A SunCam online continuing education course

Activated Carbon Odor Control Systems

by

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Course Outline:

Odor Control Options

Odor control involves removing or masking foul smells from odorous air so that the air can be released or recycled. Common applications for engineered odor control systems include the following:

- Sewers and lift stations,
- Wastewater treatment plants,
- Biosolids handling,
- Landfills,
- Compost facilities,
- Livestock, poultry, and fish processing,
- Pulp & paper manufacturing,
- Food processing,
- Breweries and beverage facilities,
- Pharmaceuticals,
- Coating processes, and
- Various industrial processes.

Odor compounds may include the following, with the most common odorants in bold:

- Acetic Acid
- Acrylates
- Alcohols
- Aldehydes
- Ammonia
- Amines
- Butyric Acid
- Carboxylic Acids
- Chlorine
- Creosols
- Dimethyl disulfide
- Dimethyl sulfide
- **Hydrogen Sulfide (H_2S)**
- Ketones
- **Mercaptans**
- Phenols
- Sketoles
- Sulfur Dioxide (SO_2)
- Volatile fatty acids
- **Volatile organic compounds (VOCs)** (various)

The dispersion of odorants can be modeled using commercially available software, as shown in Figure 1. This approach can help define how much odor removal is necessary to provide acceptable air quality at neighboring properties or public places.

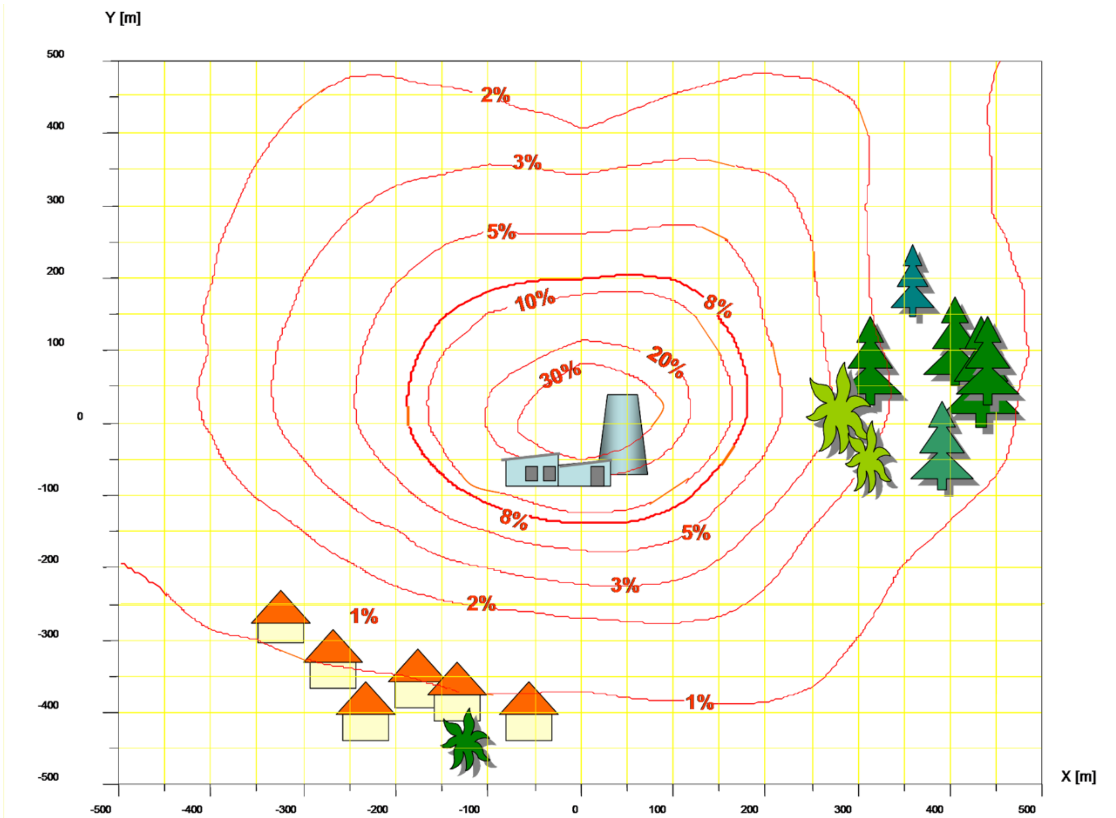


Figure 1: Atmospheric dispersion model for a factory showing how the initial odor compound concentration (100%) is reduced by natural dispersion. The closest houses are expected to experience approximately 1% of the initial concentration.

Odor Control Alternatives

Treatment options for odors fall into two categories: liquid phase and vapor phase:

1. Liquid phase treatment prevents odors from being released by altering the liquid from which the odors emerge (wastewater, sludge, leachate, etc.). Liquid phase treatment options include chemical injection for oxidation, precipitation, or pH adjustment.

2. Vapor phase treatment captures the gaseous odors and prevents them from being released through physical, chemical, or biological treatment. Vapor phase treatment options include:

- Physical treatment:
  - i. Thermal destruction
  - ii. Wet absorption/packed tower scrubbers (see Figures 2a and 2b)
  - iii. Dry adsorption systems, such as activated carbon (see Figure 3)
  - iv. Ionization systems (see Figure 4)
- Chemical treatment:
  - i. Chemical scrubbers also called chemical stripping (see Figure 2a)
  - ii. Chemical masking
- Biological treatment:
  - i. Biofilters (see Figure 5)
  - ii. Biotrickling filters (see Figure 6)
  - iii. Bioscrubbers (see Figure 7)

This course covers dry adsorption systems, with a focus on activated carbon media.

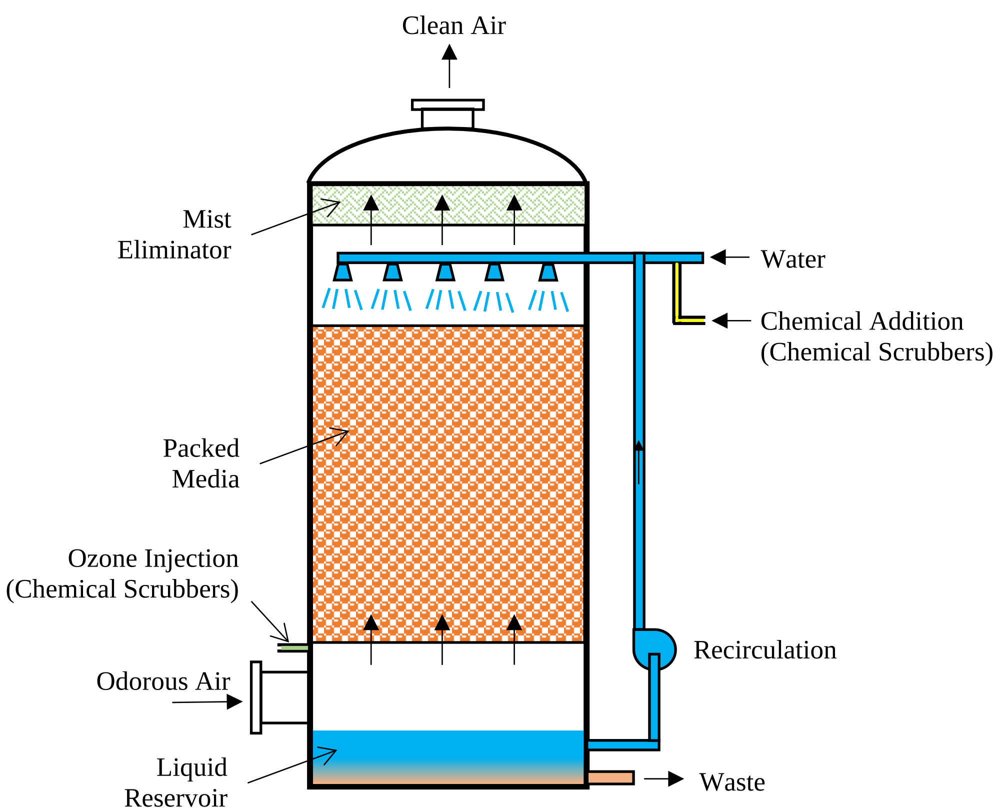


Figure 2a: Example of a packed tower scrubber and a chemical scrubber.
The difference is that chemical scrubbers include chemical or ozone addition.

Figure 2b: Example of a multi-stage packed tower scrubber.
Source: https://commons.wikimedia.org/wiki/File:ALCOSAN_Odor_Control_Systems_(6780287508).jpg, 90.5 WESA

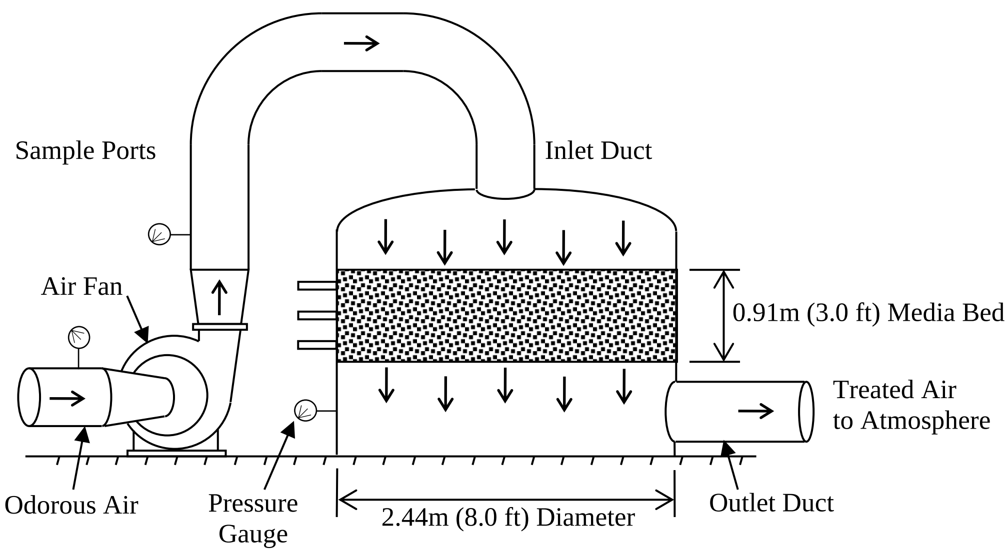


Figure 3: Schematic of an activated carbon odor control system.

Figure 4: Example of an ionization odor control system.
Inside the duct at the blue modules are a series of ion tubes.

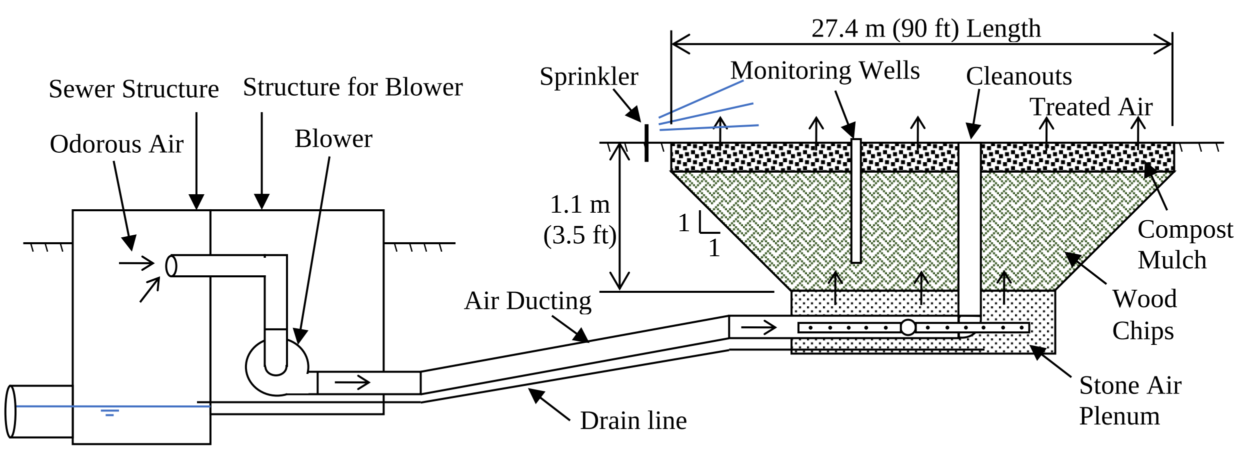


Figure 5: Example of a biofilter bed.

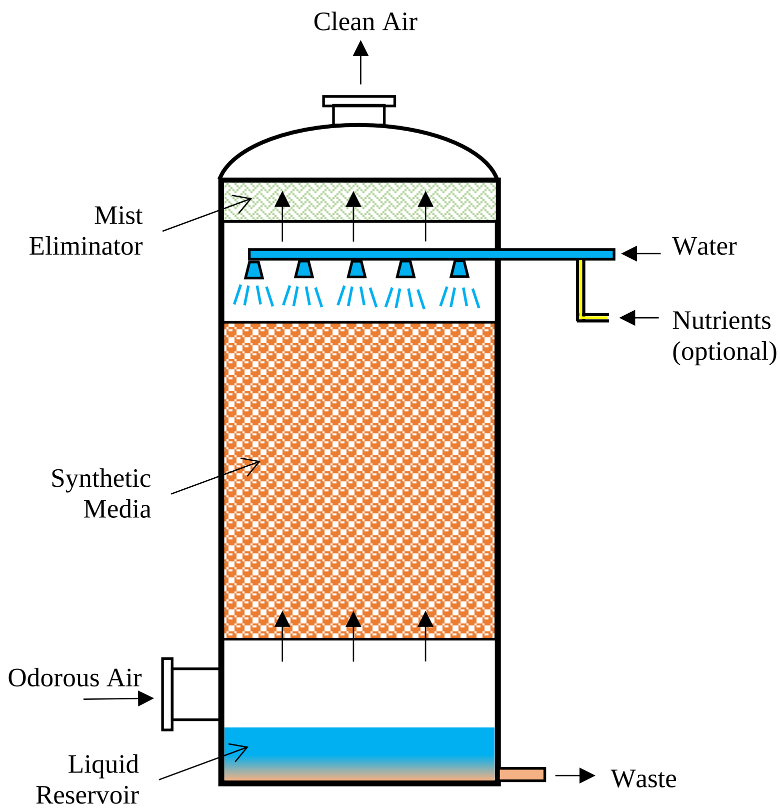


Figure 6: Schematic of a typical biotrickling filter.
Note that recirculation of water is typically not included.

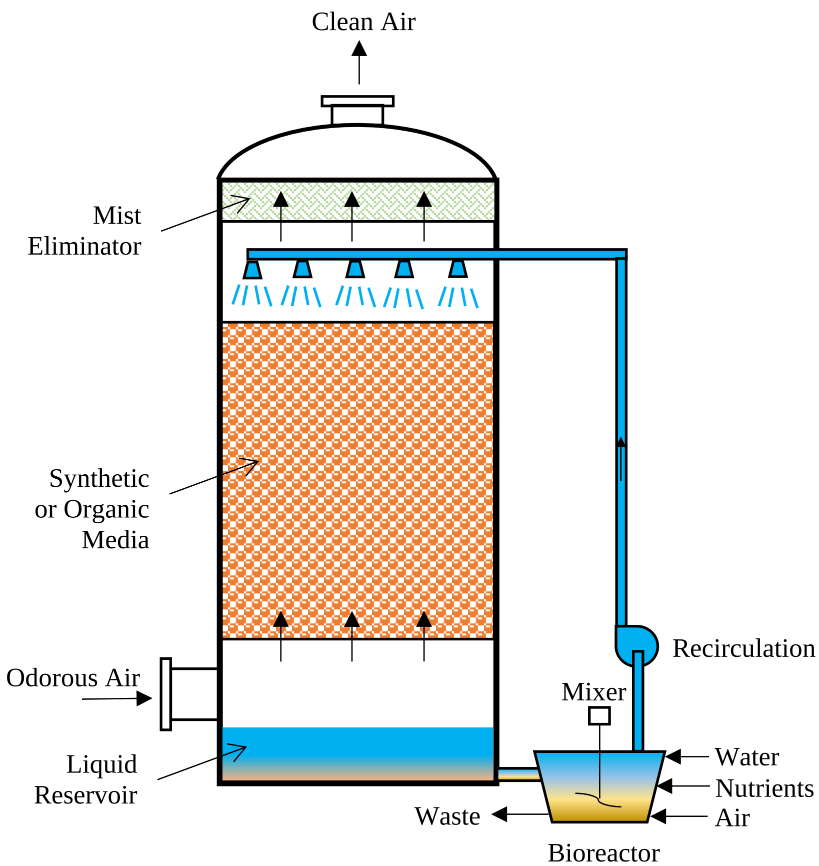


Figure 7: Schematic of a typical bioscrubber. A bioreactor with living organisms is maintained by adding nutrients (chemicals), air, and water. The mixture is a type of activated sludge and is sprayed on top of the media.

Overview of Dry Adsorption Treatment

Typical components of an activated carbon dry adsorption system include a blower, electrical controls, air ducting, enclosure for the media, service ports, activated carbon media, H_2S detector, temperature alarm system, manometer, or pressure gauges, and regeneration valves. See Figure 3 for an example arrangement.

Advantages to an activated carbon system include consistency, reliability, and simplicity. Disadvantages include frequent media replacement or regeneration, odor compound limitations, and the potential for plugging of the air stream.

Adsorption is the accumulation of substances on the surface of media, while absorption is the bulk acceptance of substances into media. For example, when sewer gas is passed over activated carbon, odorous compounds will adhere to the surface of the carbon, so this is an adsorptive treatment process. Wet adsorption is when the media is submerged in water (or heavily sprayed with water), while dry adsorption is when the air moves through dry media. This course focuses on dry adsorption with activated carbon.

In dry adsorption, molecules of gas move through a filter bed and physically contact the media surface. A physical bond occurs between odorous compounds and the available surface area due to the Van der Waals force, which is an attraction between molecules and surfaces. In some cases, an actual chemical bond occurs, and this is called chemisorption. See Figure 8 for a depiction of adsorption.

Activated carbon has a uniform (non-polar) distribution of electrical charge on the surface. This means that water molecules do not attach to the surface of the media, as H_2O is highly polar. Activated carbon attracts less polar organic compounds, including most of the common odorants. More than one layer of different media may be needed to target multiple odor compounds.

When designed properly, activated carbon media can achieve over 99% removal of hydrogen sulfide (H_2S) molecules with low H_2S concentrations in the air stream and over 95% with high H_2S concentrations.

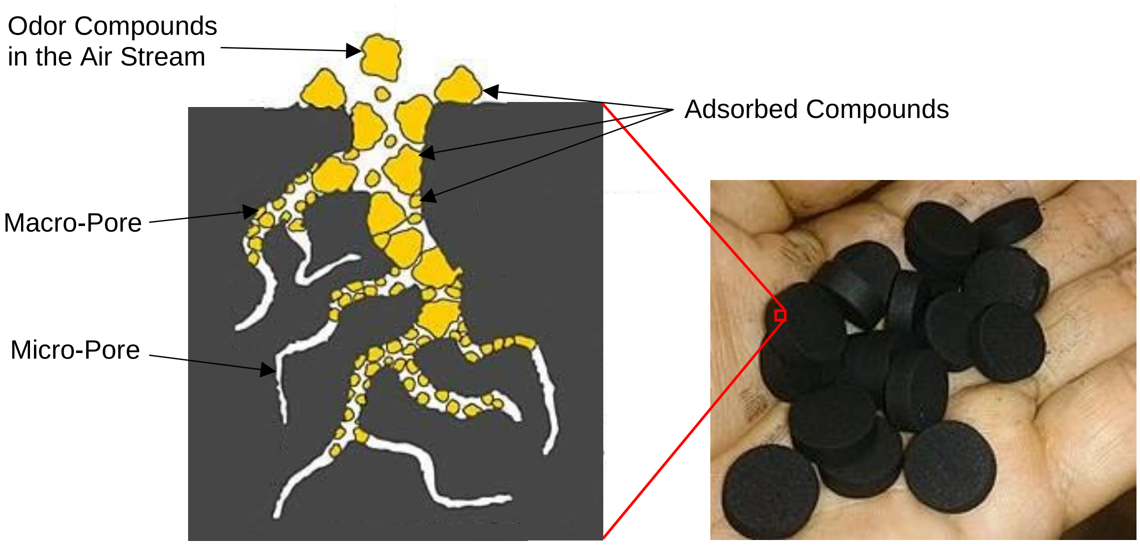


Figure 8: Activated carbon pellets (right) with zoom in on the surface (left) showing pores with additional surface area for adsorbing odor compounds.
Source left: A Citizen's Guide to Activated Carbon Treatment, EPA 542-F-12-001
Source right: commons.wikimedia.org/wiki/File:Medicinal_charcoal.jpg, ProjectManhattan, CC-BY-SA-3.0

Over time, the available surface area decreases due to the buildup of compounds on the media surface. Adsorption performance can be improved by:

- Increasing the contact time,
- Decreasing the odor concentration,
- Decreasing the air temperature,
- Increasing material purity,
- Increasing surface area,
- Decreasing the affinity to water, or
- Impregnating specific chemicals on the media surface.

Moisture

Although water molecules are not attracted to the surface of activated carbon, water droplets can still build up on the media if the relative humidity in the odorous air is too high. As a rule of thumb, a media bed should be designed and monitored to maintain a maximum of 75% relative humidity. If the relative humidity reaches 100%, condensation will form on the media surface and odor removal performance will greatly diminish. This can be a concern for applications that draw odorous air from sewers, tanks, or other humid environments, in which the odorous air is likely to be near saturated, which has 100% relative humidity.

The humidity level can be decreased through the following preconditioning options:

- Mixing humid odorous air with dry air,
- Mist eliminator,
- Dehumidifier (compressor or desiccant types),
- Cooler followed by a heater, or
- Heater.

It is important to be aware of the effect of temperature changes on the relative humidity. When air is suddenly warmed up, the relative humidity decreases, as shown in Figure 9. For example, air that is saturated with a temperature of 20°C has a water content of about 15g per kg of air. If it warms to 30°C, the same water content of 15g per kg of air results in a relative humidity of about 50%.

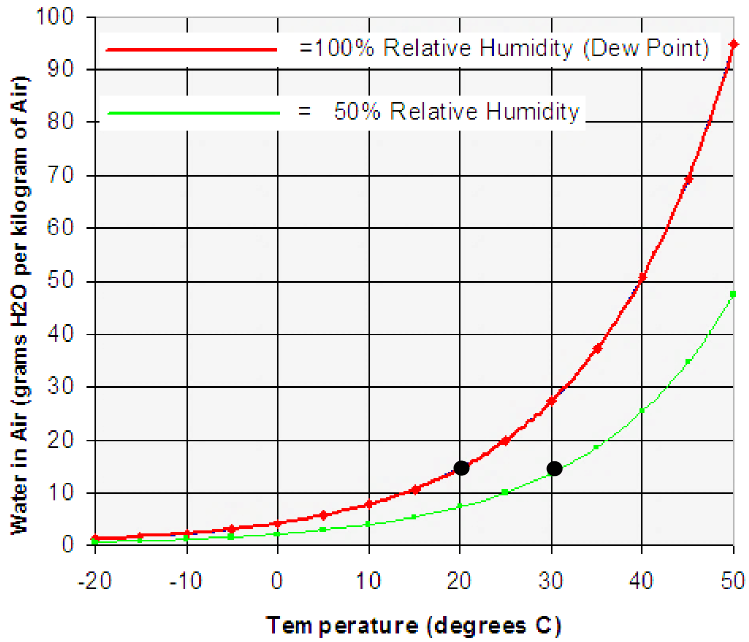


Figure 9: Plot of Water Content versus Temperature for Air at 100% and 50% relative humidity. The two points indicate the relative humidity change from 100% to 50% when the air temperature increases by 10 degrees C.

Temperature

Odor compounds have kinetic energy which is converted to heat when adsorbed to the surface of the media. The hotter the odorous air, the greater the kinetic energy of the molecules and the greater the resulting temperature of the media bed. When the bed temperature exceeds 40 degrees C, odor removal performance becomes increasingly diminished.

Media suppliers typically test each type of media for odor removal performance at different temperatures and plot the results as isotherms. See Figure 10 for an example.

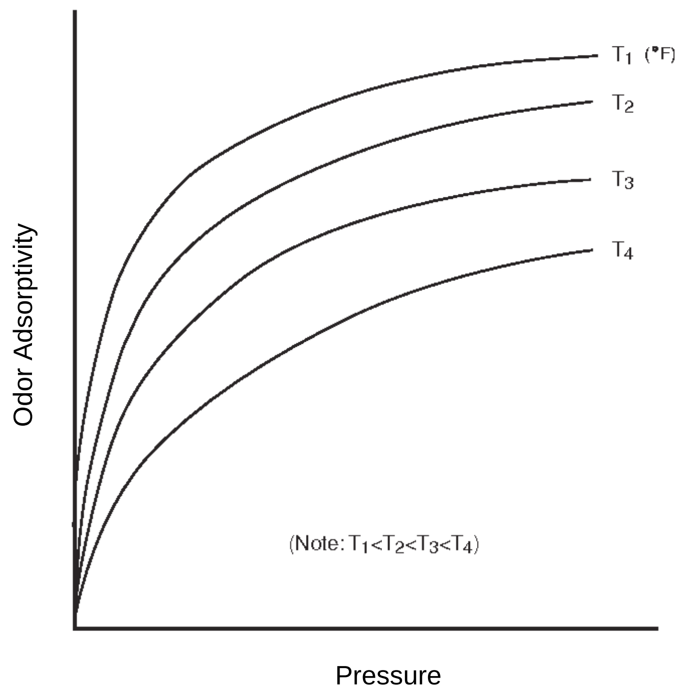


Figure 10: Example of an adsorption isotherm for activated carbon media.
At higher temperatures, the adsorption performance decreases.
Source: EPA Air Pollution Control Cost Manual, Chapter 1, EPA/452/B-02-001

Media Options

For adsorption of odor compounds, the following types of media are available:
- Activated carbon,
- Iron sponge (ferric oxide),
- Activated alumina,
- Zeolites, and
- Polymers such as silica gel.

This course focuses on activated carbon media. Activated carbon is formed by thermal processing of coal (bituminous), wood, coconut husks, bamboo, peat, coir, petroleum pitch, or lignite. There are two ways to "activate" the carbon:
1. Physical activation: The material is carbonized (or purified) by heating it with gases (argon or nitrogen) to remove volatile materials. The material is then activated by exposing it to a high-temperature gas, such as steam, carbon dioxide, or oxygen.
2. Chemical activation: The material is soaked in an acid, strong base, or salt. This impregnates the carbon with chemicals that target specific odors. The temperature is increased to 250 to 600 degrees C.

Both methods create a complex pore structure with a relatively large surface area, typically 1000 m^2/g. See Figure 11 for example images showing the rough, porous surface that results from the activation process.

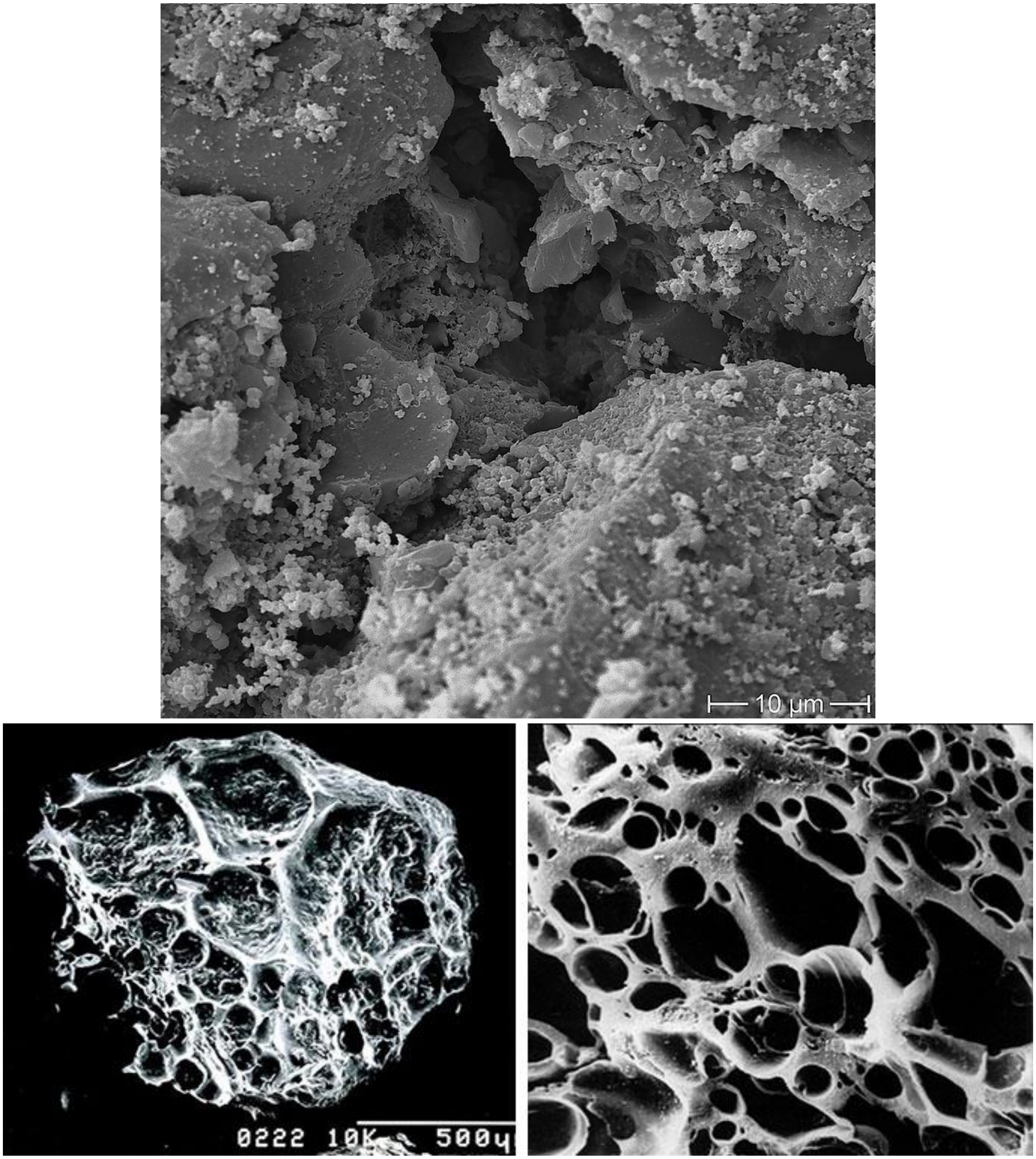


Figure 11: Scanning electron microscope images of activated carbon surfaces.
Source: https://en.wikipedia.org/wiki/Activated_carbon#/media/File:Activated_Charcoal.jpg, Mydriatic, CC BY-SA 3.0

Activated carbon can be purchased in several different forms, as summarized in Table 1, and shown in Figures 12 through 14.

Table 1: Summary of Activated Carbon Forms

Form	Size	Common Applications	Odor Control Configuration	Advantages	Disadvantages
Powdered (PAC)	<80 mesh	Air purification Water filtration Manufacturing	Air filters	• Highest surface area	• Highest pressure loss • Highest dust
Granular (GAC)	>80 mesh	Air purification Auto emissions Mining Manufacturing Water filtration	Filter bed	• Most economical • Most options available	
Extruded/ Pelletized (EAC)	0.5 to 100 mm diameter cylinder	Auto emissions CTO water filter	Filter bed	• Low pressure drop • High strength • Low dust	• Low surface area
Bead (BAC)	0.3 to 0.8 mm diameter Sphere	Water filtration	Filter bed	• Low pressure drop • High strength • Low dust	• Low surface area

Figure 12: Example of powdered activated carbon media.
Source: https://commons.wikimedia.org/wiki/File:Activated_Carbon.jpg, Ravedave, cropped, CC-BY-2.5

Figure 13: Example of granular activated carbon media.

Figure 14: Example of extruded activated carbon media.
Source: https://commons.wikimedia.org/wiki/File:ActiTube.jpg, El Mono Español, cropped, CC-BY-SA-4.0

Along with choosing the form of the media, the type of media is also to be considered. See Table 2 for different types of media along with typical hydrogen sulfide concentrations and removal capacities. The removal capacity is also known as the breakthrough capacity.

Table 2: Hydrogen Sulfide Concentrations for Types of Activated Carbon

Activated Carbon Type	H_2S Concentration		Capacity ($g\ H_2S$ / cc)	Notes
	Minimum	Maximum		
Plain, Virgin	1	10	0.05 to 0.08	Good for VOC removal
Caustic Impregnated	10	50	0.10 to 0.15	Option for regenerable
High Capacity	50	100	0.25 to 0.35	Includes catalytic chemicals
Proprietary	100	2,000	Varies	Specially formulated patented media and iron sponge formulations

Reactivation

Spent media can be reactivated through the same initial activation process (physical or chemical). The reactivation process drives the odor compounds off the carbon surface and destroys them. Costs associated with reactivation include the removal of media, transportation to an activation center and back, and reinstallation of media. Often the cost of media disposal and replacement is less than reactivation. Also, this involves a period of downtime for the odor control system or the purchase of a second batch of media. Ideally, the odor control system should be designed with a standby vessel, so that when one vessel has the media under reactivation, the remaining vessels can continue with treatment. Another option is to keep additional media in storage and fill the vessel with new media while the old media is being reactivated.

Chemical Regeneration

Exhausted media can be partially restored through a process called regeneration. This can be accomplished with a series of chemical baths within the on-site media vessel. The baths target specific compounds for removal while leaving other compounds adsorbed. Therefore, only part of the original media capacity is restored.

The chemical regeneration process typically takes about one to two weeks. Hydrogen sulfide can be removed from carbon media by soaking it in caustic soda (sodium hydroxide). The following are the chemical reactions for the caustic soda regeneration process, which removes the sulfur from the carbon surface:

Step 1: $NaOH(a) + H_2S(ads) \rightarrow NaHS(a) + H_2O(l)$

$2NaOH(a) + H_2S(ads) \rightarrow Na_2S(a) + 2H_2O(l)$

Step 2: $NaHS(a) + 0.5O_2(a) \rightarrow S(a) + NaOH(a)$

$Na_2S(a) + 0.5O_2(a) + H_2O(l) \rightarrow S(a) + 2NaOH(a)$

where (*a*), (*ads*) and (*l*) indicate aqueous, adsorbed, and liquid phases.

The odor control system should be designed with a standby vessel so that when one vessel is under regeneration, the remaining vessels can continue with treatment. Due to difficulties with chemical handling and disposal, this type of regeneration is becoming less common.

Steam Regeneration

Exhausted media can also be regenerated by filling the vessel with hot steam. The steam is blown in the opposite direction of the airflow. Then the media is dried with a flow of air and allowed to cool before being placed back in operation. See Figure 15 for an example configuration with two vessels. Only one vessel is regenerated at a time.

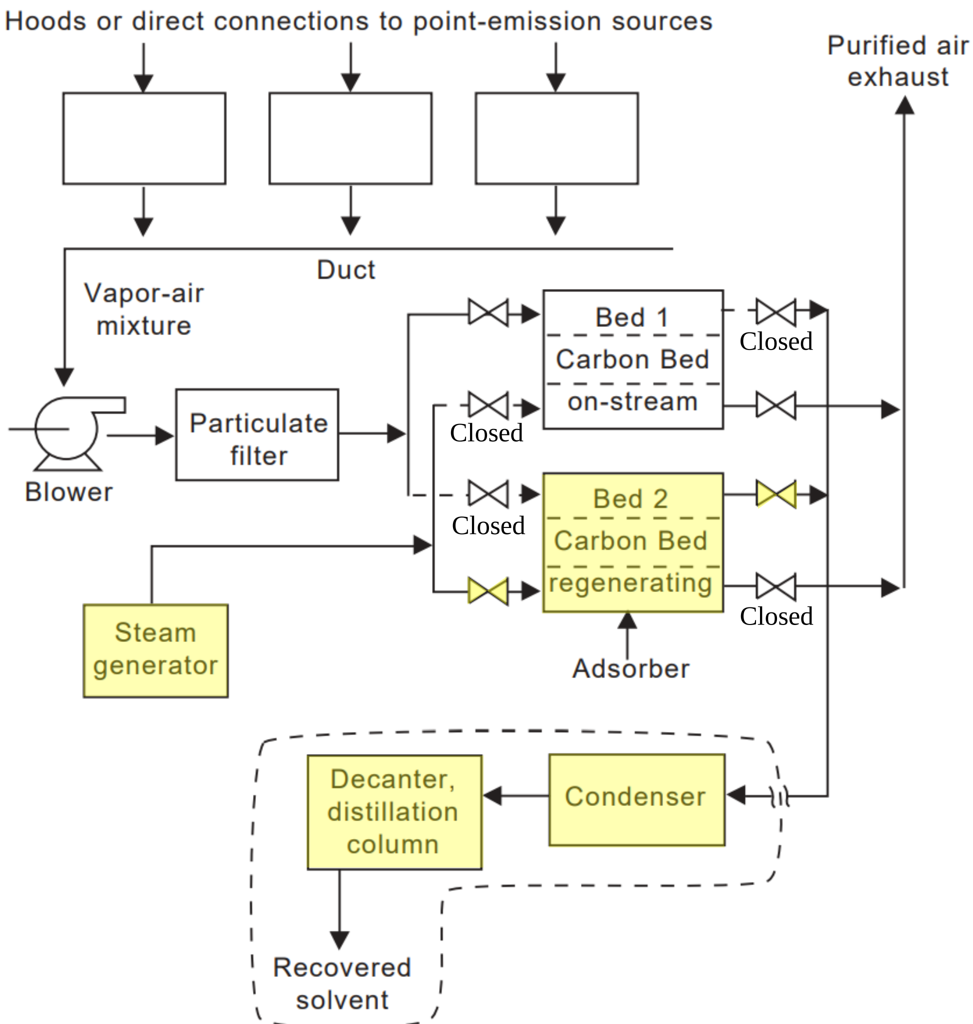


Figure 15: Process flow diagram for a two-bed, continuous odor control system. Bed 1 is treating the airstream while Bed 2 is being regenerated with steam (in yellow).
Source: EPA Air Pollution Control Cost Manual, Chapter 1, EPA/452/B-02-001

Water Regeneration

Lifecycle costs can be decreased significantly by using a surface modified non-impregnated activated carbon which can be regenerated with water instead of caustic soda. The activated carbon has an added catalytic functionality which oxidizes H_2S and converts it to water-soluble sulfur compounds, such as sulfuric acid. Regeneration can typically be done about 10 times before media replacement is required.

The water regeneration process is as follows:

1) The media vessel is filled with water.
2) Water is adsorbed, forming a film of water on the pore surface.
3) Oxygen (O_2) molecules in the water diffuse down inside the carbon pores.
4) The O_2 is adsorbed on the carbon surface and breaks down into radicals.
5) The oxygen radicals then react with the dissolved hydrosulfide ions, forming elemental sulfur and water.
6) Further oxidation to sulfur dioxide and sulfuric acid occurs with the catalyst on the activated carbon surface.
7) The sulfur-filled water is drained and disposed. Likely it is acceptable to drain the wastewater into the sewer, although the water quality parameters would need to be confirmed.

A drawback to using water regeneratable activated carbon is that the odor removal capacity is less than normal activated carbon. Therefore, the media will not last as long and will need to be regenerated more frequently than normal media would be replaced. However, the cost of water regeneration is relatively low, being mostly labor.

Example Problem 1:

Engineer Beth is comparing the maintenance cost of water regeneratable activated carbon (WRAC) and normal granular activated carbon (GAC). She estimates that WRAC will last 9 months while GAC will last 2 years. Water regeneration requires 20 hours of labor at $80 per hour, $100 for water, and $500 for wastewater disposal. GAC replacement costs $8,000. What is the annual cost for each?

Solution:
Beth calculated the regeneration cost as follows:

Regen cost = labor + water + wastewater
= $80/hr * 20 hrs + $100 + $500 = $2,200

The regeneration is needed every 9 months, which is 1.33 times per year (12 months / 9 months). Therefore, the **WRAC** annual maintenance cost is $2,200 * 1.33 = **$2,926**.

For **GAC**, the maintenance cost is $8,000 every two years, which is an annual cost of **$4,000**.

Media Bed Sizing

The media bed should be sized to satisfy the following criteria:

1. Face Velocity: The air velocity when entering the face of the bed should be high enough to prevent excessive heat in the center of the bed and low enough to provide good air distribution.
2. Contact Time: Odor compounds need time to flow into the pores and adsorb on the surface. This is satisfied by calculating the contact time (bed volume divided by flow rate) and comparing it to industry standards. Contact time is also known as empty bed residence time (EBRT) or empty bed contact time (EBCT).
3. Media Life: The media should last long enough to avoid frequent replacement or regeneration. The media life is calculated as the odor adsorption capacity of the bed divided by the odor loading rate. Media suppliers provide the adsorption capacity per unit volume. The odor loading rate is the odor concentration times the air flow rate.
4. Pressure Drop: The pressure loss through the bed should be estimated and accounted for when sizing the air fan/blower. Media suppliers provide the pressure loss per foot of bed depth. A typical bed depth is 3 feet.

These criteria are summarized in Table 3. The following example problem shows how to perform the calculations.

Table 3: Summary of Media Bed Design Criteria

Criteria	Formula	Typical Range	Common Value
Face Velocity	$\frac{\text{air flow rate}}{\text{surface area}}$	20 to 100 fpm (0.1 to 0.5 m/s)	50 fpm
Contact Time	$\frac{\text{bed volume}}{\text{air flow rate}}$	1 to 30 seconds	3 sec for H_2S<100 ppm 10 sec for H_2S>100 ppm 20 sec for H_2S>500 ppm
Media Life	$\frac{\text{removal capacity} * \text{bed volume}}{\text{odor concentration} * \text{air flow rate}}$	1 to 24 months	9 months
Pressure Drop	From Manufacturer	2” WC per foot GAC 1” WC per foot EAC	6” WC (water column)

Care must be taken in calculating the media life because of the units in the formula. The odor concentration is normally expressed in terms of parts per million by volume (ppmv). Meanwhile, the media removal capacity is expressed in terms of mass (g H_2S / cc). The following values can be used to convert from volume to mass:

• Molar volume of air	385 ft^3 / lbmol
• H_2S molecular weight	34 lb / lbmol
• Convert grams to pounds	454 g / lb
• Convert cc (cm^3) to ft^3	28,317 cm^3 / ft^3
• Convert min to months	43,800 min / month

Using these values, the media life formula can be stated in terms of the typical units for the four inputs: **W**, **X**, **Y**, and **Z**:

$$\text{Media life} = \frac{\mathbf{W}\text{ (removal capacity)} * \mathbf{X}\text{ (bed volume)}}{\mathbf{Y}\text{ (odor concentration)} * \mathbf{Z}\text{ (air flow rate)}} = \frac{\mathbf{W}\,\frac{\text{g H}_2\text{S}}{\text{cm}^3} * \mathbf{X}\,\text{ft}^3}{\mathbf{Y}\text{ ppmv H}_2\text{S} * \mathbf{Z}\,\frac{\text{ft}^3}{\text{min}}}$$

$$= \frac{\mathbf{W}\,\frac{\text{g H}_2\text{S}}{\text{cm}^3} * \frac{28{,}317\text{cm}^3}{\text{ft}^3}\frac{1\text{ lb}}{454\text{g}} * \mathbf{X}\,\text{ft}^3}{\frac{\mathbf{Y}\text{ parts H}_2\text{S}}{1{,}000{,}000\text{ parts air}} * \mathbf{Z}\,\frac{\text{ft}^3}{\text{min}} * \frac{43{,}800\text{ min}}{\text{month}} * \frac{\text{lbmol}}{385\text{ ft}^3} * \frac{34\text{ lb H}_2S}{\text{lbmol}}}$$

Example Problem 2:
Foul air is venting from a sludge storage tank and the neighboring property is being developed for condominiums. Engineer Becky is asked to design an activated carbon odor control system to reduce hydrogen sulfide odors by at least 95%. The design is to consist of a single vessel with a 3-foot deep bed of granular activated carbon (GAC) as shown in Figure 16. Becky determines an air flow rate of 2,000 cfm based on achieving 20 air changes per hour in the open space at the top of the tank, which will result in an estimated H_2S concentration of 50 ppm. The GAC media has a breakthrough capacity of 0.15 g H_2S / cc. To meet or exceed the common criteria values in Table 3, what is the most economical vessel diameter, rounded to the nearest 6 inches?

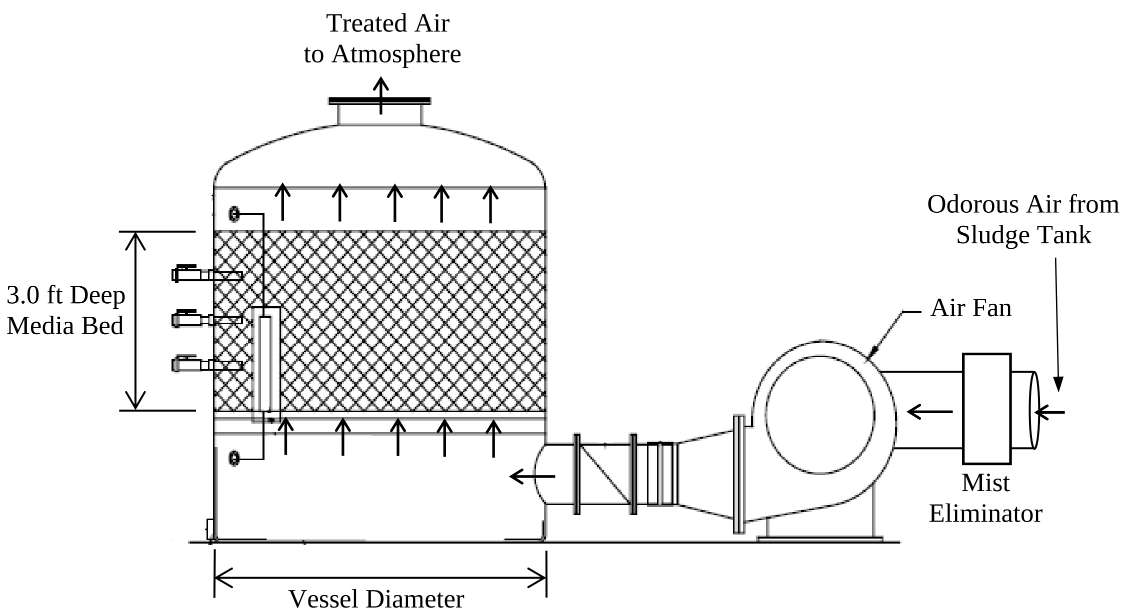


Figure 16: Schematic for Example Problem 2.

Solution:
Becky is not sure which of the criteria will control the design, so she calculates the minimum vessel diameter for each criterion, and then chooses the largest of those diameters.

Face velocity:

$$\text{face velocity} = \frac{\text{air flow rate}}{\text{surface area}}\ , \qquad \textit{rearranged}: \quad \text{surface area} = \frac{\text{air flow rate}}{\text{face velocity}}$$

$$\frac{\pi d^2}{4} = \frac{2000\ \text{ft}^3/\text{min}}{50\ \text{ft/min}}\ ,\ d = 7.14\ \text{ft}\ ,$$ round up to **7'-6"**

Contact time:

$$\text{contact time} = \frac{\text{bed volume}}{\text{air flow rate}}\ , \qquad \textit{rearranged}: \quad \text{bed volume} = \text{contact time} * \text{air flow rate}$$

$$\frac{\pi d^2}{4} * 3\text{ft} = 3\ \text{sec} * \frac{1\text{min}}{60\text{sec}} 2000 \frac{\text{ft}^3}{\text{min}}\ ,\ d = 6.51\ \text{ft}\ ,$$ round up to **7'-0"**

Media life:

$$\text{media life} = \frac{\mathbf{W}\ \frac{\text{g H}_2\text{S}}{\text{cm}^3} * \frac{28{,}317\text{cm}^3}{\text{ft}^3} \frac{1\ \text{lb}}{454\text{g}} * \mathbf{X}\ \text{ft}^3}{\frac{\mathbf{Y}\ \text{parts H}_2\text{S}}{1{,}000{,}000\ \text{parts air}} * \mathbf{Z} \frac{\text{ft}^3}{\text{min}} * \frac{43{,}800\ \text{min}}{\text{month}} * \frac{\text{lbmol}}{385\ \text{ft}^3} * \frac{34\ \text{lb H}_2 S}{\text{lbmol}}}$$

$$6\ \text{months} = \frac{\mathbf{0.15}\ \frac{\text{g H}_2\text{S}}{\text{cm}^3} * \frac{28{,}317\text{cm}^3}{\text{ft}^3} \frac{1\ \text{lb}}{454\text{g}} * \frac{\pi \mathbf{d}^2}{4} * 3\ \text{ft}}{\frac{\mathbf{50}\ \text{parts H}_2\text{S}}{1{,}000{,}000\ \text{parts air}} * \mathbf{2000} \frac{\text{ft}^3}{\text{min}} * \frac{43{,}800\ \text{min}}{\text{month}} * \frac{\text{lbmol}}{385\ \text{ft}^3} * \frac{34\ \text{lb H}_2 S}{\text{lbmol}}}$$

$d = 10.26$ ft round up to **10'-6"**

The media life criterion controls the design since it requires the largest diameter vessel. Becky proceeds with a 10'-6" diameter vessel.

Example Problem 3:
Continuing from Problem 2, what is the recommended air pipe size?

Solution:
Becky uses the common design velocity of 2,000 fpm to calculate the ideal pipe diameter.

Pipe area = flow rate / velocity
π * dia ^{2} / 4 = 2,000 ft^3/min / 2,000 ft/min
dia = 1.13 ft = 13.5 in

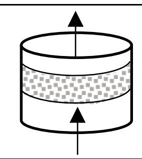
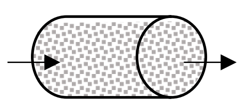
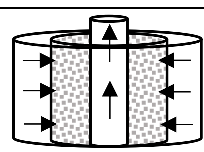
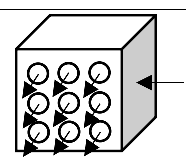
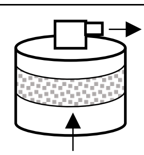
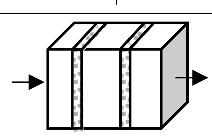
Becky chooses the closest nominal pipe size of 14".

System Configurations

Activated carbon systems have been the most successful type of odor control system for many decades and across numerous industries. This can be traced back to the use of charcoal in gas masks during World War I. Charcoal was known to remove toxic gases. By the 1940's it was discovered that small pieces of charcoal that had been heated for purification were very effective at removing odors. This product was named activated carbon. Today, activated carbon is the most popular type of adsorption media.

Table 4 provides a summary of common configurations for activated carbon odor control systems.

Table 4: Activated Carbon Odor Control System Configurations

Configuration	Flow Pattern	Description	Advantages
Vertical Bed		• Upward flow is typical • Often multiple beds due to diameter limitations	• Most common configuration • Simplicity
Horizontal Bed		• Flow in and out through sides of a large vessel	• For large flows, media change is easier • Small footprint
Radial Bed		• Outside to inside flow distribution	• Small footprint since bed can be very tall
Radial Canisters		• Multiple horizontal canisters with outside to inside flow	• Change media by hand • Auto regeneration cycle by canister
Top Mount Unit		• Package system with air fan for small flows	• Single item to install • Small footprint
Air Filters		• Series of air filters in a duct arrangement	• Change media by hand

Flow Rate Basis

Air flow rates need to be sufficient for the following:

1. Prevent the escape of odors from the source (vessel, tank, well, sewer, etc.):
    a. Air flow rate must exceed maximum wastewater influent rate (when tank is filling) plus any air addition (aeration for mixing or air supply fans),
    b. Consider how the area is sealed to prevent the escape of odors, especially in areas far from the odorous air inlet(s).
2. Meet code requirements for minimum air changes per hour (ACH) for ventilation.
3. Reduce explosion proof classification:
    a. Refer to NFPA 820 "Standard for Fire Protection in Wastewater Treatment and Collection Facilities",
    b. For example, a wet well requires >12 ACH to decrease from Class 1, Div 1 to Class 1, Div 2.
4. Provide minimum 4 ACH at normal water level, as a rule of thumb.
5. Dilute the odor concentration for ease of treatment (when applicable).

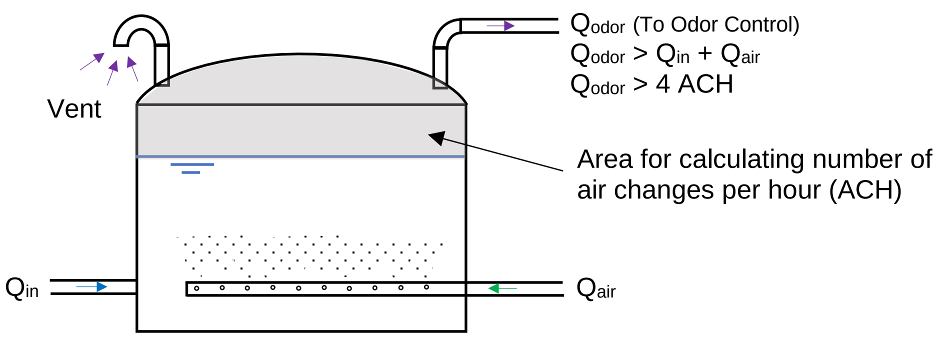


Figure 17: Tank with odorous air flow, Q_{odor}, and an intake vent on the opposite side.

Example Design

A wastewater treatment plant has multiple tanks that require regular air changes and an odor control system. The odor control system includes a single vessel, as shown in Figures 18 and 19. It consists of the following components:

- 7.5 HP (5.6 kW) blower,
- Fiberglass enclosure/vessel with 8 ft (2.44 m) diameter and 7.5 ft (2.29 m) sidewall height
- 3 ft (0.91 m) deep bed of GAC,
- 18 inch (45.7 cm) inlet ducts,
- 24 inch (61.0 cm) outlet ducts,
- Local control panel,
- Three sample ports,
- Drain port,
- Manometer (pressure differential across the bed), and
- Temperature gauges.

Figure 18: Odor control enclosure (green, center) and air fan (green, right).

Figure 19: Odor control vessel (green, center) with
a manometer (white with red stripe) and three sample ports with PVC valves.

The odor control unit removes odors and air pollutants from an airstream that originates from a total of two tanks and nine wet wells. Figure 20 shows the pipe diameters, air flow rates, and flow stream connections for the entire duct system. The exhaust pipe discharges directly to the atmosphere with the outlet located on the side of the building about 20 feet (6.1 m) above the ground.

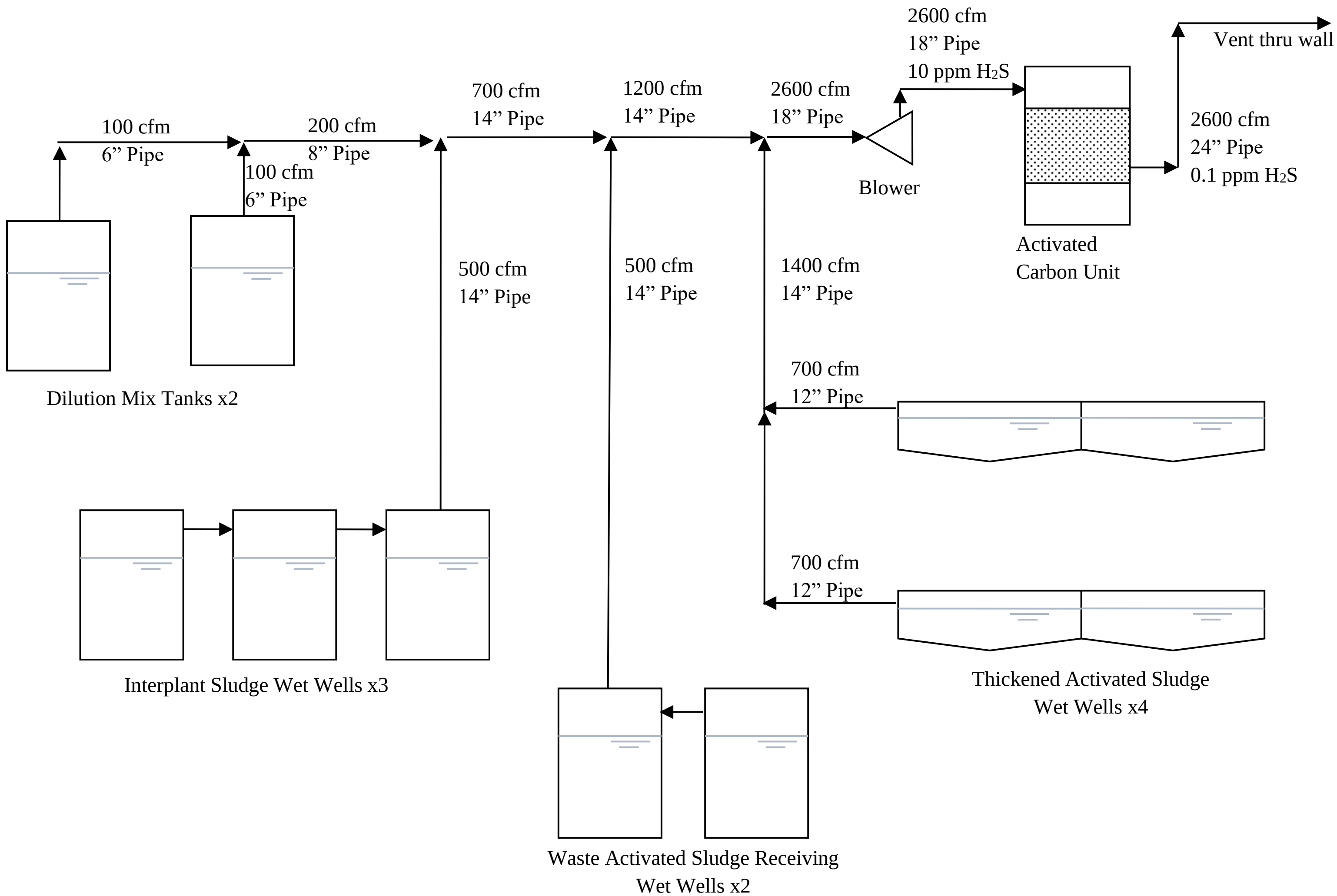


Figure 20: Process flow diagram showing airflow sources, H_2S concentrations, and flow rates.

Flow Rate Basis

The air flows are designed to give over 30 air changes per hour with the sludge at the low water level. For example, for the two WAS Receiving Wet Wells, each tank has approximately 450 cubic feet of open space when the sludge is at the low water level. This gives a total of 900 cubic feet (25.5 m^3) of odorous air between the two wells. With a design flow rate of 500 cfm (294.5 m^3/hr), 33 air changes per hour are provided.

Media Bed Design

The enclosure is designed for an 8 feet (2.4 m) diameter by 3 feet (.91 m) deep bed of activated carbon (AC). This is a media bed volume of 150.8 ft^3 (4,271,000 cm^3). The activated carbon is extruded/pelleted, caustic impregnated bituminous coal. Per the datasheets, the media has an H_2S breakthrough capacity of 0.14 g H_2S removal/ cm^3 and an installed density of approximately 36 lb/ft^3 (0.577 g/cm^3). It can be regenerated up to 10 times using an in-situ caustic solution treatment.

The unit has an air velocity of 51 fpm (0.26 m/s) and a contact time (empty bed residence time) of 3.5 seconds. This is within the manufacturer's recommend velocity range of 50 to 75 fpm (0.25 to 0.38 m/s) and contact time range of 2.5 to 4.0 seconds for low concentrations of H_2S (10 ppm in this case).

Media Replacement Estimate

The bed life is estimated based on the minimum H_2S breakthrough capacity, media volume, estimated H_2S concentration, and air flow rate (2,600 cfm):

$$\text{Media life} = \frac{\mathbf{0.14}\ \frac{\text{g H}_2\text{S}}{\text{cm}^3} * \frac{28{,}317\text{cm}^3}{\text{ft}^3}\frac{1\text{ lb}}{454\text{g}} * \mathbf{150.8}\ \text{ft}^3}{\frac{\mathbf{10}\text{ parts H}_2\text{S}}{1{,}000{,}000\text{ parts air}} * \mathbf{2{,}600}\frac{\text{ft}^3}{\text{min}} * \frac{43{,}800\text{ min}}{\text{month}} * \frac{\text{lbmol}}{385\text{ ft}^3} * \frac{34\text{ lb H}_2S}{\text{lbmol}}}$$

$$= 13.1\text{ months} = 1.1\text{ years}$$

The maintenance staff have scheduled for the replacement or regeneration of the media once a year.

Maintenance

Media regeneration or replacement is the most labor and equipment intensive process associated with the maintenance of an activated carbon odor control system. When removing the media, care should be taken to not damage the vessel. Typically, a vacuum truck is utilized to suck out the media from the top.

Although the media life can be calculated, in reality, the activated carbon may last a significantly shorter time, or a longer time, depending on actual operating conditions. Frequent monitoring of odors, moisture, and pressure will help determine when media replacement is actually needed. These readings can be recorded in a maintenance log, as shown in Figure 21.

When poor odor removal occurs, it is important to consider if the high odors are the result of an unusual or extreme condition, such as a sudden high concentration of H_2S or an extremely hot and dry day. Next, consider if the humidity is high. If so, perform maintenance on the mist eliminator or add a means to reduce moisture in the air stream.

Also, check the pressure readings. A sudden spike in pressure could indicate the air piping is blocked or a dampener is closed. A gradual increase in pressure over many months to the point of an unacceptably low flow rate indicates the bed material has become denser and needs attention or replacement.

Maintenance Log

YEAR: 2021

	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Media Change/Regen	Other: ________
Date						
Name						
Odor Sensed at Discharge?						
Odor Sensed in Building?						
Humidity at Air Fan						
Humidity at Bed						
Temperature Bed Top (°F)						
Temperature Bed Bott (°F)						
Pressure Different (in.)						
Air Pipe and Bed Drained?						
Fan Inspected?						
Bearings Greased?						
Media Replaced?						
Other/Notes:						

Figure 21: Example of a maintenance log.

Lifecycle Cost

Since odor control systems include substantial operations and maintenance costs, it is appropriate to estimate the lifecycle cost. Lifecycle cost refers to the total cost of ownership over the life of an asset. This whole-life costing includes costs incurred after an asset has been constructed or acquired, such as maintenance, energy usage, operation, and disposal.

The lifecycle cost can be calculated using the present worth approach. The formula is as follows:

$$Lifecycle\ Cost = Capital\ Cost + Annual\ Maintenance * PWF - Salvage\ Value$$

where: $PWF = Present\ Worth\ Factor = \frac{(1+i)^T - 1}{i*(1+i)^T}$

$i = interest\ rate$

$T = number\ of\ years$

Example Problem 4:
Engineer Roger is comparing odor control alternatives and needs to calculate the 40-year lifecycle cost of an activated carbon system, rounded to the nearest $1,000. The interest rate is 5%. There is no salvage value at 40 years. Capital costs are provided in Table 5 and maintenance costs are in Table 6.

Table 5: Capital Costs for Problem 4

Item	Unit	No. of Units	Unit Cost ($)	Total Cost ($)
Fiberglass Enclosure (8 ft diameter)	Item	1	70,000	70,000
Activated Carbon Media	Lbs	5420	2.27	12,300
Blower	Item	1	10,000	10,000
Piping (18-inch diameter, fiberglass)	Feet	20	100	2000
Sensors	Item	4	500	2000
Electrical and Controls	Sum	1	5000	5000
Profits, Warranty, and Contractor Overhead	Sum	1	15,000	15,000

Table 6: Annual Maintenance Costs for Problem 4

Item	Unit (/yr)	No. of Units	Unit Cost ($)	Total Cost ($/yr)
Media Replacement with Delivery	Lbs	4873	2.50	12,183
Maintenance Labor	Hrs	20	60	1200
Maintenance Materials	Sum	1	500	500
Electrical Power	kWH	39,245	0.10	3925

Solution:
Roger sums the capital costs in Table 5, which add to \$116,300. He sums the maintenance costs in Table 6, which add to \$17,808 per year.

Next, Roger calculates the present worth factor, PWF:

$$PWF = \frac{(1+0.05)^{40}-1}{0.05*(1+0.05)^{40}} = \frac{6.04}{0.35} = 17.25$$

Now, Roger calculates the lifecycle cost:

$$Lifecycle\ Cost = Capital\ Cost + Annual\ Maintenance * PWF - Salvage\ Value$$

$$Lifecycle\ Cost = \$116{,}300 + \$17{,}808 * 17.25 - 0 = \$423{,}488$$

$$Lifecycle\ Cost = \mathbf{424,000}\ \text{(rounded)}$$

Helpful References

Air & Waste Management Association (AWMA); Davis, W. T. (2000) “Air Pollution Engineering Manual”. Second Edition; John Wiley & Sons, Inc.; New York, NY.

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