Operation Of Multibed-Type Carbon Bed Adsorbers

Introduction

Adsorption involves solid-surface adhesion of gases (typically to carbon).

Carbon adsorption is a technique used to remove organic vapors from an effluent gas stream. These organic pollutants are removed by causing them to adhere to the surface of a solid. That solid is then removed from the gas stream. The pollutant molecules being removed are referred to as the **adsorbate**, while the solid is called the **adsorbent**. The adsorption process uses activated carbon particles (the adsorbent) that are highly porous and possess fine capillaries. These attributes result in a very high surface-to-volume ratio. Through capillary action and physical bonding to the particle pores, the activated carbon can adsorb large quantities of volatile organic molecules. Figure 8-1 illustrates this adsorption process.

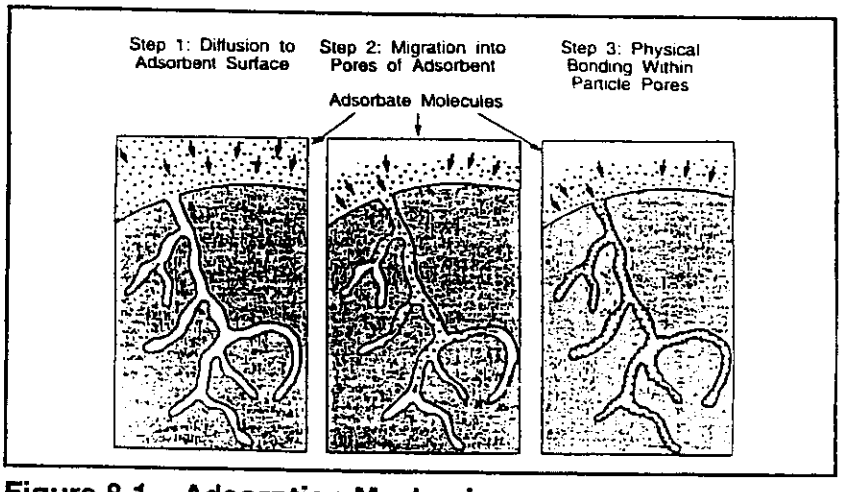


Figure 8-1. Adsorption Mechanism

Adsorption is not a final control process because the adsorbent material must be disposed of and replaced, or regenerated.

In air pollution control, adsorption is not a final control process. The contaminant molecules are merely stored on the surfaces of the pores of the adsorbent. Eventually, either the adsorbent must be disposed of and replaced, or the organic compounds must be desorbed from the adsorbent. This lesson discusses regenerable carbon bed adsorbers, in which the adsorbed material is desorbed, and the carbon is regenerated to be used again.

System Components And Operation

In a typical carbon bed adsorption system, the organic-vapor-laden gas stream passes through a filter to remove particulate matter; the gas stream then passes through a cooler, where its temperature is reduced to less than 40 °C. A fan then forces the gas stream through one of the carbon beds. The organic vapors are adsorbed by the carbon, and the purified air is discharged into the atmosphere.

What Are The Stages Of Vapor Adsorption?

Initially, adsorption occurs at efficiencies near 100 percent, but as the carbon adsorbs more and more material, there is a point (breakthrough point) at which the carbon nears saturation, and the outlet concentration begins to increase.

Vapor adsorption by activated carbon occurs in two stages. Initially, adsorption is nearly 100 percent efficient. However, eventually the carbon bed approaches saturation—the point at which it has adsorbed as many organic molecules as possible, given the specific temperature and pressure under which it is operating.

As the carbon bed approaches saturation, traces of vapor begin to appear in the exit gas stream. This is called the **breakthrough** point of carbon, beyond which its removal efficiency rapidly decreases.

When the carbon bed reaches its saturation point, the carbon is at equilibrium capacity, and the vapor concentrations at the inlet and outlet of the carbon bed adsorber are equal.

Equilibrium capacity of the carbon bed is determined by two regions—heel and working capacity.

Figure 8-2 illustrates the breakthrough curve when the active sites are depleted on the carbon surface. Equilibrium capacity is determined by two regions in the carbon pore (Figure 8-3, Region D). The first of these regions contains the heel, the "plug" of adsorbate that remains in the carbon pore after desorption (Region A). How much of a heel remains after desorption depends on desorption time and temperature. The working capacity is the area of the pore available to adsorb the pollutant (Region B); that is, it is the active absorbing area of the pore. The size of this area is determined by the size of the heel and by the portion of the pore that is too wide to "hold in" the adsorbate (Region C). The larger the working capacity, the longer the bed can be operated between desorption cycles.

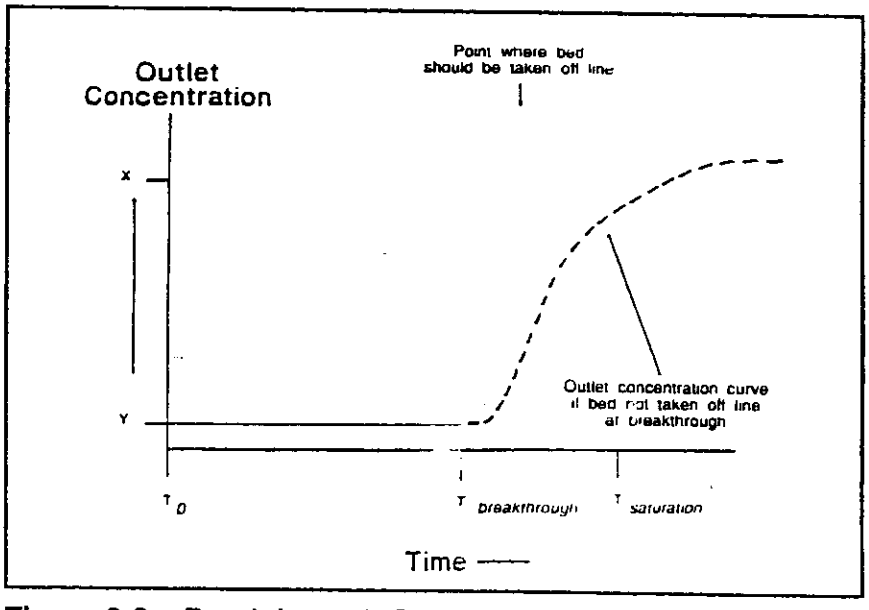
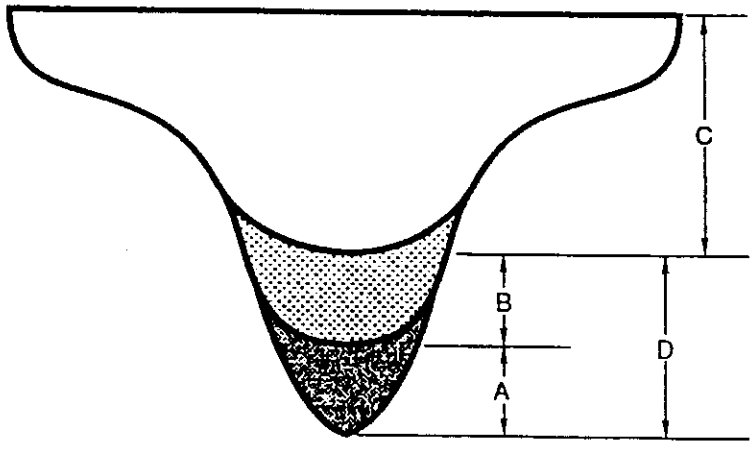


Figure 8-2. Breakthrough Curve



Working capacity (B) = Equilibrium capacity (D) - Heel (A)

A = Residual or heel (located deep in the pore and difficult to dislodge)
B = Working capacity (bounded by the heel remaining from previous cycles and portion of pore too large in diameter to retain adsorbate
C = Area of pore that is too wide to hold in the adsorbate
D = Equilibrium Capacity

Figure 8-3. Simplified Representation Of Carbon Capacity

How Are Organic Pollutants Removed From The Carbon?

After the working capacity of the carbon has been filled, either the organic pollutants must be removed from the carbon, or the carbon must be discarded. Typically, only very small carbon adsorbers use disposable carbon. In large carbon bed adsorbers, the value of the organic pollutants that can be desorbed from the carbon is high enough to justify the cost of the desorption process. For example, paint solvents can be desorbed and reused, thus saving the cost of the solvent.

What Is Regeneration?

Regeneration is the process of desorbing the collected organic pollutants from the carbon bed.

The term **regeneration** is often used to describe the desorption of organic pollutants from carbon beds. Figure 8-4 is a schematic of a two-bed carbon adsorber with Bed 1 adsorbing and Bed 2 regenerating.

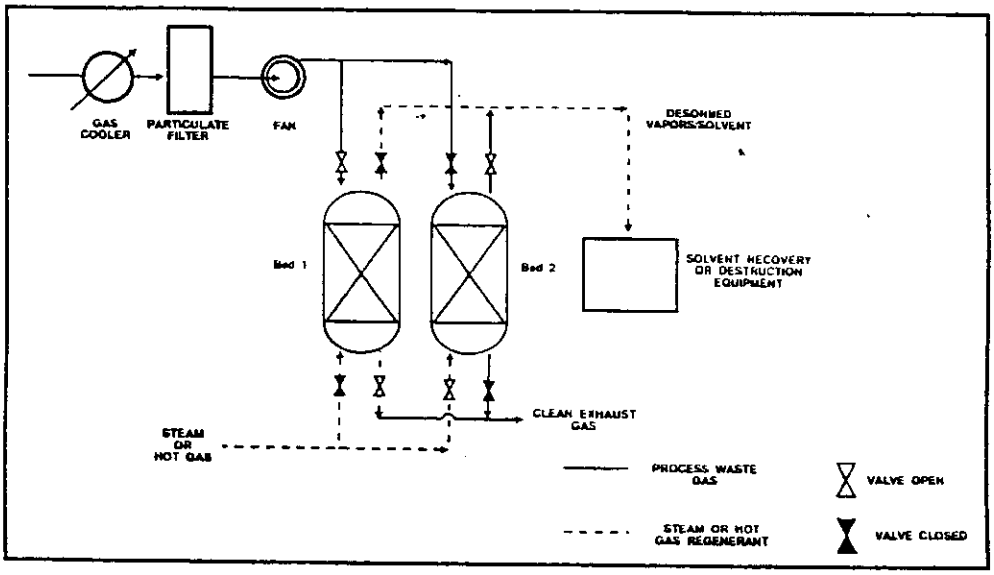


Figure 8-4. Two-Bed Adsorber: Bed 1 Adsorbing; Bed 2 Regenerating

Organic pollutants are typically desorbed by passing steam or hot gases through the bed in a direction opposite to the flow of gases during adsorption.

To regenerate a carbon bed, either steam or hot gases are passed through it. The carbon must be heated to a temperature higher than that at which the organic vapors were adsorbed. Saturated steam at low pressures is the most common desorbing medium. The steam is usually passed through the carbon bed in a direction opposite to the flow of gases during adsorption (see Figure 8-3).

The steam is condensed with the desorbed solvents, and the collected liquid is either decanted or distilled to separate the water from the recovered solvent.

The steam and the desorbed solvents are condensed. If the organic pollutant is immiscible in water, the condensate is decanted to separate the water and the recovered solvent. (Otherwise, distillation is used to separate the water and the recovered solvent.) The regeneration process leaves the carbon hot and saturated with water. In newer systems, the carbon is cooled before the bed is placed back onstream. Atmospheric air blown through the bed is the most common cooling mechanism.

How Are The Cycles Of Regeneration Controlled?

Regeneration/adsorption cycles are controlled manually or automatically. With automatic control, cycles either are executed for a predetermined length of time or vary depending on the continuous measurement of organic vapor concentration in the exhaust gas (called **breakthrough control**). With breakthrough control, the effluent concentration is monitored to identify the point at which a bed is just approaching breakthrough. The vapor-laden inlet gas stream is then switched to a regenerated bed, and the saturated bed begins regeneration.

Typical Emission Points

The uncontrolled effluents or emissions from a carbon bed are generally emitted through a stack or vent that is placed after the carbon bed or is part of the carbon bed system. Emissions can occur at points where corrosion and erosion have caused holes in the carbon bed shell and associated ductwork.

Typical Inspection Areas

The major inspection areas for the carbon bed system include:

- Stack or vent exit.
- Physical condition of the unit (corrosion and erosion).
- Static pressure gauge.

Summary

Organic vapors are removed from a gas stream by carbon bed adsorption, a process in which the vapors (adsorbate) adhere to the surface of a solid (adsorbent). The solid is then removed from the gas stream.

After the organic pollutants are removed from the gas stream by adsorption, the adsorbent must be removed and replaced, or regenerated. Regeneration, the most efficient removal process, occurs when organic materials in the adsorbent are desorbed and processed for reuse. The carbon is then ready to be used again.

Review Exercises

1. True or false? Carbon adsorption is a technique used for removing particulate matter and organic vapors from a gas stream.

2. Activated carbon is a good adsorbent because it:

   a. Is highly porous.
   b. Possesses fine capillaries.
   c. Has a very high surface-to-volume ratio.
   d. Has suitable physical bonding characteristics.
   e. All of the above.

3. Working capacity is:

   a. Equilibrium capacity – heel
   b. Equilibrium capacity + heel
   c. Heel – equilibrium capacity
   d. None of the above

4. True or false? Breakthrough occurs when the equilibrium capacity of the carbon is exceeded and traces of the organic pollutants begin to appear in the exit air stream.

5. True or false? During regeneration, the organic pollutants are desorbed from the carbon by passing steam or hot gases through the bed in a direction opposite to the flow of gases during adsorption.

6. When breakthrough nears, as measured by breakthrough control, the operator should:

   a. Continue to monitor the outlet stream until breakthrough is confirmed.
   b. Switch the vapor-laden inlet gas stream to a regenerated bed and regenerate the saturated bed.
   c. Decrease the flow of the vapor-laden inlet gas stream to extend the time available to breakthrough.
   d. Shut down the system.

Answers

1. False. It is used only to remove organic vapors.
2. e. All of the above.
3. a. Equilibrium capacity – heel
4. True
5. True
6. b. Switch the vapor-laden inlet gas stream to a regenerated bed and regenerate the saturated bed.