Entry losses, ducts and hoods
I’ll never design an LEV system. Why do I need to know this?

- Almost nobody know about it either!
- So you’ll need to explain these concepts
- Developing control recommendations and conceptual designs
- Assessing ventilation effectiveness
- Enhancing LEV performance & troubleshooting
- Easy CIH exam points!
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
Duct friction losses

- Friction losses increase linearly with duct length increasing air density, typical form:

\[ H_f = F_f P_v \frac{L}{100'} \]

- Losses depend on the duct material and wall roughness
- Losses increase with \( V^2 \) (and also \( Q^2 \))
- Losses decrease \( \sim \) with square of duct area
  - (proportional to \( 1/A^{2.5} \) but approx \( 1/A^2 \))
Principles of LEV Design

• To protect the worker’s breathing zone:
  – the contaminant is captured close to the point of release (local) and removed (exhausted) from work areas

• prevents contaminant migration to other areas

• systems are always mechanical

• volume flow rate is much less than general or dilution ventilation
Local Exhaust Hoods

• **Purpose**
  – Capture and remove contaminant at the source

• **Effectiveness determined by**
  – Hood configuration & shape
  – The extent to which the hood encloses the contaminant source
    • Cardinal rule: *enclose source to the extent possible*
  – Amount of air flow into hood (i.e. $Q_{hood}$)
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
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

$L_x = \text{greatest distance from hood face to source}$
Basic Hood Types

Enclosing

Capture
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
Receiving Hood Example – Paver Block Saw
Hood Selection Factors

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

Source: Dinardi (1998)
Enclosing Hoods

• Control velocity = \( V_f \) = face velocity
  – What velocity across hood face is necessary for proper contaminant control?
    • Nature of the process and contaminants generated
    • Hood shape and size
    • Magnitude of cross drafts
  – Higher is not always better

• Getting an even distribution of airflow at the face
  – Making the booth deeper
  – Using a baffle
  – Use of filters/air cleaning devices
Enclosing hood: Lab fume hood

• Recommended face velocity: 60 – 100 ft/min depending on
  – Room air currents
  – Location of equipment in hood relative to face

• Face velocity: > 150 ft. min
  – Air turbulence at hood face
  – Reverse airflow
  – Contaminants may exit at hood face
Slots, plenums & baffles

- **Slot hoods with plenums**
  - Useful for processes where contaminant is released across a large surface area
    - Degreasing tanks
    - Plating tanks
    - Welding tables
  - Distributes airflow more evenly across the surface

- **Slot hood**
  - A hood with a width-to-length ratio of 0.2 or less
  - Purpose – to provide uniform distribution of airflow

- **Plenum**
  - A large chamber or compartment that distributes airflow

Source: Dinardi, 1998
Hood Design

- **Design parameters for hoods**
  - Hood geometry/shape
  - Hood size
  - \( Q = \text{volumetric flow rate (CFM)} \)

\[
Q = VA
\]

- \( V = \text{air velocity in fpm} \)
- \( A = \text{area of face in square feet} \)

- flow is not measured directly
- determined by measuring face velocity (V) & knowing cross sectional area of flow (A)
Simple Hood

\[ P_{T1} = P_{T2} + \text{losses} \]

\[ Q_1 = Q_2 = Q_3 \quad P_{sh} = \text{hood static pressure} \]

Note: outside \( P_{T1} = 1 \text{ atm} \) and \( P_{V1} = 0 \), so \( P_{T1 \text{ gauge}} = 0 \)
Hood entry losses, $P_{sh}$

\[ 0 = P_{T1} \]
\[ 0 = P_{T2} + \text{losses} \]
\[ 0 = P_{sh} + P_{V2} + \text{losses} \]
\[ -P_{sh} = P_{V2} + \text{losses} \]

If we apply the sign convention, \( P_{V2} \) and losses are + terms.

- The $P_{sh}$ is the pressure needed to:
  - Set the air into motion (\( P_v \) part) aka “acceleration loss”
  - Overcome any losses in the hood

- Note ideally when no losses, $P_{sh} = P_v$; that is all the potential energy is converted into kinetic energy of the moving fluid.
Hood static pressure

- Other forms: \[ |P_{sh}| = P_V + \text{losses} \]
  - The losses are characteristic of the hood shape and are defined as the hood entry loss \( H_e \) (e=entry)
    \[ |P_{sh}| = P_V + H_e \]
  - \( H_e \) is caused by dynamic losses and turbulence in the inlet. Air can’t follow perfectly into the inlet and contracts to a flow stream that is smaller than the actual duct cross section -- known as the Vena Contracta. This creates turbulence and energy loss
Vena contracta

About d/2 is max effect
Hood entry losses

- Entry loss is proportional to $P_v$
- The loss factors have been tabulated for various shapes

\[
\begin{align*}
|P_{sh}| &= P_v + H_e \\
H_e &= F_e P_v \\
P_{sh} &= P_v + F_e P_v \\
P_{sh} &= P_v (1 + F_e) \\
\frac{P_{sh}}{P_v} &= 1 + F_e
\end{align*}
\]
Vena contracta and $F_e$
Hood Efficiency

- Hood efficiency can be evaluated in terms of the energy loss at the entry
- Say we had a perfect hood, then all potential energy would be converted to kinetic energy
- So: $P_{sh} = P_v + 0$ (no losses)
- If we define $C_e$ as the coefficient of entry

$$C_e = \frac{Q_{actual}}{Q_{ideal}}$$

- Actual flow
- Ideal flow with no losses
\( C_e \) represents efficiency

- Recall \( C_e = \) ratio of actual flow to ideal flow

\[
C_e = \frac{Q_{\text{actual}}}{Q_{\text{ideal}}}
\]

- So:

\[
C_e = \frac{4005 \sqrt{P_v \cdot \text{(area)}}}{4005 \sqrt{P_{Sh} \cdot \text{(area)}}} = \sqrt{\frac{P_v}{P_{Sh}}}
\]

- \( C_e \) represents the efficiency of the hood – it is unitless and measures how well the hood converts potential energy (\( P_S \)) into kinetic energy (\( P_v \)) in the flow
\( C_e \) is related to \( F_e \)

- Recall \( F_e \) gives hood loss in terms of \( P_v \)

\[
\frac{P_{sh}}{P_v} = 1 + F_e
\]

- So if: \( C_e = \sqrt{\frac{P_v}{P_{sh}}} \) then \( C_e^2 = \frac{1}{[1 + F_e]} \)

- So the efficiency of the hood is directly related to the flow rate, and the square of the efficiency is a measure of the entry loss factor.
Efficiency for different entries

- $C_e$ depends on the hood geometry
- Unlike $H_e$ it does not depend on $Q$ the flow rate

<table>
<thead>
<tr>
<th>HOOD TYPE</th>
<th>DESCRIPTION</th>
<th>COEFFICIENT OF ENTRY, $C_e$</th>
<th>ENTRY LOSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain Opening</td>
<td></td>
<td>0.72</td>
<td>0.93 VP</td>
</tr>
<tr>
<td>Flanged Opening</td>
<td></td>
<td>0.82</td>
<td>0.49 VP</td>
</tr>
<tr>
<td>Taper or Cone Hood</td>
<td>Varies with angle of taper or cone. See Fig. 6-10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bell Mouth Inlet</td>
<td></td>
<td>0.98</td>
<td>0.04 VP</td>
</tr>
</tbody>
</table>
Concept of capture velocity

• Capture velocity: the velocity at a point in front of the hood, that is needed to oppose room air currents and capture the contaminants
• It is an old concept that only partially works
• Ignores:
  – Mass generation at source
  – Turbulence at the inlet
• Still widely used
• Many formulas for different shapes
• DallaValle equations are an example
Capture Hoods

- Control velocity = $V_c$ or capture velocity
  - Velocity needed to overcome opposing forces
    - Cross drafts
    - Motion imparted by process, etc.

- Design parameter = $Q$
  - To determine the $Q$ needed, we can use the velocity $V_c$ needed to capture contaminant at point $x$ in front of the hood

Source: Dinardi SR. (1998)
Capture velocity

- Relationship between $Q$, $V_c$ and $X$
  - Assumptions
    - Contaminant source at point $X$
    - Point suction source
    - Air flows into point source from all directions

\[ A = 4\pi X^2 \]
Capture velocity equations

- **Point Source**
  - Shape: Sphere
  - Area $\approx 4\pi X^2$

- **Plain Duct**
  - Shape: $\sim$Sphere
  - Area $\approx 4\pi X^2 - (\pi D^2 + 4)$

- **Flanged Duct**
  - Shape: $\sim$ Half Sphere
  - Area $\approx 2\pi X^2$

- **Slot With Sides**
  - Shape: $\sim$ 1/4 Cylinder
  - Area $\approx \frac{1}{2} \pi XL$

- **Free-Standing Slot**
  - Shape: $\sim$ Cylinder ($+ Sphere$)
  - Area $\approx 2\pi XL (+4\pi X^2)$

- **5-Sided Hood**
  - Shape: Plane
  - Area $= h \times w$
More capture velocity equations

<table>
<thead>
<tr>
<th>HOOD TYPE</th>
<th>DESCRIPTION</th>
<th>ASPECT RATIO,W/L</th>
<th>AIR FLOW</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Slot Diagram" /></td>
<td>SLOT</td>
<td>0.2 OR LESS</td>
<td>Q = 3.7 LVX</td>
</tr>
<tr>
<td><img src="image2" alt="Flanged Slot Diagram" /></td>
<td>FLANGED SLOT</td>
<td>0.2 OR LESS</td>
<td>Q = 2.6 LVX</td>
</tr>
<tr>
<td><img src="image3" alt="Plain Opening Diagram" /></td>
<td>PLAIN OPENING</td>
<td>0.2 OR GREATER AND ROUND</td>
<td>Q = V(10X^2+A)</td>
</tr>
<tr>
<td><img src="image4" alt="Flanged Opening Diagram" /></td>
<td>FLANGED OPENING</td>
<td>0.2 OR GREATER AND ROUND</td>
<td>Q = 0.75V(10X^2+A)</td>
</tr>
</tbody>
</table>

Source: Plog, page 619
Effect of Flanging

- A surface parallel to the hood face to prevent unwanted air flow behind the hood
- Effects of flange:
  - Decreasing the Q needed to achieve contaminant capture (reduce by ~ 25%)
  - Improving the capture velocity of a hood
Velocity profiles
(non-flanged vs flanged)

Source: Plog, 2002, p 620
## Range of capture velocities

<table>
<thead>
<tr>
<th>Dispersion of Contaminant</th>
<th>Examples</th>
<th>Capture Velocity, ft/</th>
</tr>
</thead>
<tbody>
<tr>
<td>Released with practically no velocity into quiet air.</td>
<td>Evaporation from tank; degreasing.</td>
<td>50–100</td>
</tr>
<tr>
<td>Released at low velocity into moderately still air.</td>
<td>Spray booths; intermittent container filling; low-speed conveyor transfers; welding; plating; pickling.</td>
<td>100–200</td>
</tr>
<tr>
<td>Active generation into zone of rapid air motion.</td>
<td>Spray painting in shallow booths; barrel filling; conveyor loading; crushers.</td>
<td>200–500</td>
</tr>
<tr>
<td>Released at high initial velocity into zone of very rapid air motion.</td>
<td>Grinding; abrasive blasting; tumbling.</td>
<td>500–2000</td>
</tr>
</tbody>
</table>

In each category above, a range of capture velocities is shown. The proper choice of values depends on several factors:

### Lower End of Range
1. Room air currents minimal or favorable to capture.  
2. Contaminants low toxicity or of nuisance value only.  
3. Intermittent, low production.  
4. Large hood-large air mass in motion.

### Upper End of Range
1. Disturbing room air currents.  
2. Contaminants of high toxicity.  
3. High production, heavy use.  
4. Small hood-local control only.

(Source: From American Conference of Governmental Industrial Hygienists (ACGIH®) *Industrial Ventilation: A Manual of Recommended Practice*, 23rd ed. Copyriç

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Source: Plog (2002).
• Four example problems for homework follow
Example Problem 1

• Exterior hood with plain round opening
  – 14 inches in diameter, 24 inches deep
• Round duct leading up to hood
  – 6 inches in diameter,
• Transition section to hood
  – conical taper over 2 feet
• Required Q for system = 1000 ft$^3$
• What are the velocities at the hood face and within the duct leading to the hood?
Example Problem 2

• A 4” x 8” flanged hood is drawing 500 ft$^3$/min of air. What is the velocity 6” in front of the hood?

• Hint: where…. Centerline!
Example Problem 3

• Find $P_{sh}$ and $C_e$ for a plain end duct and $V=2000$ fpm (assume no friction loss and NTP)

• Hint: $F_e = 0.93$
Example Problem 4
Swing grinder hood

- Hood dimensions; 3 ft high x 5 ft wide
- What Q is needed to get the recommended face velocity of 150 FPM?
- What Q is needed if the opening is 4 x 6 ft?

Paint Booth
Another, albeit more sophisticated Paint Booth
Air Flow
Abrasive Blasting Booth
Enclose device, draw air from points where dust is generated
Furniture Stripping
Local Exhaust Ventilation - Welding
Local Exhaust Ventilation - Welding

LEV is ineffective unless hood is proximal to particulate generation point (~ 1 duct dia.)
Push – Pull Hood - Electroplating
Metal Grinding Process
Canopy Hood – Glass Art
Inappropriate Use of Canopy Hood
Downdraft Tables
Effective hood design?
Effective hood design!