VOC Control Devices / Scrubbers

**Course Overview**

- Volatile Organic Compound (VOC) Controls
- Examples of VOC Calculations
- Particulate Matter (PM) Options
- Inspection Strategies

**Volatile Organic Compounds**

Chemical definition of VOCs:
- Molecules which contain carbon &
- High evaporative rate at low temperatures
- \[ VP > 0.1 \text{mm Hg} \]
Legal Definition of VOCs

- Federal and State laws & regulations
  - 40 CFR § 51.100
  - Latest Definitions of VOCs and ROGs as of...
- Total Organic Gases (TOGs)
- Reactive Organic Gases (ROGs)
- Fraction of Organic Gases (FROGS)
- Local Agency rules and permit conditions

Why are VOCs Regulated?

Why is Ozone Regulated?
**Ozone Formation**

- VOCs + NO\(_x\) + sunlight > O\(_3\)
- Ozone is formed when NO\(_x\) and Volatile Organic Compounds react in sunlight

**VOC Control Process**

- Capture
- Control
- Recovery, Disposal or Destruction
VOC Calculations: Capture & Control & Retention

- General Categories of VOC Emissions
  - Fugitive (Not reasonably captured)
  - Captured > Ducted to control device
  - Consumed > Oxidized
  - Retained > Retention factors vary

VOC Capture Efficiency

\[
\text{VOC Capture Efficiency} = \frac{\text{VOCs captured}}{\text{VOCs used}} \times 100
\]

VOCs captured (entering control device) 80 lbs
VOCs used (and therefore emitted) 100 lbs
VOC capture efficiency (by calculation) 80%

* Capture Efficiency is the percentage of emissions captured and vented to a control device. — EPA
VOC Control Efficiency

\[
\% \text{ CE} = \left[ 1 - \frac{\text{outlet emission rate}}{\text{inlet emission rate}} \right] \times 100
\]

\[
\% \text{ CE} = \left[ 1 - \frac{2 \text{ lbs/hr}}{100 \text{ lbs/hr}} \right] \times 100 = 98
\]

Examples of VOC Calculations

Graphic Arts Operations

With VOC Retained in Substrate

Graphic Arts Operation
VOC Calculations

- A facility uses 100 lbs/hr of ink that has a VOC content of 35% by weight.
- 20% of the VOC is retained in the substrate.
- The incinerator has a 95% control efficiency.

How many lbs/hr of VOC is emitted?

VOC Emissions = (100 lbs/hr) (0.35) (1-0.20) (1-0.95) = 1.4 lbs/hr

Let’s Discuss Control of VOC

- Containment
- Transfer Efficiency
- Absorption
- Adsorption
- Condensation
- Oxidation

Controlled Spraying aka Pollution Prevention

- Reduces VOC emissions
- Increases transfer efficiency
- Low fluid tip pressure
- Employee gun handling training
High Volume Low Pressure (HVLP) Spray Guns

(HVLP) Spray Gun: Polyester Resin Operations

Fluid Impingement Technology: Polyester Resin Operations
Gel Coat Application in a Spray Booth

Let's Discuss Adsorption Systems

Adsorption Mechanism

Gas

+ Solid
+ surface
### Adsorption Mechanism

#### Step 1.
VOC molecule diffuses to adsorbent surface

#### Step 2.
VOC migrates into pores

#### Step 3.
VOC adsorbed and builds up on adsorbent

### Adsorption Mechanism

- Chemically unchanged
- Desorbed and recovered
- Polar and non-polar adsorbates
- Mixed adsorbates separated by distillation

### Adsorption

- Adsorption materials (adsorbents)
  - Activated carbon
  - Hydrous oxides
    - Silica gel
    - Aluminum oxide
    - Magnesium silicate
  - Zeolites (molecular sieves)
  - Naturals
    - Clays
    - Bauxite
    - Fuller’s Earth
  - Metals
Carbon Adsorbers at a Soil Remediation Site

Factors Affecting Adsorption

- Temperature
- Pressure
- Gas velocity
- Particulate matter

Adsorber Design Considerations

- Porosity of Adsorbent
- Bed Cross-Sectional Area
- Bed Length
- Multiple Organic Compounds
- Steaming Requirements
- Fouling
- Timers/Monitors
- Channeling
Pore Space Representation

- A = Residual VOCs or heel
- B = Working capacity
- C = Equilibrium Capacity
- D = Empty pore space
- E = Total pore space (total capacity)

Carbon Adsorption Keywords

- Fresh zone
  * Area where adsorption will occur
- Mass transfer zone
  * Where adsorption occurs
- Saturated zone
  * Area where adsorption has already occurred

Keywords (continued)

- Heel
  * Amount of VOCs left in the carbon after regeneration
- Breakthrough
  * VOCs that do not get captured
**Types of Adsorption Systems**

*Non-regenerative systems*

*Regenerative systems*
  - on site
  - off site

**Characteristics of Activated Carbon**

- Sources
  - Wood, coal, peat, nut shells
- Porosity
  - 600-1600 m²/g (2-3 football fields per 1/28 ounce)
- Preparation
  - Anaerobic heat then steam or CO₂
- Degree of adsorption depends on adsorbate
  - MW, BP, polarity, surfactive index, solubility
Examples of Activated Carbon

Finely Granulated Carbon

Types of Carbon Adsorption Systems
- Open
- Closed
- Rotary
- Fluidized bed
- Bulk plant adsorber and absorber
Bulk plant adsorber & absorber

Rotary Concentrator Adsorption System

Rotary ConcentratorAdsorption System
Adsorber Inspections

- Hood static pressures
- Inlet VOC concentrations
- Inlet temperatures
- Inlet VOC concentration not > 25% LEL
- Outlet VOC concentrations
- Fan motor current
- Solvent recovery rates

Let’s Discuss Absorbers

Absorbers

- Pollutants dissolved in liquid
- Absorbate dissolves in absorbent
Factors Favoring Absorption

- Pollutant solubility in liquid
- Adequate diffusion at liquid / gas interface
- Maximized contact between gas and liquid

Absorber Design

- Produce large surface area
- Minimize air flow resistance to reduce pressure drop
- Inlet pressure - outlet pressure = pressure drop

Pressure Drop: Magnehelic
Absorber Design Factors

- Select liquid solvent
- Column material
- Column size
- Column height
- Number of plates
- Pressure drop
Absorbers: Packed Columns

- Flow patterns
- Liquid reuse and treatment
- Packing material
- Packing quality

Absorbers: Plate Columns

- Maximize contact between liquid & gas
- Diameter of column
- Plates
  * Number
  * Type
  * Layout
Packed vs Plate Columns

- Packed columns
  + More common
  - Plugged by particles
  + Better for corrosive pollutants
  + Lighter than plate

Packed versus Plate Columns

- Plate columns are better for:
  + Large temperature changes
  + Lower liquid flow rates
  + Higher gas flow rates
  + Foaming liquids
  + Chemical reactions
  + Large systems

Let's Discuss Condensers
• Condensation = Process of changing a gas to a liquid.
• Condensation allows recovery of solvents and air pollution control

Contact Condensers

• Contact condensers +/-
  + Cheaper
  + More flexible
  + Less repair time
  – Wet waste disposal problem
### Surface Condensers

* Shell and tube (most common)
* Fin Fan
* Tubular

### Condensers

- Surface condensers +/-
  - Better recovery
  - Commonly used for air pollutants
  - Reduced waste disposal problems
  - More costly

### Shell and Tube
Dry Air-Cooled Heat Exchanger:
Steam Condenser

Dry Air-Cooled Condenser Fans

Condenser Concerns

- Freezing
- Fouling
- Cleaning
- Pressure drop
### Condenser Inspection

- Look for
  - Excessive corrosion and rusting
  - Leaking coolant or VOC
  - Excessive odors
  - Continuous emissions monitor

### Condenser Inspection

- Record
  - VOC outlet concentration
  - Waste stream flow rate
  - Condenser pressure drop
  - Coolant pressure
  - Coolant flow rate

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**Let's Discuss Oxidizers**

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Oxidation

• Destruction of VOCs by Combustion

Reactions with oxygen

\[ C_7H_8 + 9O_2 = 7CO_2 + 4H_2O \]

Toluene + Oxygen = Carbon Dioxide + Water

Combustion Considerations

- Time
- Temperature
- Turbulence (mixing)
- Oxygen (air)
- Nitrogen (air)
Combustion Devices

- Thermal incinerator (uses a flame)
- Catalytic incinerators (uses a catalyst)
- Boilers (burn VOCs to make steam)
- Process heaters (burn VOCs to add heat in chemical plants and refineries)
- Flares (simple flame)
Can Type RTO

Catalytic Oxidizer/Incinerator
Selection Criteria

- Type of VOCs
- Concentration of VOCs
- Process flow rate
- Economics

Catalytic vs. Thermal for VOC Control

<table>
<thead>
<tr>
<th>Catalytic</th>
<th>Thermal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Operating Temp. &amp; Lower Fuel Usage</td>
<td>Higher Operating Temp. &amp; Higher Fuel Usage</td>
</tr>
<tr>
<td>Higher Capital &amp; Maintenance Costs</td>
<td>Lower Capital &amp; Maintenance Costs</td>
</tr>
<tr>
<td>Catalyst Fouling &amp; Poisoning</td>
<td>No Catalyst Involved Here</td>
</tr>
</tbody>
</table>
## Catalyst Problems

- Scouring
- Thermal burnout
- Thermal aging
- Masking
- Catalyst fouling and poisoning

## Catalytic Poisons

- **Fast acting poisons**
  - phosphorus P, bismuth Bi, lead Pb,
  - arsenic As, antimony Sb, mercury Hg
- **Slow acting**
  - iron Fe, tin Sn, silica Si
- **Reversible**
  - sulfur S, zinc Zn, chlorine, bromine,
  - fluorine etc. halogens

## Catalyst Efficiency

- Operating temperature
- Space velocity
- VOC composition
- VOC concentration
- Catalyst properties
- Poisons and inhibitors
There are two basic types of heat exchangers used for thermal or catalytic oxidizers:

- Metal Heat Exchangers or “recuperative heat exchangers”
- Ceramic Bed Heat Exchangers or “regenerative heat exchangers”
Boilers, Process Heaters & Flares

• Boilers make steam
• Process heaters add heat to material
• Flares are thermal incinerators without a combustion chamber
Let’s Discuss

Flares

Flare Types – Open or Elevated

Flare Types – Enclosed or Ground
Shell Deer Park Refinery in Texas on the Houston Ship Channel.

Flaring gases from an oil platform.

Incinerator Inspection

- Look for
  - Excessive corrosion and rust
  - Holes in incinerator shell or ducts
  - Visible emissions
  - Excessive odors
  - Last time catalyst was replaced
Incinerator Inspection

- Record
  - VOC outlet concentration
  - Incinerator inlet temperature
  - Incinerator outlet temperature
  - Pressure drop
Three Stages

• Pre-Inspection
  * file review, rule review, inspection forms, copy of permit, safety equipment check
• Inspection
  * facility safety indoctrination, pre-inspection meeting
• Post-Inspection Interview

Pre-Inspection Guidelines

• Regulation review
• Equipment check
• Pre-entry and entry
• Pre-inspection meeting
• Permit check

Pre-Inspection Meeting

• Facility name and ownership
• Address including city and zip
• Contact name and title
• Phone number including area code
• Production rate
Pre-Inspection Meeting

- Operating schedule
- Operation season
- Date of last source test
- Fuel usage and sulfur content

Inspection Report

- Description of facility & processes
- Flowchart with equipment location & emission points
- Process diagram (materials handled, flow rates, temperatures, pressures)
- Statement as to compliance or non-compliance
- Enforcement action recommendation

Usage Records

- Review usage records
- Obtain necessary copies
Six points of Inspection
Capture, Transport, Air Mover, Instrumentation, Control, Subsystem

Capture

• Are process emissions drawn into a control device at the point of release?

• Are they drawn into a collection device?
Transport

- Are the emissions moved to the control device without loss?
- Are there any leaks?

Air Mover

- Is the fan big enough for the job?
- Is it operating as designed and permitted?
Instrumentation

- Are the proper instruments present?
- Are they functioning?
- Are they calibrated regularly?
- Are they showing the proper units?

Control Device

- Is it functioning?
- Are there any visible leaks?
- Can the device handle the job?
## Subsystem

- What is the ultimate fate of captured or concentrated emissions?
  - Pressure gauges for accuracy & change
  - Fines system for leaks & proper discharge
  - Motor for proper operation

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The End