Calculations and Occupational Exposure Limits

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EOH 466A

The Occupational Environment

Definitions

- Vapors
- Gases
- Aerosols
  - Particulates: dust, fume, fibers, nanoparticles, smoke
  - Mist
- Particle size considerations
  - Inspirable Particulate Mass (IPM)
  - Thoracic Particulate Mass (TPM)
  - Respiratory Particulate Mass (RPM)

OELs

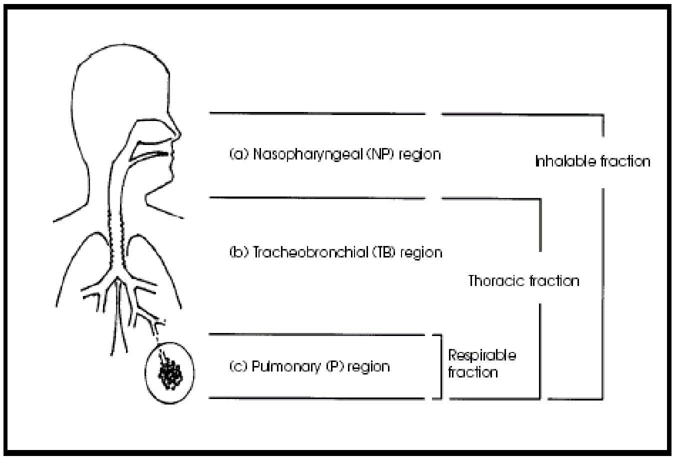

Figure 12.3 — Regions of the respiratory tract: (a) the NP region conditions inhaled air to body temperature and essentially 100% relative humidity and efficiently removes larger particles; (b) the TB region conducts inhaled air quickly and evenly from the mouth and nose to the pulmonary spaces; (c) the P region performs the gas exchange function of respiration.

OELs

- Concentration
  - Parts per million
    - Maximum vapor concentration = $VP_l / VP_{atm} \times 10^6$
  - Milligrams per cubic meter
- Normal temperature and pressure
  - 760 mm Hg and 25 C
  - Molar volume = 24.5 Liters per mole

OELs

- Time-weighted average (TWA)
- Ceiling value (C)
- Short-Term Exposure Limit (STEL)
- Immediately Dangerous to Life and Health (IDLH)

OELs

- Exposure limits for gases and vapors are established in terms of ppm
- mg/M^3 values are determined by calculation, conversion based upon an assumption of NTP
- If samples are taken at P and T conditions very different from NTP and results are in mg/M^3, results must be corrected.

OELs

- Conversion between ppm and mg/M^3

$$Y\ ppm = \frac{X\ \frac{mg}{M^3} \times 24.45\ \frac{l}{mole}}{MW\ \frac{g}{mole}}$$

$$X\ \frac{mg}{M^3} = \frac{Y\ ppm \times MW\ \frac{g}{mole}}{24.45\ \frac{l}{mole}}$$

OELs

- Time weighted average concentration is measured by taking one or more measurements of concentration over a work shift.

$$\mathrm{TWA} = \frac{\sum_{i=1}^{n} C_i T_i}{\sum_{i=1}^{n} T_i}$$

OELs

- 8-hour TWA: average exposure over an eight hour time period (normal work shift)

$$8 - hour\ TWA = \frac{\sum_{i=1}^{n} C_i T_i}{8\ hours}$$

OELs

- Example: A press cleaner is monitored for exposure to ethanol. The data are:

Time Period (number)	Concentration (ppm)	Sample Duration (hours)
1	410	1.5
2	250	3.5
3	75	2

OELs

- Sample TWA calculation

$$\text{TWA} = \frac{410\,ppm \times 1.5hrs + 250\,ppm \times 3.5hrs + 75\,ppm \times 2hrs}{1.5hrs + 3.5hrs + 2hrs}$$

$$= \frac{1640\,ppm - hrs}{7hrs} = 234\,ppm$$

$$8 - hr\ TWA = \frac{1640\,ppm - hrs}{8hrs} = 205\,ppm$$

OELs

- Short Term Exposure Limit (STEL)
- The concentration to which workers can be exposed continuously for a short period of time without suffering:
  - Irritation
  - Chronic or irreversible tissue damage
  - Narcosis of sufficient degree to increase the likelihood of accidental injury, impaired self-rescue or materially reduce work efficiency

OELs

- Short Term Exposure Limits
  - Usually a 15-minute period
  - Should not be exceeded anytime during a workday, even if the 8-hour TWA is below the OEL. (8-hour TWA OEL will be a lower concentration)

OELs

- Short Term Exposure Limits
  - Exposures above 8-hour OEL but below STEL
    - Should not be longer than 15 minutes
    - Should not occur more than 4 times per day
    - There should be at least 60 minutes between exposures in this range.
    - Example: diethylamine, TLV:
      - 8-hour is 5 ppm.
      - STEL is 15 ppm.

OELs

- Ceiling Value
- Concentration that should not be exceeded during any part of the work day.
- Designated by a “C” preceding substance listing.
  - Example, Acetaldehyde, STEL = 25 ppm, and has a ‘C’ designation.

OELs

- Mixtures
- If the biological effects of a group of chemicals are independent, compare each exposure to the OEL.
- If the ratio: 8-hour TWA / OEL is
  - < 1 exposure is below OEL
  - > 1 exposure is above OEL
  - Do this for each chemical independently

OELs

- Additive effects
    - Similar toxic effects
    - sum the ratios of 8-hour TWA / OEL
    - K = sum of these ratios
    - If K < 1, combined exposure is below OEL
    - K > 1, combined exposure is above OEL

OELs

- Adjusting OELs to different work shifts
- Allowed exposure should be changed to account for duration of exposure
- OSHA model
- Brief and Scala Model

OELs

- OSHA Model (T > 8 hours)

$$\text{TWA}' = \text{PEL} \times \frac{8\ \text{hrs}}{\text{T hrs}}$$

OELs

- Brief and Scala Model (T is shift in hours)

$$\text{TLV}' = \frac{8\ \text{hrs}}{\text{T hrs}} \times \frac{24 - \text{T hrs}}{16\ \text{hrs}} \times \text{TLV}$$

OELs

- Example
- 1,2 trichloroethane (a solvent) has a biological half life of 16 hours.
- What modified PEL or TLV would be appropriate for people who work 3 12-hour shifts per week exposed to the compound?
- TLV and PEL are both 10 ppm

OELs

- Solution

OSHA MODEL

$$\mathrm{PEL}' = \frac{8\ \mathrm{hrs}}{12\ \mathrm{hrs}} \times 10\mathrm{ppm} = 6.7\mathrm{ppm}$$

Brief and Scala Model

$$\mathrm{TLV}' = \frac{8\ \mathrm{hrs}}{12\ \mathrm{hrs}} \times \frac{24-12\ \mathrm{hrs}}{16\ \mathrm{hrs}} \times 10 = 5\mathrm{ppm}$$

Evaluation and Control

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Pre Inspection Research

- Before you visit, research the process.
- Learn some terms before visit.
- Look for records of previous inspections.
- Become aware of hazards you might expect to see.

Initial Walk Through

- Observe work practices and environmental conditions. Look for evidence of potential safety and health hazards: dust, grime in air or on surfaces. Other signs?
- Observe operations: cutting, heating, mixing, bagging.
- Observe controls: engineering, administrative, personal protective equipment.
- Interview Workers: often have important and relevant information
- Make flow diagrams, notes, take photos if possible.

Basic Elements: Qualitative IH Survey

- ***List locations covered by the survey***. The elements of this list will depend on the size of the facility being evaluated as well as the level of evaluation.
- ***Description of operations.*** For each worksite (location) listed, list the operations conducted. This description should include some mention of the operations that may generate hazards.
- ***List of hazardous materials.*** A list of materials used at each operation should also be listed. This list should be based on the material content, not the manufacturer: so if several suppliers of acetone are used, they can be counted together.
- ***List of hazardous physical agents.*** Sources of heat, noise, nonionizing radiation (microwaves), ionizing radiation, ergonomic hazards noted should be listed.
- ***Existing controls.*** Describe ventilation used, personal protection worn and administrative controls in place.
- ***Personnel information.*** Number and job titles of personnel working in the area should be collected. Comments from interviewed workers should be organized.

Quantitative IH Survey

- OSHA Inspection
- Exposure characterization
- Statistically reliable evaluation requires many measurements
- Sampling strategy is needed
- Design of survey will depend on a qualitative IH survey

Quantitative IH Survey: How are Measurements Taken?

- Integrated over time: minutes to hours
- Grab sampling
- Size-selective sampling
- Direct reading instruments
- Colorimetric tubes
- Sampling media
- OSHA or NIOSH methods
- Accredited laboratory for analysis

Quantitative IH Survey: Record Keeping

- Minimum data elements
  - Plant, location, date, worker ID, job titles, process name, time on/off, inspector name
  - Document calibration and sample handling
  - Provide a sound basis for future reference (legal proceedings?)
- Notify affected workers of monitoring results

Initial Design of Control

- Design Stage: Plan new construction, systems with worker protection in mind.
- Also consider:
  - air pollution
  - water pollution
  - waste minimization
  - hazardous waste control
  - accident/disaster control

Industrial Hygiene Control

- Once a system is constructed, methods to follow in correcting a problem.
- Priority of control
  - substitution, process change
  - ventilation/engineering
  - administrative
  - personal protection

Dilution Ventilation

- Also known as General Exhaust Ventilation
  - substances of low toxicity.
  - contaminant source large or diffuse.
  - prevent buildup of explosive concentrations in a storage area.
  - applies to gaseous hazards, not particulates.
  - when local exhaust ventilation is not feasible.
  - costs of clean air (make up air) not prohibitive.

Local exhaust ventilation

- Preferred with:
  - substances of high toxicity
  - unpredictable or sporadic generation
  - point sources
  - aerosols
  - prevent pollution of air, water, etc.

Dilution Ventilation Theory

- Dilution ventilation may be applied in situations where vapor concentration build-up and decay can be predicted.
- Assumptions when applying equations:
  - perfect mixing in work area
  - constant generation rate
  - clean dilution air is used
  - no other sources of product in air
  - no other removal mechanisms than dilution

General Equation to Predict Concentration

$$C_2 = \left(\frac{1}{Q}\right)\left[G - \left(G - QC_1\right)e^{\left(\frac{Q}{V}\right)\left(t_2 - t_1\right)}\right]$$

- Q = Volumetric flow of dilution air
- V = the room volume
- t = time
- C = concentration
- G = generation rate of vapor

Special Cases

- $C_1 = 0$; $t_1 = 0$; $G > 0$

$$C_2 = \frac{G}{Q}\left(1 - e^{-\frac{Q}{V}t}\right)$$

Special Cases

- If a long time has passed, then exponent drops out (long is more than 3 air changes, Qt / V > 3)
- $C_{max} = G/Q$

Special Cases

- Concentration decay; no more generation.

$$C_2 = C_1 e^{-\frac{Q}{V}\left(t_2 - t_1\right)}$$

Special Cases

- How much ventilation is needed to reduce concentration to safe levels?

$$Q_2 = \frac{C_1 - C_2}{C_2} Q_1$$

Special Cases

- Volume of air needed to make sure solvent concentration is kept below TLV.
  Generation rate is known. K is mixing factor.

$$CFM = \frac{387 \times \frac{lbs}{\min} \times 10^6 \times K}{\mathrm{MW} \times \mathrm{OEL}}$$

$$M^3/\sec = \frac{0.0244 \times \frac{\mathrm{g}}{\sec} \times 10^6 \times K}{\mathrm{MW} \times \mathrm{OEL}}$$

General Exhaust Ventilation

- Relative to Local Exhaust Ventilation, dilution (general) ventilation is usually less satisfactory.
  - exposure is spread around a workplace
  - more air is usually needed to operate a system
  - cleaning the air is a problem

Local Exhaust Ventilation

- Consists of
  - hood
  - ductwork
  - air cleaner
  - air mover (fans)
  - exhaust stack

Hoods

- Enclosing hoods
  - – Completely enclosing hoods: glove boxes primary example.
  - – Problem: lack of access to the operation; application may be limited.

Glove Box

Enclosing Hoods: Booths

- Booths, with one open side for access. Examples include spray paint booths, laboratory hoods. Allows access to part.
- Problem: material may escape at the opening.

Laboratory Fume Hood

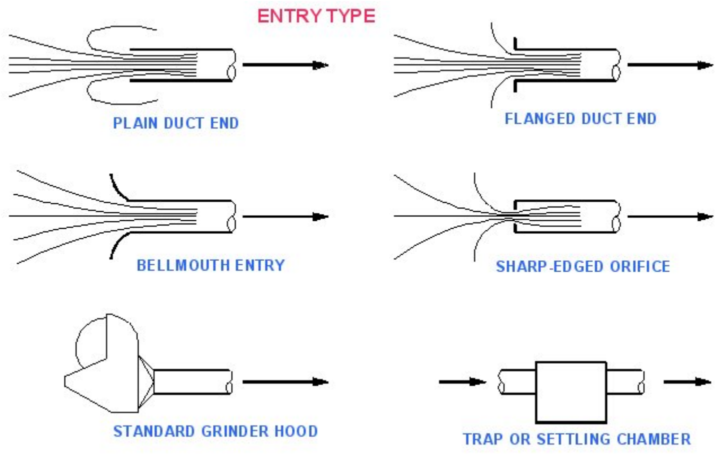
Enclosing Hoods: Tunnels

- Two open faces. Example is conveyer ventilation, drying oven. Advantage is to allow parts/material to be passed through booth on construction line; amenable to automated processes.
- Problem: two open faces allowing escape of toxic substances.

Exterior Hoods

- Capture vapors or aerosols emitted by a process, using air flow
- Receiving hoods: designed to capture materials that are 'thrown' to them
    - Canopy hoods rely on rising air currents, usually heated air, to capture material. exhaust flow must be large enough to capture rising air.
    - Grinding wheel hoods rely on particle momentum to capture particles thrown off with high momentum.

Exterior Hoods



Design considerations

- more enclosure = less cross draft.
- Capture velocity: the air velocity needed to transport contaminant from point of generation into the hood.
- Face velocity: air velocity at the face of the hood (hood opening)
- Slot velocity: air velocity at slot openings in slot-type hoods. Slots help distribute airflow across the face of the hood.
- Plenum velocity: air velocity in plenum (body of the hood), behind face of hood.

Design Considerations

- Required capture velocity can be calculated, and depends on hood design and airflow into the hood.
  - Round or square openings: Velocity drops with square of distance from hood opening.

$$V = \frac{Q}{10x^2 + A} \quad (no\ \ flange)$$

$$V = \frac{Q}{0.75\left(10x^2 + A\right)} \quad (\ flange)$$

Design Considerations

- Round or square openings
  - Bell mouth inlet

Design Considerations

- Canopy hood design incorporates dimensions of the hood and height of the hood above operation:
  - V = Q / (1.4 x Perimeter x H)

Design Considerations

- Slot hoods are used to distribute airflow along a wide surface, such as a tank

$$V = \frac{Q}{3.7Lx} \quad (no\ \ flange)$$

$$V = \frac{Q}{2.8Lx} \quad (flanged)$$

Design Considerations

- Slot hood

Ductwork

- Must carry air and aerosol from the point of generation (capture) to air cleaning system.
- Terms
  - Static pressure: negative (or positive pressure created by a fan, drives the air flow in the system.
  - Velocity pressure: Pressure of moving air: this can be measured and is used to measure air velocity.

Ductwork

- The air velocity must be high enough to carry dust in the system without allowing deposition.
- Friction loss: is due to contact of moving air with duct walls.
- Other losses: elbows, junctions; change in duct diameter may add to the energy required to 'drive' the system.

Ductwork

- Common problems
  - sharp turns, junctions in the system.
  - incorrect fan (does not supply adequate SP) or incorrectly installed fan
  - use of heating/cooling ducting: air cleaning systems usually use round duct, in order to limit friction loss.

Ventilation System Design

- System design calculates energy loss due to friction, elbows, junctions, etc, to calculate system static pressure needed to 'drive' the system.
- Subject of another course: EOH 466C

Air Cleaning System

- Particulate removing.
  - gravity settling devices. Good for particles 50 um and larger. Low pressure drop
  - centrifugal collectors.
    - Low pressure 1 "w.g. 75 % 40 μ.
    - High pressure 5 "w.g. 75 % 10 μ

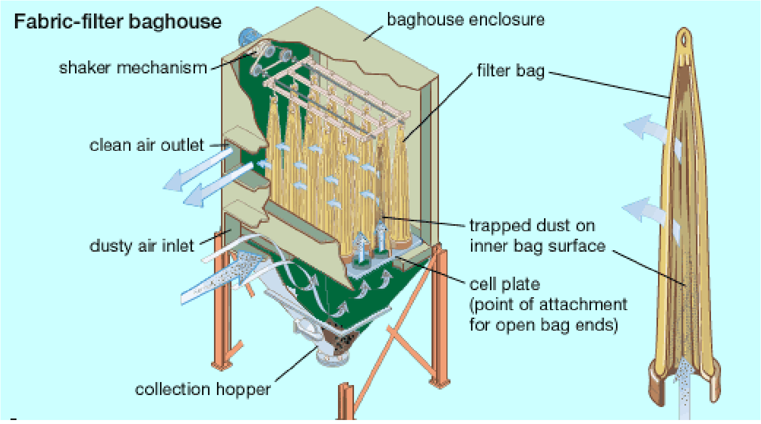
Air Cleaning Systems (Centrifugal Collector)

- Source sugardog.com
- For this and subsequent illustrations

Air Cleaning Systems

- Particulate removing
  - Filters. Wide variety of material, often reusable.
    - media filters: capture particles on individual filter elements.
    - HEPA filters: for toxic dusts. low dust capacity, high pressure drop.
      - 99.95 % efficiency 0.3 μ
    - fabric filters. very common type. can be cleaned.
      - 99 % efficiency 0.3 μ 8 " w.g.

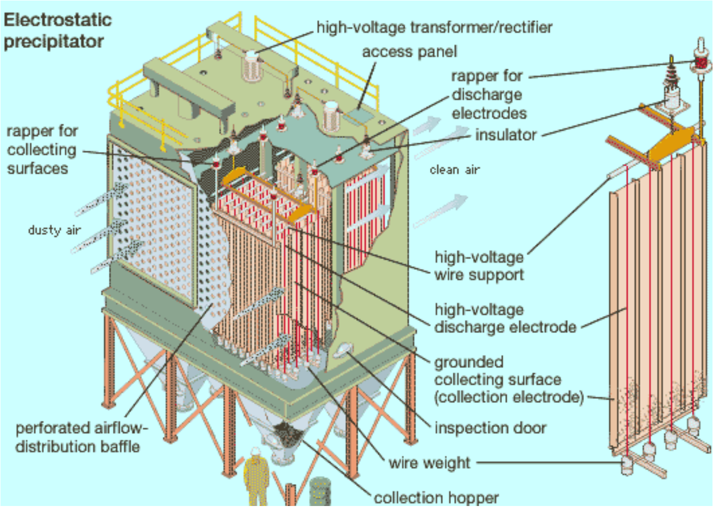
Air Cleaning Systems (Bag Filter)



Air Cleaning Systems

- Particulate removing
  - Electrostatic precipitators: use electric field to collect particles that have been given an electric charge. generally low loading situations.
    - 99+ % efficiency < 1 μ particles

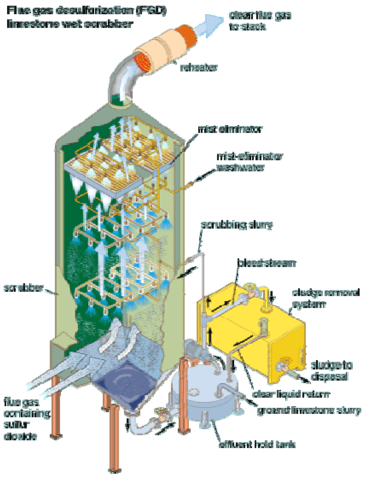
Air Cleaning Systems (Electrostatic Precipitator)



Air Cleaning Systems

- Scrubbers: remove particles by contact with a liquid. (wet scrubbers)
  - spray chamber 5 " wg
  - packed towers 2.5 " wg
  - wet centrifugal 4 " wg
  - Venturi scrubber 10 " wg 90 % eff

Air Cleaning Systems (Wet Scrubber)



Air Cleaning Systems

- Gas and vapor removers
  - Absorbers: diffusion of gas molecules to the surface of a liquid. Perforated plates or special packing material is used to increase the surface area of the liquid. (packed tower)
  - Adsorbers: diffusion of gas molecules to the surface of a solid. Second step: diffuse into the solid. Third step: diffuse into pores. Two forms: polar and nonpolar adsorbents - depends on surface charges.

Air Cleaning Systems

- Gas and vapor removers
  - Carbon is only important nonpolar adsorbent. Very efficient at attracting nonpolar molecules (many organic solvents.) Activated carbon has been treated to increase surface area.
  - Silica gel, Fuller's earth, diatomaceous earth, aluminum oxide are examples of polar adsorbents. Useful for water vapor, ammonia, formaldehyde, sulfur dioxide and acetone.

Air Cleaning Systems

- Gas and vapor removers
  - Chemical reaction devices: burning - direct is vapor concentration is high enough to burn, afterburner if too low to burn. Catalytic converter in a car is a catalytic afterburner use to remove exhaust gases.

Fans

- Axial flow fans: fan is parallel to axis of rotation. air does not have to change direction when going through the fan.
  - Propeller fans: common configuration. Principle advantage is ability to move large volumes or air. Disadvantage is they cannot move air against much resistance. (more than 0.5 in H2O).
    - common application as wall or ceiling fans: adequate replacement air must be provided, or fan will not function well. Not effective in local exhaust ventilation systems, usually, due to low pressure tolerance.

Fans

- Tube axial fans: modified propeller fans, designed to fit in a duct. Can operate at up to 3 inches H2O pressure; one-hood systems.
- Vane axial fans: modified tube axial fans, they can work at higher pressures, up to 10 inches H2O. Have more applications, but are more expensive than tube axial fans. Limited to use where space is at a premium, due to cost.

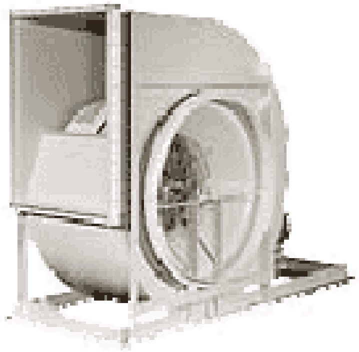
Fans

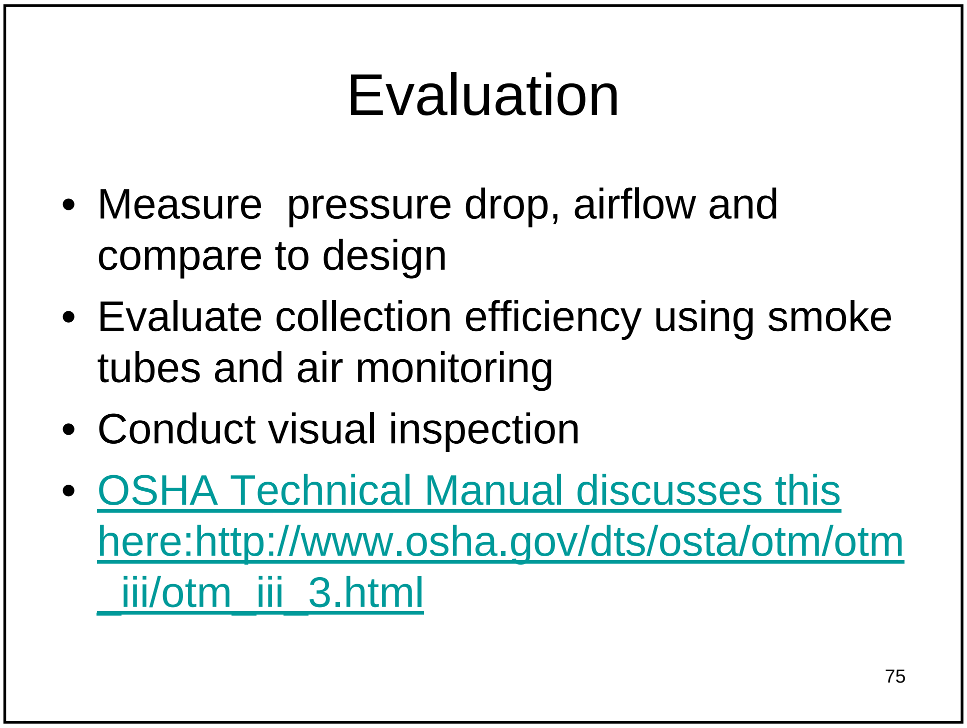
- Centrifugal fans: air leaves the fan perpendicular to the axis of rotation. air enters along the axis of rotation of the fan, and exits along the axis of rotation.
  - radial blade fans
  - backward-curved-blade fans
  - airfoil blade fans: Shaped blades.
  - forward-curved-blade fans
- Air Ejectors

Fans

- Axial flow fan

- Centrifugal flow fan





Evaluation

- Measure pressure drop, airflow and compare to design
- Evaluate collection efficiency using smoke tubes and air monitoring
- Conduct visual inspection
- OSHA Technical Manual discusses this here:http://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_3.html