1998.)

CONTROL POINT: Design, Construction, Operations, Maintenance

(7) *Fire or Explosion (Conditioning Inlet Air for Temperate and Humidity).*
Description. Vapor-phase carbon systems operate more efficiently if the inlet waste stream is at or below 50% relative humidity, for which inlet heaters may be used. However, if inlet vapors are overheated, the carbon beds can spontaneously ignite.

Control. Controls for temperature include:

- Train the operators on the relationship of the vapors, carbon bed, and temperature at which spontaneous ignition may occur.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct all deficiencies found.
- Install temperature instrumentation to monitor and control the operating temperature of the system.
- Use alarms or automatic heat, fan, blower, or pump shutdowns if the carbon bed temperature exceeds 120°F (50°C).

CONTROL POINT: Design, Operations, Maintenance

(8) *Electrical Shock*.
Description. All system components rely on electricity for their operation and control. Personnel who contact electricity can be shocked, burned, or killed.

Control. Controls for electrical shock include:

- Verify that drawings indicate the hazardous area classifications, as defined in NFPA 70, Chapter 5, sections 500.1 through 500.10.
- Use controls, wiring, and equipment that meet the requirements of EM 385-1-1, Section 11, NFPA 70, and UFGS 16415A “Electrical Work, Interior,” for the identified hazard areas.
- Perform all electrical work in accordance with applicable electrical codes and under the supervision of a state licensed master electrician.

- Train operators for electrical hazards of equipment and environmental factors that contribute to the generation of static electricity.
- Post electrical hazard warning signs.
- Never allow the use of ungrounded, temporary wiring for minor maintenance work on the pretreatment or carbon bed systems, or wiring not approved for contact with water, or on wet or damp surfaces when working under these conditions.

CONTROL POINT: Design, Construction, Operations, Maintenance

(9) *Treatment Buildings*.
Description. Permanent or semi-permanent treatment buildings may present life safety hazards such as inadequate egress, fire suppression systems, or emergency lighting systems.

Control. Controls for treatment buildings include:

- Meet the following construction requirements for permanent and semi-permanent treatment buildings: ANSI 58-1, "Minimum Design Loads for Buildings and Other Structures," the "National Fire Code," the "National Standard Plumbing Code," "Life Safety Code," and the "Uniform Building Code."
- Make sure structures comply with either the Air Force Manuals on Air Force bases, the USACE Technical Manuals on Army installations or local building codes on Superfund, BRAC, or FUDS project sites.

CONTROL POINT: Design, Operations

(10) *Emergency Wash Equipment*.
Description. Emergency shower/eyewash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards or walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.
- Equip showers/eyewash equipment with accompanying functional drains to isolate and collect the shower/eyewash water from unprotected electrical equipment and walking surfaces that, when wet, create slipping hazards.

CONTROL POINT: Design

(11) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and

other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:

- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *VOC Exposure (Exhaust).*
Description. If the vapor-phase carbon adsorber becomes saturated or is operated on hot days, the carbon may adsorb VOCs less efficiently, causing an increase in VOC concentration in the exhaust. Workers in the area of the exhaust may be exposed to VOCs.

Control. Controls for VOCs exposure include:

- Monitor the discharge for VOCs and shut down the system if the VOC inlet concentration exceeds a predetermined level.
- Use respiratory protection (e.g., air-purifying respirator with organic vapor cartridges) against vapor exposures.
- Train workers in potential chemical exposure hazards and controls (see 29 CFR 1910.1200).

CONTROL POINT: Design, Operations, Maintenance

(2) *VOC Exposure (Breakthrough of Carbon Bed).*
Description. Workers may be exposed to VOCs via inhalation when breakthrough of the activated carbon bed occurs. Breakthrough may result in high VOC concentrations in the exhaust.

Control. Controls for VOC exposure include:

- Monitor effluent to determine when breakthrough occurs.
- Replace or regenerate carbon on a predetermined, regular schedule based on the concentration and adsorption properties of the vapor being treated.
- Use respiratory protection (e.g., air-purifying respirator with organic vapor cartridges) to protect against vapor exposures.
- Train workers in potential chemical exposure hazards, controls, and personal protection equipment (PPE) (see 29 CFR 1910.1200).

CONTROL POINT: Operations, Maintenance

(3) *Chemical Exposure (Vessel/Pipe Corrosion).*
Description. Workers may be exposed to waste chemicals from system leaks when activated carbon corrodes vessels and piping systems that are made from carbon steel or other corrodible material incompatible with the waste vapor stream to be treated.

Control. Controls for chemical exposure include:

- Do not use carbon steel to construct activated carbon vessels. Use stainless steel, thermoplastic, or other chemically inert vessel materials. Consult EM 11101-1-4008, "Liquid Process Piping," and UFGS 15200A, "Liquid Process Piping," for appropriate materials for processing various fluids.
- Paint, coat, or line tank interiors to prevent contact between activated carbon and the carbon steel or corrodible vessels and transfer systems where these materials must be used.
- Install spill or leak detection instruments, including alarms.
- Include drip pans or receivers to monitor leaks, corrosion, and sources of potential exposures where leaks may occur.
- Locate, install, and maintain emergency eyewash and showers at critical points throughout the system where chemical breakthrough is possible. (See ANSI Z358.1 – 1998.)
- Train workers in potential chemical exposure hazards and controls (see 29 CFR 1910.1200).

CONTROL POINT: Design, Construction, Maintenance

(4) *VOC Exposure (Saturated Carbon).*
Description. During removal of saturated carbon, workers my be exposed to VOCs.

Control. Controls for VOC exposure include:

- Monitor worker exposure to VOCs during carbon removal.
- Use respiratory protection appropriate for VOCs present (e.g., air-purifying respirator equipped with organic vapor cartridges) if worker exposure levels exceed permissible exposure levels (PELs).

CONTROL POINT: Operations, Maintenance

c. Radiological Hazards.

Radioactive Devices.
Description. Fire and smoke detection devices and other process monitors and switches may contain radioactive devices potentially exposing workers through lack of identification or mishandling.

Control. Controls for inadvertent handling or exposure to radioactive devices include:

- Workers should be prevented from and warned against tampering with the devices.
- The location of the devices should be recorded so as for safe retrieval and disposal in case of a system failure and equipment replacement.

CONTROL POINT: Design, Operations and Maintenance

d. Biological Hazards.

Opportunistic Insects and Animals.
Description. For all sites but especially in cooler climates, opportunistic insects or animals can nest in and around warm process equipment. Vermin, insect, and arthropod control measures should be considered in any design.

Control. Controls of opportunistic insect and animals include:

- Electrical cabinets and other infrequently opened enclosures should be opened carefully and checked for black widow and brown recluse spiders, and evidence of rodents. As rodents can cause damage to electrical cables, all wiring should be inspected regularly.
- Ensure all storage is off the ground, palleted, and kept dry. Damp areas attract scorpions, rodents, and the snakes that eat them.
- Design ceiling corners and other high areas to discourage nesting by swallows, pigeons, and other birds. Birds are carriers of diseases, especially in their droppings, which can foul cranes and process equipment.

CONTROL POINT: Design, Operations and Maintenance