

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)

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OELs

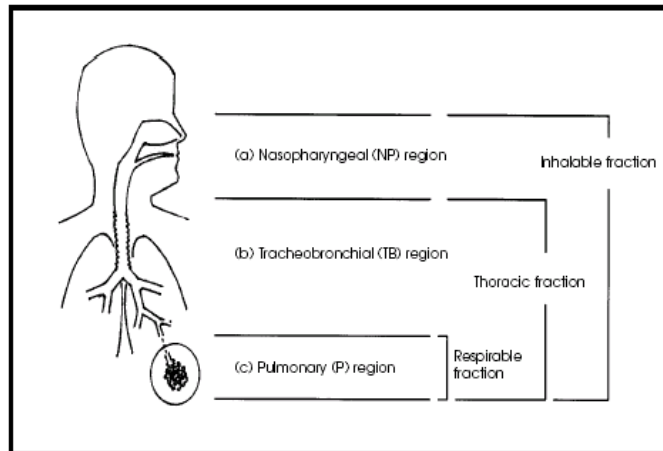


Figure 12.3 — Regions of the respiratory tract: (a) the NP region conditions inhaled air to body temperature and essentially 100% relative humidity and efficiently removes larger particles; (b) the TB region conducts inhaled air quickly and evenly from the mouth and nose to the pulmonary spaces; (c)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

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OELs

- Concentration
 - Parts per million
 - Maximum vapor concentration = $VP_1 / VP_{atm} \times 10^6$
 - Milligrams per cubic meter
- Normal temperature and pressure
 - 760 mm Hg and 25 C
 - Molar volume = 24.5 Liters per mole

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OELs

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

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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.

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OELs

- Conversion between ppm and mg/M³

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

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

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OELs

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

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

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OELs

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

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

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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

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OELs

- Sample TWA calculation

$$\begin{aligned} \text{TWA} &= \frac{410 \text{ ppm} \times 1.5 \text{ hrs} + 250 \text{ ppm} \times 3.5 \text{ hrs} + 75 \text{ ppm} \times 2 \text{ hrs}}{1.5 \text{ hrs} + 3.5 \text{ hrs} + 2 \text{ hrs}} \\ &= \frac{1640 \text{ ppm} - \text{hrs}}{7 \text{ hrs}} = 234 \text{ ppm} \end{aligned}$$

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

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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

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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)

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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.

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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.

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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

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OELs

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

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OELs

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

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OELs

- OSHA Model (T > 8 hours)

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

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OELs

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

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

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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

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OELs

- Solution

OSHA MODEL

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

Brief and Scala Model

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

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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.

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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.

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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.

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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

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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

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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

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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

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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

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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.

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Local exhaust ventilation

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

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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

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General Equation to Predict Concentration

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

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

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Special Cases

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

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

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Special Cases

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

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Special Cases

- Concentration decay; no more generation.

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

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Special Cases

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

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

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Special Cases

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

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

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

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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

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Local Exhaust Ventilation

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

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Hoods

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

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Glove Box



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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.

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Laboratory Fume Hood



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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.

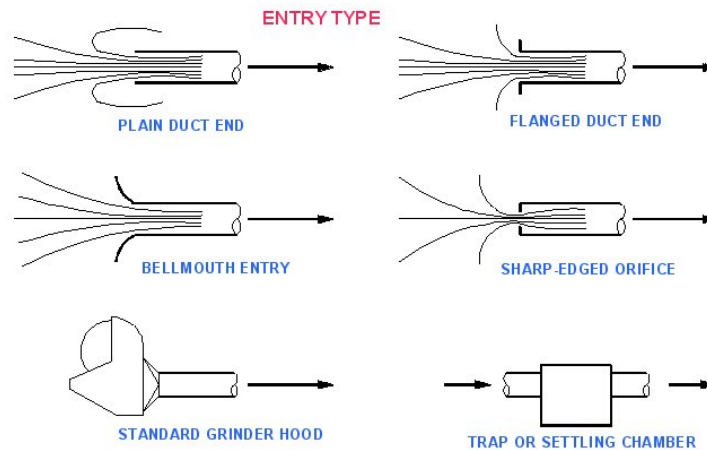
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Exterior Hoods

- 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.

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Exterior Hoods



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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.

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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.

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

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

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Design Considerations

- Round or square openings
 - Bell mouth inlet



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Design Considerations

- Canopy hood design incorporates dimensions of the hood and height of the hood above operation:
 - $V = Q / (1.4 \times \text{Perimeter} \times H)$



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Design Considerations

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

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

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

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Design Considerations

- Slot hood



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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.

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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.

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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.

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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

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Air Cleaning System

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

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Air Cleaning Systems (Centrifugal Collector)



- Source sugardog.com
- For this and subsequent illustrations

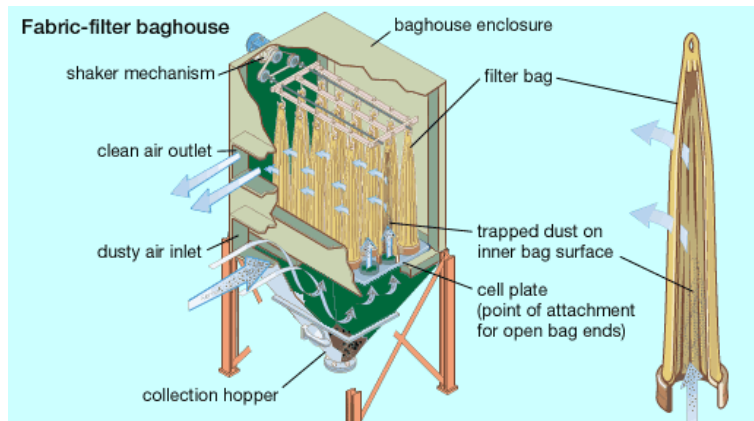
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Air Cleaning Systems

- 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.

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Air Cleaning Systems (Bag Filter)



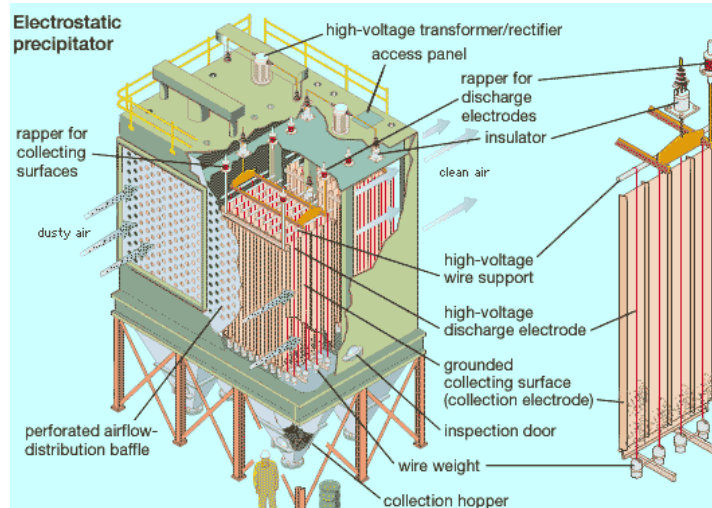
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Air Cleaning Systems

- 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

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Air Cleaning Systems (Electrostatic Precipitator)



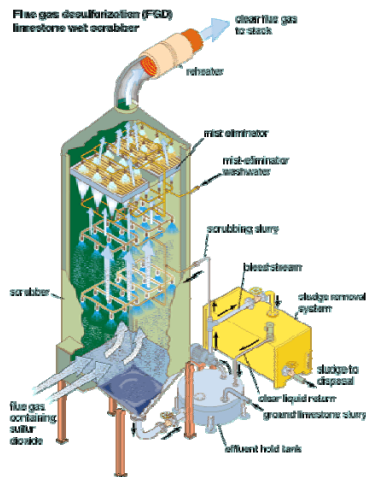
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Air Cleaning Systems

- 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

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Air Cleaning Systems (Wet Scrubber)



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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.

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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.

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Air Cleaning Systems

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

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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 of 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.

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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.

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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

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Fans

- Axial flow fan
- Centrifugal flow fan



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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](http://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_3.html)

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