Ventilation

CIH Review – PDC March 2012

Objectives

- Understand the terms and concepts associated with general ventilation
- Characterize the differences between dilution ventilation and exhaust ventilation
- Illustrate the theories of ventilation systems and the proper evaluation of those systems
- Review common equations and variations for ventilation

Ventilation Systems

- Purpose of Industrial Ventilation Systems is to:
  - Dilute or remove hazardous air for health
  - Dilute or remove hazardous air to control for fire and explosion (safety)
  - Dilute or remove air for heat control (heat stress)
  - Contribute to temperature control

Definitions

- Dilution Ventilation – a method of decreasing the concentration of an airborne substance by increasing the presence of “non-contaminated” air
- General ventilation – ventilation for comfort (i.e., temperature, humidity, and odor control). HVAC
- Local Exhaust Ventilation (LEV) – a specific exhaust system tailored to capture and emission at the source thereby limiting the contamination to the air space

Air Properties

- $P = \rho RT$

- $d_c = T_{STP}/T_{actual} \times P_B/P_{BSTP}$

- $\rho_{actual} = \rho_{STP} \times d_c$

- IH Vent STP = 70F, 29.92 inches Hg, 21C, 760 mm Hg, dry air
- HVAC STP = 68F, 29.92 inches Hg, 20C, 760 mm Hg, 50% RH

Physics of Air - Definitions

"Air is Matter, Just Like Solids and Liquids"

- ATMOSPHERIC PRESSURE
  - The pressure exerted in all directions by the atmosphere. At sea level, mean atmospheric pressure is 29.92 in Hg, 14.7 psi, 407 in w.g., or 760 mm Hg.
- AIR DENSITY
  - The weight of air in lbs per cubic foot. Dry standard air at T=68° F (20° C) and BP = 29.92 in Hg (760 mm Hg) has a density of 0.075 lb/cu ft.
  - At 28.3 ft^3/L and 10^3L/m^3, 1 m^3 contains 28,300 ft^3, and one cubic meter of air weighs over 1 ton
- in. w.g. (inches of water)
  - A unit of pressure. One inch of water is equal to 0.0735 in. of mercury, or 0.036 psi. Atmospheric pressure at standard conditions is 407 in. w.g.

Physics of Air - Definitions

- LAMINAR FLOW (also Streamline Flow)
  - Air flow in which air molecules travel parallel to all other molecules; laminar flow is characterized by the absence of turbulence.
- STANDARD AIR, STANDARD CONDITIONS
  - Dry air at 68° F (20° C), 29.92 in Hg (760 mm Hg).
- TURBULENT FLOW
  - Air flow characterized by transverse velocity components as well as velocity in the primary direction of flow in a duct; mixing velocities.
- BTU
  - Thermal energy input (or removal) required to raise (or lower) the temperature of 1 lb air 1 °F is described by the specific heat of dry air, = 0.24 BTU/lb/°F. 1 BTU = energy needed to raise temperature of 1 lb water 1 °F

Non-standard Air Conditions

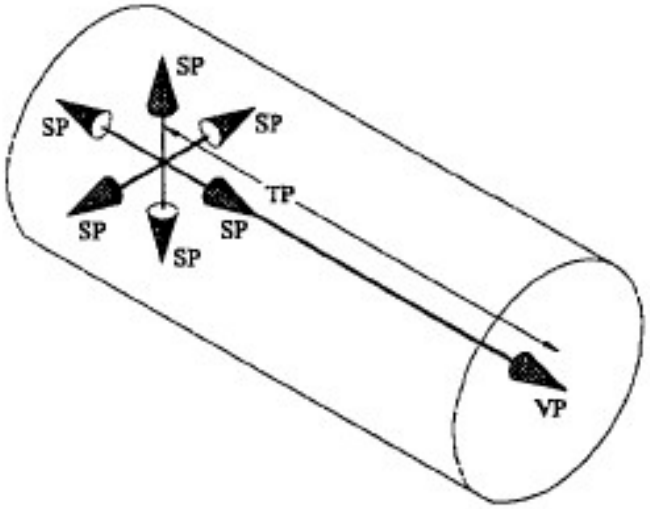
- Moisture content >0.02 lbs water/lb dry air at temps >100F
- Temp <44F or >100F
- System is >1000 ft below or above sea level

Definitions

1. Static Pressure (SP): The potential pressure exerted in all directions by a fluid at rest. For a fluid in motion, it is measured in a direction normal to the direction of flow. Usually expressed in inches water gauge when dealing with air (the tendency to either burst or collapse the pipe)

2. Velocity Pressure (VP): The kinetic pressure in the direction of flow necessary to cause a fluid at rest to flow at a given velocity -usually expressed in inches water gauge

3. Total Pressure (TP): The algebraic sum of the velocity pressure and the static pressure (with due regard to sign)



Units

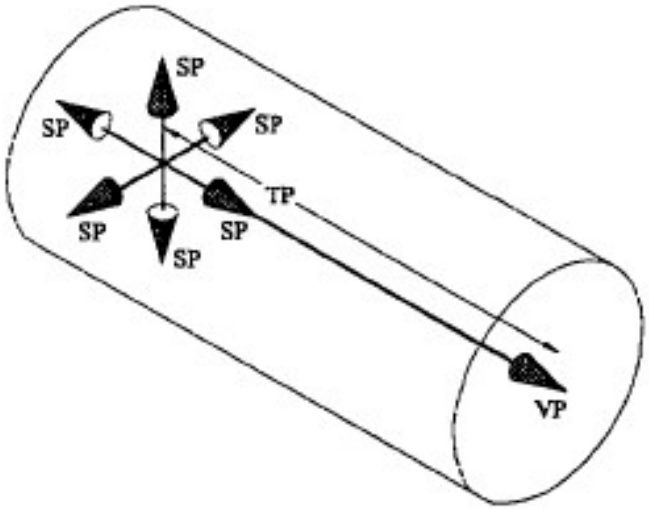
1. Velocity (fpm)

2. Volumetric flow = cross sectional area (ft^2) x linear velocity ft/min = ft^3/min or cfm

3. Pressure = inches wg

4. Mass = lbs

5. Temperature = °F

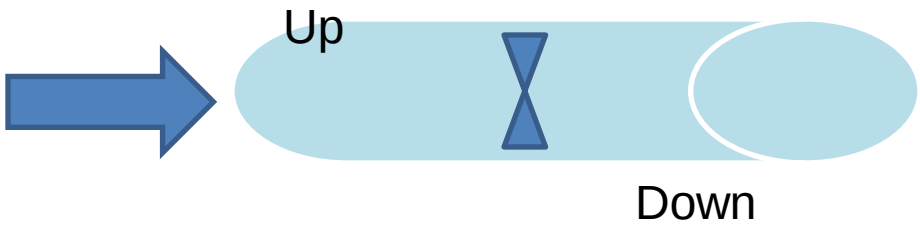


Design Equations

- TP = SP + VP

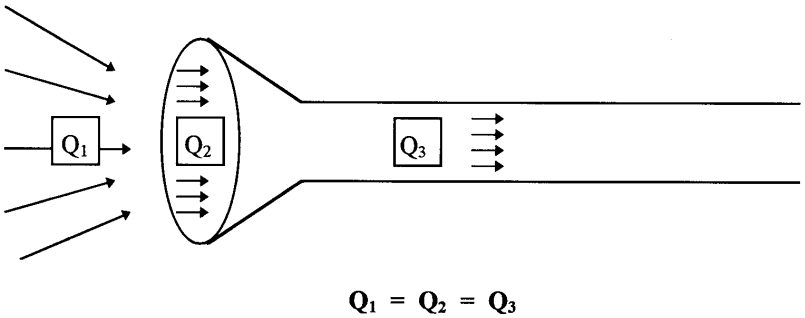
	TP	SP	VP
Upstream	-	-	+
Downstream	+	+	+

- $V = 1096\ (VP/\rho)^{1/2}$



- $V = 4005\ (VP)^{1/2}$
  - Velocity = 4005 (constant) x square root of the velocity pressure

- Q = VA



Physical Assumptions for Ventilation System Design

1. Heat transfer effects are neglected

2. Compressibility effects are neglected

3. The air is assumed to be dry

4. The weight and volume of the contaminant in the air stream is ignored

System Loss Coefficients

- Most of system losses (resistance) are due to friction
  - Duct walls
  - Elbows
  - Hood configurations
  - Branch or “wye” fittings
  - Contractions
  - Cleaners

Losses

- $\delta SP = (F)(VP)$

F is a coefficient

Loss is also defined as $h_{x,}$ where the "x" represents the hood, duct, elbow, etc.

- h values are available in tables
- Fa – acceleration coefficient "Bernoulli" coefficient is 1

Dilution Ventilation

Decreasing the concentration of an emission by increasing the presence and movement of supply air **NOT REMOVAL**

- Requires confidence that supply air creating the dilution effect of the emission (contaminant) is safe
- Specifies a need to understand the amount of supply air necessary to dilute the emission to a non-hazardous level (mixing dynamics?)

$$\text{*Concentration of Emission} = \frac{\text{Emission rate from source}}{\text{Ventilation rate of supply}}$$

* Emission source is at equilibrium

Dilution Ventilation

- Used when:
  - Small quantities released into workroom at fairly uniform rates
  - Sufficient distance from worker to contaminant source to allow for dilution to safe levels
  - Contaminants are relatively low toxicity or fire hazard
  - No air cleaning device is needed prior to exhaust
  - No corrosion or other problems arise from contaminants in workroom air
- Disadvantages
  - Large volumes of air may be needed
    - System size
    - Cost
  - Employee exposures are difficult to control near contaminant source where dilution has not occurred

Dilution Ventilation Principles

- Select the amount of air required for satisfactory dilution of contaminant.
- Locate the exhaust openings near the source of contaminant.
- Locate the supply and exhaust openings such that air passes through the contaminant zone.
- Replace exhausted air with replacement air system.
- Avoid re-entry of exhausted air by discharging high above the roof line or ensuring there are no openings near exhaust.

How does it work?

- Simple model is linear flow
  - Air inlet to exhaust fan (like pulling a contaminant through an invisible duct)
- DOES NOT OCCUR THIS WAY

- Incoming air diffuses throughout room, passing zone of contamination and diluting some. As it moves farther through room, it dilutes farther until removed
  - Could take a long time

Adjusting “Theoretical” Calculations

- Assume contaminant is released at a certain rate (ft3/min) so ventilation must move correct airflow (ft3/min).
  - Assumes complete mixing – in reality – RARE
  - Includes “K” factor to account for this
  - Fire and explosion must add additional safety factor
- Assumes dilution exactly to “target concentration”.
  - If TLV or PEL used, this is where contaminant will reach
  - Need safety factor of “Sf” for % LEL

General Dilution Ventilation Equation

- Rate of Accumulation =

  Rate of Generation – Rate of Removal
- $VdCg = Gdt - Q'Cgdt$

V = room volume

G = rate of generation

Q’ = effective volumetric flow rate

Cg = concentration of contaminant at time t

t = time

Steady State

- $Q = \frac{F \times sp\ gr \times W \times K \times 10^6}{MW \times L}$

F = conversion factor

sp gr = specific gravity

W = amount of liquid used per time

K = mixing

MW = molecular weight

L = target airborne concentration, ppm

W	F
Pts/hr	6.7
Pts/min	403
Gal/hr	53.7
Gal/min	3222
l/hr	14.1
l/min	846

Concentration Build-up

- Until reach steady state
- $Q' = Q/K$
- $G = \frac{F \times sp\ gr \times W}{MW}$

Q' = effective ventilation

G = vapor generation rate

- $Ct = \frac{G[1-e^{(-Q' \times t/Vr)}] \times 10^6}{Q'}$

Ct = concentration at any elapsed time, t, ppm

t = time since release began, min

Vr = room volume, ft3

Purging

- $Ct = C_{orig}[e^{(-Q' \times t/Vr)}]$

- Ct = concentration at time, t, ppm
- C_{orig} = concentration when generation ceased, ppm
- t = time since release ceased, min

Fire and Explosion Prevention

- $Q = \frac{F \times sp\ gr \times W \times Sf \times 100}{MW \times LEL \times B}$

F = conversion factor

sp gr = specific gravity

W = amount of liquid used per time

Sf = Safety factor depending on percentage of LEL acceptable for safe conditions

MW = molecular weight

LEL = lower explosive limit, percent

B = LEL decreasing at elevated temps

B = 1, up to 250F

B = 0.7 above 250F

Mixtures

- Option A: If know similar effects, Add Q values like C/TLV
- Option B: If different effects, determine Q values and use highest
- In absence, use Option A

- Fire and explosion – regard the mixture as containing the components requiring the highest amount of dilution and calculate based on this.
  - Highest value for (SG/MW x LEL)

Air Changes/Hour

- $ACH = \frac{Q \times 60}{V}$

Local Exhaust Ventilation Systems

- Components of a local exhaust ventilation system
  - Hood
  - Duct
  - Air Cleaning Device
  - Fan
  - Stack

Reminder:
All ventilation techniques are focused on keeping the emission out of the Breathing Zone

Design – Velocity is Velocity?

Capture Velocity –The speed of air movement into the hood that is sufficient to pull the air contaminant into the LEV system

Volumetric Flow Rate – The amount of air that can move through LEV duct

- Face Velocities: Velocity of the face (opening) of the hood
- Duct Velocity: Velocity of air moving through the duct
  - Generally (rule of thumb, depending on the system), duct measurements should be made 10X duct diameter away from the hood/face.

    (Ex. 6” duct, measure at 60” from hood/face.)

Hood Types

- Enclosing – completely or partially enclose the process or contamination generation point.
  - Complete enclosure – laboratory glovebox
  - Partial enclosure – paint spray booth

- Exterior – located adjacent to the emission source without enclosing it.
  - Capture – welding hood on flexible duct
  - Receiving – canopy hood

Contaminant Characteristics for Hood Design

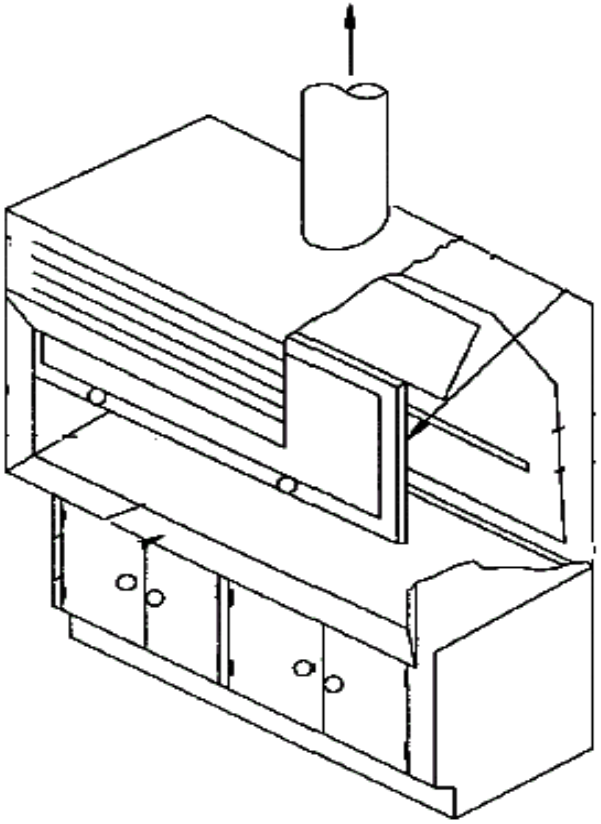
- Inertial Effects
  - Gases, vapors and fumes will not be impacted.
  - Particles 20um or less not significant.
  - Larger particles concern
- Specific Gravity
  - Frequently design based on “contaminant heavier/lighter than air”. If airborne, not an issue.
- Wake Effects
  - Obstacle produces a boundary layer separation which leads to mixing and recirculation.
  - Worker must be out of this zone.

Hoods

Lab “enclosure” Hoods

- **Want velocity even across the face**
  - **Minimize obstruction to air flow**

- **Faster is NOT better**
- **Recommended Face Velocity ~ 100 ft/min**



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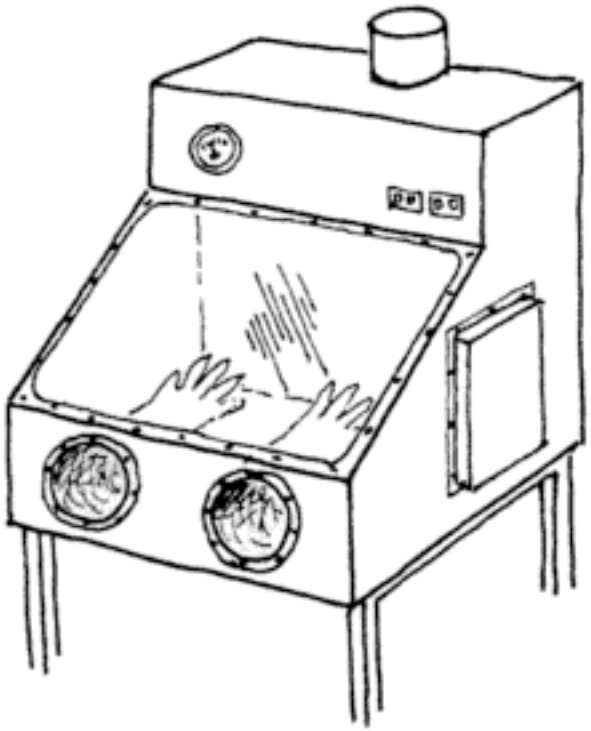
Hoods

- Complete Exposure Removal from the worker and away from the work environment

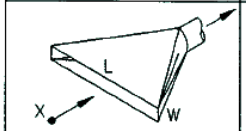
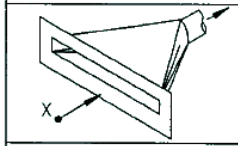
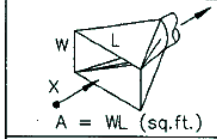
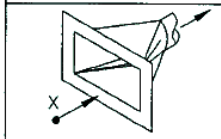
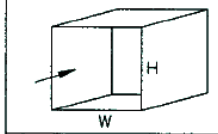
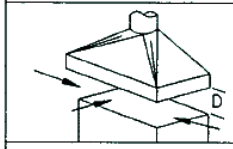
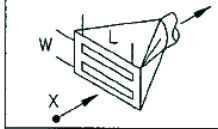
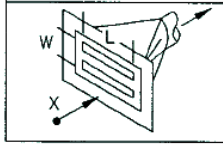
- Generally used for operations like sandblasting (crystalline silica).
- Large walk-in types exist
  - 100% enclosed for bystanders, worker uses supplied-air respirator, PPE.



Industrial Ventilation Design Guidebook By Howard D. Goodfellow, Esko Tähti

Hoods

- Round Plain opening
- Square plain opening
- Slot
- Multi-slot
- Canopy
- Adjustable Slot & Enclosures
  - Chemical “Fume” hoods
  - Biological Safety Cabinets

HOOD TYPE	DESCRIPTION	ASPECT RATIO,W/L	AIR FLOW
	SLOT	0.2 OR LESS	Q = 3.7 LVX
	FLANGED SLOT	0.2 OR LESS	Q = 2.6 LVX
	PLAIN OPENING	0.2 OR GREATER AND ROUND	$Q = V(10X^2+A)$
	FLANGED OPENING	0.2 OR GREATER AND ROUND	$Q = 0.75V(10X^2+A)$
	BOOTH	TO SUIT WORK	Q = VA = VWH
	CANOPY	TO SUIT WORK	Q = 1.4 PVD SEE VS– 99-03 P = PERIMETER D = HEIGHT ABOVE WORK
	PLAIN MULTIPLE SLOT OPENING 2 OR MORE SLOTS	0.2 OR GREATER	$Q = V(10X^2+A)$
	FLANGED MULTIPLE SLOT OPENING 2 OR MORE SLOTS	0.2 OR GREATER	$Q = 0.75V(10X^2+A)$

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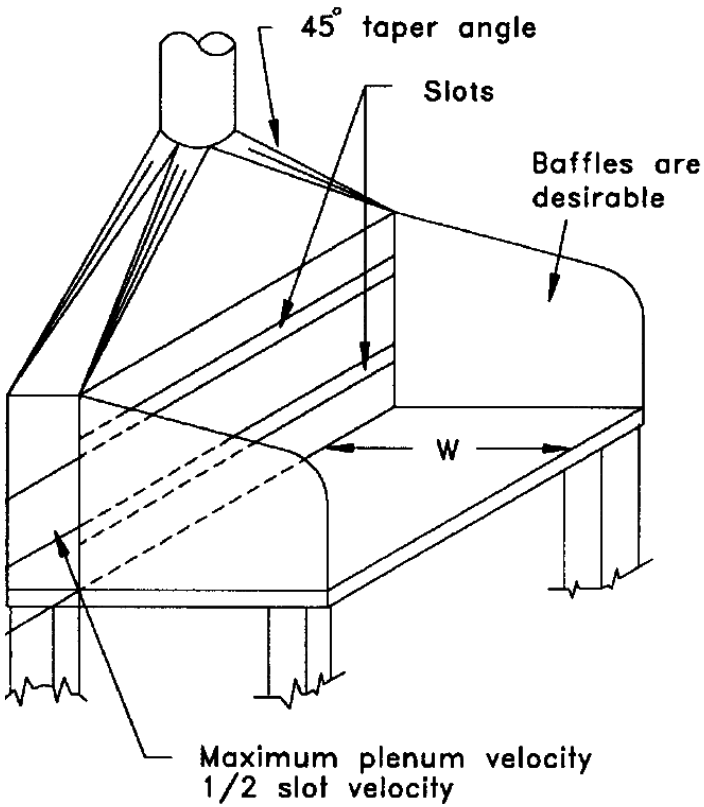
Hoods

Table Slot Hoods



- **Not to increase capture velocity. Provides <u>even flow</u> across the surface**

- **Plenum vs. slot velocity?**
- **Typical Plenum Velocity ~ 1,000 fpm**
- **Typical Slot Velocity ~ 2,000 fpm**

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Hood Losses

The basic equations used (for simple hood) are . . .

$SP_h = h_{ed} + VP_d$

Where

SP_h = hood static pressure, “wg

h_{ed} = entry loss transition ($F_h * VP_d$)

VP_d = duct velocity pressure

- Entry losses occur due to formation of venacontracta at the entrance of duct.
- The hood entry loss represents the energy necessary to overcome the loss as the air enters the duct.
- The losses increase with increase in flow area.
- Hoods with two or more points of loss are compound hoods.

Hood Losses
For compound hoods:

$SP_h = (F_S)(VP_S) + (F_D)(VP_D) + VP_D$

This is when duct velocity is greater than slot velocity.

Where:

SP_h = hood static pressure, “wg

F_S = entry loss factor for slot

VP_S = slot velocity pressure, “wg

F_D = entry loss factor for duct

VP_D = duct velocity pressure, “wg

LEV Equations

- $Q = 4005\ C_e\ A\ (|SP_h|)^{1/2}$
- $C_e = (VP/|SP_h|)^{1/2}$ hood flow coefficient

Duct Design Considerations

- Branch entries – make as gradual as possible
  - 90 degree entry results in turbulence
- Contractions and Expansions
  - Size transitions alter VP and SP.
  - Make gradual
- Duct material friction loss
- Friction loss for non-circular ducts

Fans

- Provide static pressure to physically move air
- Two Basic Types
  - Ejectors – Used when not desirable to have contaminated air pass through air moving device (i.e., corrosive, flammable, explosive, hot or sticky materials)
  - Fans
    - Axial
    - Centrifugal
    - Special types

Axial Fans

- Propeller – low SP and general ventilation. Very sensitive to added resistance → reduced flow rate
  - Disc blade – no duct
  - Narrow/propeller – low SP
- Tubeaxial – narrow or propeller blades in short cylindrical housing. Good up to 2”wg.
- Vaneaxial – propeller configurations with hub and airfoil blades. Most efficient and good to 8”wg. Clean air only.

Centrifugal Fans

- Forward Curved – blades curve toward direction of rotation. Low speeds and quiet. Low to moderate SP. HVAC and supply systems. Not for dusts or particulates.
- Radial Impellers – straight blades. Resists material build-up. Used when particulates must pass through fan.
- Backward Inclined/Backward Curved – blades inclined opposite direction of fan rotation. High speed and high efficiency. Blade shape conducive to material build-up.
  - Single thickness blade - light dust loading or moisture
  - Airfoil blade – higher efficiency and lower noise, hollow so erode and can fill with liquid. Clean air only.

Special Type Fans

- Tubular Centrifugal – backward inclined blades with fitting for straight duct line
  - Similar to Centrifugal with same blade characteristics
- Power Exhausters/Power Roof Ventilators – axial or centrifugal. Downward deflecting or upblast discharge
- Fan and Dust Collector Combo – Package. Consult manufacturer for application.

Fan Performance & Selection

- Depends on fan size (SIZE), rotation rate (RPM), gas density (ρ), flow rate (Q), pressure (P), power requirement (PWR) and efficiency.
- Pressure can be represented by TP, VP, SP, fan static pressure (FSP) or fan total pressure (FTP).
- Selection:
  - Capacity – Q and P

- Fan Ratings

$$FSP = SP_{out} - SP_{in} - VP_{in}$$

$$FTP = TP_{out} - TP_{in}$$

Fan Laws

- 3 Fan Laws

$Q_2 = Q_1 (SIZE_2/SIZE_1)^3 (RPM_2/RPM_1)$ → $Q_2 = Q_1 (RPM_2/RPM_1)$

$P_2 = P_1 (SIZE_2/SIZE_1)^2 (RPM_2/RPM_1)^2 (\rho_2/\rho_1)$ → $P_2 = P_1 (RPM_2/RPM_1)^2$

$PWR_2 = PWR_1 (SIZE_2/SIZE_1)^5 (RPM_2/RPM_1)^3 (\rho_2/\rho_1)$ →

$PWR_2 = PWR_1 (RPM_2/RPM_1)^3$

Air Cleaners

- No standard for measuring efficiency
- Mass rate of emission will influence selection
  - Greater Q, better equipment needed
- Air pollution regulations have impact
  - Visibility function of light reflecting on surface area of escaping particles
- Other considerations
  - Temperature of air stream
  - Condensation of water
  - Corrosive nature

Dust Collectors

- **Electrostatic Precipitator** – high potential electric field between opposite electrical charged electrodes. Gas molecules separated and go to opposite plates. Removed by washing, gravity or vibration
  - Cottrell – single stage – high voltage, heavy duty
  - Penny – two stage – low voltage, <0.025 grains/ft3, Hydrocarbon emissions
  - Wet ESP (WESP) – good for submicron aerosol particulates

Dust Collectors

- **Fabric** – strain, impinge, intercept, diffusion, electrostatic charge
  - Shaker – shaking removes dust cake – reconditioning
  - Tube – air enters bottom and gas flows in to out
  - Envelope – gas flows out to in, supported open
  - SP loss – 2-5 “wg at start and end of cycle
- **Reverse-Pulse Jet** – brief burst of high pressure air (80-100 psi) to recondition
  - Dust collected on outside, gas flows out to in
  - Higher Q possible due to short reconditioning

Dust Collectors - Wet

- **Scrubbers** –
  - SP loss 1.5-100 “wg
  - Efficiency depends on energy utilized in air to water contact
  - Good for moisture laden and high temp gases
  - Concerns – freezing and corrosive
  - Good for air pollution but water becomes HW
- **Chamber/Spray Tower** – impact dust with water droplets
  - SP loss – 0.5 – 1.5 “wg
- **Packed Tower** – contact bed gas and liquid, pass concurrently, counter-currently, or cross-flow
  - SP loss 1.5 – 3.5 “wg
  - Good for gas, mist, vapor and high temp

Dust Collectors

- Wet Centrifugal –
  - SP loss 2 - 6 “wg
- Venturi
  - SP loss 5 – 100 “wg
- Oriface
  - SP loss 3 – 6 “wg

- Dry
  - Gravity
  - Inertial
  - Cyclone
    - SP loss – 0.75 – 1.5 “wg
    - Low cost and low maintenance

Gas & Vapor Collectors

- **Absorption** – soluble or chemical reaction of gas through contact with liquid
  - Packed Scrubber: 4 configurations including Packed Tower
  - Staged Scrubber: Horizontal metal plates gas flows opposite to liquid
- **Adsorption** – solid second phase uses van der Waals forces (weak) and strong forces through activated or chemisorption – charcoal, silica, alumina
- Incineration/oxidation – combustion for VOCs, organic aerosols, odorous compounds
- Catalytic oxidation - VOCs

Stack Design Considerations

- Consider pattern of air as it passes the building
- Place on highest roof of building
- Good velocity is 3000 fpm
  - Prevents downwash and rain entry
  - Increases effective stack height
- Discharge velocity and gas temperature influence stack height
- Consider location of intakes and other building entry points

Testing and Monitoring Equipment

- Air Velocity Instruments - Velometers
  - Thermal anemometers
  - Rotating Vane anemometers
  - Swinging Vane anemometers
  - Balometer

- Pressure Sensors
  - Pitot Tubes
  - Manometers

- Other Concerns
  - CO2 Meters
  - Thermometers
  - Psychrometers

Thermal Anemometer

- Respond to heat removed by air stream passing a heated probe, allowing calibration to the velocity for a given density.
- Most instruments have 2 sensors
  - Velocity
  - Temperature
- Good for high and low velocities – above 30 fpm
- Sensitive to small movements, especially at low velocities and hood faces

Rotating Vane Anemometers

- Used for large (>4ft2) openings
- Propeller or revolving vane connected to gear train – rotations per time converted to distance
- Fragile and not good for dusty or corrosive atmospheres

Swinging Vane Anemometers

- Versatile and wide range – both velocity and SP
  - Replaced by thermal anemometer for low velocity
  - Replaced by digital manometer for high velocity and SP.
- Dust, moisture and corrosive materials are a concern
- Large cross section and must be held vertical so can impact flows

Pitot Tubes

- Probes used to conduct pressure to a pressure sensor, such as a manometer.
- Actually a tube within a tube
  - Outer tube is static pressure
  - Inner tube is total pressure
- Insert into centerline of duct and perpendicular to airflow (stem)

Manometers

- U-tube – Precision of readings depends on scale. Connected to pitot tube
- Inclined – spreads out vertical rise in fluid level over a broader scale.
- If pitot tube connected on both sides, affected equally by SP, so all that is left if VP.

DataChem Questions Reviewed

- During the review course, the following questions were reviewed or targeted for review:
- 767, 769, 770, 771, 774, 775, 776, 777, 778, 780, 781, 783, 786, 787, 791, 792, 794, 797, 800, 801, 802, 804, 806, 808, 809, 814, 817, 827, 832, 837, 841, 849