Entry losses, ducts and hoods

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

  \[
  H_f = f \frac{L}{D} P_{v_1}
  \]

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

Friction losses

- We use a simplified form where $H_f$ is proportional to $P_v$ and $L$
  - 

  \[
  H_f = F_f P_v L
  \]

- $F_f$ is determined from charts and figures eg.vent manual or curve fitting
- For example in a galvanized straight duct:

  \[
  H_f = 0.38 \frac{L}{D^{1.22}} (P_v)
  \]
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
  \( \text{-(proportional to } 1/A^{2.5} \text{ but approx } 1/A^2) \)

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

Dynamic Losses - entries

- Hoods are the business end of the capture system
- The hood is the only place where you can capture the contaminant
- Hoods should
  - Minimize the loss of contaminant into the room
  - Not interfere with the work process
  - Minimize energy losses into the system

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. \( Q_{hood} \))
Simple Hood

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

\( P_{sh} \) = hood static pressure

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

Hood entry losses, \( P_{sh} \)

\[
\begin{align*}
0 &= P_{T1} \\
0 &= P_{T2} + \text{losses} \\
0 &= P_{sh} + P_{V2} + \text{losses} \\
\Rightarrow P_{sh} &= P_{V2} + \text{losses} \\
\end{align*}
\]

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

\[
|P_{sh}| = P_v + H_e \\
H_e = F_e P_v \\
P_{sh} = P_v (1 + F_e) \\
\frac{P_{sh}}{P_v} = 1 + F_e
\]

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

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

$C_e$ represents efficiency

- Recall $C_e$ = ratio of actual flow to ideal flow

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

- 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 ($P_h$) into kinetic energy ($P_v$) in the flow
**Ce** is related to **Fe**

- Recall Fe gives hood loss in terms of P:
  \[
  \frac{P_{sh}}{P} = 1 + F_e
  \]

- So if: \( C_e = \sqrt{\frac{P}{P_{sh}}} \) 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 hoods**

- **Ce** depends on the hood geometry
- Unlike **He** it does not depend on **Q** the flow rate

<table>
<thead>
<tr>
<th>HOOD TYPE</th>
<th>DESCRIPTION</th>
<th>COEFFICIENT OF ENTRY LOSS</th>
<th>HOOD LOSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan Opening</td>
<td>Flat</td>
<td>0.75</td>
<td>0.05 mPa</td>
</tr>
<tr>
<td>Flanged Opening</td>
<td>Flanged with capture</td>
<td>0.82</td>
<td>0.06 mPa</td>
</tr>
<tr>
<td>Dome in Core Hood</td>
<td>Dome in core with capture</td>
<td>0.82</td>
<td>0.06 mPa</td>
</tr>
<tr>
<td>Bell Mouth Pull</td>
<td>Bell mouth pull</td>
<td>0.98</td>
<td>0.04 mPa</td>
</tr>
</tbody>
</table>

---

**In class example**

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

**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
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 & knowing cross sectional area of flow

Airflow for capture hoods

• **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

Capture Hoods

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

Continuity of airflow

$Q_1 = Q_2 = Q_3$

Capture velocity

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

Capture velocity equations

- Point Source
  - Shape: Sphere
  - Area: \( A = 4\pi R^2 \)

- Plain Dust Source
  - Shape: Sphere
  - Area: \( A = 6\pi R^2 \)

- Flanged Dust Source
  - Shape: Half Sphere
  - Area: \( A = 2\pi R^2 \)

- Slot With Sides
  - Shape: \( \sim \) Quarter Cylinder
  - Area: \( A = \frac{1}{2}\pi RX + \pi R^2 \)

- Free-Standing Slot
  - Shape: Plane
  - Area: \( A = 2\pi RX + \frac{4}{3}\pi R^3 \)

- 5-Sided Hood
  - Shape: Plane
  - Area: \( A = 5W + H \)

More capture velocity equations

<table>
<thead>
<tr>
<th>HOOD TYPE</th>
<th>DESCRIPTION</th>
<th>ASPECT RATIO/AREA</th>
<th>AIR FLOW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slot</td>
<td>0.2 or less</td>
<td>( A )</td>
<td>( V = 3.7 \text{ L/s} )</td>
</tr>
<tr>
<td>Flanged Slot</td>
<td>0.2 or less</td>
<td>( A )</td>
<td>( V = 3.6 \text{ L/s} )</td>
</tr>
<tr>
<td>Plain Opening</td>
<td>0.2 or greater</td>
<td>( A, W, H )</td>
<td>( V = \frac{4}{3}\pi R^2 + A )</td>
</tr>
<tr>
<td>Flanged Opening</td>
<td>0.2 or greater</td>
<td>( A, W, H )</td>
<td>( V = \frac{6}{3}\pi R^2 + A )</td>
</tr>
</tbody>
</table>

Source: Plog, page 619

Example

- Exterior hood with plain round opening
  - 12 inches in diameter
- Round duct leading to hood
  - 6 inches in diameter
- Required Q for system = 1000 ft³

What are the velocities at the hood face and within the duct leading to the hood?
Example

- A 4” x 8” flanged hood is drawing 500 ft³/min of air. What is the velocity 6” in front of the hood?

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, page 620

Range of capture velocities

<table>
<thead>
<tr>
<th>Examples</th>
<th>Capture Velocity, ft/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporation from tank, degassing</td>
<td>50–100</td>
</tr>
<tr>
<td>Spray booths, intermittent container filling, com-</td>
<td>100–200</td>
</tr>
<tr>
<td>pacted conveyer transfer, welding, filling,</td>
<td></td>
</tr>
<tr>
<td>polishing</td>
<td></td>
</tr>
<tr>
<td>Spray painting in shallow booths, barrel filling,</td>
<td>200–300</td>
</tr>
<tr>
<td>conveyor loading, crushers</td>
<td></td>
</tr>
<tr>
<td>Grinding, abrasive finishing, tumbling</td>
<td>500–2000</td>
</tr>
</tbody>
</table>

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

- **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

- **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

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

Eg. 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

Swing grinder hood example

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

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
Slot & plenum

Source: Dinardi, 1998

END here