B.11 CARBON ADSORBERS

B.11.1 Background

Carbon adsorbers control VOC emissions in exhaust gas streams. Adsorbers are used for both air pollution control and solvent or product recovery. There are three basic types of adsorption systems, which can be categorized by the manner in which the adsorbent bed is maintained or handled during the adsorption and regeneration cycles. These three types of systems are: (1) fixed or stationary bed, (2) moving bed or rotary concentrator, and (3) fluidized bed. The stationary bed design is the most common. Units typically have two identical beds, one adsorbing while the other is desorbing, but may also consist of multiple identical beds depending on the volumetric flow and concentration of the stream to be controlled. In a typical stationary bed system, the vapor is collected from various point sources, transported through a particulate filter and into one of two carbon adsorption beds. As the carbon adsorber operates, three zones form within the bed: the saturated zone, mass transfer zone, and fresh zone. In the saturated zone, which is located at the entrance to the bed, the carbon has already adsorbed its working capacity of VOC; no additional mass transfer can occur in this zone. The mass transfer zone is where VOC is removed from the gas stream. The carbon in this zone is at various degrees of saturation, but is still capable of adsorbing VOC. The fresh zone is the region of the bed that has not encountered VOC-laden air since the last regeneration. This zone has a full working capacity available for adsorption of additional VOC.

As the carbon bed operates, the mass transfer zone moves through the bed in the direction of flow toward the bed outlet. Breakthrough occurs when the mass transfer zone first reaches the bed outlet. At this point, a sharp increase in the outlet VOC concentration occurs. The available adsorption time (the time before breakthrough occurs) depends on the amount of carbon in the bed, the working capacity of the bed, and the VOC concentration and mass flow rate of the gas stream. Once the breakthrough point is reached, the carbon bed must be regenerated. When this occurs, the flow of VOC-laden air is redirected to the second bed, while the first bed undergoes a regeneration cycle.

Most carbon adsorption beds are regenerated using steam. Regeneration removes the adsorbed VOC vapor from the carbon and restores the carbon’s ability to adsorb VOC for the next cycle. The steam desorbs the VOC from the carbon bed and carries the VOC through a condenser, then through a decanter and/or distillation column for separation of the VOC from the steam condensate. An ambient air stream is often passed through the bed to dry the bed and reduce the bed temperature following the steam desorption. The regenerated carbon bed is then ready to be put back online before the second bed reaches breakthrough.

Carbon bed systems may also be regenerated by vacuum. Regeneration is accomplished with a combination of high vacuum and purge air stripping.

A moving bed or rotary concentrator adsorber consists of a rotating cylindrical shell within which is a second cylindrical shell containing the carbon bed. The carbon bed is
partitioned into several pie-shaped sections that are parallel to the axis of the shell. The VOC-laden gas enters the unit, flows through a section of the bed, then exits the unit. As the unit operates, one section of the bed is online, while the section that has just come offline undergoes regeneration. During each rotation of the unit, each bed section undergoes an adsorption cycle and a regeneration cycle. Regeneration of a rotary concentrator unit is often conducted with hot gas rather than steam or vacuum. Two advantages of rotary adsorbers are lower pressure differentials and shorter bed lengths. The main disadvantage of rotary bed adsorbers is that, unlike stationary bed units, rotary bed units contain moving parts and seals that contact moving parts.

In a fluidized bed adsorber, the VOC-laden gas flows up through the carbon at high velocity. The granular carbon, which is fluidized by the upward flowing gas, migrates to the bottom of the bed, where it continuously exits the bed and is transported to a separate regeneration chamber, then fed back into the top of the bed. The countercurrent movement of the incoming gas and carbon increases the effectiveness of the carbon. The main disadvantage to a fluidized bed adsorber is that some carbon is suspended in the outlet gas stream and is lost.

Adequate auxiliary equipment is needed to collect, transport, and filter vapor-laden air streams to a carbon adsorber. The ducts and piping must be sized properly for the air flows required to optimize adsorber efficiency. A fan forces the gas stream into and out of the unit; designing and sizing this equipment is critical. The placement of a particulate matter (PM) filter varies, depending on the adsorber configuration and the inlet gas stream characteristics. Placed before the inlet air stream (in stationary or rotary bed units), the PM filter will reduce possible contamination of the adsorbent and fouling of the bed. In a fluidized-bed adsorber, the PM filter is placed at the outlet to reduce emissions of suspended carbon. Additional auxiliary equipment is also required for recovery of the contaminant from the regeneration cycle. Generally, a condenser and separator installed in series are used to recover VOC from the regeneration stream in traditional fixed bed units with stream regeneration. For rotary concentrators or moving bed units, other devices such as thermal oxidizers or catalytic oxidizers may be used to handle the regeneration stream.

Inlet gas stream characteristics are important to the design and operation of adsorption systems. Characteristics that may be important include: specific compounds present in the gas stream and their concentration, flow rate, temperature, and relative humidity.

Bed fouling and channeling gradually reduce the carbon’s adsorption capacity. Carbon particles erode with time, the capillaries become plugged with contaminants, and the carbon may become masked. This erosion and contamination results in the carbon granules losing their ability to adsorb and retain VOC molecules; consequently, control efficiency decreases over time. A routine maintenance program should provide for scheduled inspections of all equipment components as well as all necessary monitoring of operating parameters to ensure continued proper operation of the control equipment. Four major categories of system components that require routine maintenance include: air handling, adsorbing, regeneration, and recovery.
Routine maintenance also may include yearly sampling and testing of the carbon to evaluate its working capacity.

**B.11.2 Indicators of Carbon Adsorber Performance**

The primary indicators of the performance of carbon adsorbers are the adsorber outlet VOC concentration, regeneration cycle timing, total regeneration stream (steam or nitrogen) flow or the vacuum achieved during regeneration, and carbon bed activity sampling. Other indicators of adsorber performance include bed operating temperature, inlet gas temperature, gas flow rate, inlet VOC concentration, pressure differential, inlet gas moisture content, and leak check monitoring. Each of these indicators is described in the following paragraphs. Table B-11 lists these indicators and illustrates potential monitoring options for carbon adsorbers.

**Outlet VOC concentration.** The most direct indicator of performance of a carbon adsorber in removing VOC from the exhaust stream is the VOC concentration at the bed outlet.

**Regeneration cycle timing or Bed replacement interval.** The timing of the regeneration cycle is critical to the continued performance of a carbon adsorber. Specifically, the frequency and length of regeneration cycles are key operating parameters that affect the adsorption capacity of the bed. If regeneration cycles do not occur before or immediately after breakthrough, periods of high VOC emissions are likely. In addition, the length of regeneration cycles must be adequate to allow complete or near complete desorption of the bed. Otherwise, breakthrough will occur sooner once the bed is back online.

If the carbon bed is not regenerated onsite (e.g., if a carbon drum is used and sent back to the manufacturer for regeneration), the replacement interval is an important parameter. The amount of time the unit is online and adsorbing VOC will indicate when it is time to replace the unit, based on the rated capacity of the unit and a mass balance calculation.

**Total regeneration stream flow.** This parameter is important for carbon beds regenerated using steam or nitrogen. The total regeneration stream flow, which is a measure of the total mass of the regenerating fluid (e.g., steam, nitrogen) used over the course of a complete regeneration cycle, determines the extent to which the bed is desorbed during regeneration. If the total regeneration stream flow decreases, the bed may not be fully regenerated when it is put back online (depending on the VOC loading during the adsorption cycle), and the bed may reach breakthrough sooner than expected.

**Vacuum profile during regeneration cycle.** The vacuum profile during regeneration is an important variable in the performance of the unit. Sufficient vacuum must be achieved at a long enough interval to assure desorption of VOC from the carbon bed. If the carbon bed is saturated, the time to achieve certain vacuum levels will be longer. This parameter is important only for carbon beds that employ vacuum regeneration.
Carbon bed activity sampling. When the carbon in the bed becomes contaminated or masked or erodes over time, the carbon loses its adsorptive ability and the control efficiency of the unit decreases. The carbon should be tested periodically to determine its activity.

Bed operating temperature and Bed regeneration temperature. The adsorptive capacity of the bed decreases with increasing bed temperature. Therefore, bed operating temperature can provide an indication of the need to adjust the regeneration cycle frequency. The bed temperature also can indicate problems in the unit (e.g., VOC combustion in the bed). For steam regeneration, measuring the maximum temperature achieved during the regeneration cycle can indicate that a temperature sufficient to regenerate the bed was reached (e.g., a temperature at or above the boiling point of the least volatile component). Similarly, measuring the minimum temperature achieved before the regenerated bed is placed back into adsorption service indicates that the bed has cooled sufficiently to operate within the prescribed range of bed operating temperature.

Inlet gas temperature. The bed operating temperature is a better indicator of adsorber performance than inlet gas temperature because inlet temperature measurements do not account for chemical reactions occurring within the bed that generate additional heat. However, if monitoring bed temperature is impractical, monitoring the inlet gas temperature is an option.

Gas flow rate. An increase in gas flow rate results in a decrease in the time period before the carbon bed reaches breakthrough. By monitoring the gas flow rate, regeneration cycle timing can be adjusted as needed. The pressure in the carbon adsorber inlet duct can be used as an indicator of flow and can be used to trigger bypass if excess pressure builds up in the inlet line.

Inlet VOC concentration. The inlet VOC concentration can be monitored to ensure that the adsorption system is operating within design limits. If inlet VOC concentrations increase, it may be necessary to change the timing of the regeneration cycles. If an applicable rule requires the control device to achieve a certain control efficiency, monitoring the inlet and outlet VOC concentration provides the most accurate measurement of compliance.

Pressure differential. An increase in pressure differential across the adsorber is an indication of bed fouling or plugging. A decrease in pressure differential across the bed may indicate channeling (the vapor is not flowing through all areas of the bed).

Inlet gas moisture content. At moderate to low inlet VOC concentrations (less than 1,000 ppm), moisture competes with adsorbate (VOC) for adsorption sites on the carbon. As a result, the adsorptive capacity of the bed is reduced and adjustments should be made to the regeneration cycle timing.

Leak check. Vapor leaks in the vapor collection or recovery system mean VOC emissions are not being controlled. Periodic checks while the unit is online ensure that there are no leaks and all captured VOC emissions are routed to the carbon adsorber. A leak is defined as greater than or equal to 10,000 ppmv, as methane.
B.11.3 Illustrations

The following illustrations present examples of compliance assurance monitoring for carbon adsorbers:

11a: Regeneration cycle frequency, total regeneration stream flow, maximum bed temperature during regeneration cycle, minimum bed temperature at end of cooling cycle, and carbon bed activity.
11b: Monitoring bed replacement interval.
11c: [Add CAM example.]

B.11.4 Bibliography
### Table B-11. Summary of Performance Indicators for Carbon Adsorbers

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Performance indication</th>
<th>Approach No.</th>
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<th>6</th>
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<th>8</th>
<th>9</th>
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</thead>
<tbody>
<tr>
<td>Outlet VOC concentration</td>
<td>Direct measure of outlet concentration. Most direct indicator of adsorber performance; can be monitored continuously or periodically.</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Regeneration cycle timing</td>
<td>Key factor in determining adsorptive capacity of bed. If regeneration cycles are too infrequent, VOC emissions may be excessive; if regeneration times are too short, the adsorption capacity of the bed is reduced.</td>
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<td>X</td>
<td></td>
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<td></td>
<td></td>
<td>X</td>
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<tr>
<td>Bed replacement interval</td>
<td>For non-regenerative units, frequency of carbon replacement is important.</td>
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<td></td>
<td></td>
<td>X</td>
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<tr>
<td>Total regeneration stream flow</td>
<td>Indicates extent to which bed is desorbed (regenerated). Decreases in regeneration stream flow result in a shorter time period to reach breakthrough.</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>Vacuum profile during regeneration cycle</td>
<td>Indicates extent to which bed is desorbed (regenerated). If the maximum vacuum is not achieved during the regeneration cycle, the bed may not be fully regenerated and may reach breakthrough more quickly during the next adsorption cycle.</td>
<td></td>
<td>X</td>
<td>X</td>
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<tr>
<td>Carbon bed activity sampling</td>
<td>Indicates contamination or masking of the carbon and its adsorptive ability; the control efficiency of the unit decreases as carbon activity decreases.</td>
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<tr>
<td></td>
<td>Illustration No.</td>
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<td>11a</td>
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<td></td>
<td>Example CAM Submittals</td>
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<td>A18</td>
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<td></td>
<td>A5</td>
<td>A24</td>
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<table>
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<th>Other Performance Indicators</th>
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<tbody>
<tr>
<td>Bed operating temperature</td>
<td>Affects adsorptive capacity of bed. Indicates problems such as fire in the bed. Adsorptive capacity decreases with increasing temperature.</td>
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<tr>
<td>Bed regeneration temperatures</td>
<td>Measuring maximum temperature during regeneration cycle assures temperature required for regeneration was reached; measuring minimum temperature to which bed is cooled after regeneration before adsorption cycle begins assures bed is at proper operating temperature; applies to steam regeneration only.</td>
<td>X</td>
<td></td>
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<tr>
<td>Inlet gas temperature</td>
<td>Indirect indicator of bed operating temperature. See comments for Bed operating temperature. Not as useful as bed operating temperature but can be used as an alternative.</td>
<td>X</td>
<td></td>
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<tr>
<td>Inlet VOC concentration</td>
<td>Indicator that system is operating within design limits. Increases in VOC concentrations may require adjustments to regeneration cycle timing.</td>
<td>X</td>
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<tr>
<td>Leak check of unit</td>
<td>Identifies vapor leaks in the system and reduces VOC emissions from leaks; a leak is defined as greater than or equal to 10,000 ppmv, as methane.</td>
<td>X</td>
<td></td>
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<tr>
<td>Example CAM Submittals</td>
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Comments:
- Approach 2: 40 CFR, Subpart MMM (Pesticides)
- Approach 3: 40 CFR 60, Subparts III, NNN, RRR; 40 CFR 63, Subparts G (HON), U (Polymers and Resins I), Y (Monhe Tank Vessel Loading), DD (Offsite Waste and Recovery), HH (Oil and Natural Gas), JJ (???), KK (???), JJJ (Polymer and Resins IV), and OOO (Polymers and Resins III).
- Approach 4: 40 CFR 60, Subpart FF; 40 CFR 63, Subparts G (HON), DD (Offsite Waste and Recovery), EE (Magnetic Tape), GG, HH (Oil and Natural Gas), and MMM (Pesticides).
- Approach 6: 40 CFR 63, Subparts EE (Magnetic Tape), GG.
- Approach 7: 40 CFR 63, Subpart Y (Regeneration Time and Vacuum D).
- Approach 8: 40 CFR 60, Subparts BBB, DDD, III, NNN (Wool Fiberglass), QQQ, RRR, SSS, and VVV; 40 CFR 61, Subparts L, BB, FF; 40 CFR 63, Subparts G (HON), M (Perchloroethylene Dry Cleaning), R (Gasoline Distribution), T, U (Polymers and Resins I), W (Polymers and Resins II), Y (Monhe Tank Vessel Loading), DD (Offsite Waste and Recovery), EE (Magnetic Tape), GG, HH (Oil and Natural Gas), JJ, KK, III, MMM (Pesticides), OOO (Polymers and Resins III).
- Approach 9: 40 CFR 63, Subpart Y.
1. APPLICABILITY

1.1 Control Technology: Carbon adsorption system [048]

1.2 Pollutants
   Primary: Volatile organic compounds (VOCs)
   Other: Higher molecular weight organic compounds

1.3 Process/Emissions units: Coating, spraying, printing, polymer manufacturing, distillation units, wastewater treatment units, dry cleaning, degreasing, pharmaceuticals, equipment leaks

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored: Regeneration cycle timing, total regeneration stream flow, bed regeneration temperature, bed temperature to which bed is cooled after regeneration, and carbon activity.

2.2 Rationale for Monitoring Approach
   • Regeneration cycle timing: The timing of the regeneration cycle is critical to the continued performance of the carbon adsorber. The minimum regeneration frequency (i.e., operating time since last regeneration) is established and monitored.
   • Total regeneration stream flow: The total regeneration stream flow determines the extent to which the bed is desorbed during regeneration. If the total regeneration stream flow decreases, the bed may not be fully regenerated when it is put back online.
   • Bed regeneration temperature: Measuring the temperature achieved during the regeneration cycle indicates that a temperature sufficient to regenerate the bed was reached.
   • Bed temperature after regeneration: The adsorptive capacity of the carbon bed decreases with increasing bed temperature. Monitoring the bed temperature after regeneration assures the proper operating temperature is achieved before returning the bed to the absorption cycle.
   • Carbon activity: Periodic checks of the bed for poisoning assure that bed activity still meets specifications.

2.3 Monitoring Location
   • Regeneration cycle timing: Each bed.
   • Total regeneration stream flow: Carbon bed inlet during each regeneration cycle.
   • Bed regeneration temperature: Each carbon bed.
   • Bed temperature after regeneration: Each carbon bed.
   • Carbon activity: Sample of bed material.

2.4 Analytical Devices Required
   • Regeneration cycle timing: Clock.
   • Total regeneration stream flow: Mass flow meter.
• Bed regeneration temperature: Thermocouple, RTD, or other temperature sensing device; see section 4.2 for additional information on devices.
• Bed temperature after regeneration: Thermocouple, RTD, or other temperature sensing device; see section 4.2 for additional information on devices.
• Carbon activity: Analytical laboratory to evaluate per manufacturer’s instructions.

2.5 Data Acquisition and Measurement System Operation

• Frequency of measurement:
  – Regeneration cycle timing: Each cycle.
  – Total regeneration stream flow: Hourly, or continuously during each regeneration cycle on strip chart or data acquisition system.
  – Bed regeneration temperature: Hourly, or continuously during each regeneration cycle on strip chart or data acquisition system.
  – Bed temperature after regeneration: Hourly, or continuously during cooling cycle, on strip chart or data acquisition system.
  – Carbon activity: Annually.

• Reporting units:
  – Regeneration cycle timing: Minutes or hours.
  – Total regeneration stream flow: Pounds or other unit of mass.
  – Bed regeneration temperature: Degrees Fahrenheit or degrees Celsius.
  – Bed temperature after regeneration: Degrees Fahrenheit or degrees Celsius.
  – Carbon activity: Activity level per manufacturer’s specifications.

• Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.

2.6 Data Requirements

• Baseline regeneration cycle timing, total regeneration stream flow, bed regeneration temperature, and bed temperature after regeneration measurements concurrent with emission test data, and manufacturer’s (supplier’s) specifications for carbon activity.
• Historical plant records on regeneration cycle timing, total regeneration stream flow, bed regeneration temperature, bed temperature after regeneration measurements, and carbon activity levels.

2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer’s specifications.

2.8 References: 11, 19.

3. COMMENTS

None.
1. APPLICABILITY

1.1 Control Technology: Non-regenerative carbon adsorption system [048]

1.2 Pollutants
   Primary: Volatile organic compounds (VOCs)
   Other: Higher molecular weight organic compounds

1.3 Process/Emissions units: Coating, spraying, printing, polymer manufacturing, distillation units, wastewater treatment units, dry cleaning, degreasing, pharmaceuticals, equipment leaks

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored: Bed replacement interval.

2.2 Rationale for Monitoring Approach
   • Bed replacement interval: The carbon replacement interval ensures that periods of high VOC emissions do not occur. The replacement interval can be determined based on design and engineering calculations (e.g., mass balance).

2.3 Monitoring Location
   • Bed replacement interval: Each carbon bed.

2.4 Analytical Devices Required
   • Bed replacement interval: Timers or alternative methods/instrumentation that conform to performance specifications acceptable to the Administrator.

2.5 Data Acquisition and Measurement System Operation
   • Frequency of measurement:
     – Bed replacement interval: Each cycle.
   • Reporting units:
     – Bed replacement interval: Hours, days, months, or other unit of time, as appropriate.
   • Recording process:
     – Bed replacement interval: Operators log replacement interval data manually.

2.6 Data Requirements
   • Design and mass balance calculations on which the replacement interval is based; or
   • Historical plant records on bed replacement interval with periodic VOC measurements establishing that interval is adequate.

2.7 Specific QA/QC Procedures: NA.

2.8 References: 11, 19.

3. COMMENTS

3.1 The time interval may be based upon design calculations under worst case conditions. Alternatively, the VOC concentration level in the exhaust vent stream from the
adsorption system may be periodically monitored (e.g., daily or at an interval no greater than 20 percent of the time required to consume the total carbon working capacity under worst case conditions) to assure breakthrough has not occurred.
CAM ILLUSTRATION
No. 11c. CARBON ADSORBER FOR VOC CONTROL [Add CAM example]