Hoods and Local Exhaust Ventilation

Essential pressure and flow relationships

Bulk Air Flow in a Duct

- Air movement always follows the pressure gradient
  - Flow goes from higher (abs) pressure to lower (abs) pressure regions
- This is the effect of molecular-level collisions
  - More energetic molecules collide with neighbors, and increase the velocity of the surrounding molecules (and pressure)
- Flowing air has momentum and viscosity
  - momentum forces it to travel in ~ straight lines
  - viscosity forces it to flow into and fill the available volume
  - the conflict of these forces induces eddy currents in turbulent flow
- With continued collisions, added energy is gradually transformed from the energy of flow to the heat energy of increased velocities of individual molecules. Any energy input is transformed from its initial state to flow energy and finally to heat.

System Nomenclature

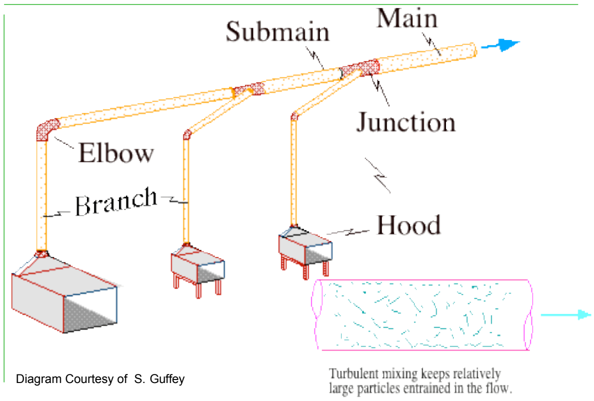
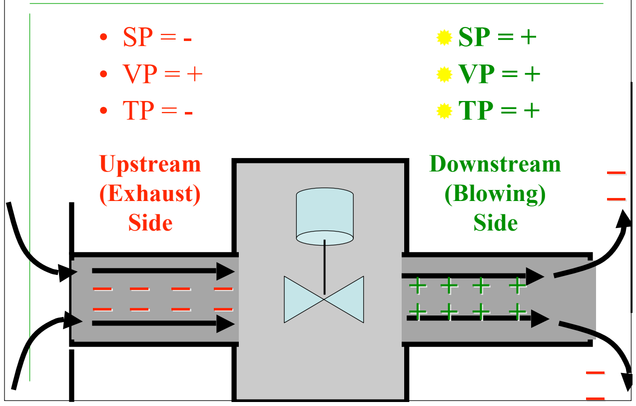


Diagram Courtesy of S. Guffey

Inside a ventilation system



Air as a fluid

- Air has mass, just like any other fluid
- Generally have a mixture of water vapor and dry air
- Most Vent tables and charts refer to air at Normal Conditions
- Pressure 29.921 “Hg Temp 70ºF
- Humidity 0.008 lb H2O/ lb dry air (abs)
- Humid volume 13.52 ft^3/lb dry air
- Density 0.075 lb/ft^3
- Enthalpy 25.54 BTU/lb dry air
- Relative humidity 50%
- Density factor = 1

System Design Requirements

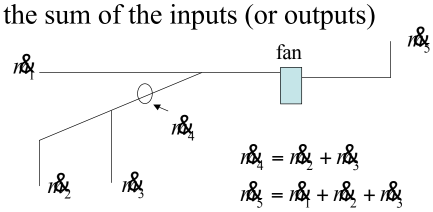
- In ventilation systems, we want to specify:
  - the volume of air moving in the system branches
  - the pressures that are required to move air in the system branches
  - the fan capacity needed to operate the system
- To compute this in the system we apply:
  - Conservation of mass
  - Conservation of energy

Conservation laws

- Conservation of Mass
  - Used to compute the volume flow rate (Q) and duct velocities
- Conservation of Energy
  - Used to computer the system pressures and fan horsepower requirements

Conservation of Mass

- Mass cannot be created or destroyed; so the total mass flow in the system is just given by the sum of the inputs (or outputs)



$$\dot{m}_4 = \dot{m}_2 + \dot{m}_3$$

$$\dot{m}_5 = \dot{m}_1 + \dot{m}_2 + \dot{m}_3$$

$\dot{m}$ = Mass flow rate in lbs/min (or kg/s)

Conservation of mass (Continuity eqn.)

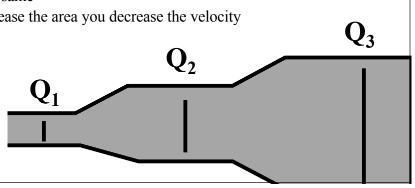
- Conservation of mass means
  - If we know the density we can write eqns in terms of a volume flow rate Q (ft^3/min)
  - i.e. $\dot{m}_i = \rho_i Q_i = \rho_i V_i A_i$
  - m in lbs/min; Q in ft^3/min; _ in lbs/ft^3
- so that $\dot{m}_4 = \dot{m}_2 + \dot{m}_3$
- becomes $\rho_4 Q_4 = \rho_2 Q_2 + \rho_3 Q_3$
- This general equation is always true in the system

Conservation of mass- Volume Flow

- Often the continuity equation uses volume flow rate rather than mass flow; assuming rho=constant
  - Note that a volume flow rate Q (ft^3/min)
  - Can be written as: $Q_i = \bar{V}_i A_i = \dot{m}/\rho_i$
  - V bar represents the average velocity in the duct
- so that $\rho_4 Q_4 = \rho_2 Q_2 + \rho_3 Q_3$
- becomes $Q_4 = Q_2 + Q_3$
- This equation is approximately true in most ventilation systems

Volumetric Flow Rate

- The volume of air flowing through a system past a certain cross section point
  - Q
  - Given in Cubic Feet Per Minute (CFM)
    - The amount of air flowing through any point has to be the same
      - Volume of air has to be the same, but the area and the velocity do not remain the same
      - If you increase the area you decrease the velocity



Constant density assumption

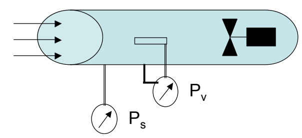
- The constant density assumption requires that T, w, and P are constant in the system. This is never strictly true (P_s changes) but density changes are often small enough to be a useful approximation
- Example: say $P_S = 10\text{''}H_20$ in the duct, then density change ~10/407= 0.025 or 2.5%
- Thus constant density is a good assumption

Density at normal conditions

- Density of standard air = 0.075 lb/ft3
  - Air density affected by: moisture, temperature & altitude above sea level
  - Density corrections needed, when:
    - Moisture exceeds 0.02 lbs water/lb of air
    - Air temp outside of 40 – 100 F range
    - Pressure 28.4 < P < 31.4
    - Altitude exceeds +1000 ft relative to mean sea level
      - At other heights:

$$P_{bar} = (P_{STD}) \cdot \exp - \left(\frac{altitude}{24{,}400} \right)$$

Duct Pressures



- $P_T = P_S + P_V$ ← i.e. A statement of an energy balance
- Static pressure ~ potential energy term
- Velocity pressure ~ Kinetic Energy term
- Total pressure ~ total energy term
- Recall KE is _ mV^2 so KE term is proportional to V^2

Density effect on Pv

- At NTP, $P_V = (V/4005)^2$ for V in ft/min, P_V in inches H_2O
- OR $\boxed{V = 4005\sqrt{P_V}}$
- At non standard conditions

$$V = 1096\sqrt{P_V / \rho_{actual}} = 4005\sqrt{P_V / d_f}$$

- Where d_f is the density correction factor:

$$d_f = \frac{\rho_{actual}}{\rho_{NTP}}$$

- Note that Pv becomes very small when V is small so the method is limited to fairly high velocities above ~ 1000 FPM
- Q: if we can read +/- .005 " H20, what is the error at V=600 FPM?

Density correction

$$P_V = \left(\frac{V}{4005} \right)^2 \left(\frac{Density_{actual}}{0.075\ lb/ft^3} \right)$$

$$Density_{actual} = \frac{0.075 lb}{ft^3} x \frac{530^\circ F}{(460 + t)} x \frac{Pressure}{29.92}$$

$Density_{actual}$ = air density in lb/ft3
t = temperature in °F
Pressure = pressure in inches of mercury

Also given by :
Where _p is in feet of air
Note: 1"H2O = 69.333 ft of air

$$V = 4005 P_V = \sqrt{2g\Delta p}$$

$$4005 = \sqrt{2(32.17)69.333}\ (60\,\text{min/sec})$$

Sign Convention for pressure

- Total pressure (P_T) and Static Pressure (P_S)
  - Minus sign upstream of fan
  - Positive sign downstream of fan

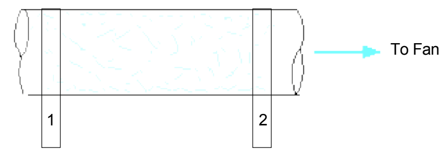
$P_T = P_S + P_v$

Total Pressure = Static Pressure + Velocity Pressure

- Velocity Pressure (P_V)
  - Always has a positive sign

Serial flow in a duct section

- We use conservation of energy to find pressure



$$P_{T_1} = P_{S_1} + P_{V_1} \qquad P_{T_2} = P_{S_2} + P_{V_2}$$

Energy Balance says: $P_{T_1} = P_{T_2} + losses$

$$\boxed{P_{S_1} + P_{V_1} = P_{S_2} + P_{V_2} + losses}$$

Ideally P_s and P_V can be converted back and forth, but losses always occur

Conservation of energy

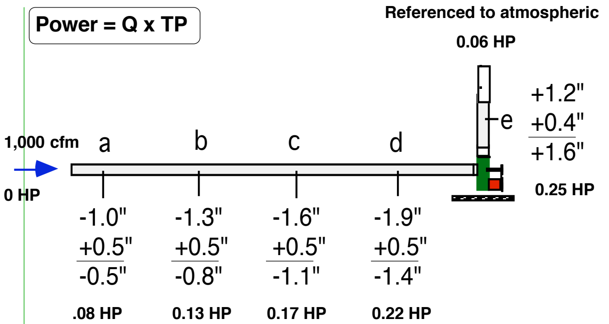
Direction of entropy

- Energy is proportion to pressure, so changes in pressure reflect changes in energy (or power).
- On an absolute pressure scale, the air always flows from regions of higher pressure toward lower pressure
- Air flow begins at 1 atm at potential energy proportional to 407 "w.g.
- On the upstream side, the fan creates a lower inlet pressure; it "digs a hole" in the air and air "falls" into the fan
- On the downstream side, the fan creates a pressure higher than 1 atm in the duct; it pushes air out the exhaust
- The fan energy must overcoming friction, various losses and restore the air to atmospheric pressure at the outlet

Power in duct flows

- Conservation of energy says that the energy needed is the sum of the energy used to accelerate the flow and the energy needed to overcome friction and system losses
- Recall: P_T is proportional to total energy
- <u>In fact:</u> Q* P_T = power used in system
  - Power is in Watts if P is in Pa and Q in M^3/s
  - Conversion: 1"H_2O=249 Pa; 1000 CFM=0.472 M^3/s
  - Watts = P_T *Q*0.1175 for P_T in "H_2O and Q in CFM
  - (Note: 0.1175 watts / ("H_2O –CFM) = 249*.472/1000)
  - 1 HP = 745 Watts, so in principle we also can estimate fan horsepower!

Change in Total Pressure for Serial Flow increasing dissipated power as air flows



Fan Power= 0.22 HP+ 0.25 HP

Types of losses

- Friction Losses:
  - Fluid in motion encounters drag along the surface
  - Energy is needed to overcome the drag force
  - The drag force is due to the fluid viscosity
- Dynamic losses
  - Turbulence and eddies in the flow
  - Momentum losses due to change in direction
  - Found in expansions, contractions, elbows, junctions and hood entries

Friction losses

- Friction losses H_f are proportional to the kinetic energy in the moving fluid
  - In general form: Weisbach-Darcy friction eqn:

$$H_f = f\frac{L}{D}P_{V_1}$$

- Losses factor f is function of Pv, Re, and surface roughness

Friction losses

- We use a simplified form where H_f is proportional Pv $$H_f = kP_{V_1}$$
- k is determined from charts and figures eg vent manual or curve fitting
- For example in a straight duct:

$$H_f = 0.38\frac{L}{D^{1.22}}(P_{V_1})$$

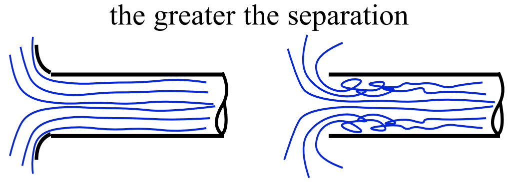
Friction losses

- Friction losses increase linearly with duct length increasing air density
- Losses depend on the duct material and wall roughness
- Losses increase with V^2(and also Q^2)
- Losses decrease ~ with square of duct area
  - (proportional to $1/A^{2.5}$ but approx $1/A^2$)

Dynamic Losses - entries

- Hoods are the business end of the capture system
- The hood is the only place where you can capture the contaminant
- Purpose:
  - To enclose or contain the source
  - Direct the contaminate into the system
  - Minimize the loss of contaminant into the room
  - Minimize energy losses into the system

The more abrupt the change in direction, the greater the separation



Flow into a rounded entry

Flow into a plain duct entry

ΔTP = F x VP for most components
F depends on smoothness of turns

Hood Design

- Design parameter for hoods = Q
  - Q = volumetric flow rate in cubic feet /min

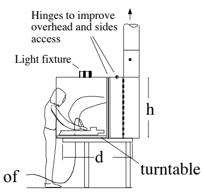
$$Q = VA$$

V = air velocity in fpm
A = area of duct in square feet

- flow is not measured directly
- determined by measuring velocity & knowing cross sectional area of flow

Hood Types

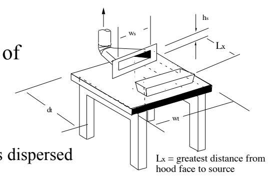
- Enclosing Hood
  - contaminant source contained within hood
  - examples:
    - lab fume hood
    - glove box, paint booth
  - good for:
    - contaminants with high toxicity
    - areas where there is a high cross draft potential
  - Airflow requirements determined by the product of velocity x area of enclosure
  - The more complete the enclosure – the less airflow requirement needed
  - Less susceptible to outside air currents



Side View (Enclosure transparent)

Hood Types

- Capture Hood
  - creates exhaust airflow in front of opening to capture & remove contaminant
  - capture velocity or V_c
    - a factor of how the contaminant is dispersed
    - room air currents
    - how far the source is from the hood opening
  - Disadvantages
    - May require large airflow requirements
    - Subject to crossdrafts
    - The effective "reach" is limited to ~ 1 diameter or less

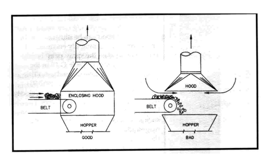


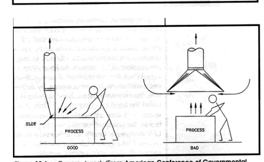
Hood Types

- Receiving or Capture Hoods: utilize natural movement of contaminant toward hood opening
  - good for:
    - canopy over hot process (range hood)
    - radial arm saw hood
  - not good for:
    - fine particles
    - high toxicity contaminants
    - cold processes

Hood Selection Factors

- Potential for outside air currents
- nature of the process which generates the contaminant
- Potential for contaminating the breathing zone (canopy hoods)





Source: Dinardi SR. *The Occupational Environment – Its evaluation & Control* (1998)

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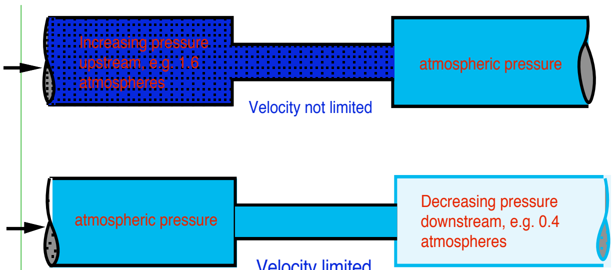
Critical flow conditions



Critical Orifices and Pressures Upstream and Downstream