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:

$$H_f = F_f P_{V_1} \frac{L}{100'}$$

- 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 $1/A^2$)

Principles of LEV Design

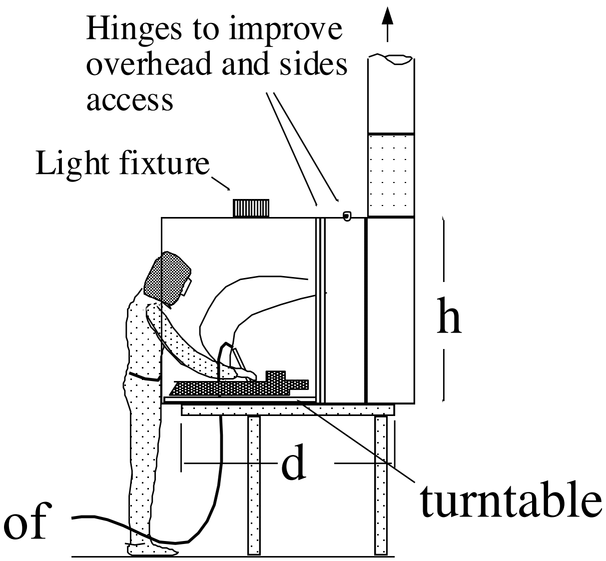
- To protect the worker's breathing zone:
  - the contaminant is captured close to the point of release (local) and removed (exhausted) from work areas
- prevents contaminant migration to other areas
- systems are always mechanical
- volume flow rate is much less than general or dilution ventilation

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

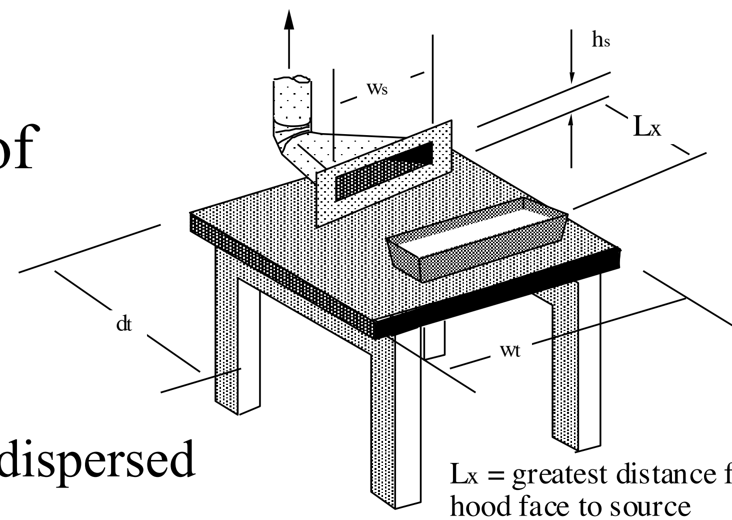
- Enclosing Hood
  - contaminant source contained within hood
  - examples:
    - lab fume hood
    - glove box, paint booth
  - good for:
    - contaminants with high toxicity
    - areas where there is a high cross draft potential
  - Airflow requirements determined by the product of velocity x area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



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



Lx = greatest distance from hood face to source

Basic Hood Types

Enclosing

Capture

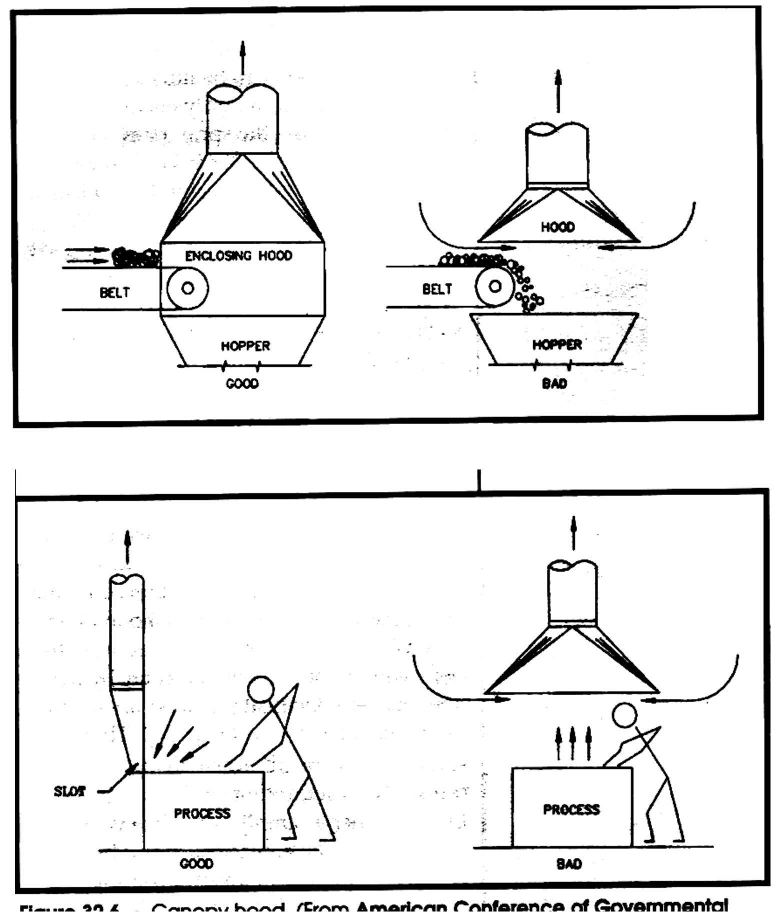
Hood Types

- 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

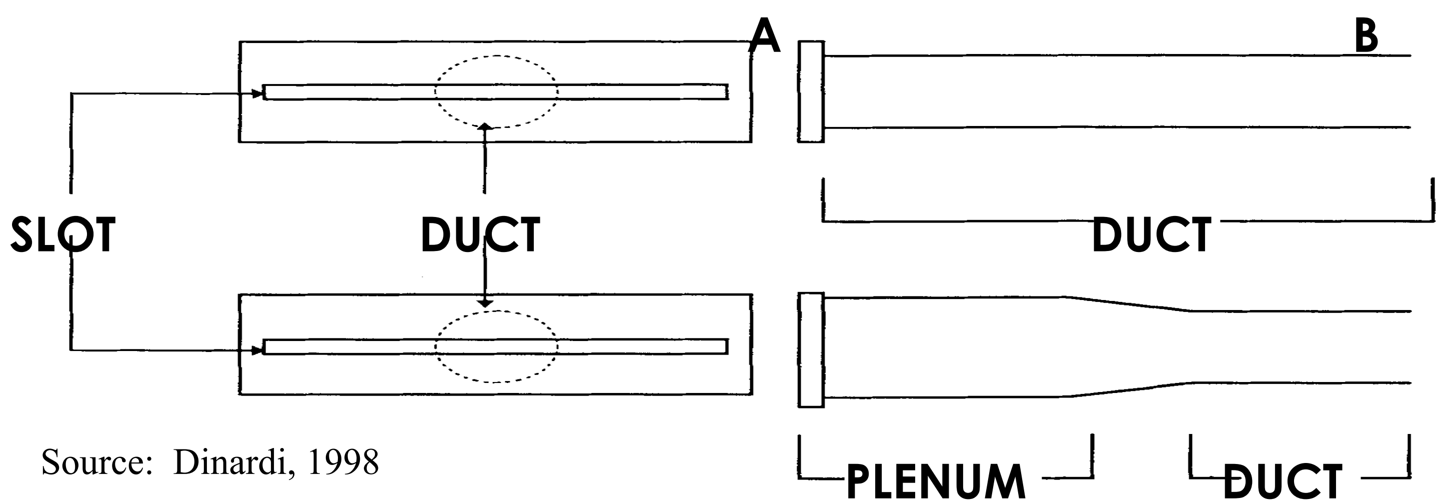
- Control velocity = V_f = face velocity
  - What velocity across hood face is necessary for proper contaminant control?
    - Nature of the process and contaminants generated
    - Hood shape and size
    - Magnitude of cross drafts
  - Higher is not always better
- Getting an even distribution of airflow 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

- <u>Design parameters for hoods</u>

  Hood geometry/shape

  Hood size

  Q = volumetric flow rate (CFM)

$$Q = VA$$

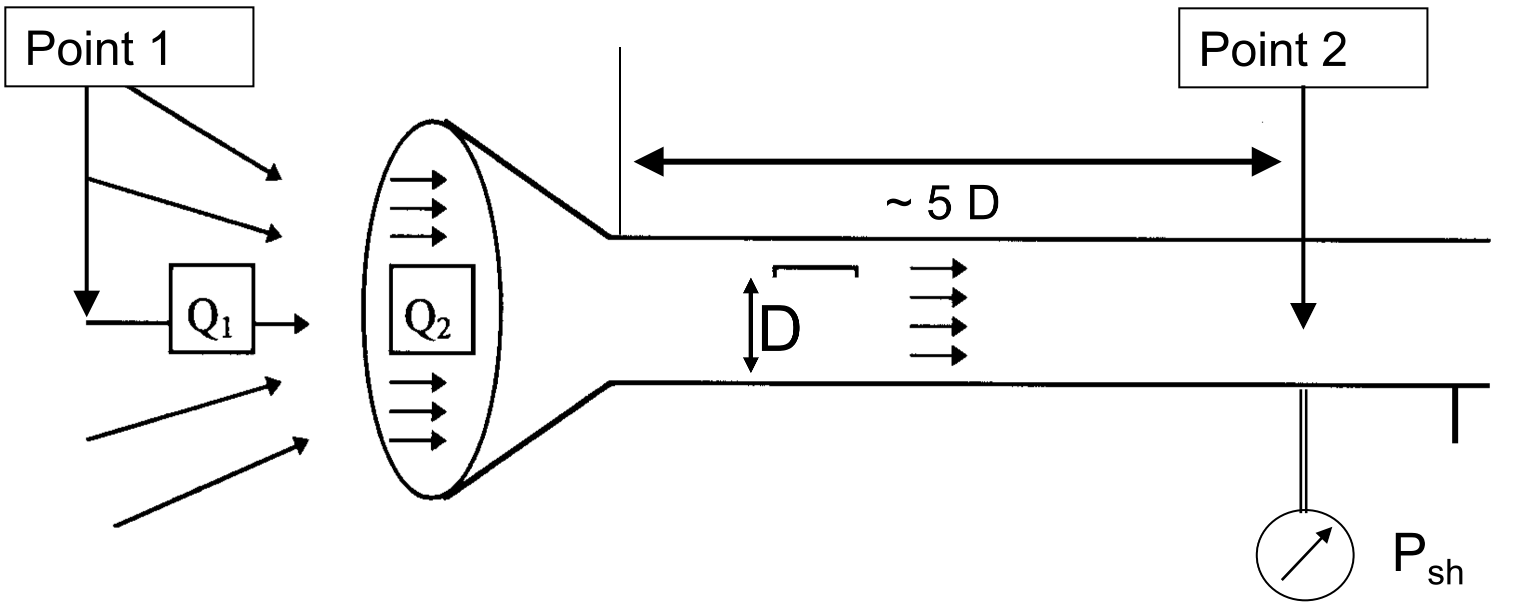
V = air velocity in fpm

A = 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

$$P_{T1} = P_{T2} + \text{losses}$$



$Q_1 = Q_2 = Q_3$

P_{sh} = hood static pressure

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

Hood entry losses, P_{sh}

$$0 = P_{T1}$$

$$0 = P_{T2} + losses$$

$$0 = P_{sh} + P_{V2} + losses$$

$$\boxed{-P_{sh} = P_{V2} + losses}$$

If we apply the sign convention,

Pv2 and losses are + terms

- The P_{sh} is the pressure needed to:
  - Set the air into motion (Pv 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

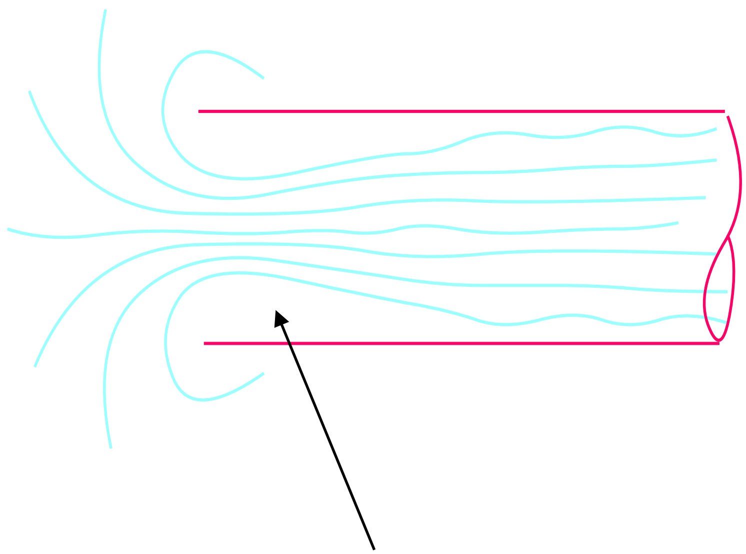
Hood static pressure

- Other forms: $\left|P_{sh}\right| = P_V + losses$
  - The losses are characteristic of the hood shape and are defined as the hood entry loss H_e (e=entry)

$$\left|P_{sh}\right| = P_V + H_e$$

  - 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

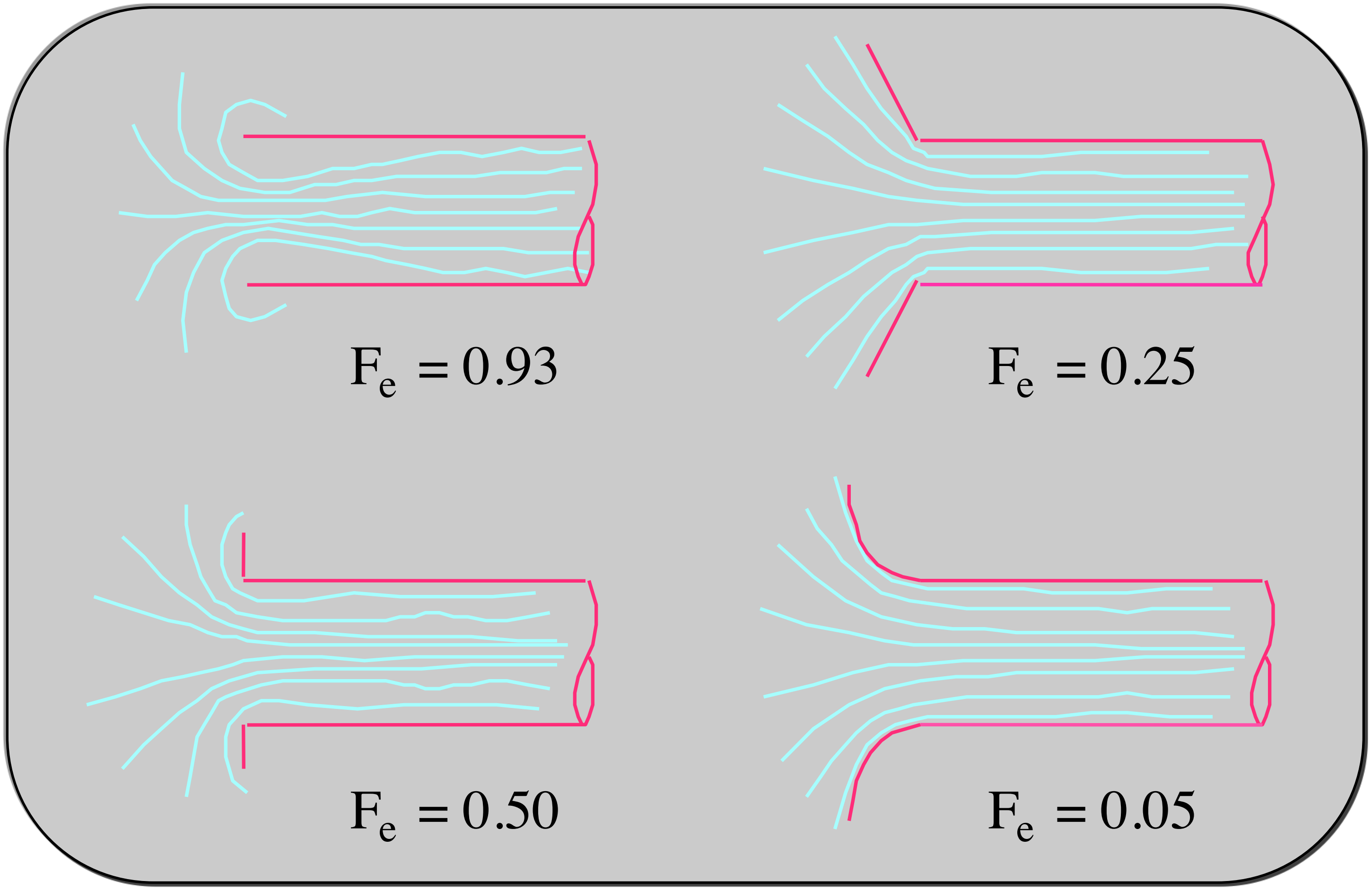
$$\left|P_{sh}\right| = P_V + H_e$$

$$H_e = F_e P_V$$

$$P_{sh} = P_V + F_e P_V$$

$$P_{sh} = P_V (1 + F_e)$$

$$\frac{P_{sh}}{P_V} = 1 + F_e$$



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 Ce as the coefficient of entry

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

Q_{actual} ← Actual flow

Q_{ideal} ← Ideal flow with no losses

C_e represents efficiency

- Recall C_e = ratio of actual flow to ideal flow

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

- So: $$C_e = \frac{4005\sqrt{P_V}\cdot(area)}{4005\sqrt{P_{Sh}}\cdot(area)} = \sqrt{P_V / P_{Sh}}$$
- Ce 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 Fe gives hood loss in terms of P_v

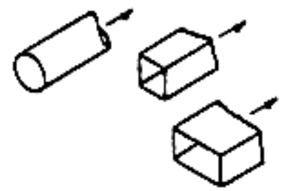
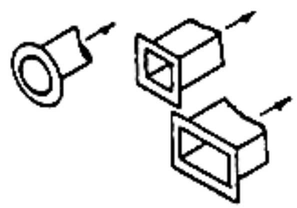
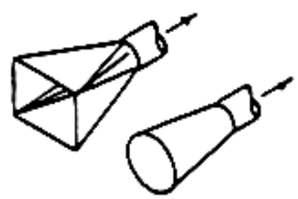
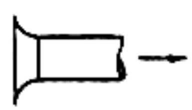
$$\frac{P_{sh}}{P_V} = 1 + F_e$$

- So if: $C_e = \sqrt{P_V / P_{Sh}}$ then $\boxed{C_e^{\,2} = \frac{1}{[1 + F_e]}}$

- 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

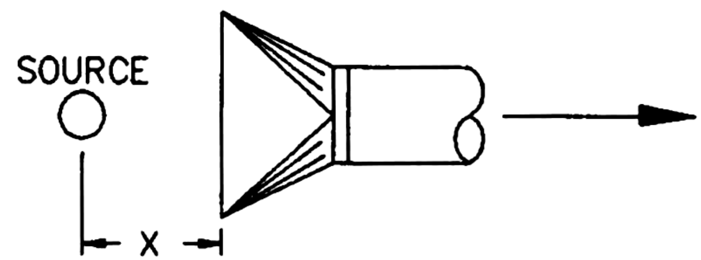
HOOD TYPE	DESCRIPTION	COEFFICIENT OF ENTRY, Ce	ENTRY LOSS
	PLAIN OPENING	0.72	0.93 VP
	FLANGED OPENING	0.82	0.49 VP
	TAPER or CONE HOOD	Varies with angle of taper or cone. See Fig. 6-10	
	BELL MOUTH INLET	0.98	0.04 VP

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

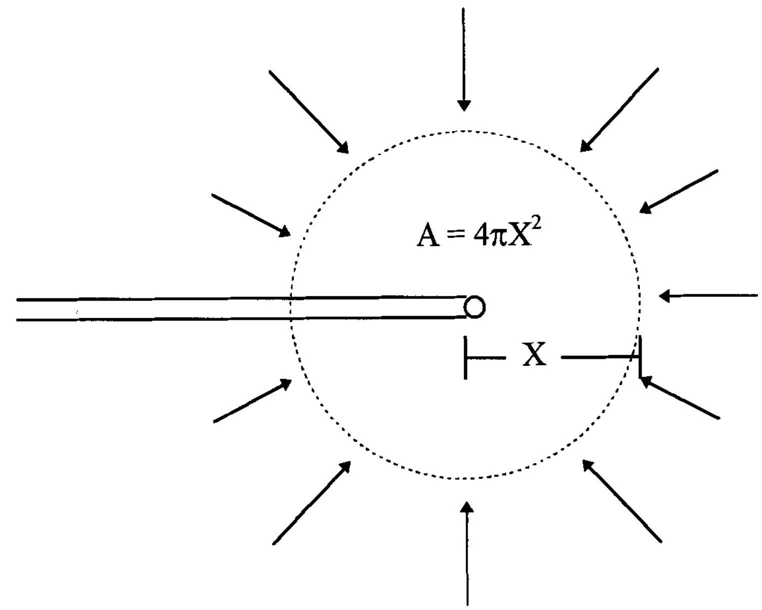
- Control velocity = V_c or capture velocity
  - Velocity needed to overcome opposing forces
    - Cross drafts
    - Motion imparted by process, etc.
- Design parameter = Q
  - To determine the Q needed, we can use the velocity Vc needed to capture contaminant at point x in front of the hood



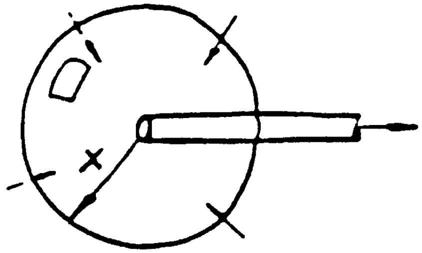
Source: Dinardi SR. (1998)

Capture velocity

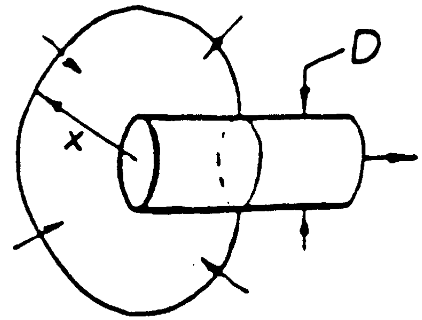
- Relationship between Q, Vc and X
  - Assumptions
    - Contaminant source at point X
    - Point suction source
    - Air flows into point source from all directions



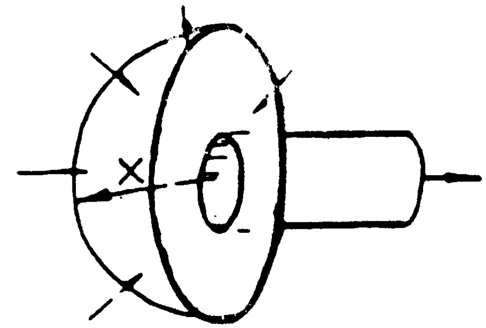
Capture velocity equations



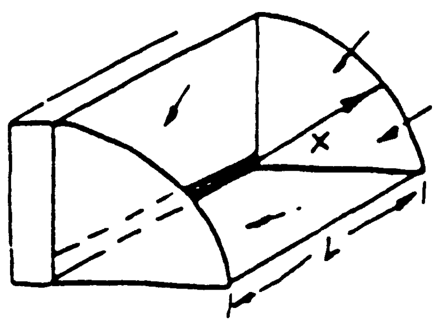
Point Source
Shape - Sphere
Area ≅ $4\pi X^2$



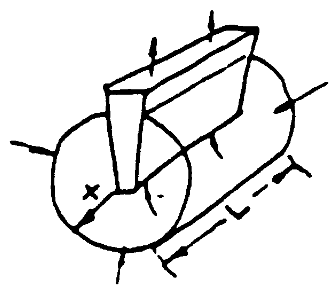
Plain Duct
Shape - ~Sphere
Area ≅ $4\pi X^2 - (\pi D^2 \div 4)$



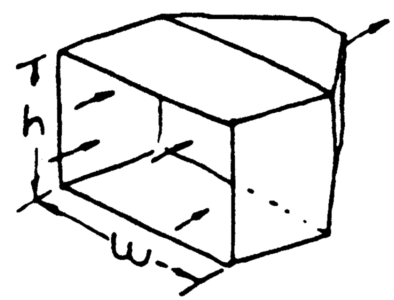
Flanged Duct
Shape ~ Half Sphere
Area ≅ $2\pi X^2$



Slot With Sides
Shape ~ 1/4 Cylinder
Area ≅ $1/2\ \pi XL$

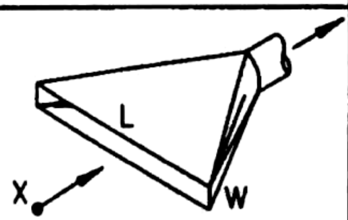
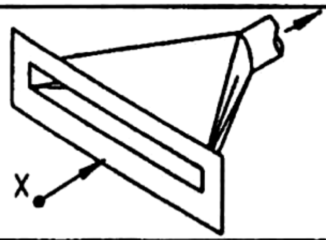
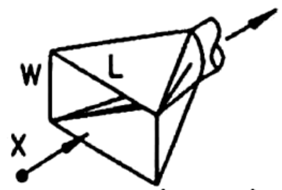
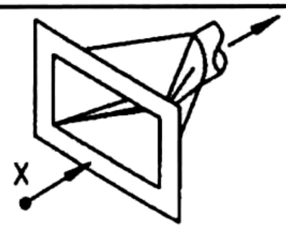


Free-Standing Slot
Shape ~ Cylinder
(+ Sphere)
Area ≅ $2\pi XL\ (+4\pi X^2)$



5-Sided Hood
Shape - Plane
Area = h × w

More capture velocity equations

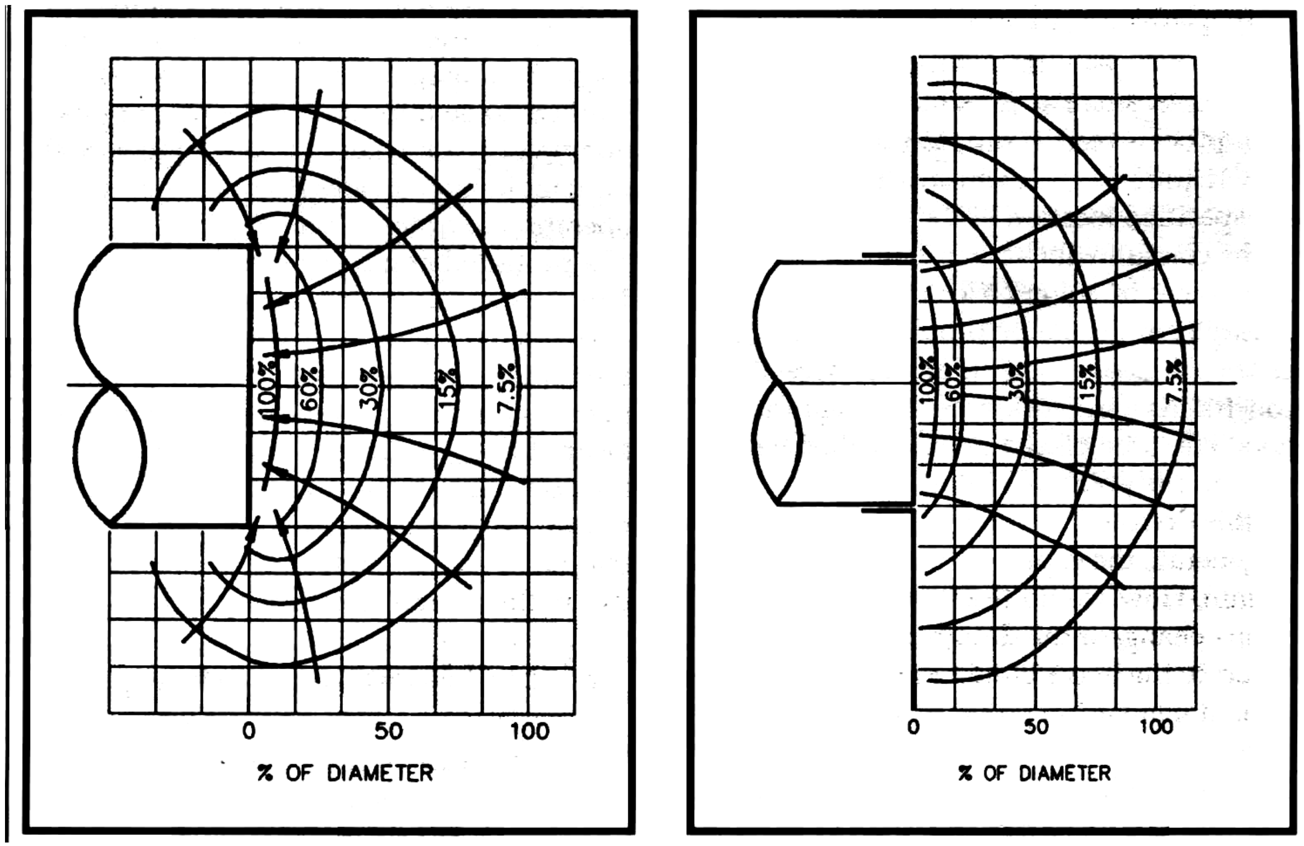
HOOD TYPE	DESCRIPTION	ASPECT RATIO, W/L	AIR FLOW
	SLOT	0.2 OR LESS	$Q = 3.7\ LVX$
	FLANGED SLOT	0.2 OR LESS	$Q = 2.6\ LVX$
 A = WL (sq.ft.)	PLAIN OPENING	0.2 OR GREATER AND ROUND	$Q = V(10X^2 + A)$
	FLANGED OPENING	0.2 OR GREATER AND ROUND	$Q = 0.75V(10X^2 + A)$

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 19–A. *Range of Capture Velocities*

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

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

Lower End of Range	*Upper End of Range*
1. Room air currents minimal or favorable to capture.	1. Disturbing room air currents.
2. Contaminants low toxicity or of nuisance value only.	2. Contaminants of high toxicity.
3. Intermittent, low production.	3. High production, heavy use.
4. Large hood-large air mass in motion.	4. Small hood-local control only.

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

Source: Plog (2002).

END here

- 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!

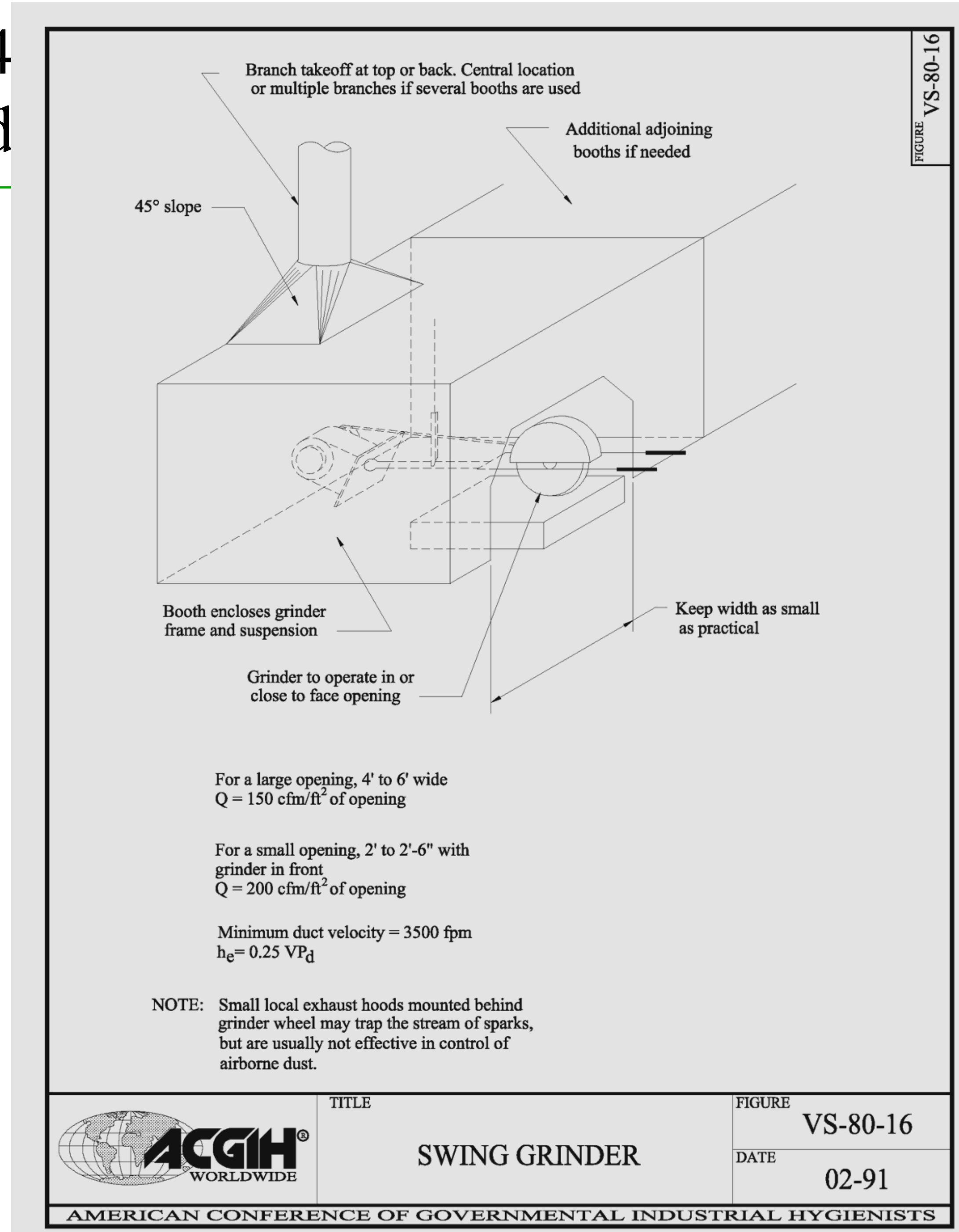
Example Problem 3

- 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?
- Refer to Vent Manual, page 10-138 (25th ed)



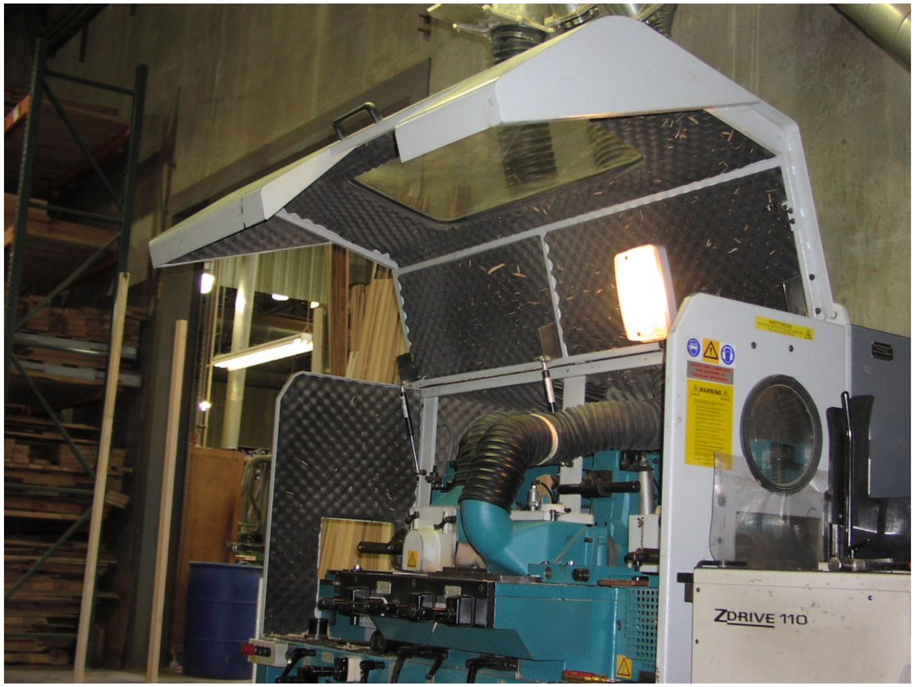
Paint Booth

Another, albeit more sophisticated Paint Booth


Air Flow

Abrasive Blasting Booth

Wood Products Manufacturing

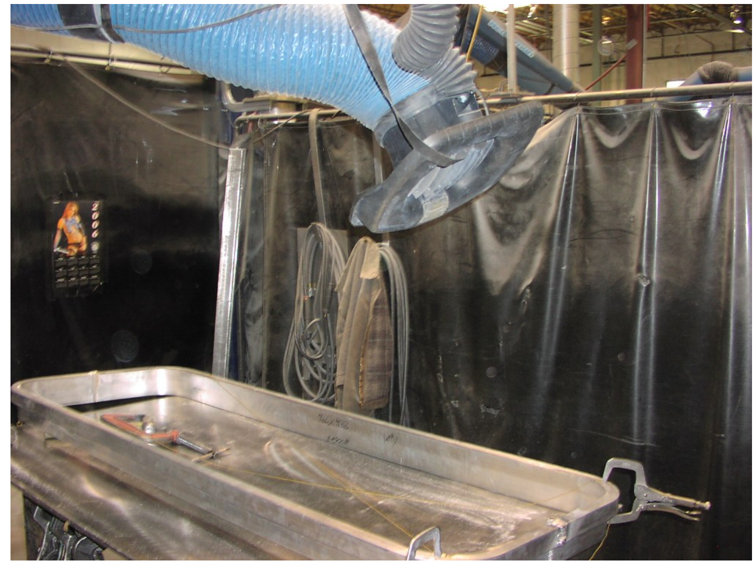


Enclose device, draw air from points where dust is generated

Furniture Stripping

Local Exhaust Ventilation - Welding

Local Exhaust Ventilation - Welding

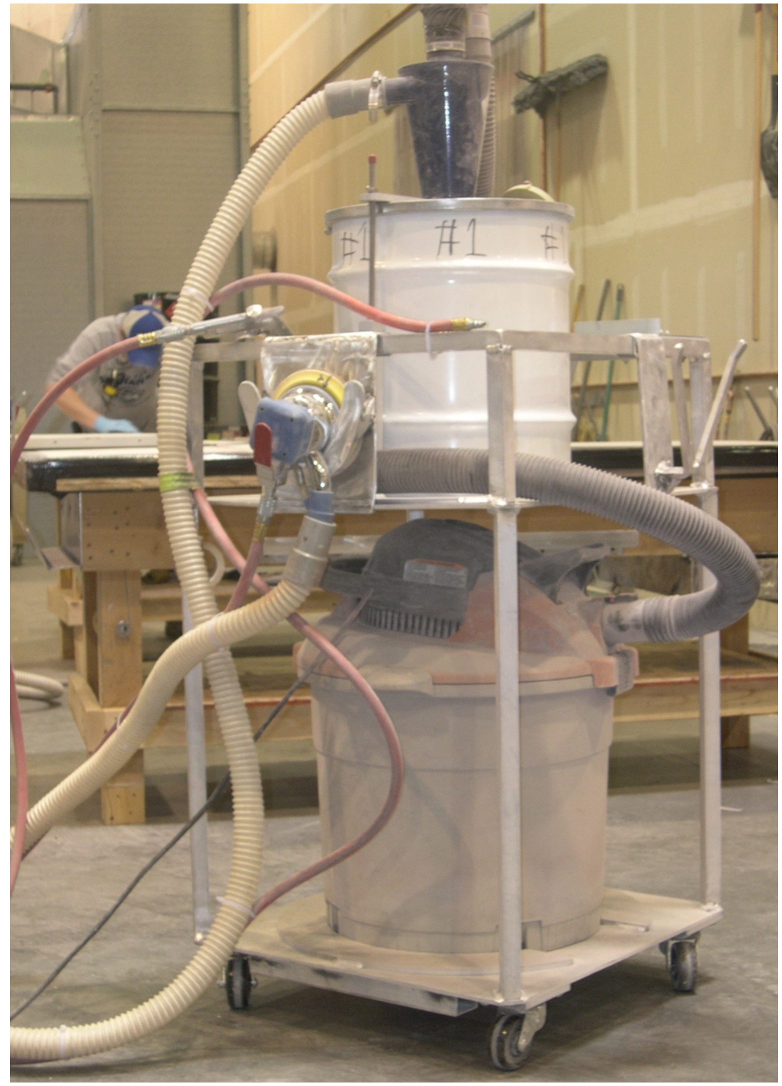


LEV is ineffective unless hood is proximal to particulate generation point (~ 1 duct dia.)

Push – Pull Hood - Electroplating


Metal Grinding Process

Tool Equipped LEV

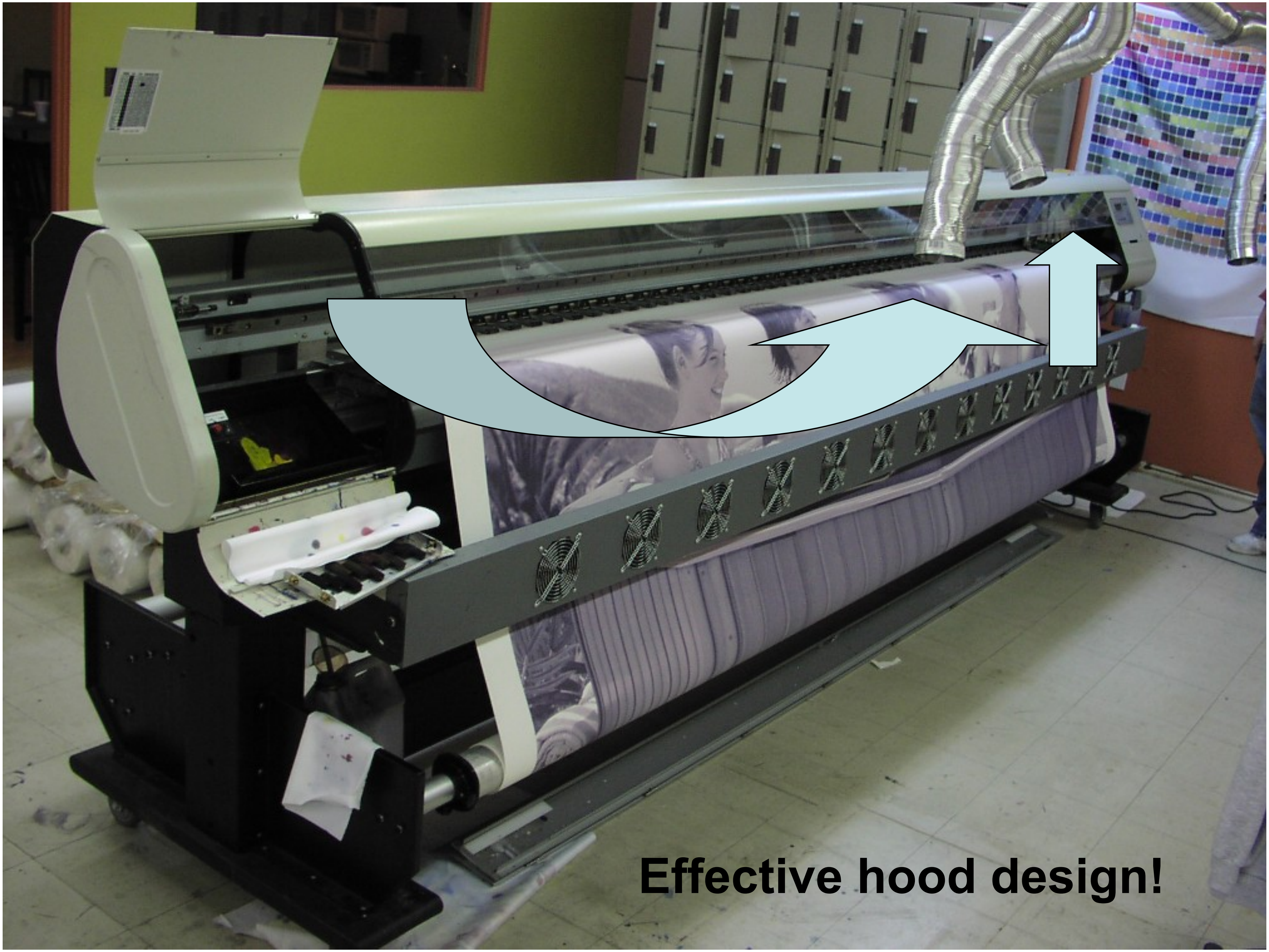


Canopy Hood – Glass Art

Inappropriate Use of Canopy Hood

Downdraft Tables

Effective hood design?


Effective hood design!