Ventilation System Maintenance and Program Management

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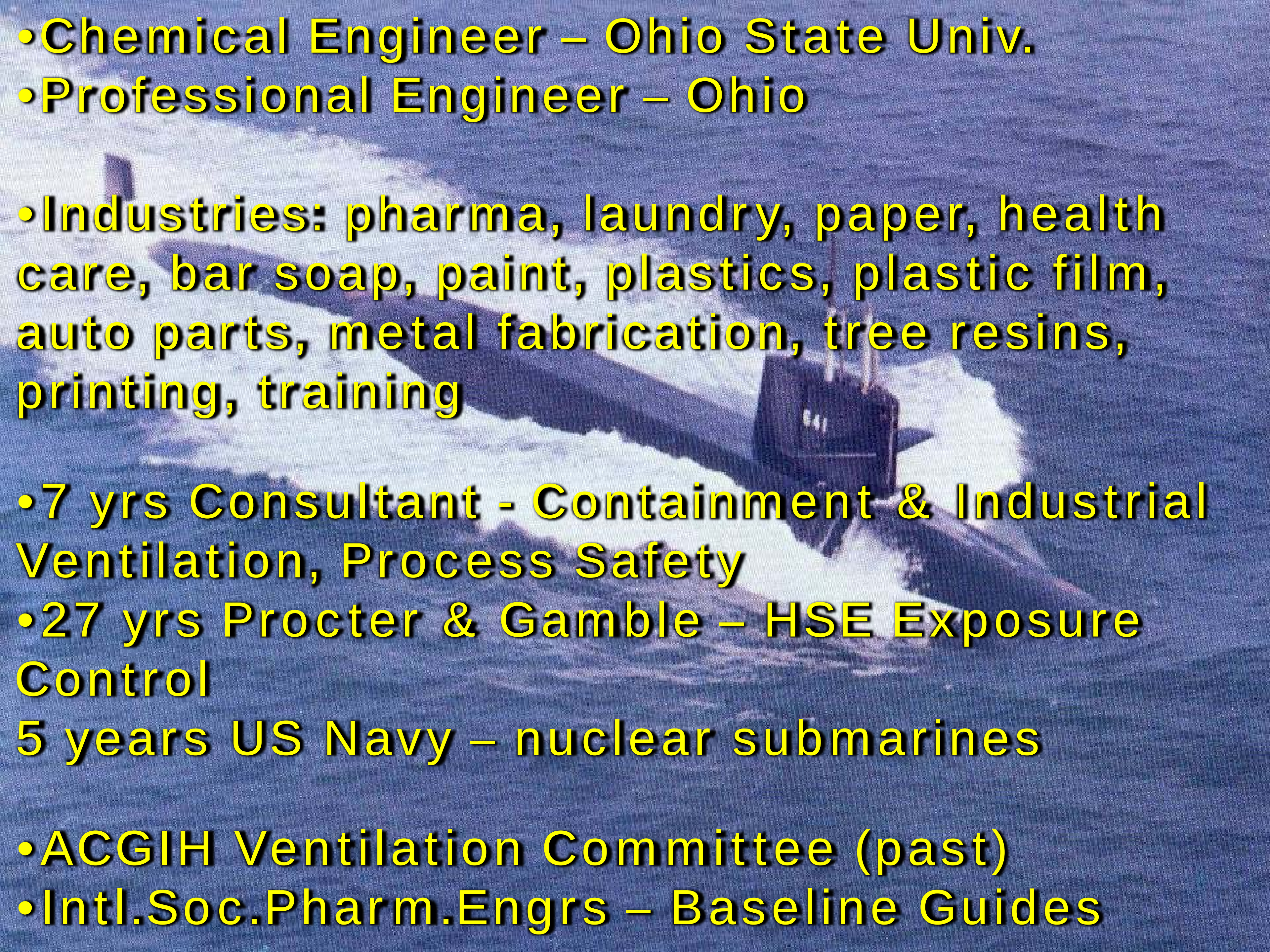
Workplace Exposure Solutions LLC
NASA Occupational Health Meeting
Cleveland, OH – July 13, 2009

Course Agenda

- Learning Objectives
  - Explain ventilation system management best practices
  - Describe practical monitoring and maintenance tips for NASA local exhaust ventilation systems
- Agenda
  - Management best practices
  - Ventilation failure modes and routine monitoring
  - Troubleshooting
  - Deciding monitoring frequency – Maintenance Risk Assessment
  - Commissioning Lab Hoods
  - Emerging technology issues and wrap up



- Chemical Engineer – Ohio State Univ.
- Professional Engineer – Ohio

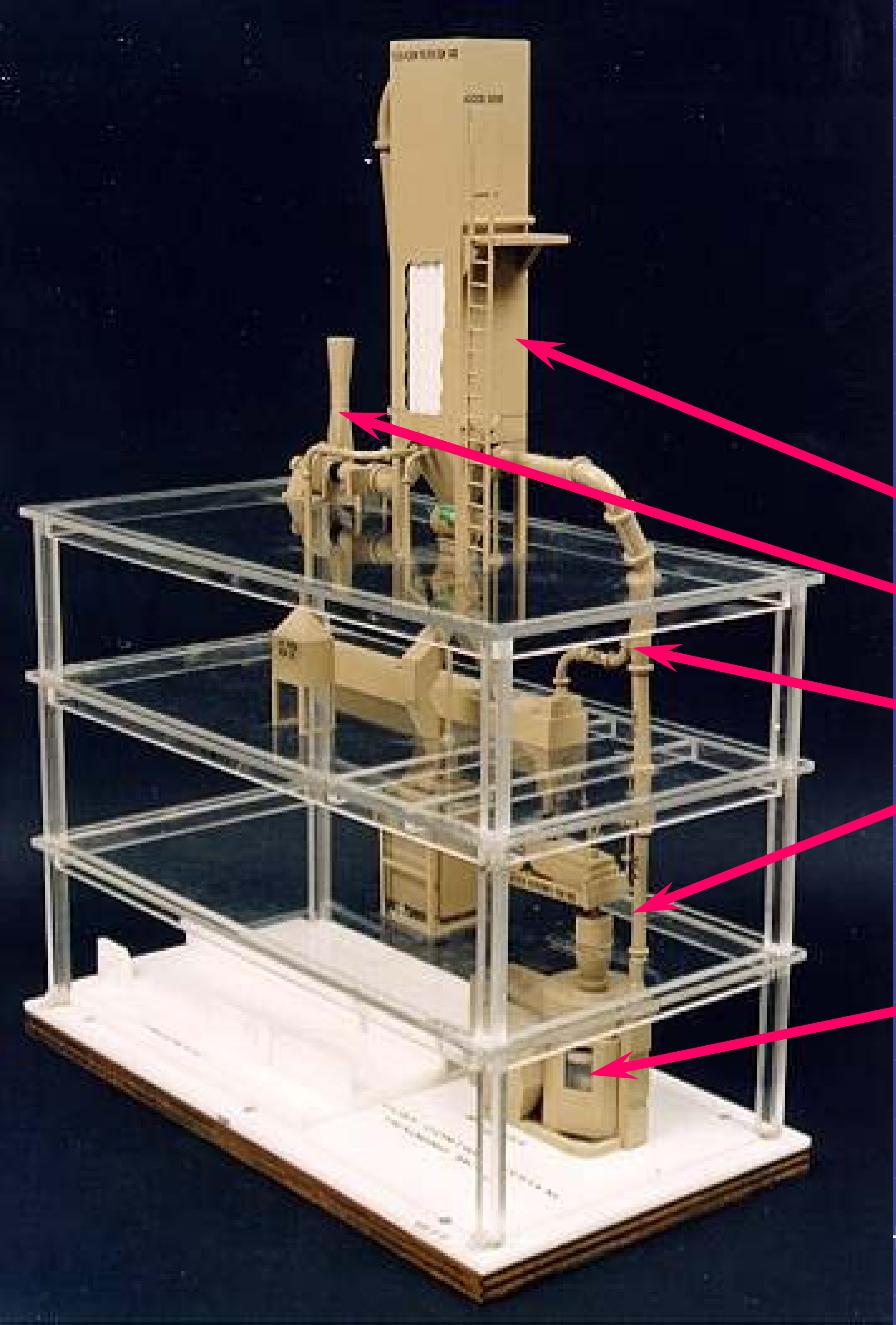
- Industries: pharma, laundry, paper, health care, bar soap, paint, plastics, plastic film, auto parts, metal fabrication, tree resins, printing, training

- 7 yrs Consultant - Containment & Industrial Ventilation, Process Safety
- 27 yrs Procter & Gamble – HSE Exposure Control

5 years US Navy – nuclear submarines

- ACGIH Ventilation Committee (past)
- Intl.Soc.Pharm.Engrs – Baseline Guides

4 C's of IVS (Functions)



Filter - COLLECT

Ducts & Fan - CONVEY

Carton Filler Cabinet – CONTAIN

Dust Ring - CAPTURE

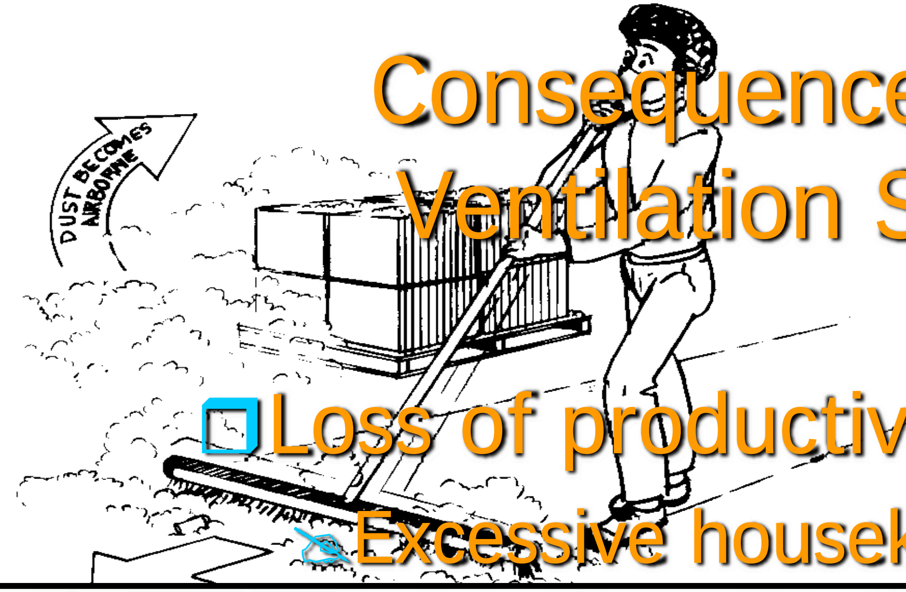
How Does an IVS Protect?

- Contains or captures contaminants with shaped air flow patterns at each pickup point for the process
- IVS reliably provides exhaust airflow from each contaminant pickup by
  - Maintaining target range for contaminant conveying velocity in all duct branches
  - Operating collector at consistent differential pressure
  - Operating collector to meet environmental emission limits
  - Running the exhaust fan to provide constant exhaust flow and static pressure for the system

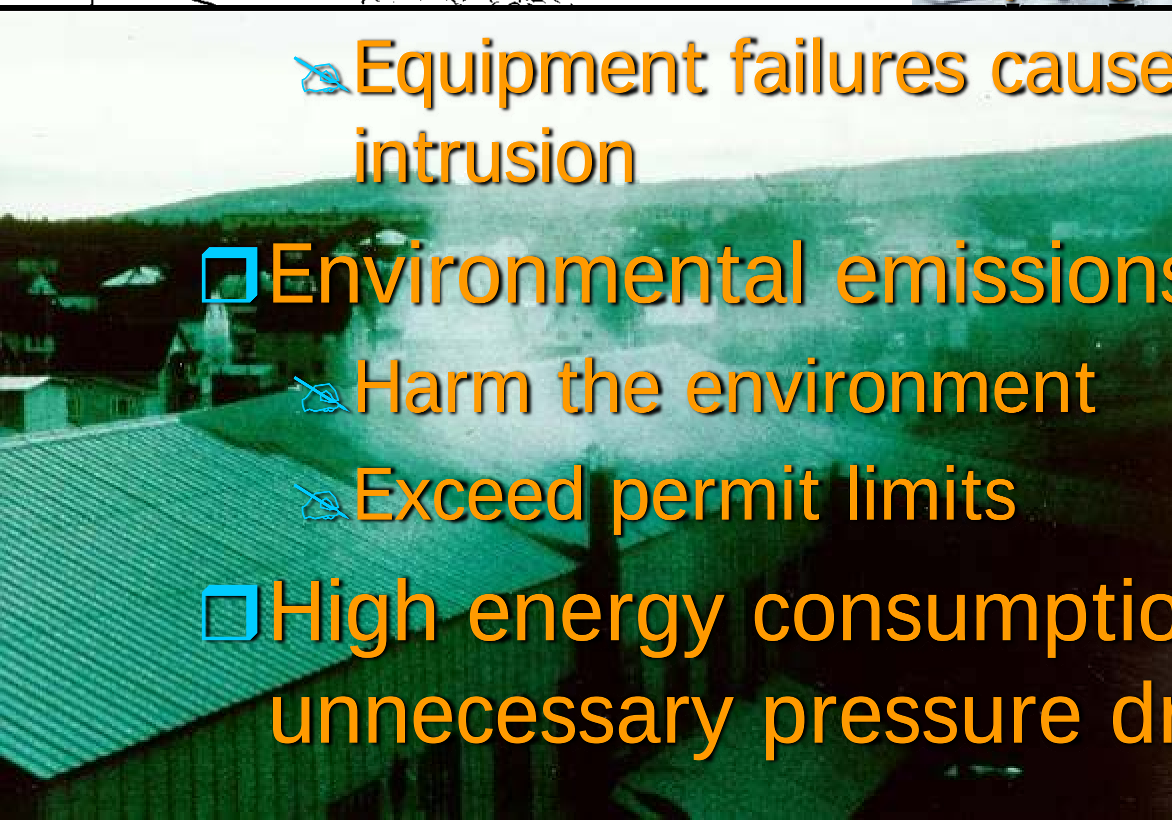
Consequences of Industrial Ventilation System Failure

- **Worker overexposure to irritating or toxic materials**
- **Combustible dust or flammable vapor explosions due to accumulations in**
  - **Workplace**
  - **Ductwork**
- **Unacceptable product quality due to**
  - **Drafts changing formulation**
  - **Contaminants drawn in**

Consequences of Industrial Ventilation System Failure



- Loss of productivity due to
  - Excessive housekeeping effort
  - Equipment failures caused by dust intrusion

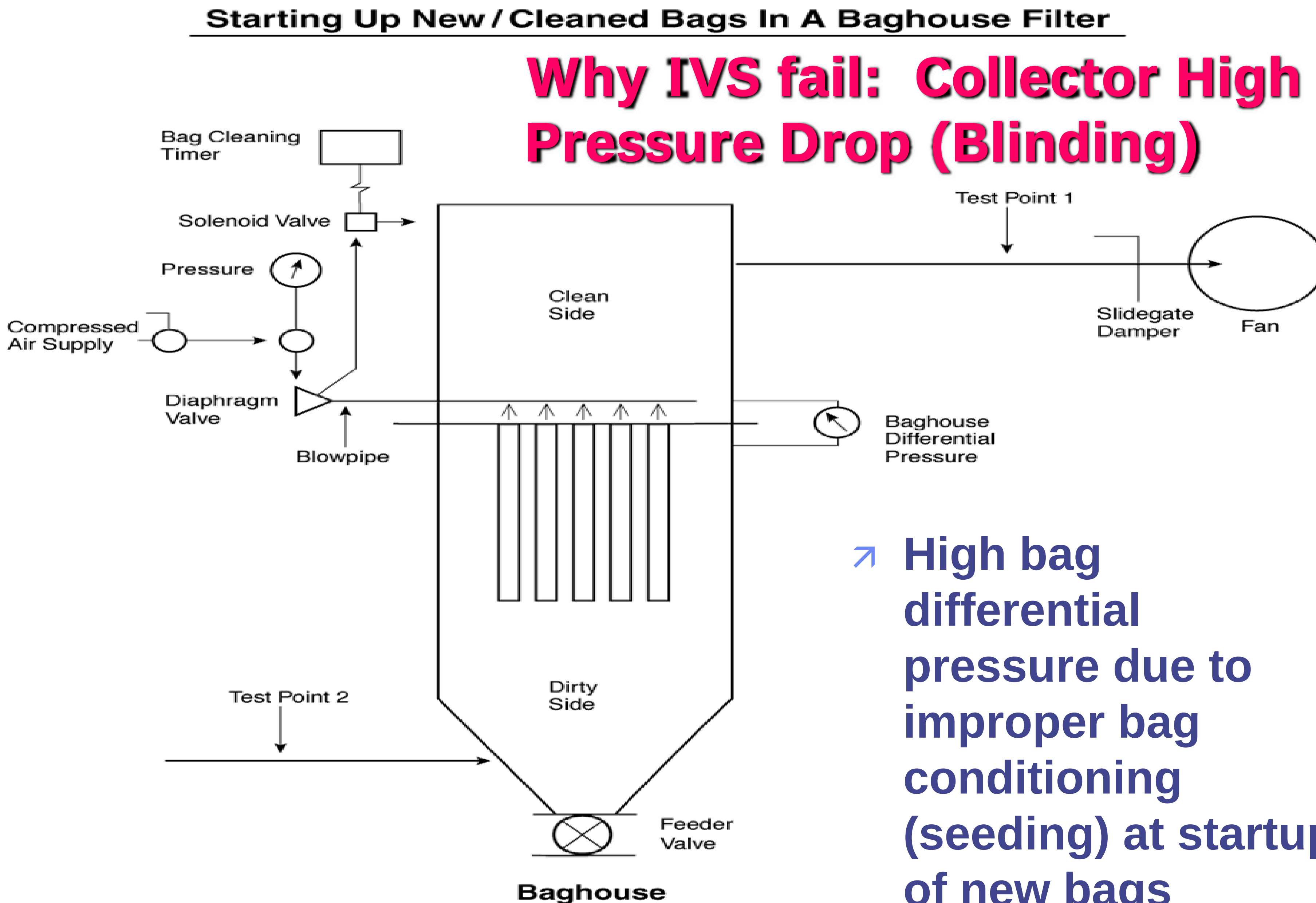


- Environmental emissions that
  - Harm the environment
  - Exceed permit limits
- High energy consumption due to unnecessary pressure drop

Why IV Systems fail: Duct Buildup

- Dust builds up on elbows or straight duct due to: Smearing, Dropout, Gunk

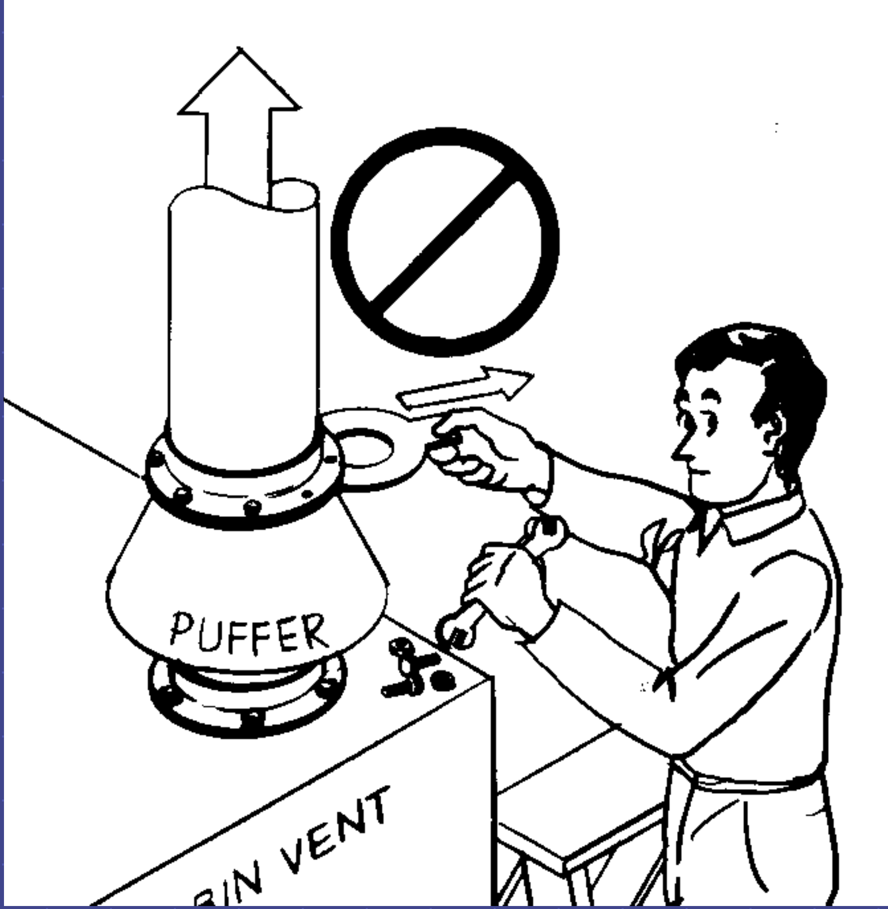
Why IVS fail: Collector High Pressure Drop (Blinding)



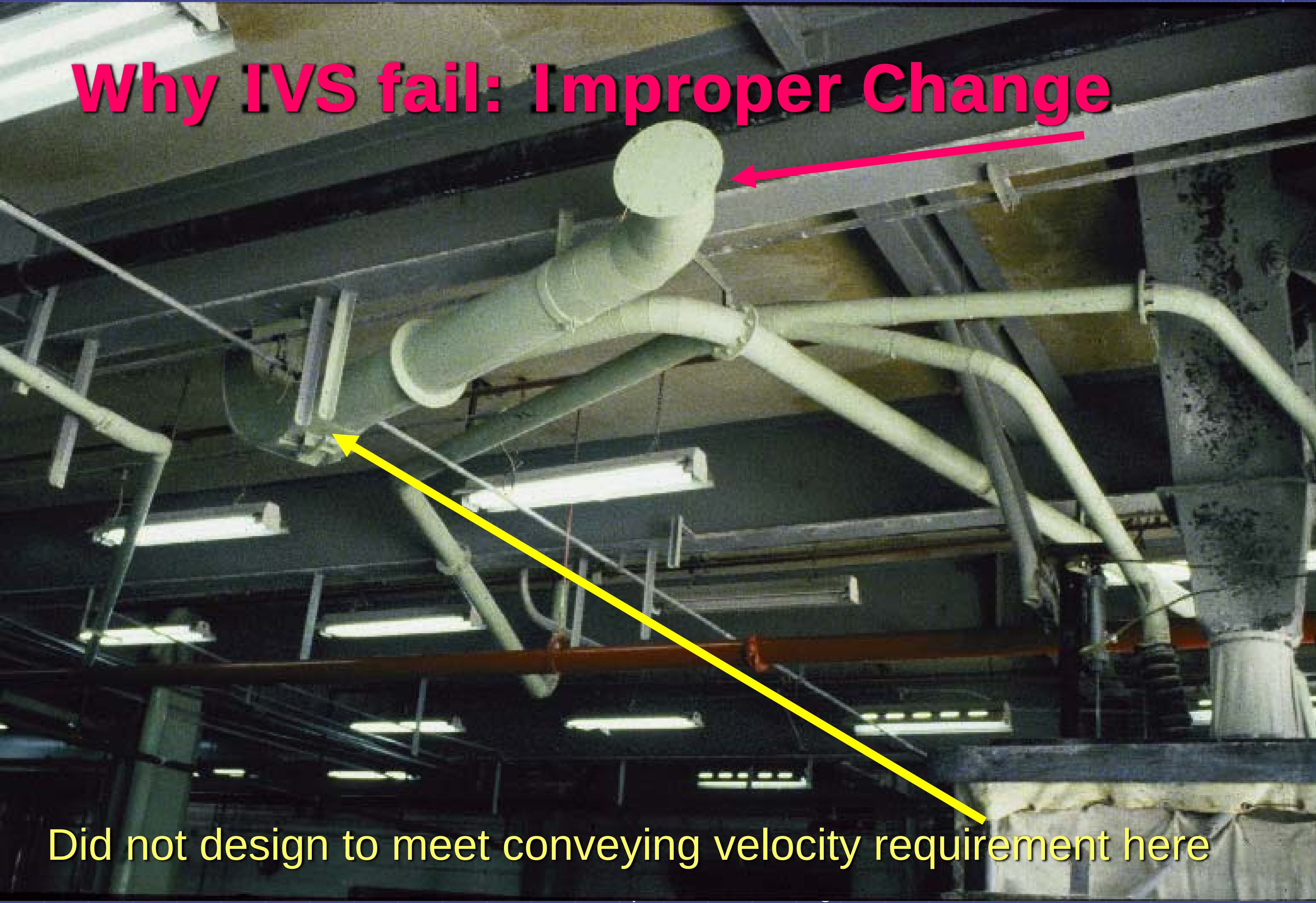
- High bag differential pressure due to improper bag conditioning (seeding) at startup of new bags

Why IVS fail: Changing Balancing Devices

- Remove balancing orifice
- Opening blast gate



Why IVS fail: Improper Change



Did not design to meet conveying velocity requirement here

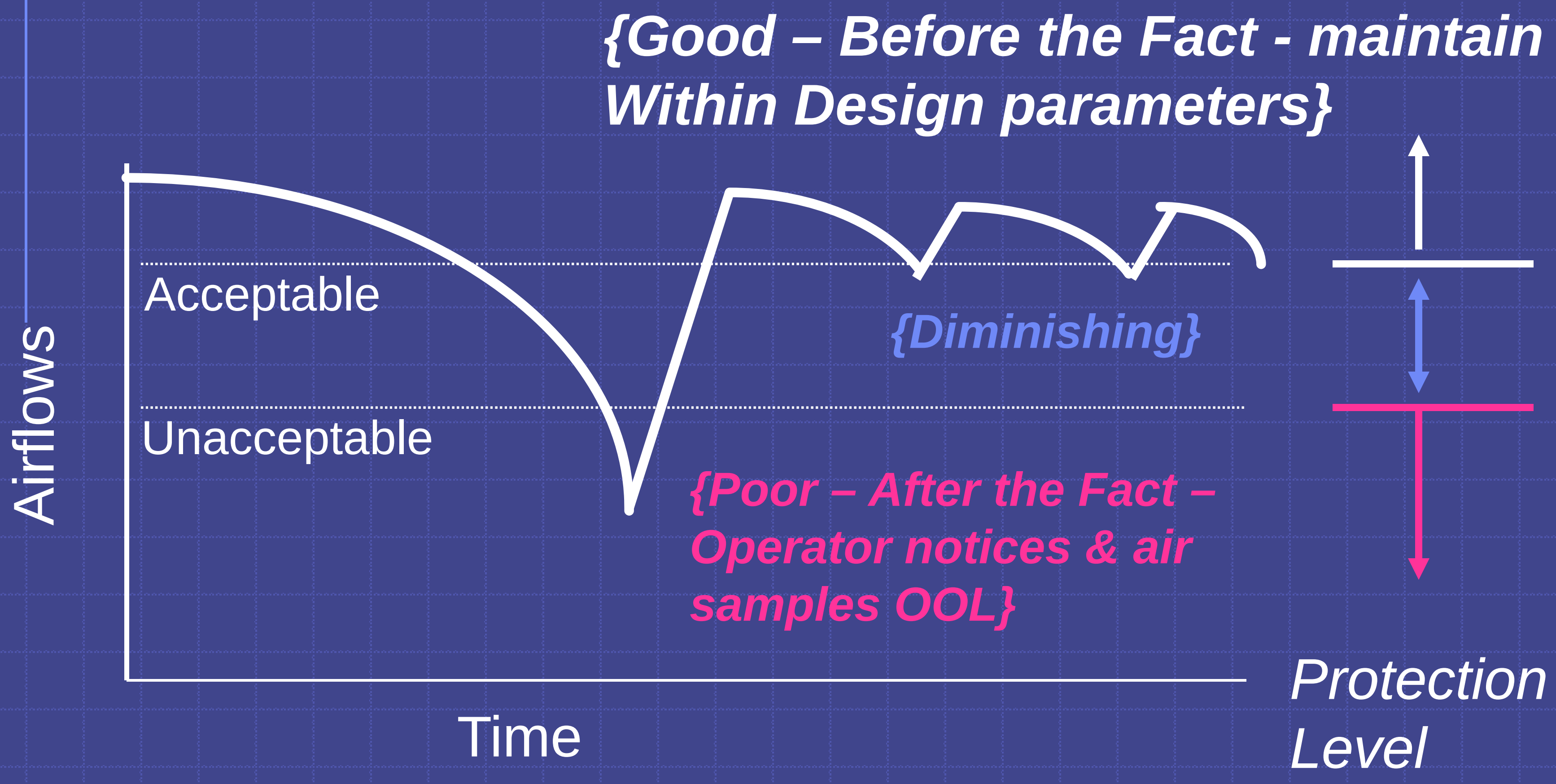
Why IVS fail: Changes to Calculated System Resistance :

- Dust plugs ducts, elbows first - more resistance
- Baghouse filter media blinds - poor startup seeding
- Bags bridge in filter - dust removal failure
- Access door left open or even ajar - bypassing
- Fan belts wear and slip
- Balancing orifices or blast gates removed/changed
- Unauthorized changes to system
- Design not robust enough to minimize duct pluggage
- Proof of performance not measured or documented

Why IVS fail: Management Omissions

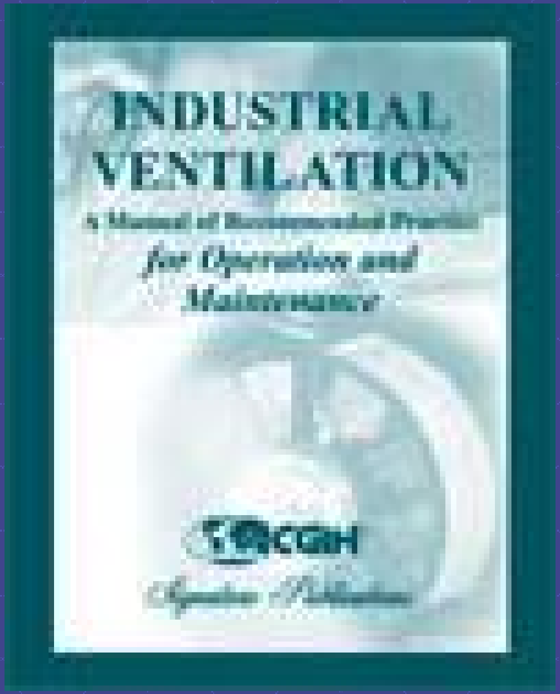
- Lack of management ownership and support
- No one accountable for system operation
- No trained personnel on site
- Breakdown rather than predictive maintenance
- No scheduled maintenance checks
- Cannot get downtime to clean/maintain system
- No system in place to ensure changes done by competent resources

Graphical View of System Performance Degradation



Ventilation Management Best Practices

1. Construction
2. Commissioning
3. Measurements
4. Balancing with Dampers
5. Monitoring & Maintenance
6. Air Cleaning Devices
7. Troubleshooting
8. IVS Changes
9. Operator Training



IV-O&M, ACGIH, 1st Edition, 2007

ANSI/AIHA Z9.2 – Fundamentals Governing the Design and Operation of Local Exhaust Ventilation Systems

1. Scope
2. Referenced Stds, Publ.
3. Definitions
4. General Requirements
5. Plant Layout and Construction
6. Makeup Air Systems
7. Exhaust Hoods
8. Ductwork and Stacks

(Available AIHA.org)

9. Air Cleaning Equipment
10. Fans and Air Moving Devices
11. Management of LEV Systems
12. Construction and Installation
13. Operations and Maintenance
14. Testing, Balancing, and Operational Checks

Key Elements of Ventilation System IV-O&M Management Best Practices – Chapter 5

- Comply with EPA and OSHA regulatory limits & NFPA standards
- Provide Baseline verification
- Take corrective action with deviation from Baseline
- Conduct Maintenance Risk Assessment – *how long can system be out of design limits?*
- Implement ALERT Monitoring
- Implement DEGRADATION Monitoring
- Document management expectations
- Provide adequate staffing
- Seek continuous improvement
- Changes redesign IVS to maintain velocities

Management Best Practices Compliance with regulatory limits

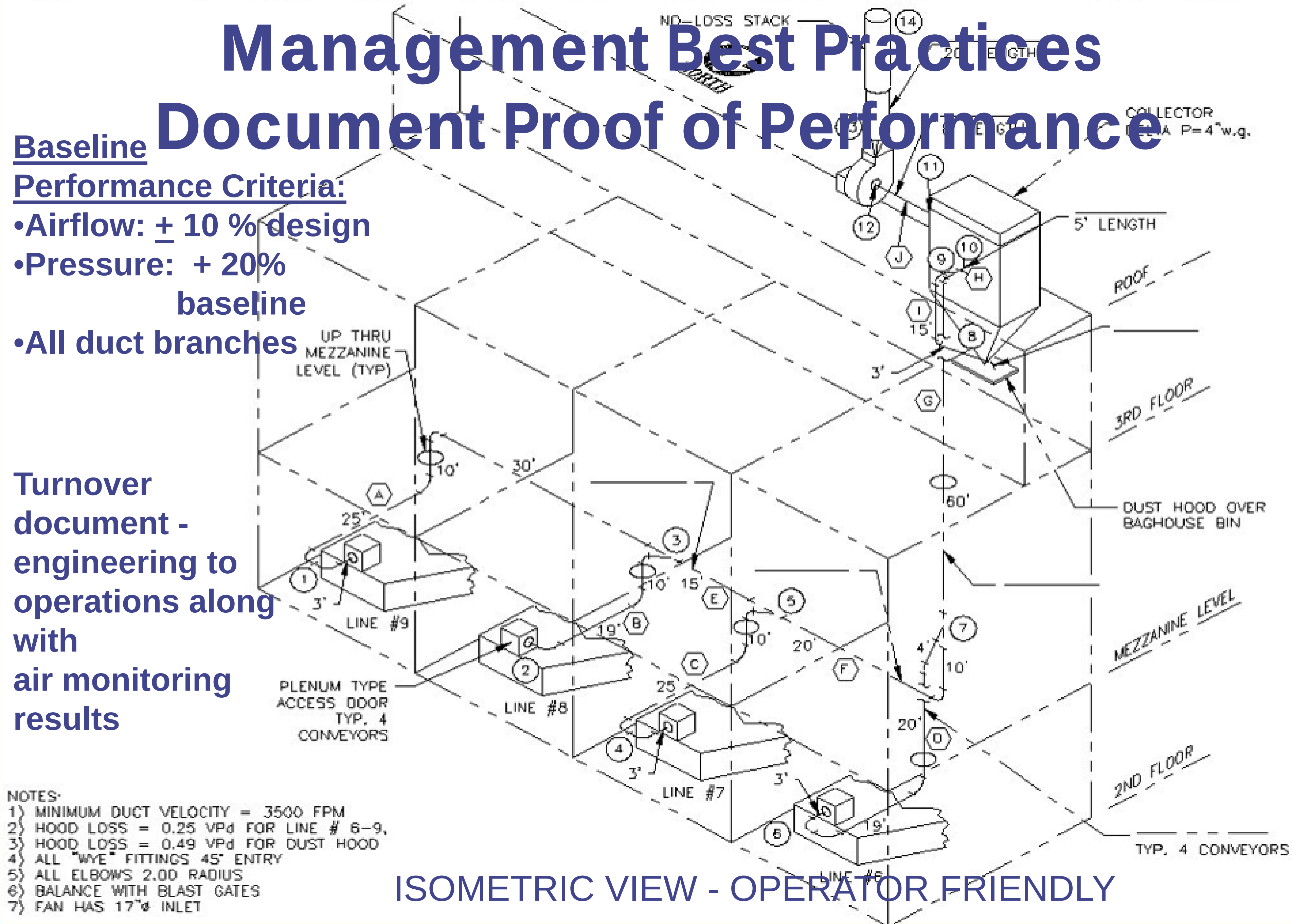
- Environmental emissions
  - State or Federal emissions permit limits
  - Data gathering and action limits
- Health and Safety limits
  - OSHA PEL's, ACGIH TLV's, NIOSH REL's
  - OSHA Ventilation regulations – see handout
- National Fire Protection standards – see handout
  - Flammable and combustible liquids
  - Combustible dusts
- Build applicable requirements into management program – see references in handout

Management Best Practices
Document Proof of Performance

Baseline Performance Criteria:

- Airflow: ± 10 % design
- Pressure: + 20% baseline
- All duct branches

Turnover document - engineering to operations along with air monitoring results



ISOMETRIC VIEW - OPERATOR FRIENDLY

Expectations: System Documentation

- Suggestion: All technical data for one IVS in one notebook which contains:
  - Monitoring & Maintenance Schedule
  - Calculations, Baseline measurements and date
  - As Built System Isometrics and schematics
  - Hood design basis, dimensions, airflows, SP's
  - Equipment Specification Data & Drawings
  - Operating log sheets with action limits indicated
  - Trend tracking logs/charts and corrective action
  - Mechanical maintenance and corrective action

Reference Information Needed for Maintenance

- Face velocities at all dust pickups
- Startup room air monitoring results
- Airflows and static pressures at all duct network test points - design and baseline
- Airflow balancing devices and locations
  - Orifice diameters OR
  - Blast gate settings
- Collector & collected emissions removal system design information
- Exhaust fan design information

Management Best Practices Maintenance Risk Assessment

- Objective:
  - Starting frequency for system monitoring
- Q1: How long can system be out of limits (*before the fact* design parameters, not *after the fact* IH samples) due to
  - Health, Flammability, Reactivity properties?
  - Specific Material Regulatory Requirements?
- Q2: How rapidly would the IVS degrade due to:
  - Problem contaminants?
  - Poor system design or operation?

Management Best Practices Identifying Sudden Failures

- ALERT Monitoring
  - Provide warning of rapid changes that could potentially hurt IVS performance (ie, fan failure, plastic bag, etc.)
  - Change to long term frequency based on monitoring data and experience
  - What are risks if system not operating within best practice design parameters (health, combustible dusts, quality, etc.)

ALERT:

Visual Indication or Automatic Alarms

Management Best Practices
Identifying Gradual Failures

DEGRADATION Monitoring

- Establish on-going degradation and trend monitoring of the IVS System to:
- Identify the places where and when the system routinely begins to degrade, helpful for troubleshooting, and
- Provide confidence that the ALERT monitoring locations give adequate early warning
- Change to long term frequency based on monitoring data and experience – ALERT monitoring points may be enough based on data from experience

Management Best Practices Document Expectations

1. Consistently meet environmental permit requirements
2. Consistently operate system within baseline limits
3. Monitoring and Maintenance plan and data is documented
4. Adequate resources for operating & maintenance
5. Continuous improvement philosophy

Management Best Practices - Adequate staffing with time to do the work

- 5 functional levels of increasing skill
  - General Awareness
  - IVS User
  - IVS Operator
  - IVS Troubleshooter
  - IVS Change Reviewer
- Site complexity determines job description and number of people trained at each level

Management Best Practices
Continuous Improvement Philosophy

- Maintenance is necessary to provide capability to operate with hazardous materials
- Maintenance workers get exposed to the contaminants drawn away from operating areas – peak exposures likely
- Reduce maintenance exposures by improving the process or IVS design or both so exposure events have a lower:
  - Frequency
  - Duration
  - Magnitude

Management Best Practices Change Management

- ANSI Z9.2 & NFPA 91 - IVS changes made after system redesign to ensure adequate conveying velocity
- Use qualified resources to make changes
- IVS capability sustained through changes
- Chapter 8 gives examples of changes done correctly

IVS Component Failure Modes

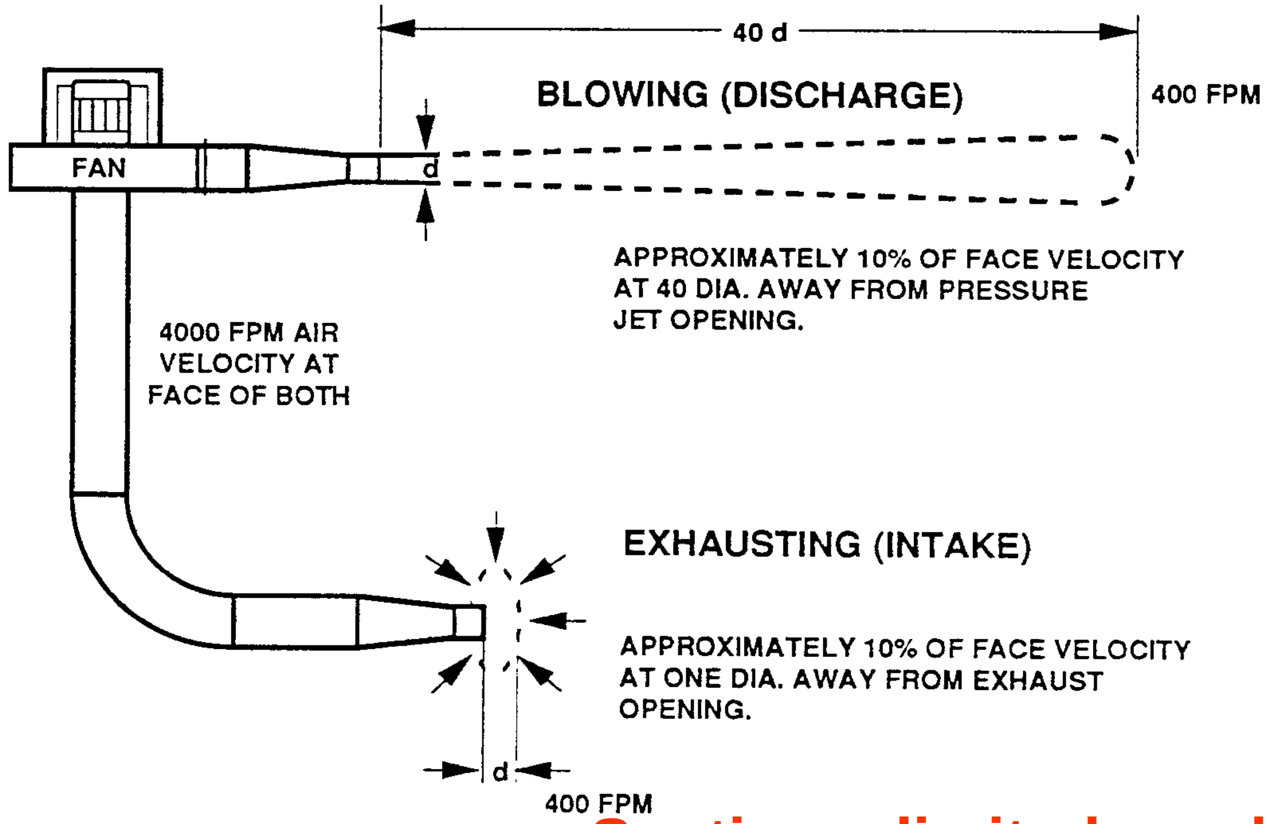
- Hoods & Enclosures
- Ducts
- Fans
- Collectors

CAPTURE: Open Hoods

- Dust source between person and hood
- Protection is general air movement into hood
- Low air velocity must pull dust into hood
- Airflow requirement increases with distance
- Welding hoods, simple “elephant trunk” hoods

Psychological dust control?

LIMITATIONS OF HOODS



Suction – limited reach

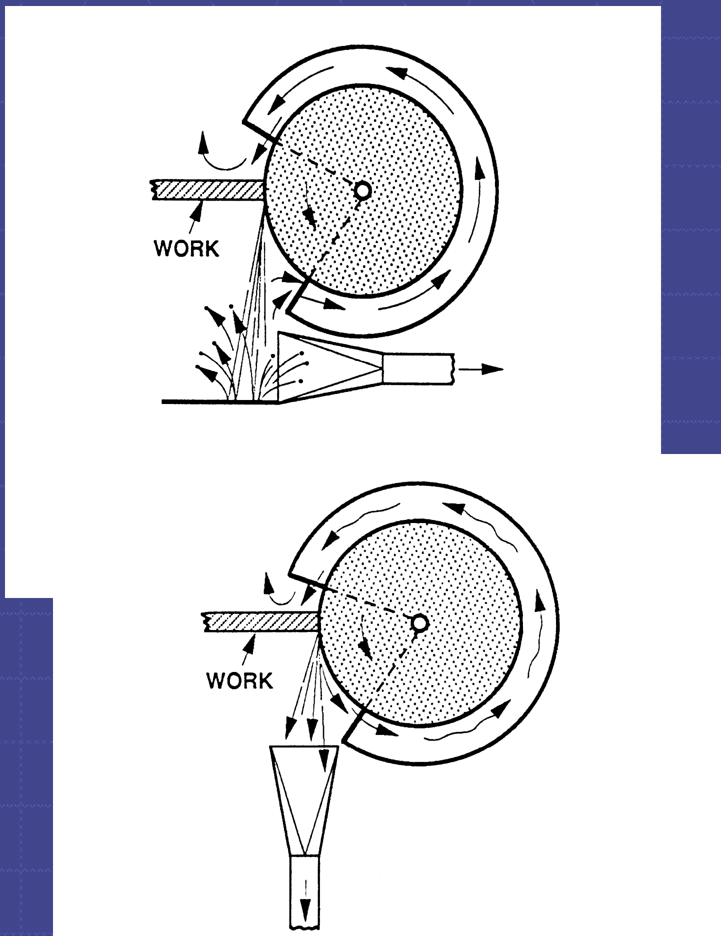
NASA Example – "Snorkel" Hood

Proper placement of hood?

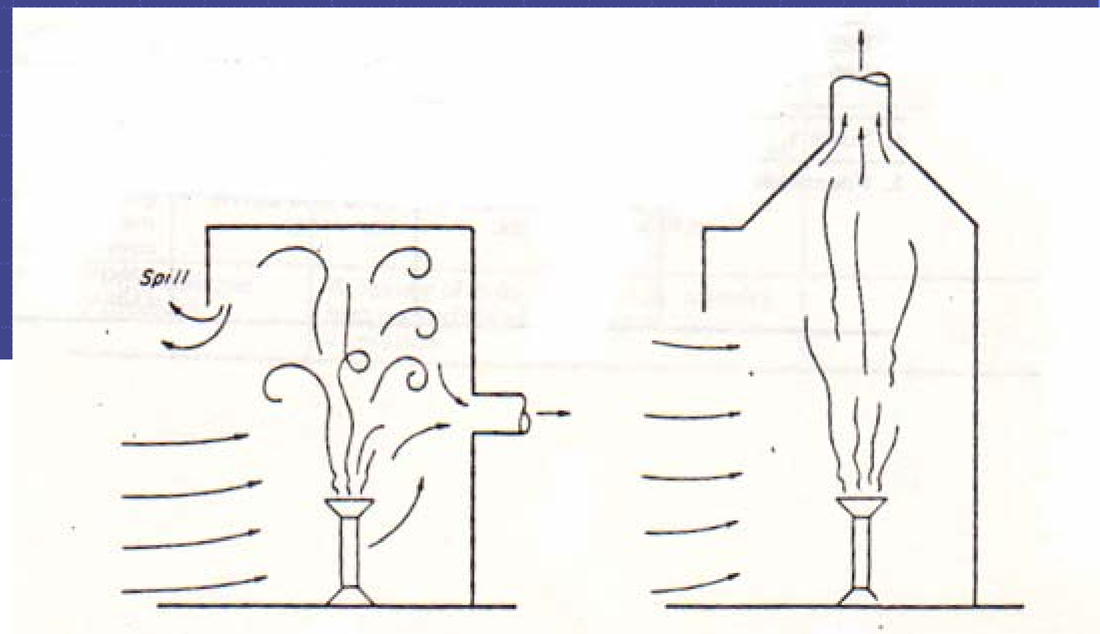
NASA C

CAPTURE: Open Slotted Hoods

Receiving Hoods
- Use Contaminant Momentum



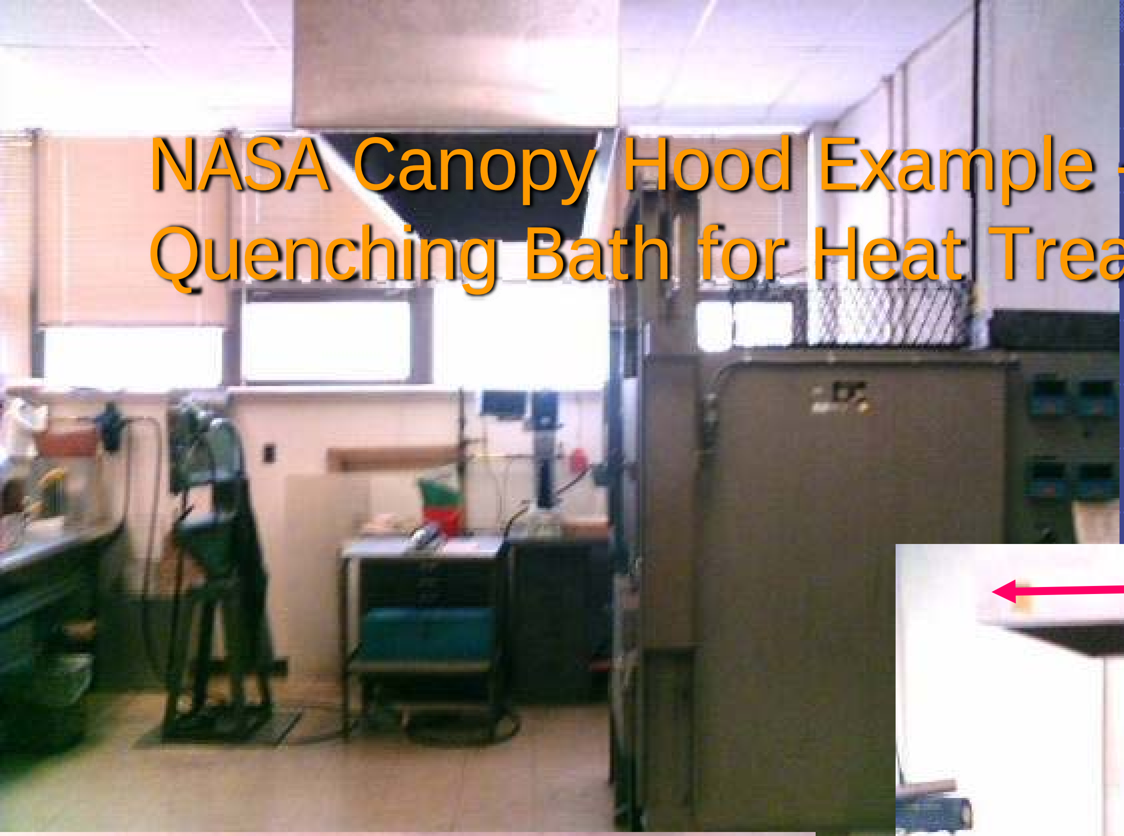
Taking Advantage of Particle Momentum



Taking Advantage of Thermal Buoyancy

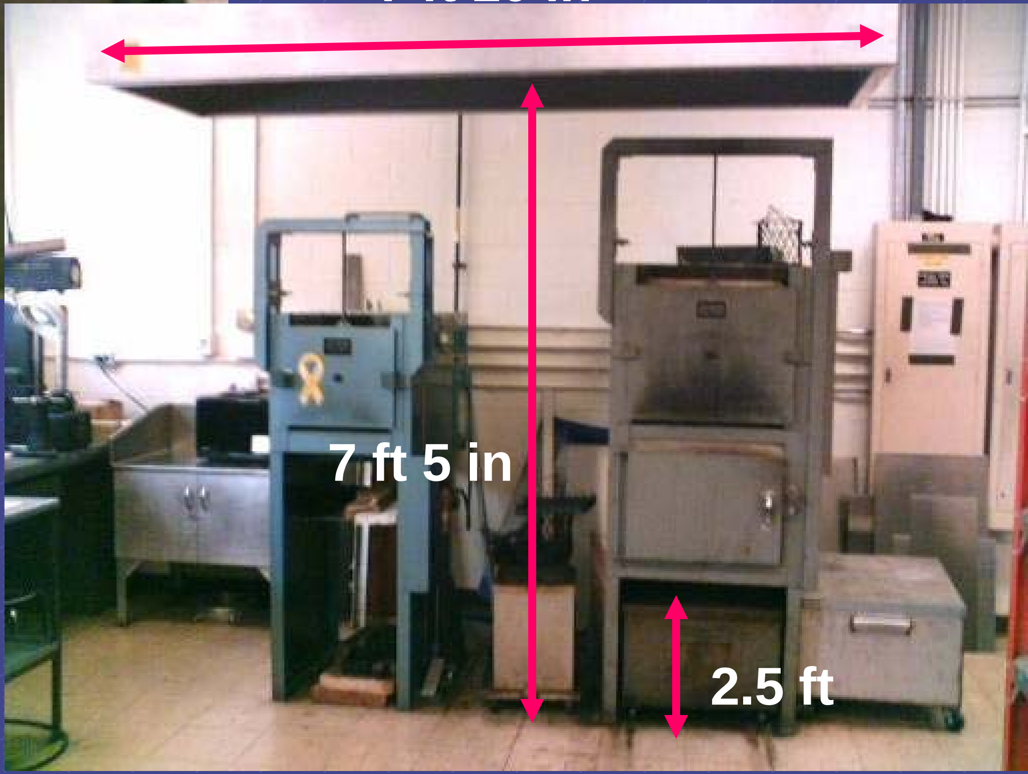
Fig. 4-7 & 4-3, from *Plant and Process Ventilation*, W.C.L.Hemeon, 1999, reprinted with permission

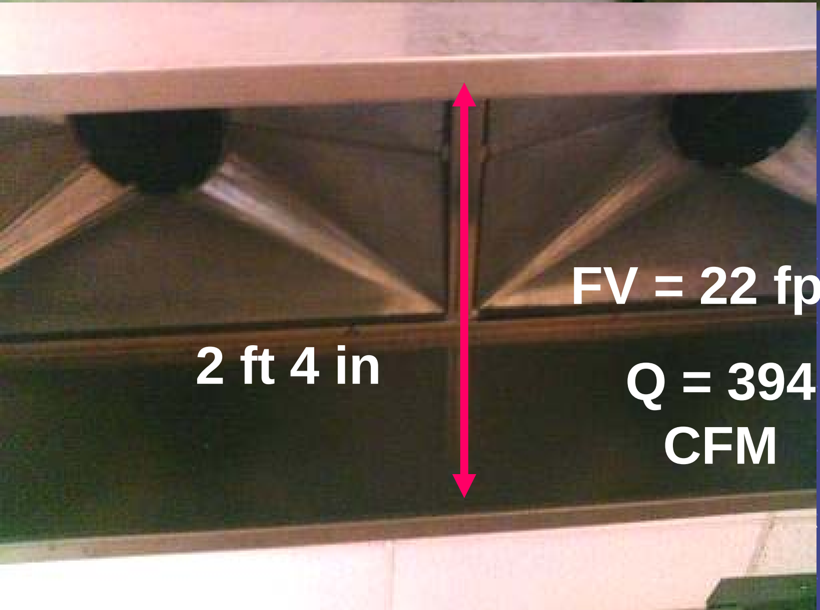
NASA Canopy Hood Example – Wallops Island Quenching Bath for Heat Treatment



See video

7 ft 10 in



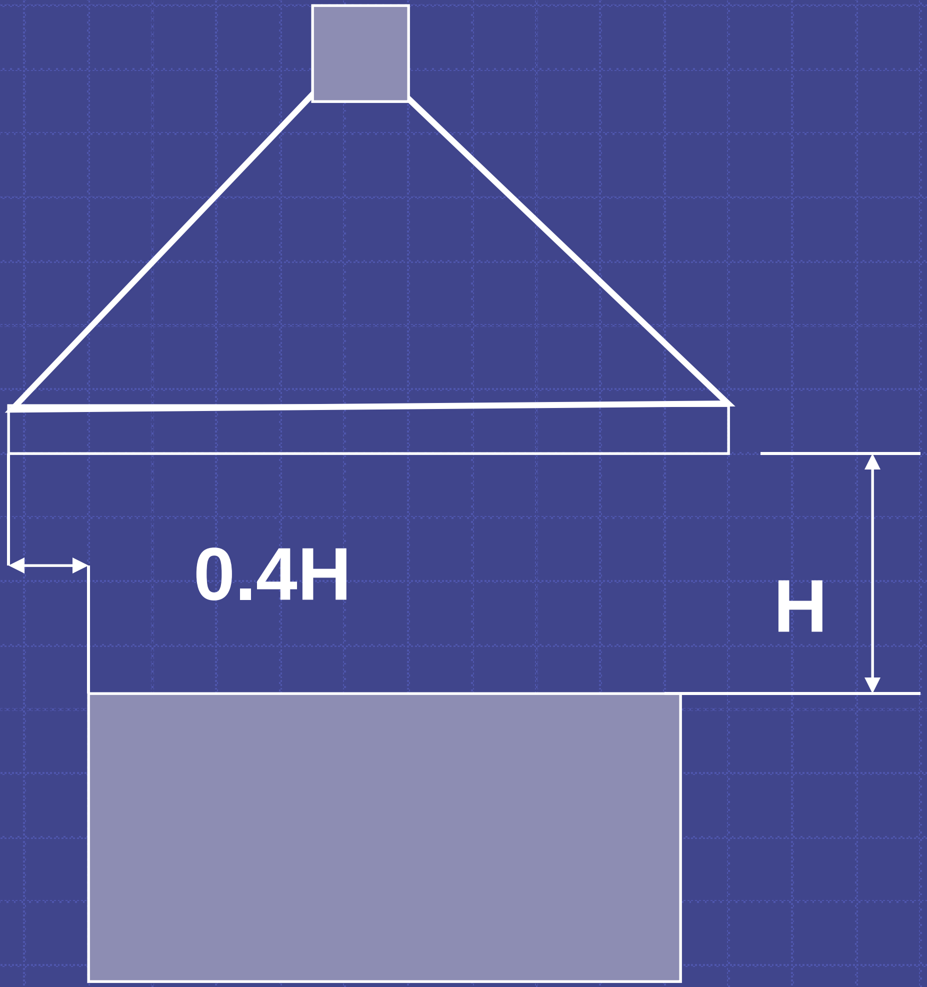


FV = 22 fpm

Q = 394 CFM

NASA Canopy Hood – Basic Geometry?

- Thermal buoyancy effect – expanding column of rising hot air
- Hood shape, Exhaust flow rate
  - Q = 1.4 PHV where
  - P = tank perimeter, ft
  - H = height, ft
  - V = 50-500 ft/min



Canopy Hood Velocity

Wallops Island Hood is 2.5 ft by 4 ft – is it adequate size?

See Handout sheet with equations and calculations.

Conclusion:

Existing size and exhaust airflow do not meet best practice to capture hot gases.

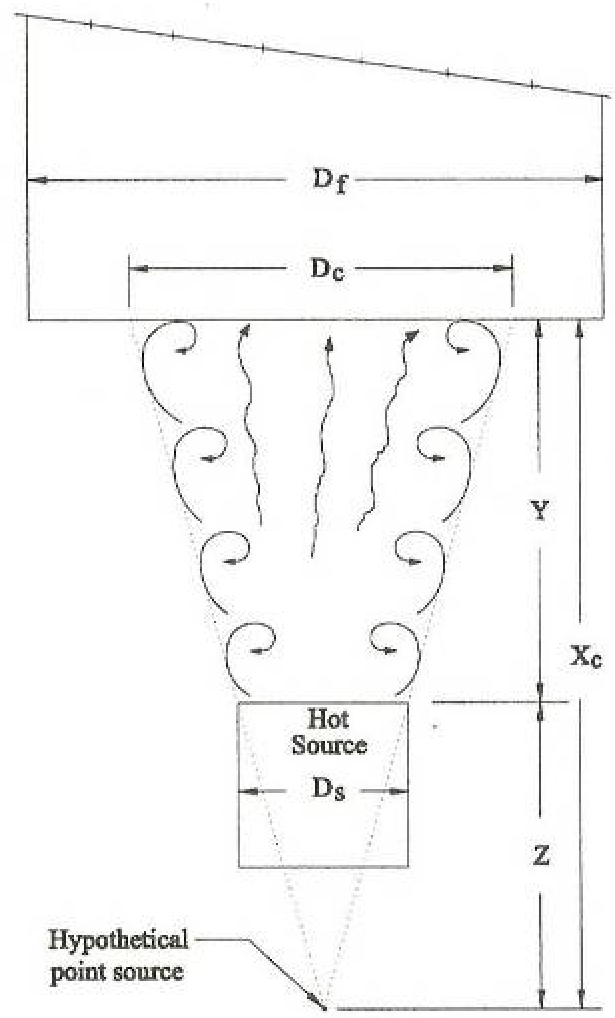
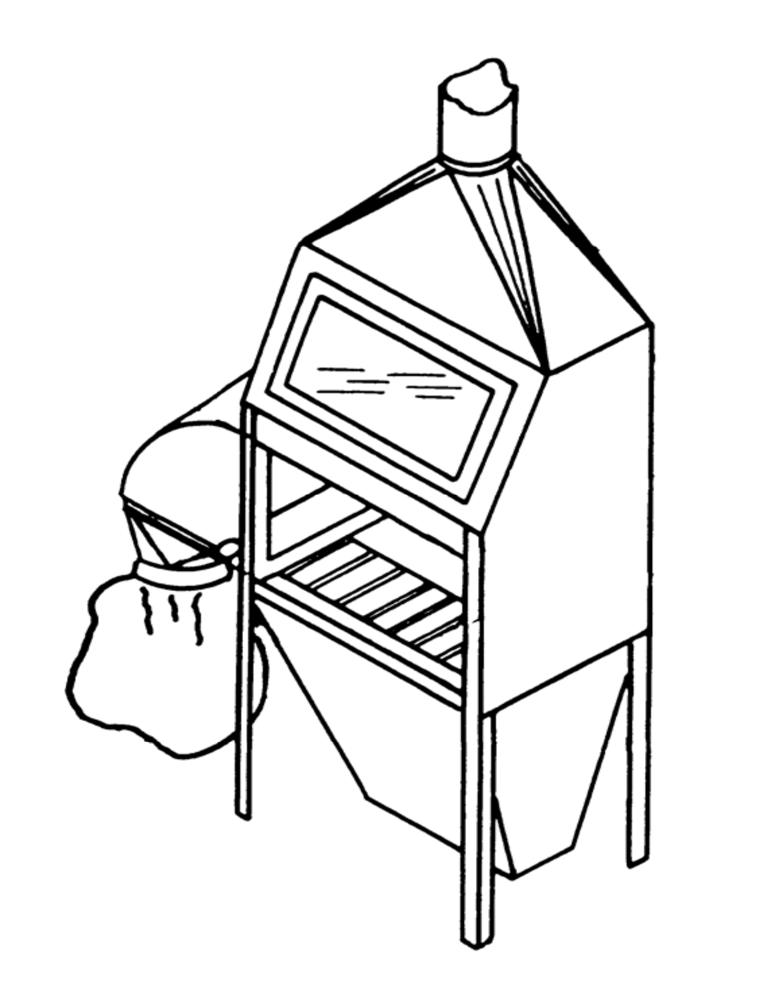


FIGURE 6–18. Dimensions used to design high-canopy hoods for h
sources (Ref. 6-16)

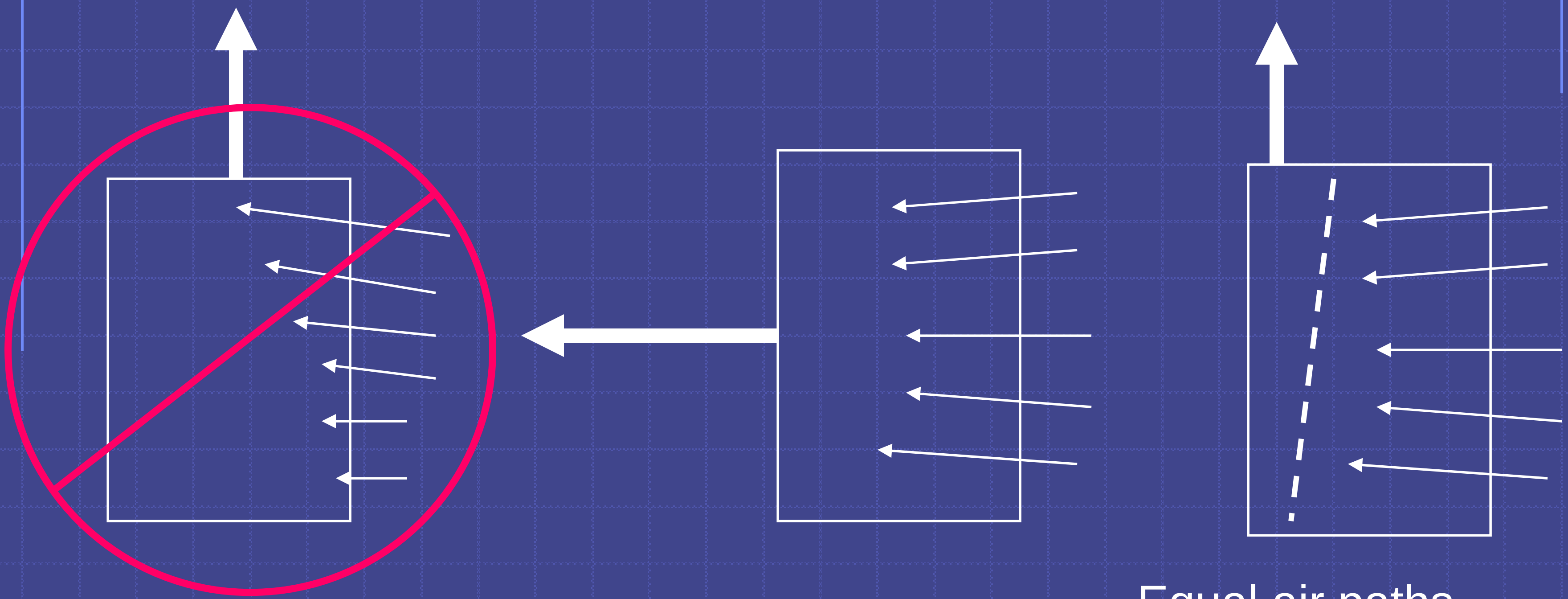
Fig 6-18: From American Conference of Governmental Industrial Hygienists (ACGIH®), *Industrial Ventilation: A Manual of Recommended Practice for Design*, 26th Edition. Copyright 2007. Reprinted with permission.

CONTAIN: Open Enclosures

- Person in front of cabinet, dust inside cabinet
- Protection: low velocity inward air movement
- Avoid giving particle escape velocity from process or manual handling procedure
- Bag dumps, super sack dumps, dump cabinets, *lab hoods*, paint spray booths



Open Faced Enclosures
Getting a Uniform Velocity Profile



Unequal air paths

to exhaust point

Equal air paths

To *horizontal duct*

Equal air paths

Back wall has slots and plenum to *vertical duct*

Open Faced Enclosure with Hood Static Pressure Gauge

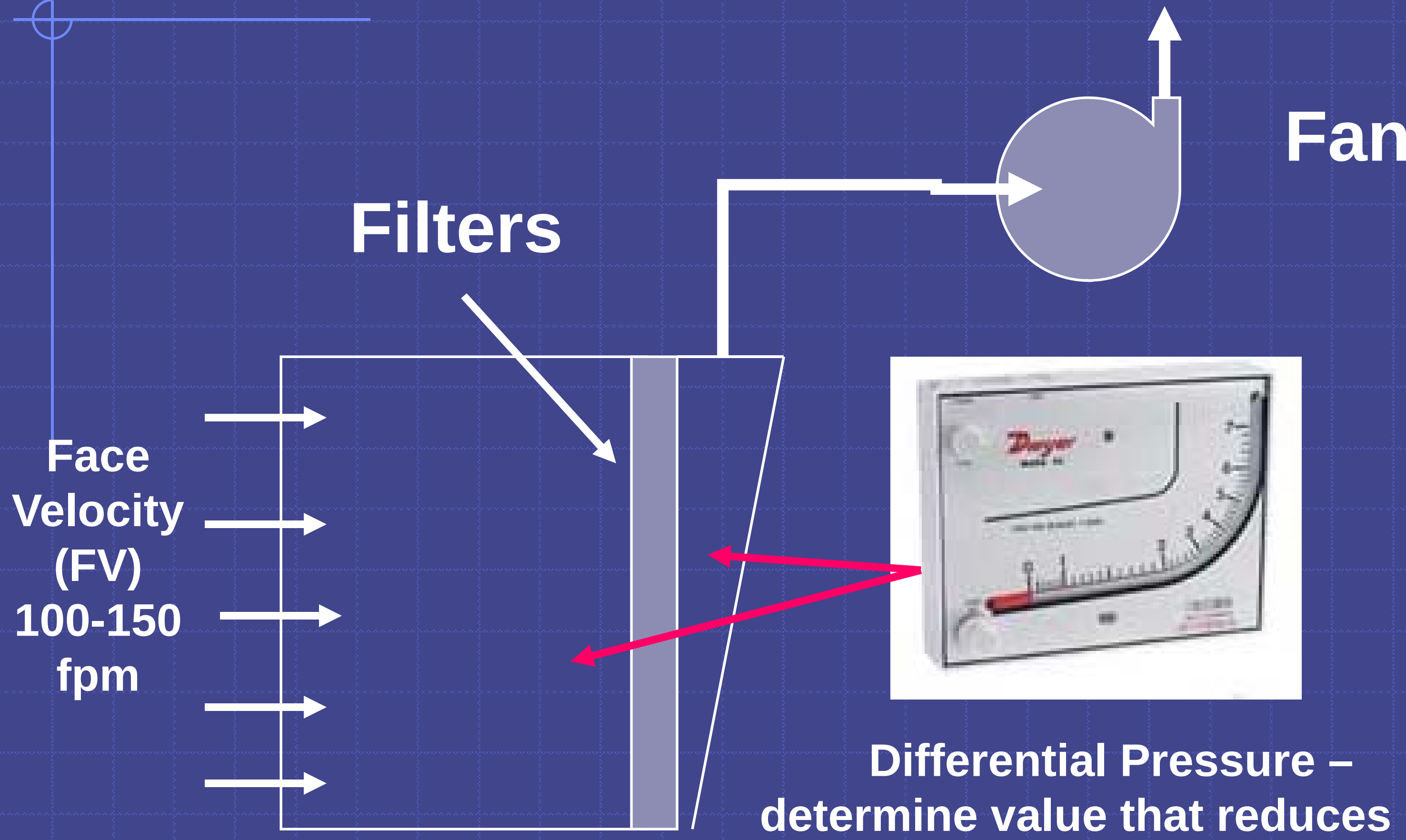
Uniform Velocity Profile - Slots

Paint Spray Booths

Operator technique?

Control = face velocity + operator technique

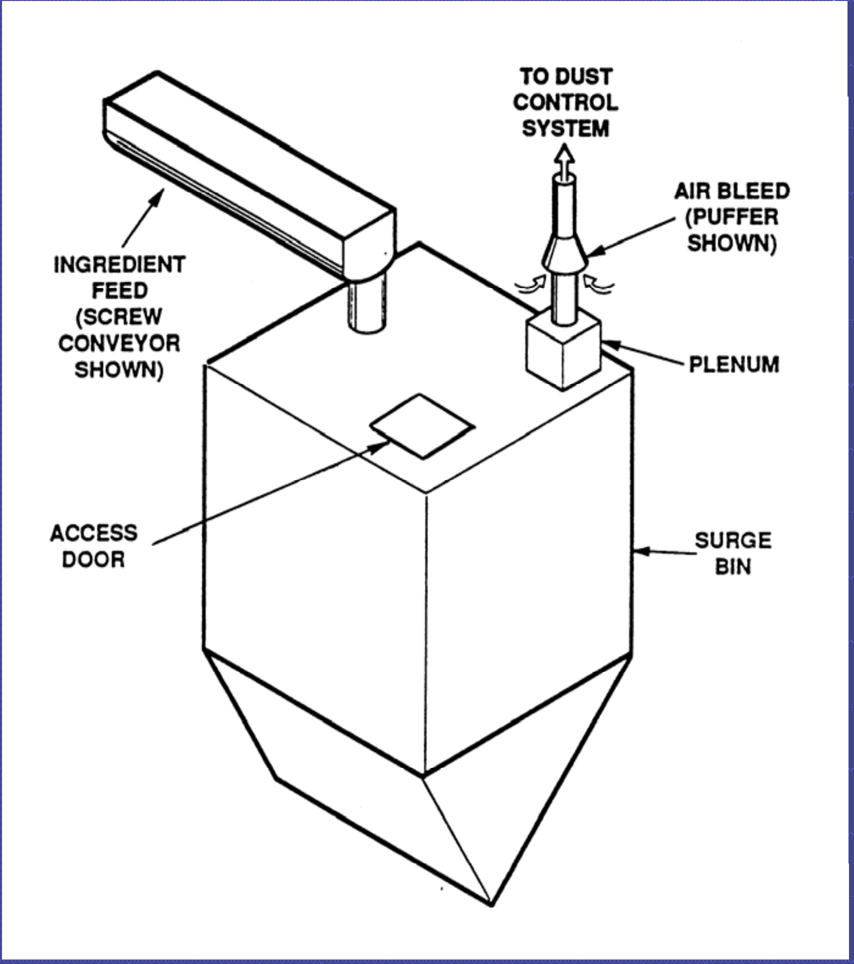
Paint Spray Booth Filter Maintenance



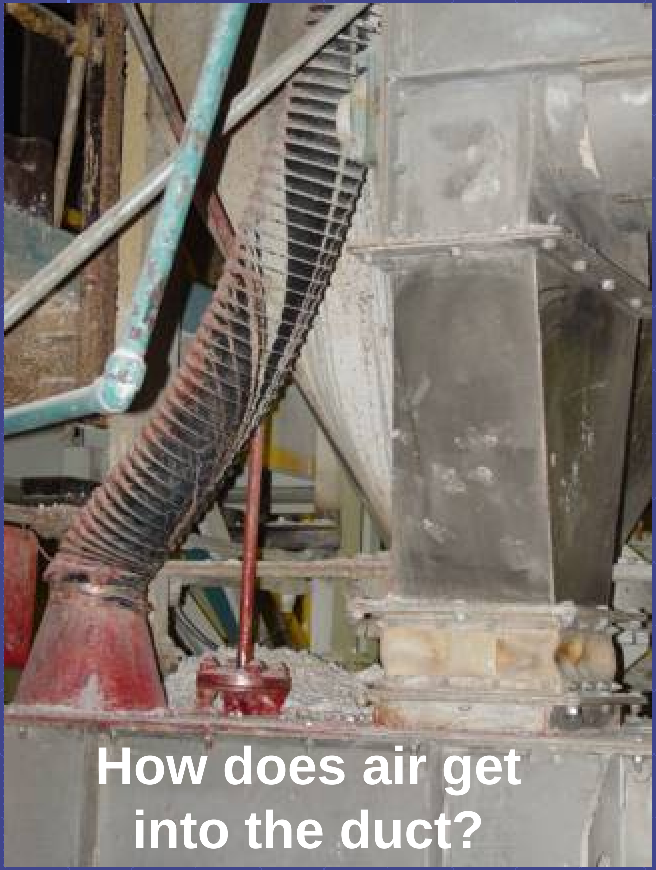
Differential Pressure – determine value that reduces FV to 90% of target - use as action limit to replace filters

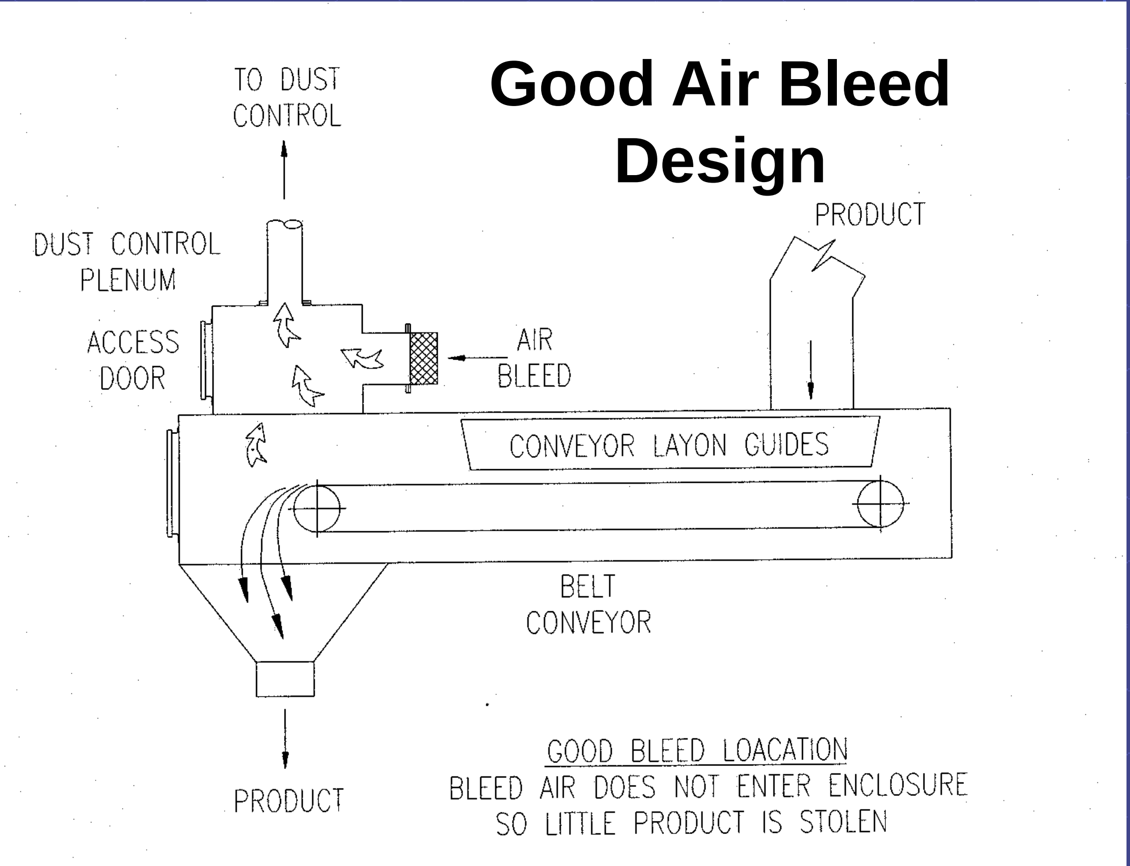
CONTAIN: Sealed Enclosures

- Contaminant totally surrounded by enclosure
- Protection: negative pressure and inward air movement
- Low air velocity at access openings
- Avoid enclosure positive pressure - dusting
- Examples: belt conveyor housings, bins, Loss In Weight bins
- Need air bleed to maintain duct conveying velocity



CONTAIN & CONVEY: Air Bleeds – Maintain Duct Conveying Velocity with Sealed Enclosures





NASA Sealed Enclosure Examples

Chemical Vapor Deposition Glove Box

Gas cylinder cabinets

Interfering Room Air Currents – Common Hood Failure Mode

Open windows

Pedestal fans

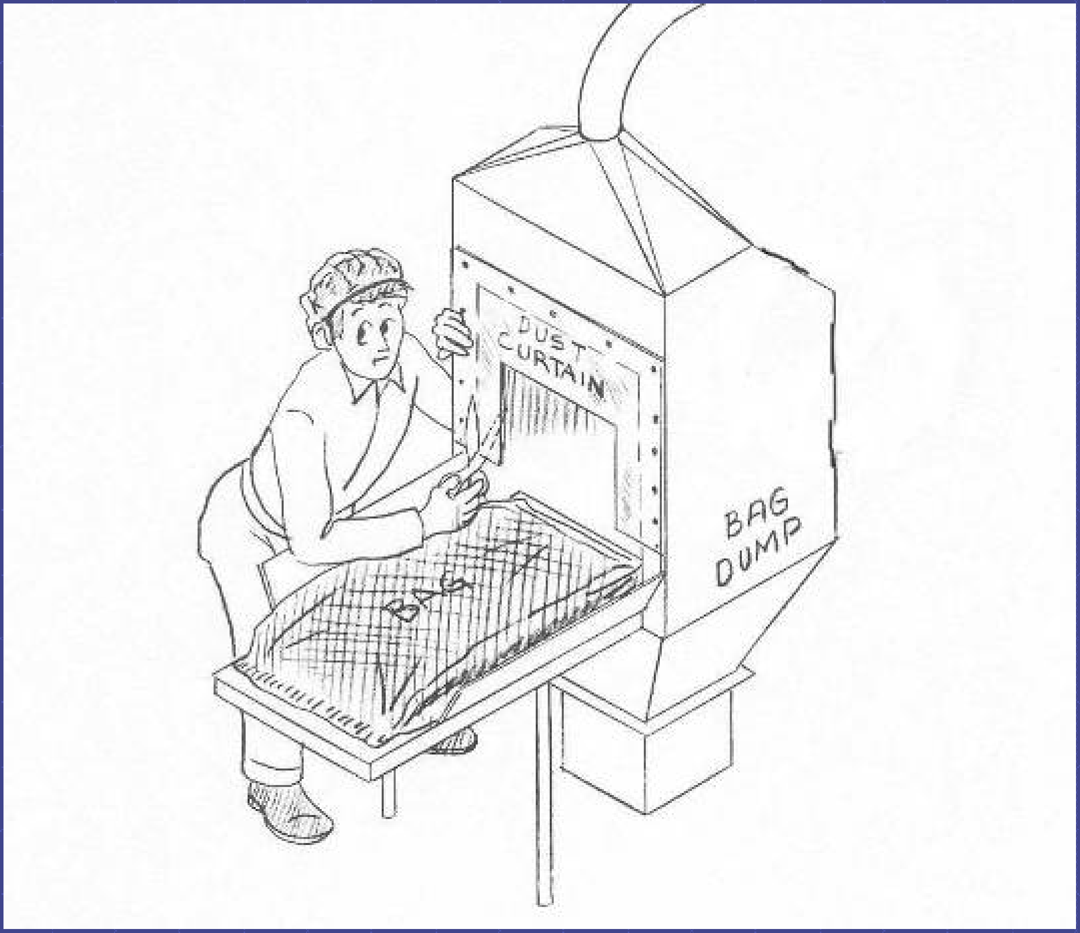
High velocity HVAC diffusers

Can’t Get the Door Open?

HVAC and LEV not in balance

Can be a problem for low velocity and static pressure lab hoods

Face Velocity Impact: Unauthorized Changes



NASA Occup. Health Training

Source Identification
Side lighting

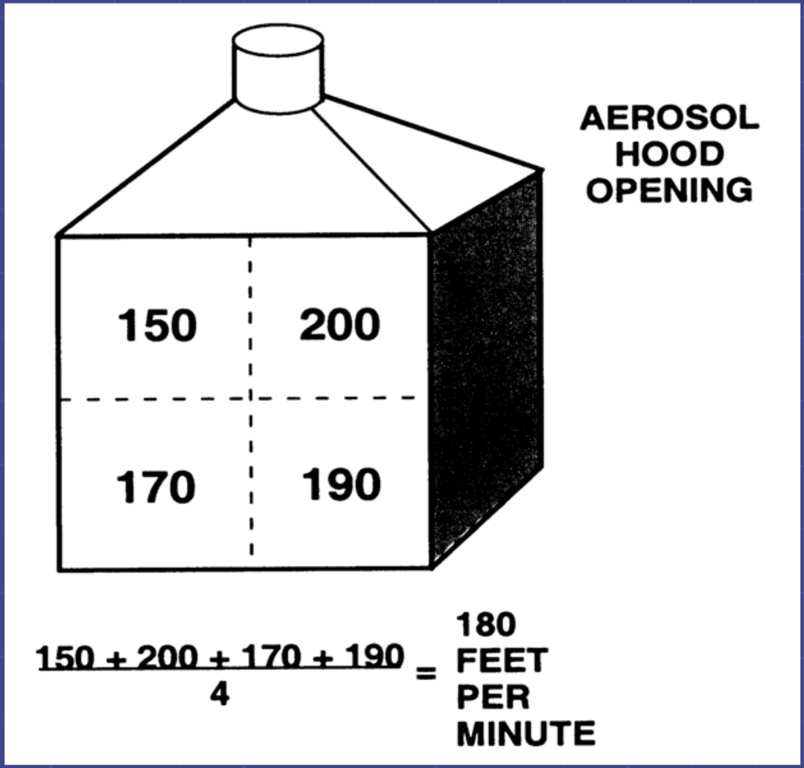
Source ID – Smoke visualization

Smoke Tubes

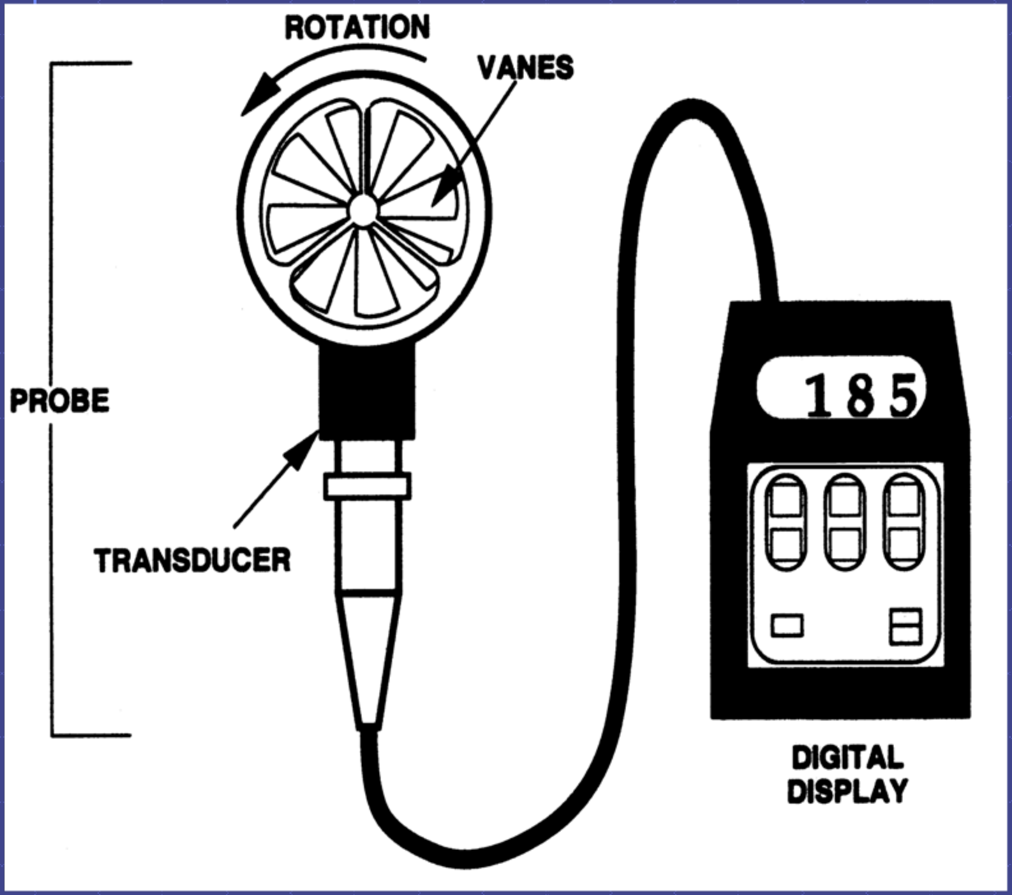
Theater fogging machine

Hood monitoring: Face Velocity Measurement

- What/Where:
  - Airflow Through IVS Controlled Openings
- Units:
  - Feet per minute (fpm)
  - Meters per second (mps)
- Instruments:
  - Rotary Vane Anemometer
  - Thermal Anemometer
  - Multipoint Pressure
  - Hood Static Pressure



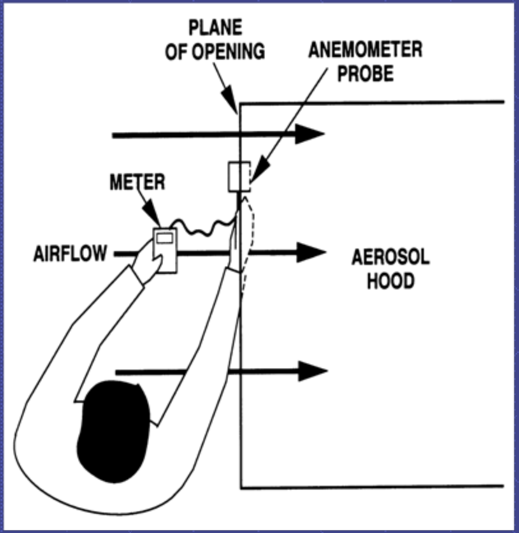
Rotary Vane Anemometer



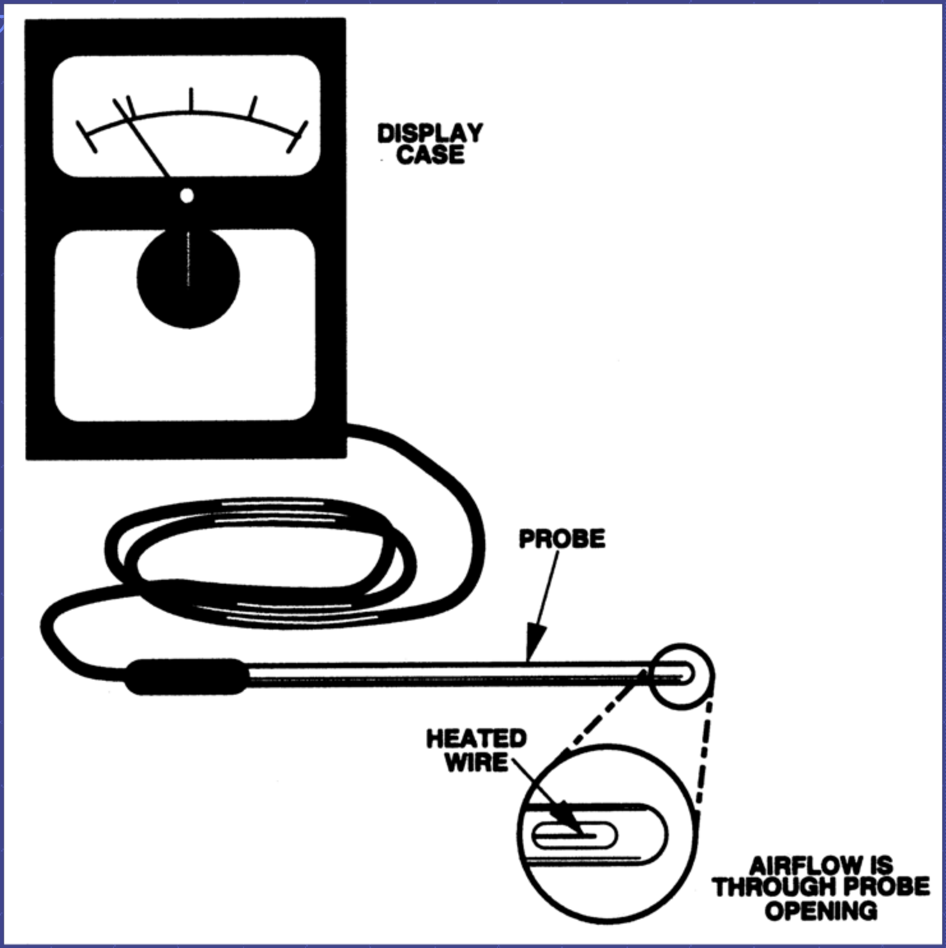
Vane blade rotations counted by tachometer

- Must be calibrated
- Should not exceed 5% of cross sectional area
- Measures air velocity over time period over probe area

-Range 50 fpm – 3,000 fpm

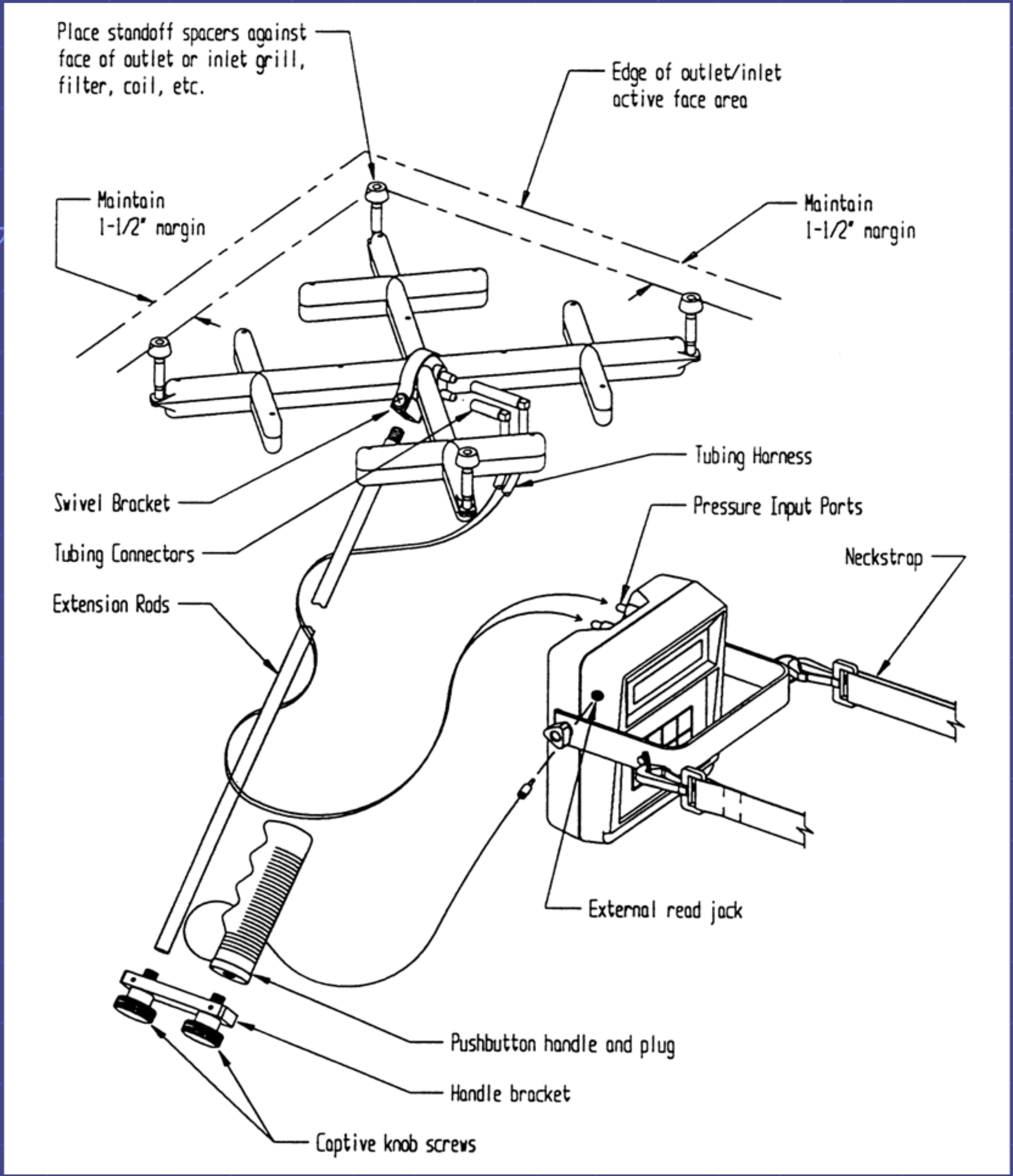


Thermal Anemometer



Measures cooling of wire as air passes probe

- Probe orientation is key
- Must be calibrated
-Range 30 fpm – 6,000 fpm
- Wire easily fouled by contaminants



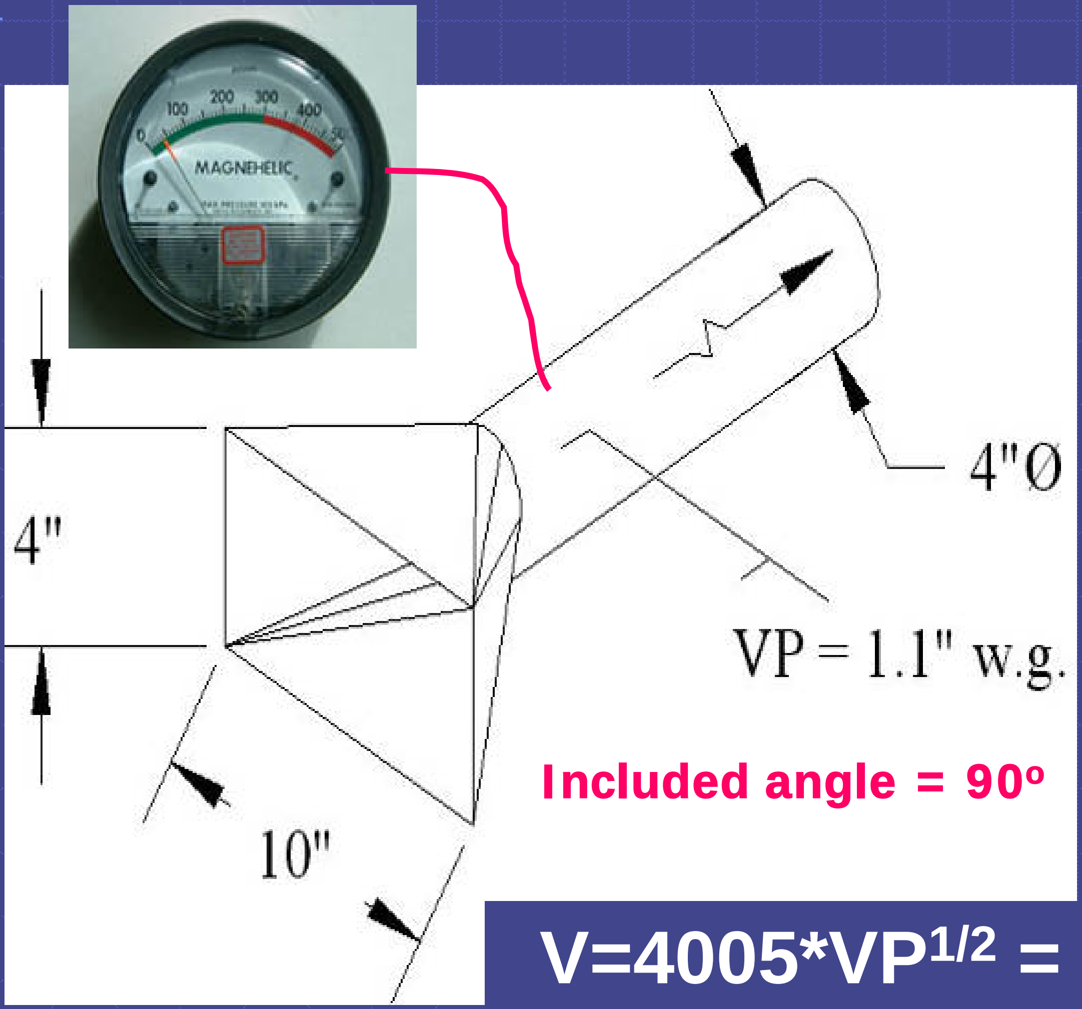
Shortridge Velgrid Anemometer

Grid gives average over larger area

Using Hood Static Pressure (SP_h) for Monitoring

- Every hood has a specific SP_h based on its shape and the airflow through it.
- SP_h values can be found in Industrial Ventilation, A Recommended Practice for Design
- SP_h values can be measured in the field at startup
- Local SP_h indication (Magnehelic or manometer) provides operator warning of IVS problems

Hood SP – Visual Control for Airflow



$V=4005*VP^{1/2}$ = 4200 fpm

Hood Entry Losses – Shapes

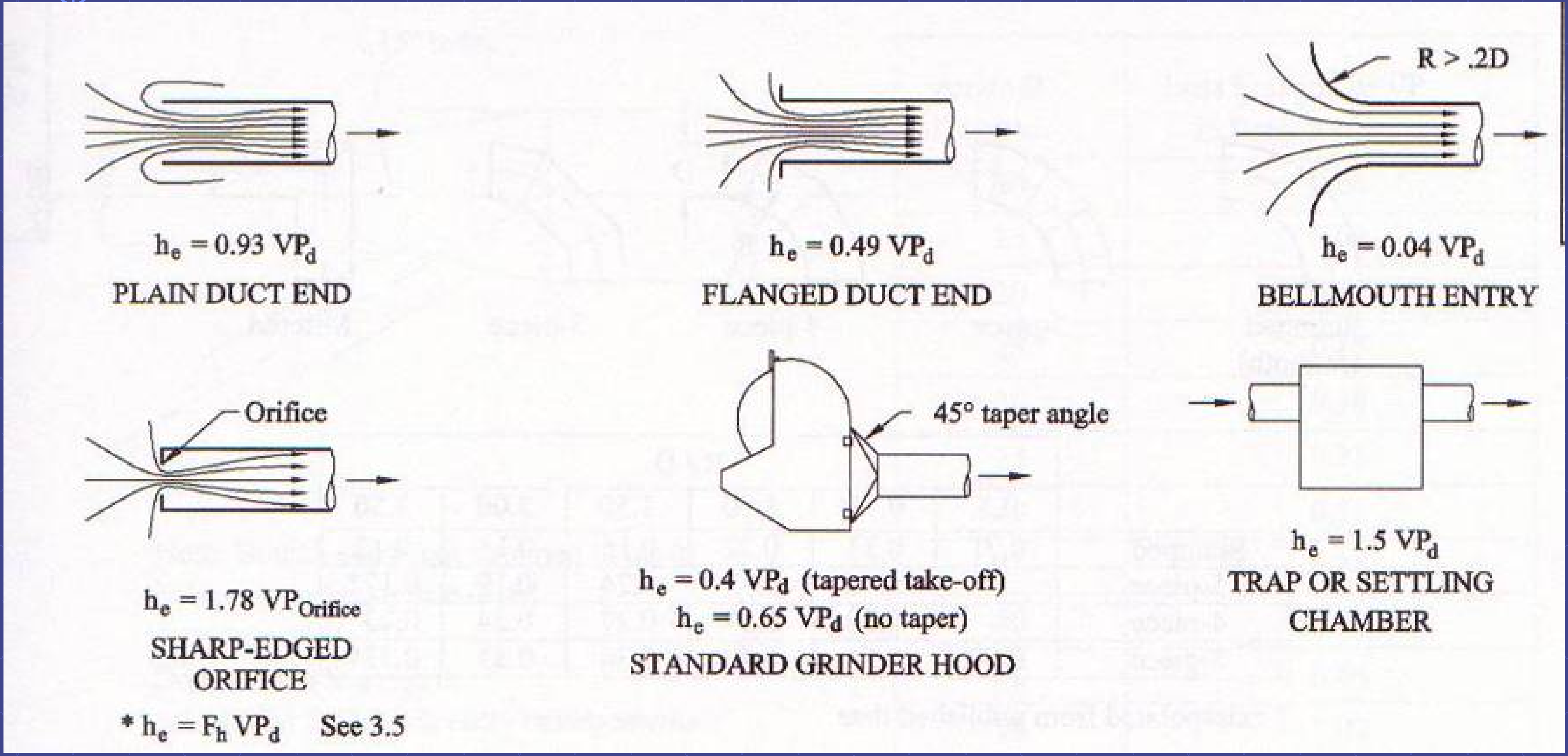
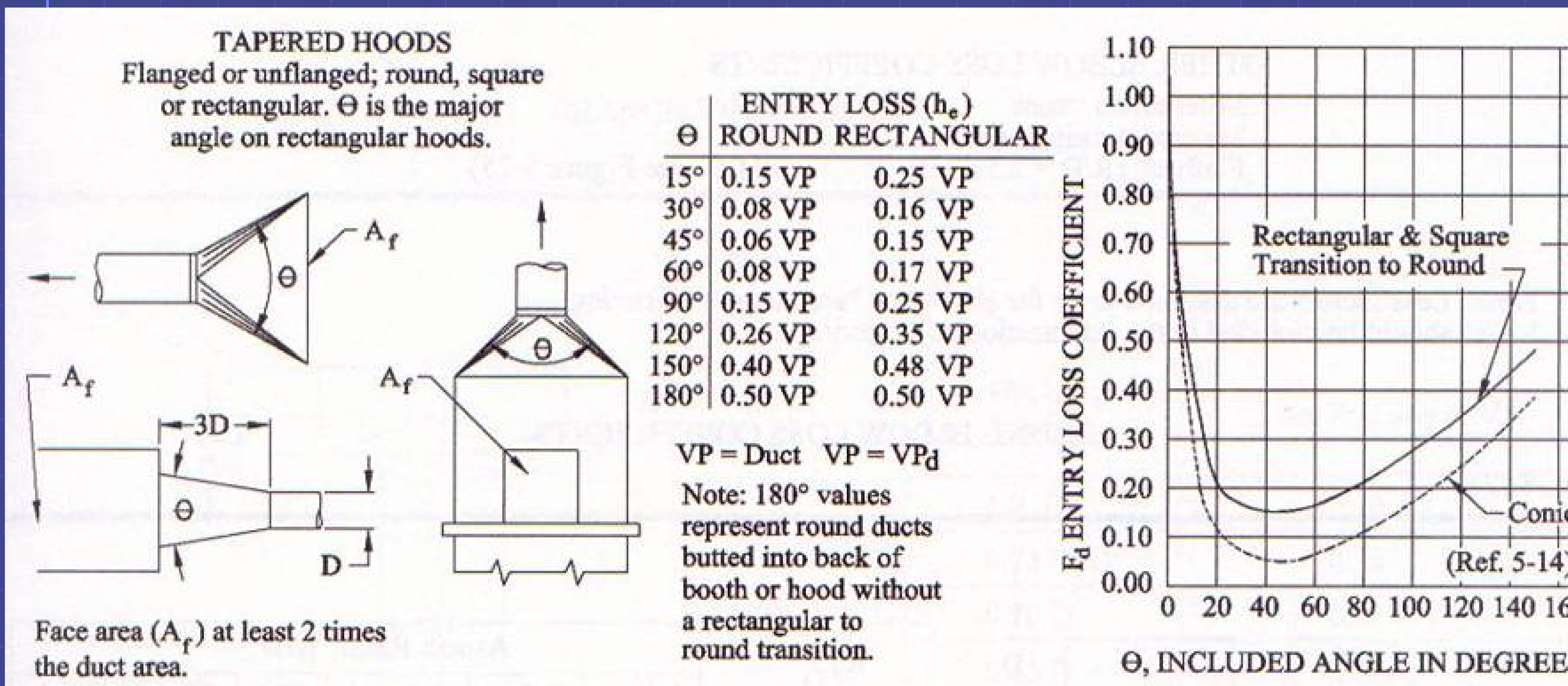


Fig. 9-a: From American Conference of Governmental Industrial Hygienists (ACGIH®), *Industrial Ventilation: A Manual of Recommended Practice for Design*, 26th Edition. Copyright 2007. Reprinted with permission.

Hood Entry Losses - Transitions



Θ	ENTRY LOSS (h_e) ROUND	RECTANGULAR
15°	0.15 VP	0.25 VP
30°	0.08 VP	0.16 VP
45°	0.06 VP	0.15 VP
60°	0.08 VP	0.17 VP
90°	0.15 VP	0.25 VP
120°	0.26 VP	0.35 VP
150°	0.40 VP	0.48 VP
180°	0.50 VP	0.50 VP

Fig.9a: From American Conference of Governmental Industrial Hygienists (ACGIH®), Industrial Ventilation: A Manual of Recommended Practice, 26th Edition. Copyright 2007. Reprinted with permission.

Calculate Hood SP

1. Duct VP = 1.1”w.c.
2. Entry loss = 0.25 x VP
3. Acceleration loss = 1 x VP
4. Hood SP

   = acceleration loss + entry loss

   = 1VP+0.25VP=VP(1+0.25)

   =1.1x1.25 = ***1.4”w.c.***

Hood Maintenance

Thermometer showing visual controls

- Visual Checks
  - React to visible emissions to room
  - Check for hood modifications or relocation
- First line of defense – monitor air flow
  - Install Hood Static Pressure gauges with action limits (± 20% Baseline)

  OR

  - take routine Face Velocity measurements

Hood Maintenance, cont.

- Things that can change airflow:
  - Dirty screens
  - Deposited contaminants in plenum behind hood opening
  - Bypassing thru open access doors
  - *Hood face modifications*

Hood/Enclosure Troubleshooting

- Contaminant source within hood influence?
- Hood matched to dust source?
  - Shape, location
  - Operator technique
  - Contaminant momentum > face velocity
- Hood airflow pattern changed?
  - Blocked screen, debris in hood plenum
  - Poor face velocity profile
- Reduced suction from IV system?
- Interference
  - Excessive room air currents?
  - Lack of makeup air?

Ductwork Failure Modes

- Inadequate conveying velocity design
- Ductwork changes without redesign
- System branches not balanced
- Dust plugging or air leaks
- Dust collector or fan problems

CONVEY - Duct Sizing

- Size Ducts for Conveying Velocity Range
  - Dust Control Systems: 3500 to 4500 FPM.
  - Aerosol or other small particle Control Systems: 2500 to 3500 FPM.

$$A = \frac{Q}{V}$$

where :

$A =$ cross - sectional area of duct (ft^2)

$Q =$ exhaust volume (ft^3 / min)

$V =$ velocity of airstream in duct (ft/min)

Convey: Range of Minimum Duct Design Velocities

Nature of Contaminant	Examples	Minimum Design Velocity, fpm
Vapors, gases, smoke	All vapors, gases, smoke	Any desired velocity - economic optimum velocity usually 1000-2000
Fumes	Welding	2000 – 2500
Very fine light dust	Fine rubber dust, Bakelite molding powder dust, jute lint, cotton dust, shavings (light,) soap dust, leather shavings	3000 – 4000

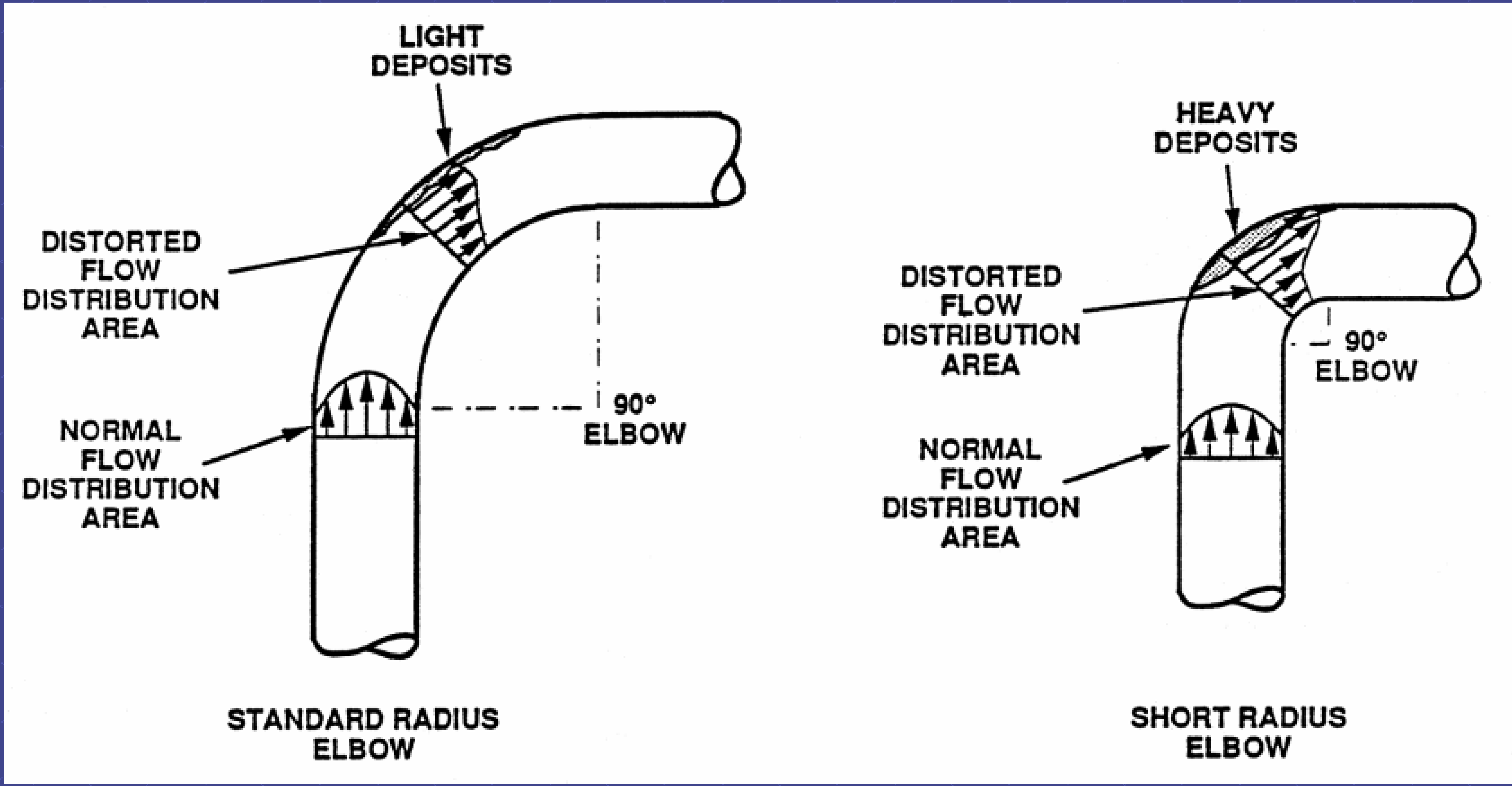
Table 3-1: From American Conference of Governmental Industrial Hygienists (ACGIH®), Industrial Ventilation: A Manual of Recommended Practice, 25th Edition. Copyright 2004. Reprinted with permission.

Range of Minimum Duct Design Velocities, cont.

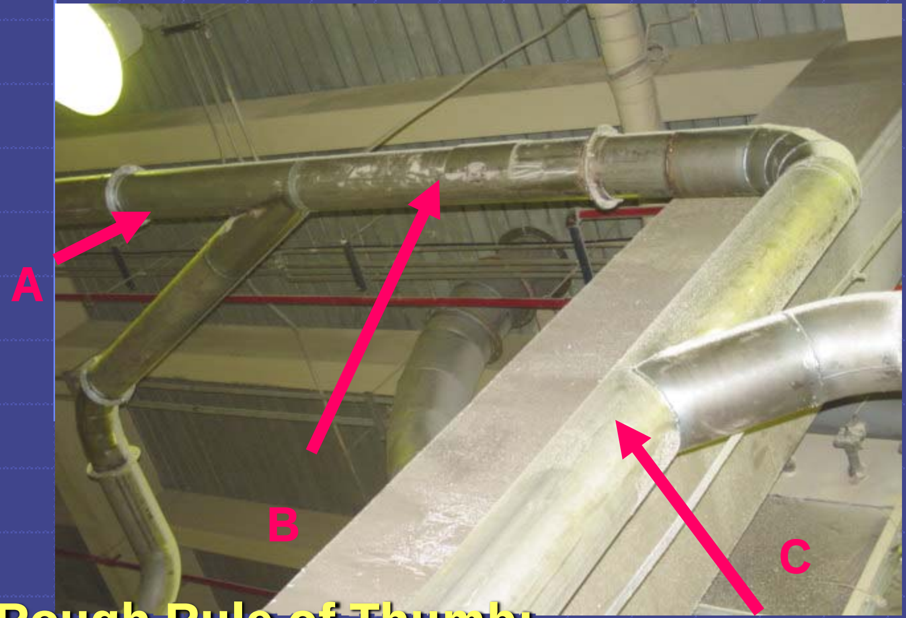
Nature of contaminant	Examples	Minimum transport velocity, fpm
Average industrial dust	Grinding dust, buffing lint (dry), wool jute, coffee beans, shoe dust, granite dust, general material handling, brick dust, clay dust, foundry (general,) limestone dust	3500 - 4000
Heavy dusts	Sawdust (heavy & wet,) metal turnings, foundry tumbling barrels and shake-out, sand blast dust, wood blocks, hog waste, brass turnings, cast iron boring dust, lead dust	4000-4500
Heavy or moist	Lead dusts with small chips, moist cement dust, asbestos chunks from transite pipe cutting machines, buffing lint (sticky,) quick lime dust	> 4500

Table 3-1: From American Conference of Governmental Industrial Hygienists (ACGIH®), Industrial Ventilation: A Manual of Recommended Practice, 25th Edition. Copyright 2004. Reprinted with permission.

Maintenance Saver – Long Radius Elbows



At junctions, duct must get larger



ID	D, inches	Q, CFM	V, fpm	"VP/100'
A	8	1500	4200	3.4
B	8	3000	8400	13
C	8	4500	16800	350

Rough Rule of Thumb:

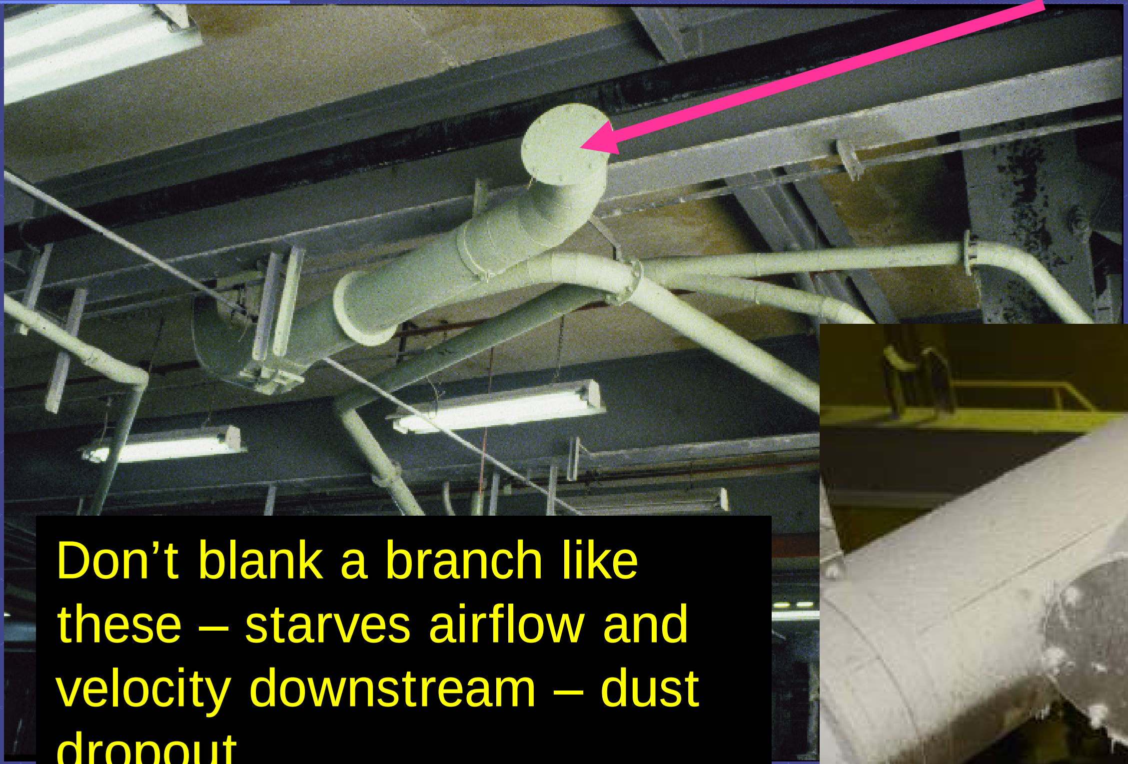
Downstream duct diameter² ~ sum of squares of upstream duct diameters

$8^2+8^2 = 128 \sim 11^2$ or 121

$11^2+8^2 = 185 \sim 14^2$ or 196, $\sim 13^2$ or 169

Impossible conveying velocity requirements that fans cannot deliver. Only option with this duct is branch ON/OFF procedure – ***good luck***!

Don't blank unneeded ducts – downstream conveying velocity?



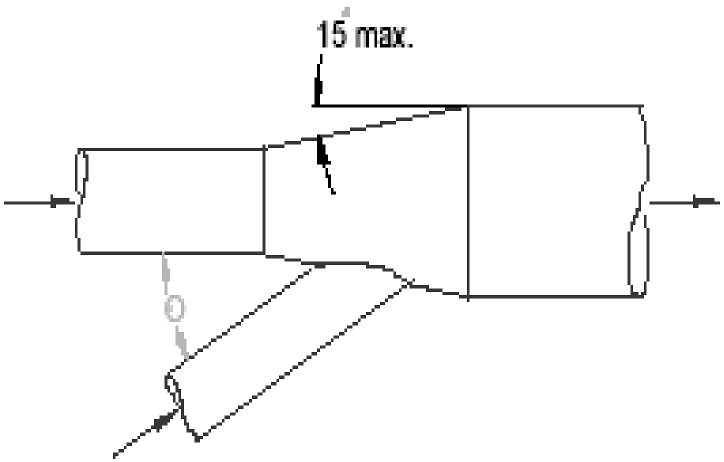
Don't blank a branch like these – starves airflow and velocity downstream – dust dropout

Unless downstream duct changed, orifice bleed air on removed branch.

Flexible versus Metal Ducts

- For reliable airflow & conveying velocity, must overcome:
  - 2x Smooth Duct Resistance (fan speedup needed?)
  - Rougher inner surface plugs more readily (more fan speedup?)
- NFPA 664:
  - Conductive ducts recommended
  - Use flex duct only for equipment that needs to move

Pressure Loss – Branch Entries



Angle θ- Degrees	Loss Fraction of VP in Branch	
10	0.06	
15	0.09	Very sticky
20	0.12	
25	0.15	
30	0.18	Mildly sticky
35	0.21	
40	0.25	
45	0.28	Dry, free flow
50	0.32	
60	0.44	
90	1.00	NO, don't do this!!!!

Note: Branch entry loss assumed to occur in branch and is so calculated.

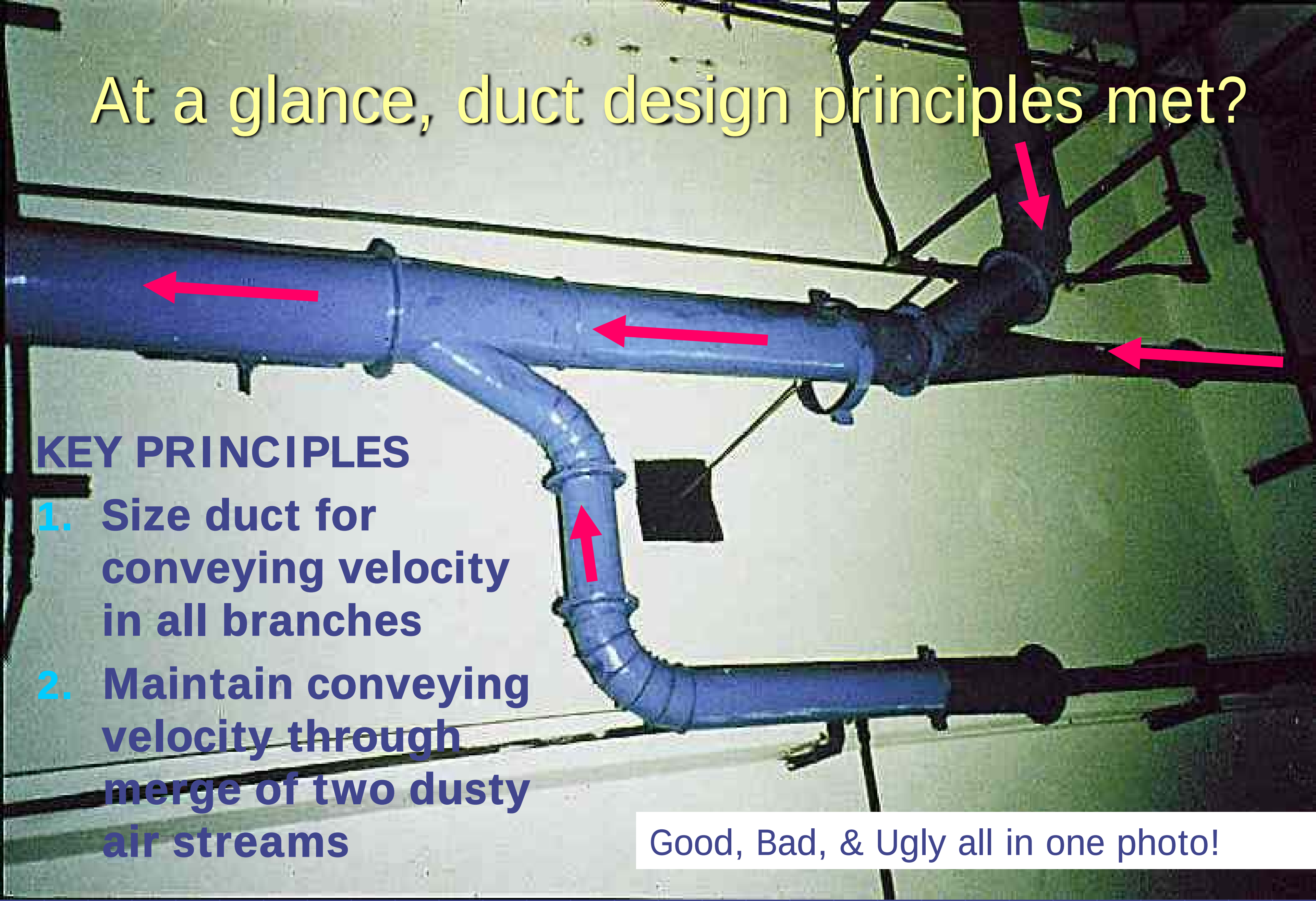
Do not include an enlargement regain calculation for branch entry enlargements.

BRANCH ENTRY LOSSES

Fig. 9-f: From American Conference of Governmental Industrial Hygienists (ACGIH®), *Industrial Ventilation: A Manual of Recommended Practice for Design*, 26th Edition. Copyright 2007. Reprinted with permission.

Branch Entries: Do not use T-Connection

At a glance, duct design principles met?

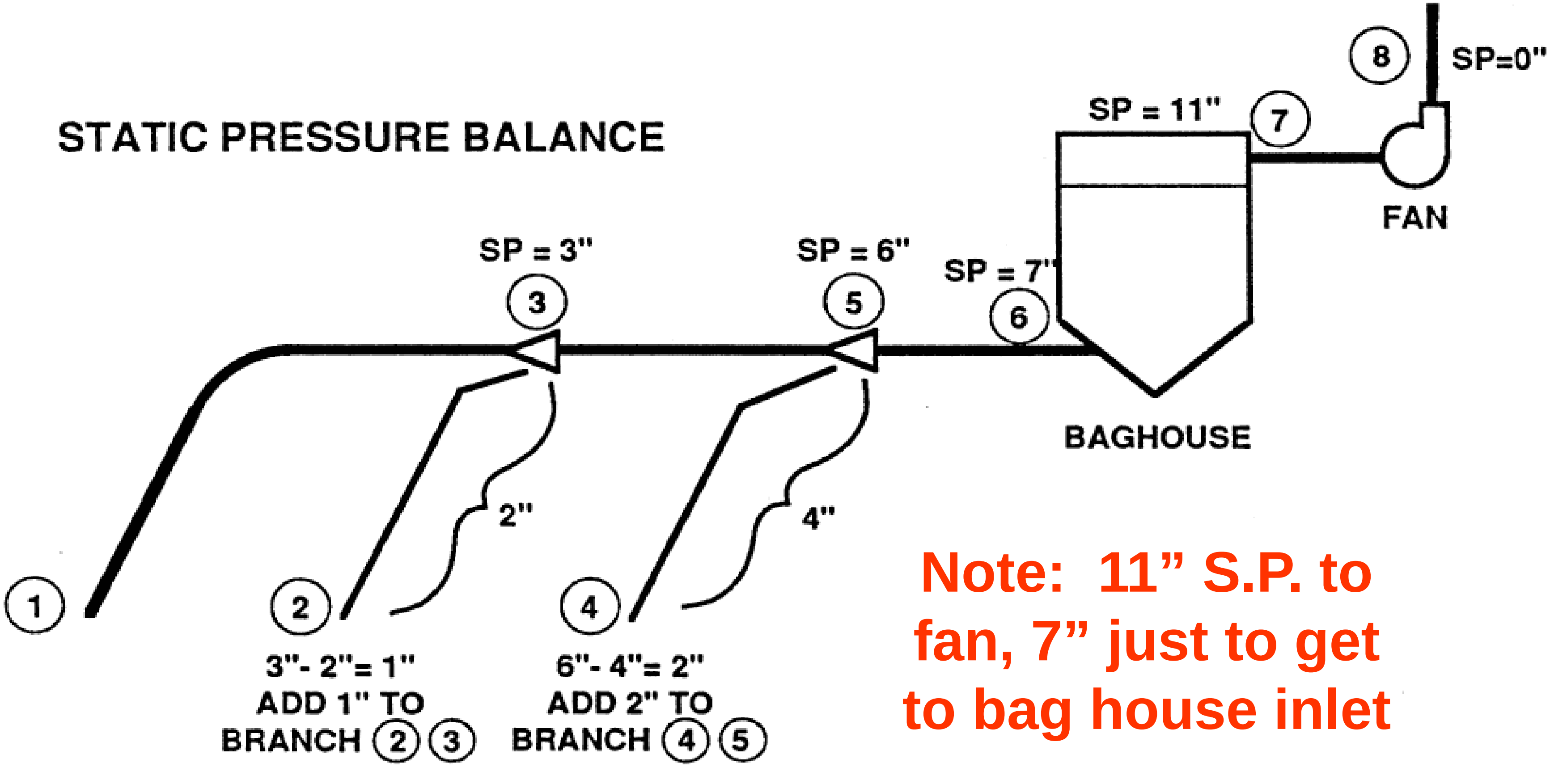


KEY PRINCIPLES

1. **Size duct for conveying velocity in all branches**
2. **Maintain conveying velocity through merge of two dusty air streams**

Good, Bad, & Ugly all in one photo!

CONVEY - Static Pressure Balancing



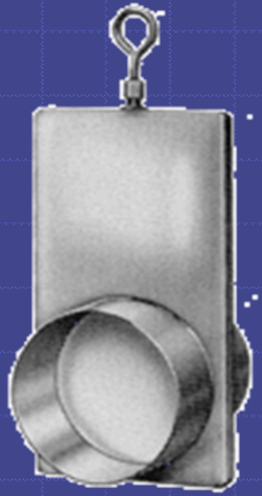
Note: 11" S.P. to fan, 7" just to get to bag house inlet

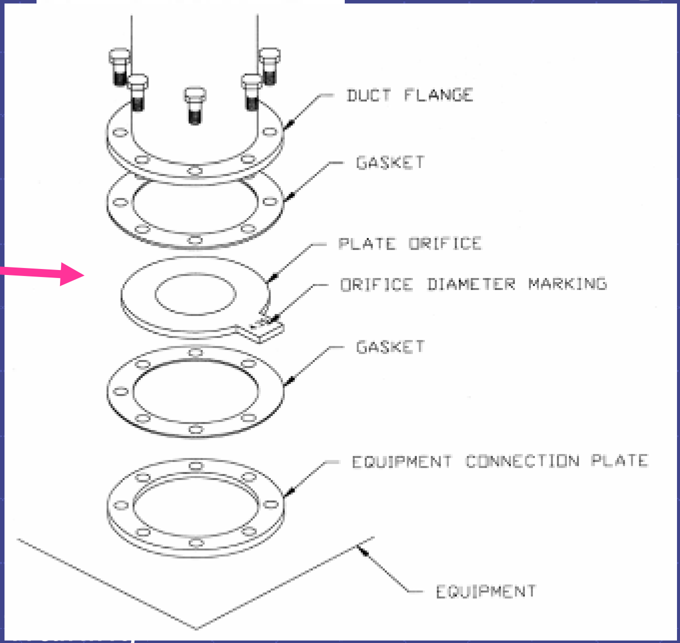
THE NEGATIVE SIGNS ON SP VALUES (INDICATING VACUUM) HAVE BEEN ELIMINATED FOR SIMPLICITY.

w/o balancing devices, airflow takes path of least resistance

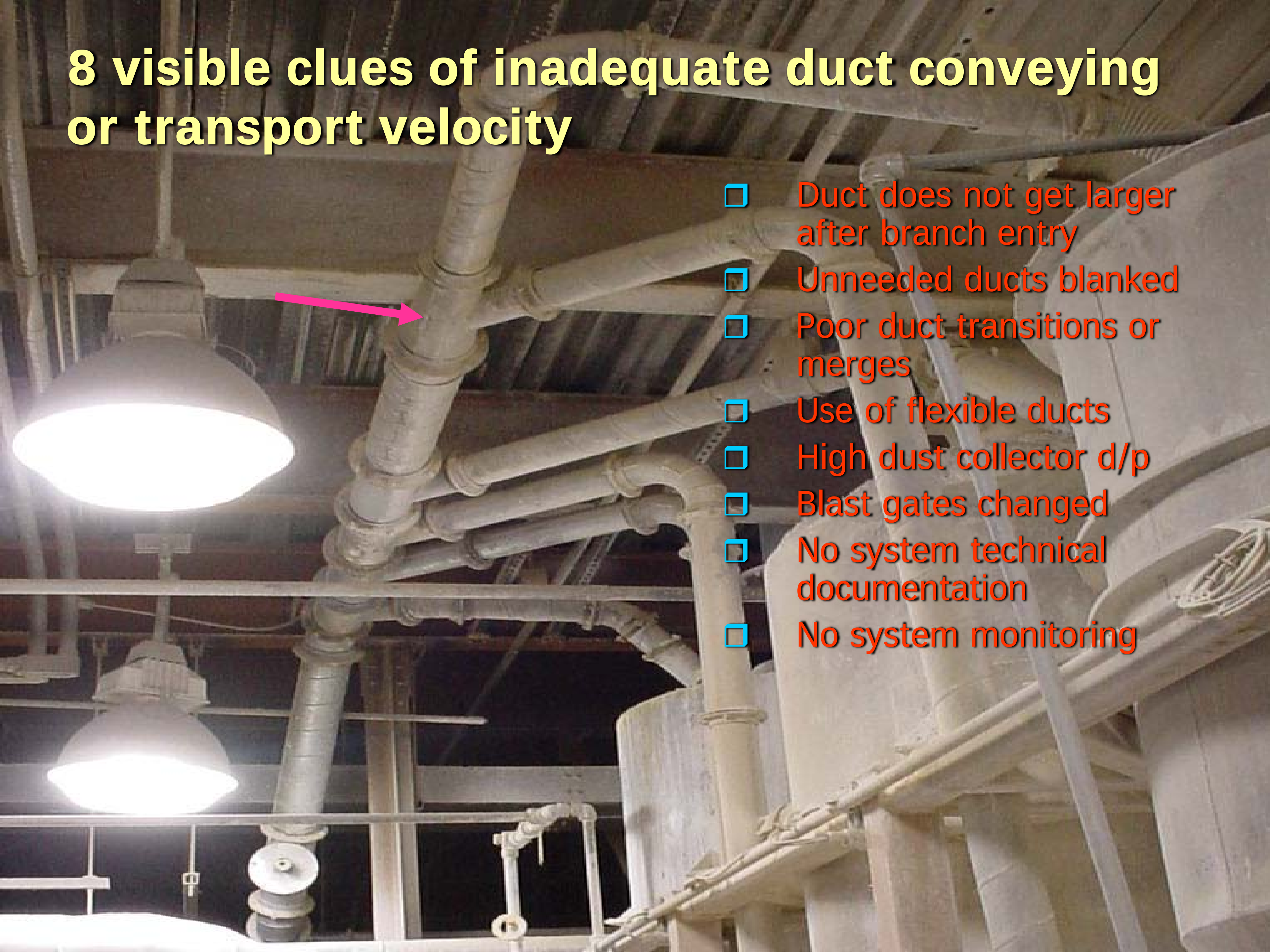
Which Method to Balance Systems Is Used at Your Site?

- Balance by Design
  - Size ducts to restrict flow or add flow
  - Adds 10-20% more airflow to system
- Balance by Blast Gate
  - Adjustable (both advantage and disadvantage)
- Balance by Fixed Orifice
  - Pre-calculate orifice size based on actual duct construction – most accurate balance





8 visible clues of inadequate duct conveying or transport velocity

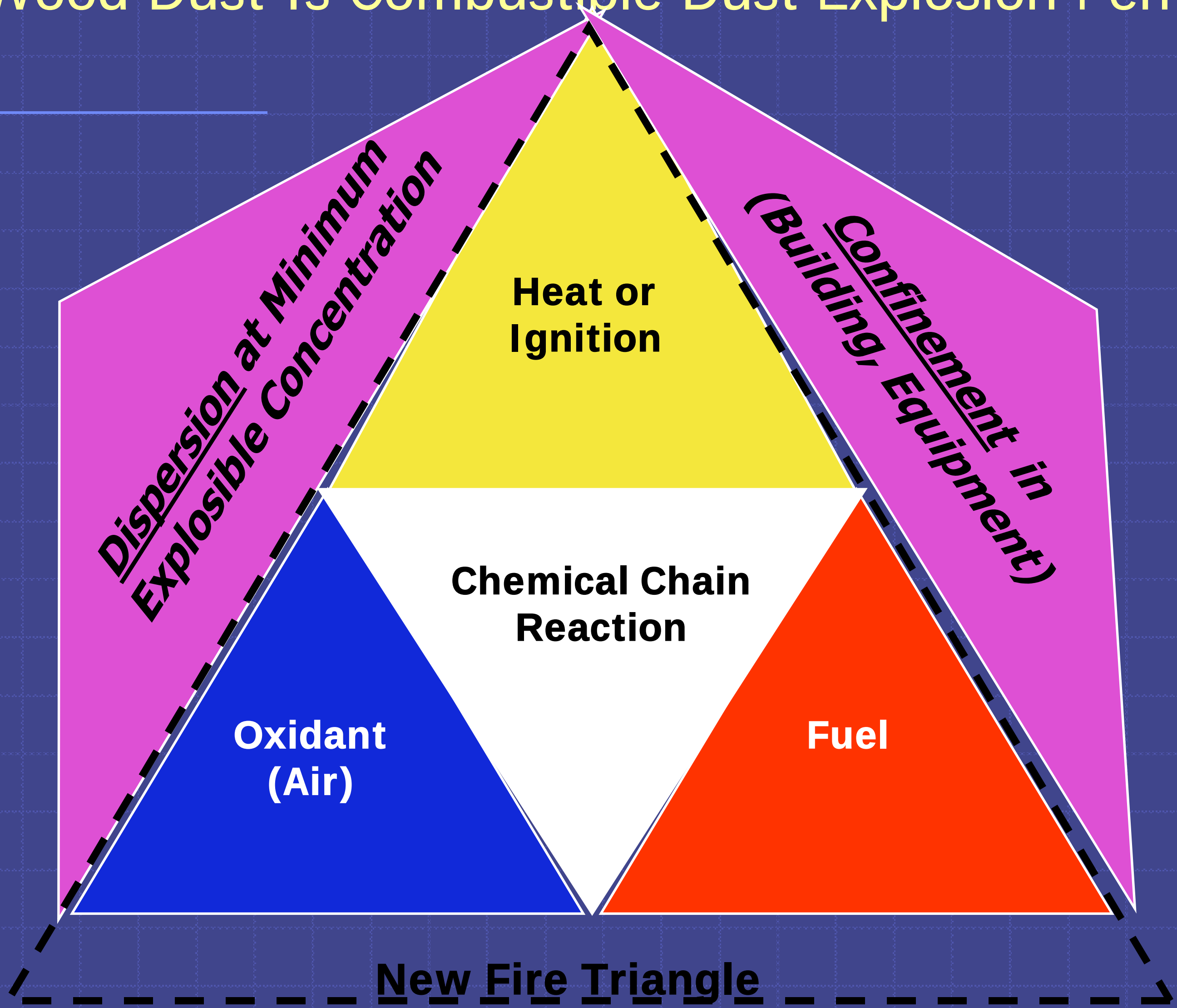


- Duct does not get larger after branch entry
- Unneeded ducts blanked
- Poor duct transitions or merges
- Use of flexible ducts
- High dust collector d/p
- Blast gates changed
- No system technical documentation
- No system monitoring

NASA Dust Conveying Issues
Carpenter shops

- Need for reliable exhaust airflows & conveying velocity
  - Wood species have sensitization potential
  - Wood dusts combustible (NFPA 664) – have hazard analysis on file?
- Challenges maintaining conveying velocity
  - Woodworking machines generate a lot of dust
  - Machines operated irregularly
  - Exhaust systems not sized for all machines running at once
  - Keeping ducts free of combustible dusts in an ON/OFF operating mode

Wood Dust Is Combustible Dust Explosion Pentagon



Vented Explosions

Even a designed vent explosion is a violent event – safe place to discharge?

Combustible Dust Design Data

STRENGTH OF DEFLAGRATION?

- 20 L vessel - Deflagration index, Kst
  - Pmax, bar
  - dP/dt max press. rise – bar/sec
  - Min. Explosible Conc. – gm/m^3

EASE OF IGNITION?

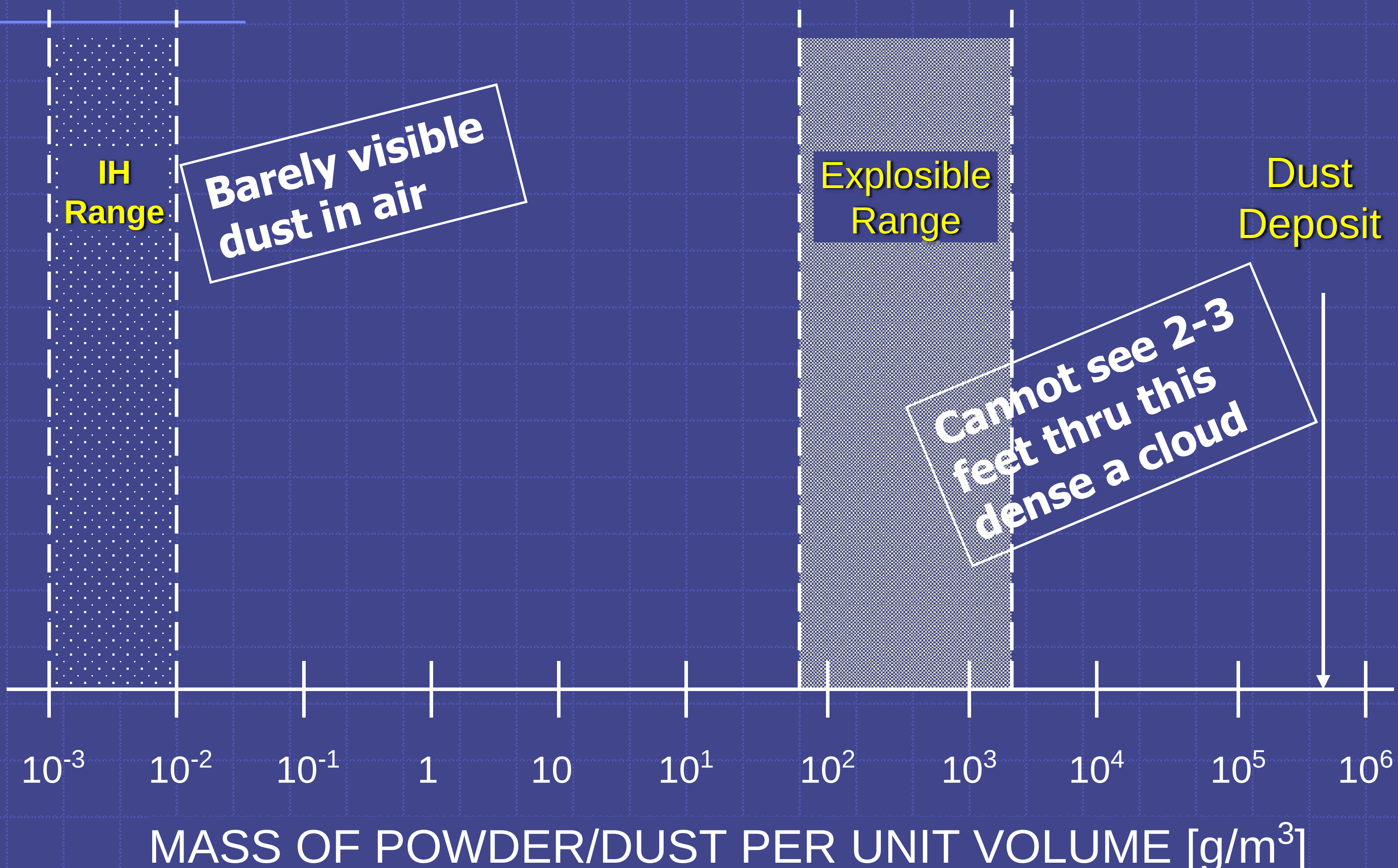
- Min. Ignition Energy, milliJoules
- Min. Ignit. Temp., cloud or layer - T^oC

- NFPA – use actual test results versus literature

Example combustible dusts (NFPA 68)

Hazard Class	Kst (bar-m/sec)	Pmax (bar)	Some examples
ST-1	<200	10	powdered milk, charcoal, sulfur, zinc
ST-2	200-300	10	cellulose, wood flour, methyl acrylate
ST-3	>300	12	anthraquinone, aluminum, magnesium

Explosible Concentration Range



Source: Dust Explosions in the Process Industries, Second Edition, Rolf K Eckhoff

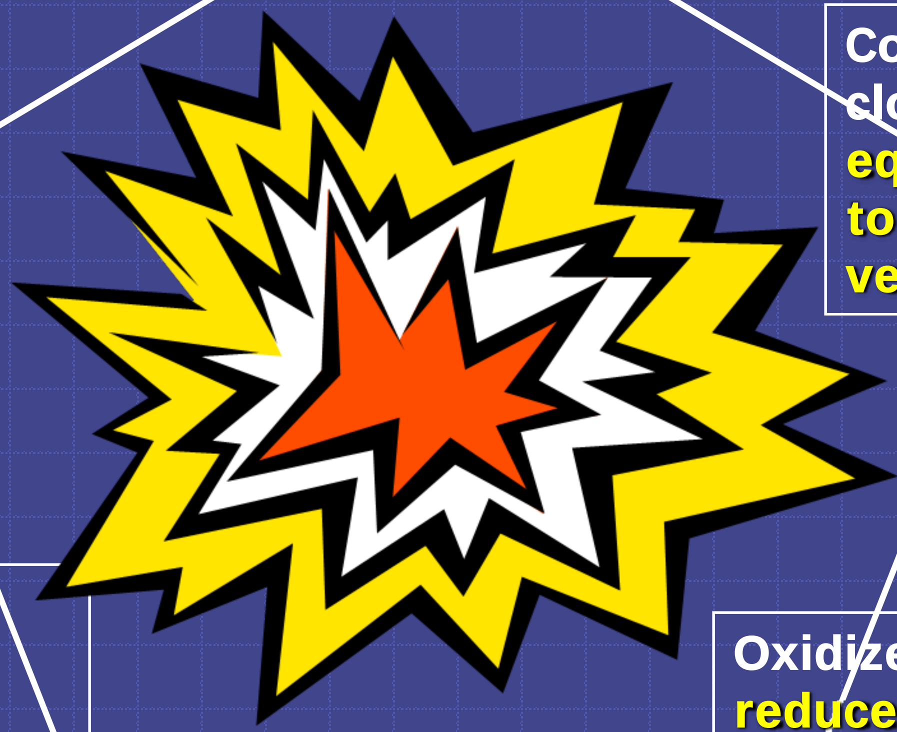
NASA Occup. Health Training

Dust Explosion Pentagon: Multiple Strategies to Reduce Risk

Heat or ignition source: prevent static electricity, sparks, smolders

Dispersion of dust particles: prevent dust layer getting airborne – relief device vent path

Confinement of dust cloud: building & equipment designed to safely contain or vent



Combustible dust (fuel): prevent accumulation – design, housekeeping

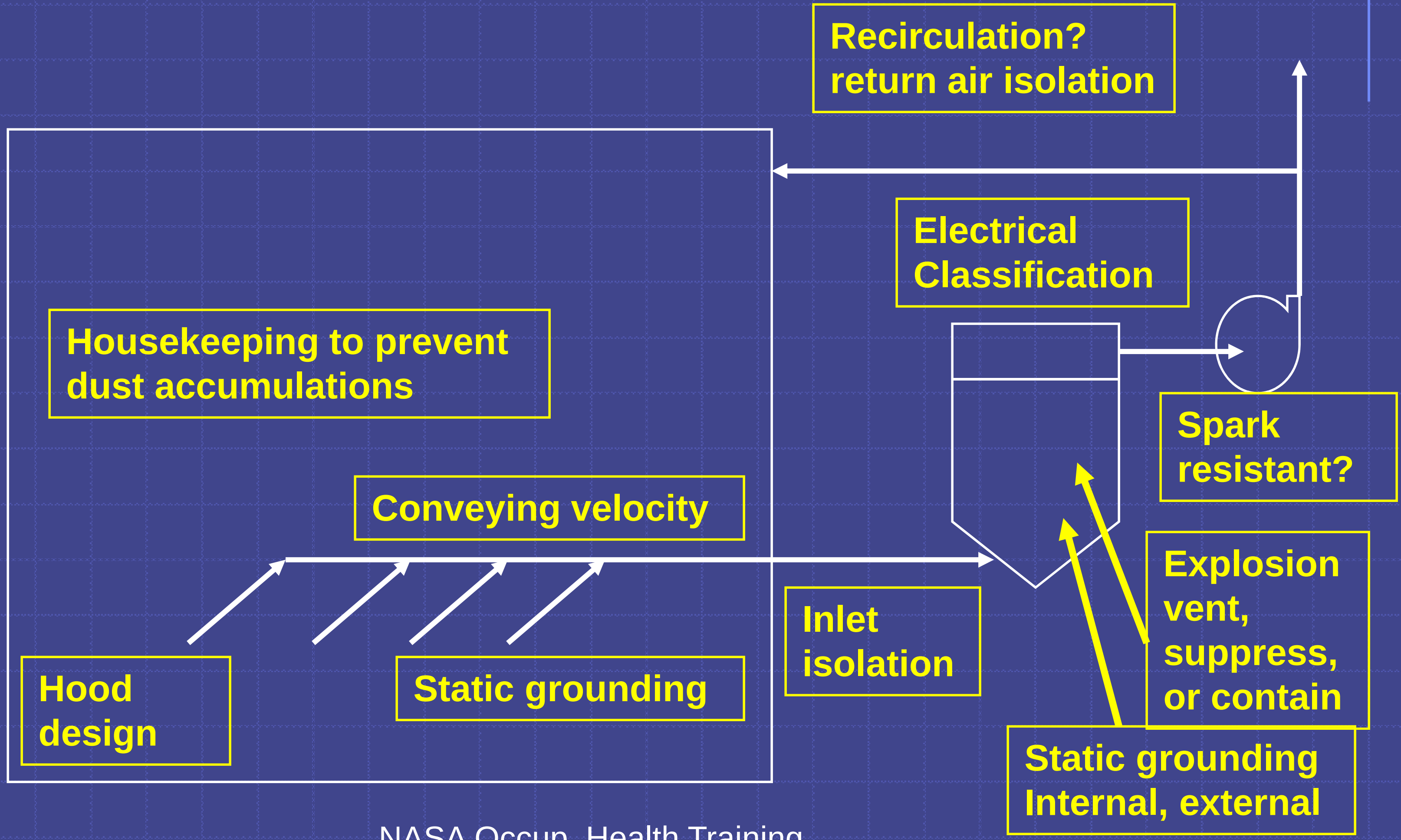
Oxidizer (oxygen in air): reduce O_2 with inert gas (asphyxiation hazard?)

Hazard Analysis (NFPA 664) Accident Scenarios to Assess

- Explosion within process equipment
  - Ignition sources (frictional heating, smoldering dust layers, electrostatic sparks)
  - Equipment with dust clouds > MEC (blenders, driers, size reduction) - Will not be covering details of NFPA 654 requirements for process equipment, building construction or fire protection – very process specific
  - Dust collectors have dust clouds > MEC (> 40% of incidents))
- Explosion propagation – interconnected equipment (spark or deflagration)
- Secondary explosions (dust accumulations, often more significant than primary explosion) – ***1/8" wood dust***

{Zalosh, et al, "Safely Handle Powdered Solids," Chemical Engineering Progress Magazine, Dec. 2005}

Complete Dust Collection System Explosion Protection Overview



Explosion Venting Options

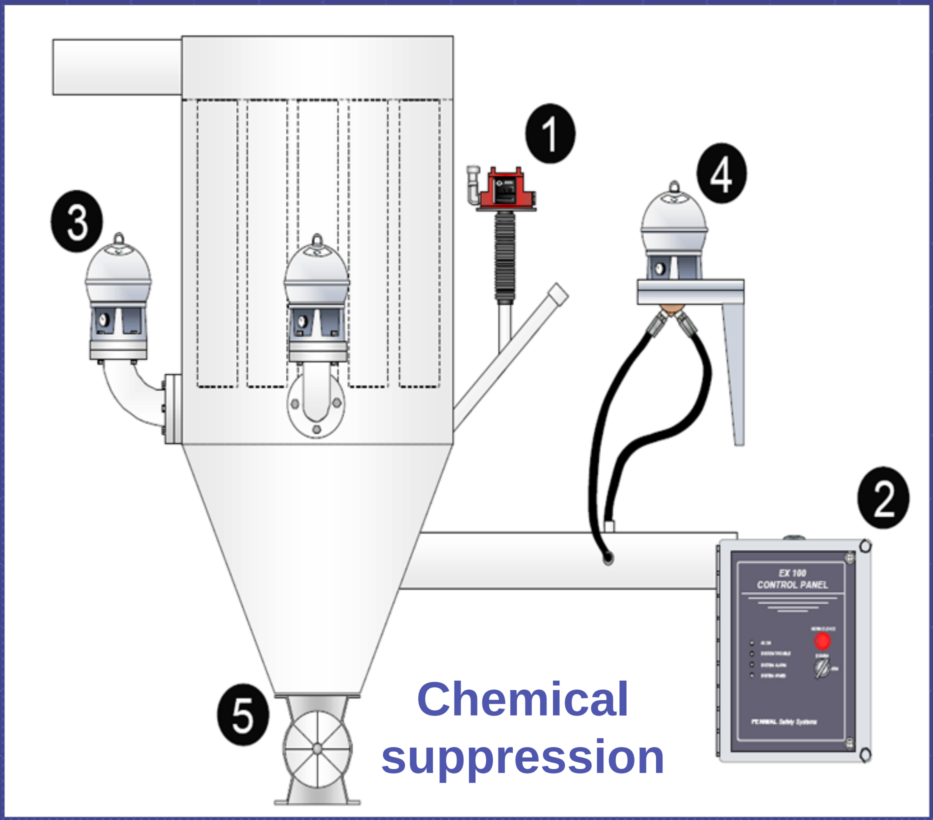
Explosion door

Domed panels resist pressure cycling better than flat panels – 4-20x longer

Domed panel

Flame arresting vent (indoors application)

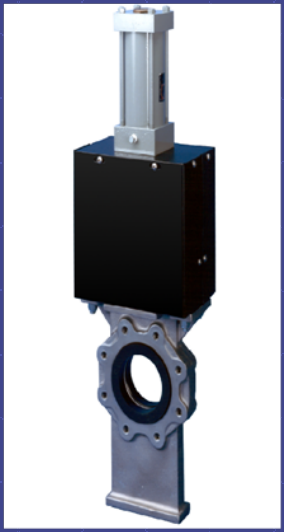
Explosion Prevention & Isolation Options



Flamefront diverter

Back draft valve

High speed isolation valve



Carpenter shop combustible dust protection

- In work area – housekeeping to keep dust layers < 1/8" (NFPA 664)
- Preventing duct accumulations – options
  - Resize duct network so all branches have conveying velocity at all times
  - Reorganize duct layout with multiple branches serving similar exhaust requirements equipment so conveying velocity assured on branch when any single eqpt. operates
- Explosion protection
  - Explosion venting or protection on collector (locate outside)
  - Isolation device on duct at collector inlet
  - Static electrical grounding of dust control system

Lists of woodworking equipment exhaust airflows in Chapter 13, <u>Industrial Ventilation, A Manual of Recommended Practice for Design</u>, 26th Edition, ACGIH, 2007

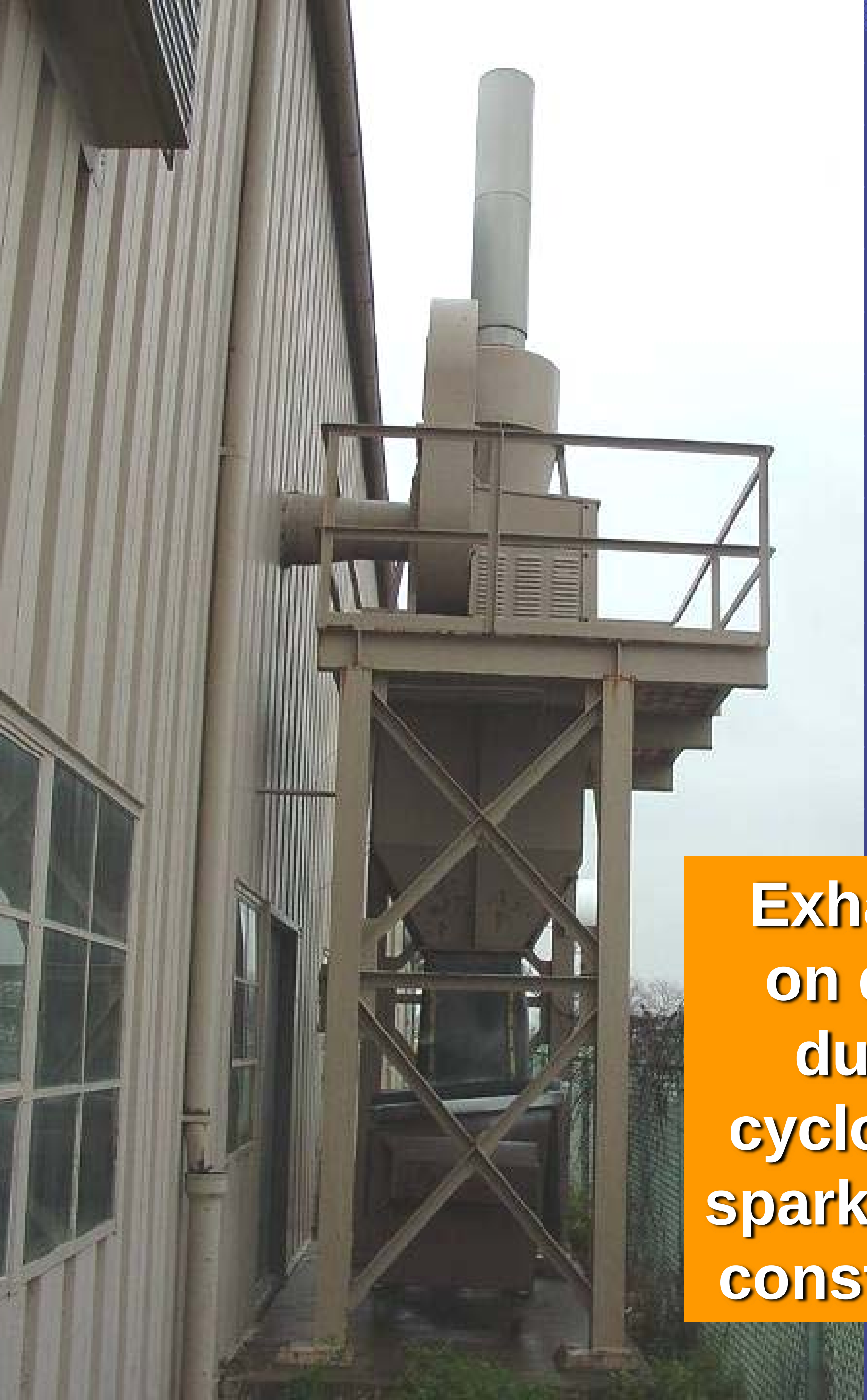
Planer - 1500 CFM

Table saw – 550 CFM

Does this junction maintain conveying velocity?

Equipment scattered everywhere

NASA Occup. He



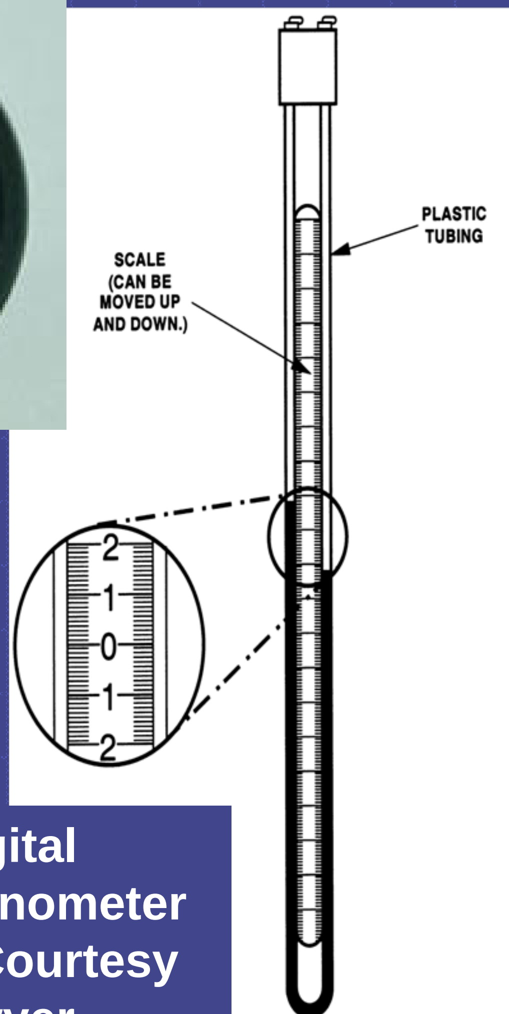
Exhaust fan on dirty air duct into cyclone – fan spark resistant construction?

Strategies for getting reliable conveying velocity

1. CFM requirements each machine?
2. Duct diameters for minimum 3500 fpm?
3. Which machines must run simultaneously?
4. Put machines with similar CFM requirements on same branches for ON/OFF controls - alternate is size entire system for all equipment running
5. Consider impact on dust collector
6. Consider new fan static pressure – fan ok?

Static Pressure Monitoring

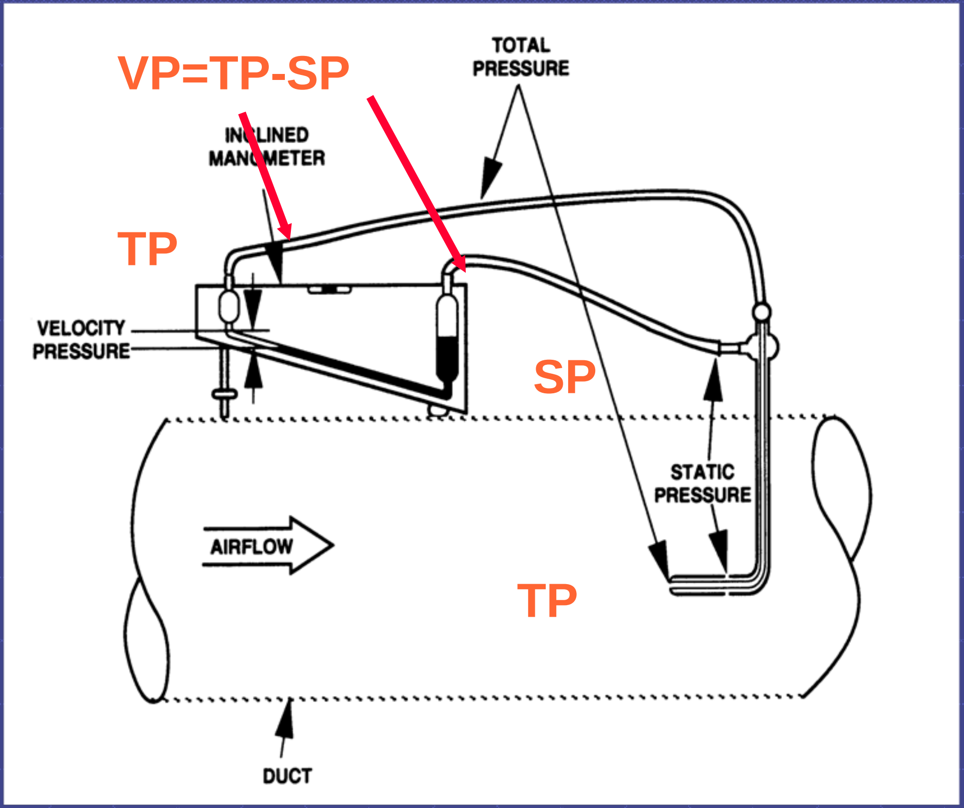
- **What / Where:**
  - **Vacuum or pressure force exerted on the inside of the ductwork**
- **Units:**
  - **Inches water column or water gauge (in.w.c., in w.g.) – or Mercury for high vacuums**
  - **Millimeters water column, Pascals**
- **Instruments:**
  - **Slack or U-tube Manometer & Metal Tube with Rubber Stopper**
  - **Magnehelic gauge**
  - **Digital Manometer**



Digital Manometer – Courtesy Dwyer

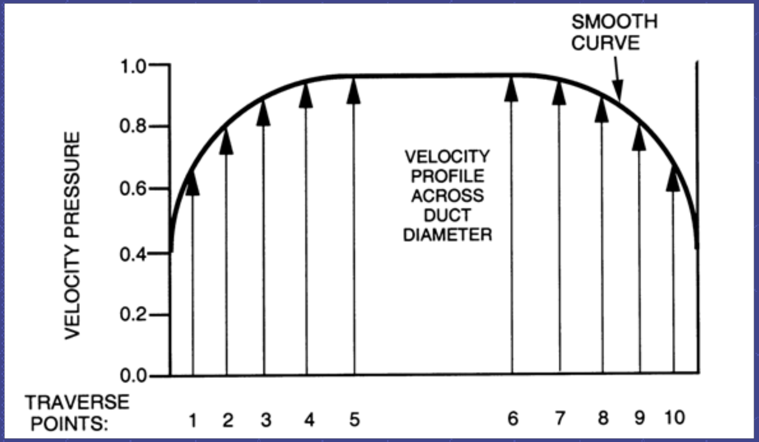
Velocity Pressure Monitoring:

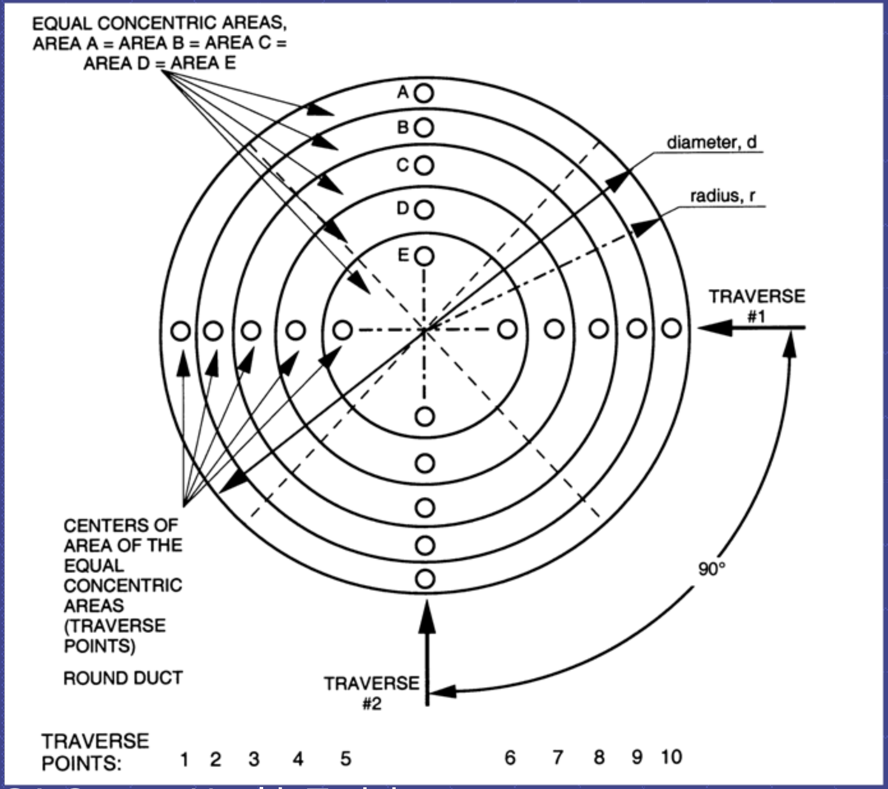
- **What / Where:**
  - **In the linear flow of the airstream**
- **Units:**
  - **Same as static pressure, Inches or mm of water column**
- **Instruments:**
  - **Pitot Tube and**
    - **Inclined Manometer**
    - **Slack or U-tube Manometer**
    - **Digital Manometer**



Duct Velocity Profile

Duct Traverse Points – Equal Concentric Areas – Good Averaging





Log Linear Pitot Traverse also used

Velocicalc by TSI

Data download capable

Model 8386

Use with pitot tube for duct air velocity

Use good measurements technique

What are the problems here?

Duct Troubleshooting

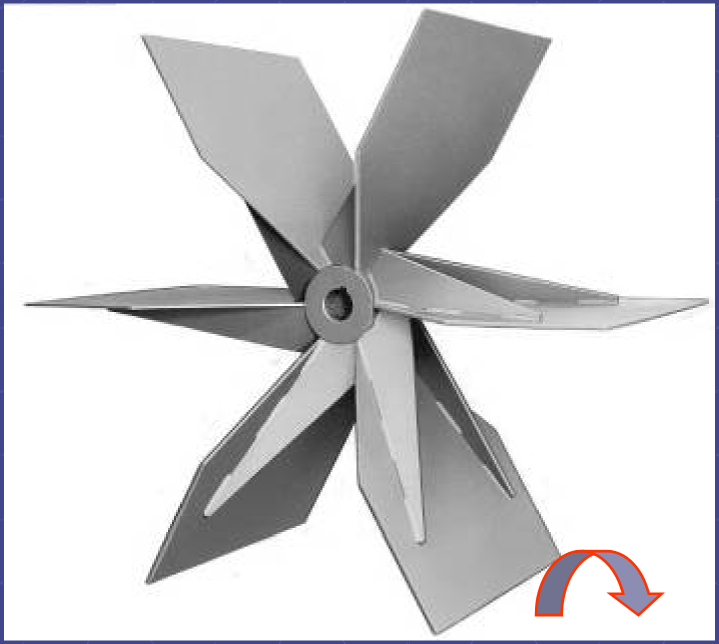
- Visual
  - Damage-dents, holes?
  - Duct access doors ajar or open?
- Routine monitoring
  - Duct network static pressures
  - Strategic airflows
- Take Troubleshooting action > ± 20% Baseline static pressure – more in Troubleshooting section

Local gauges with action limits

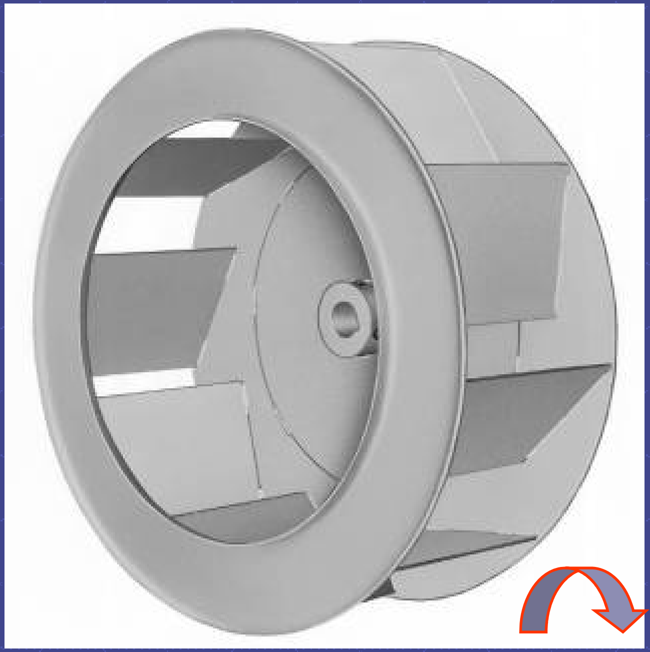
Fan Failure Modes

- Fan sized for current ductwork SP loss
- Fan mechanical drive
- Fan aerodynamic performance
- Fan “system effects” degrade capability

Centrifugal Fan Impellers



Radial Impeller: strength for dusts, solids



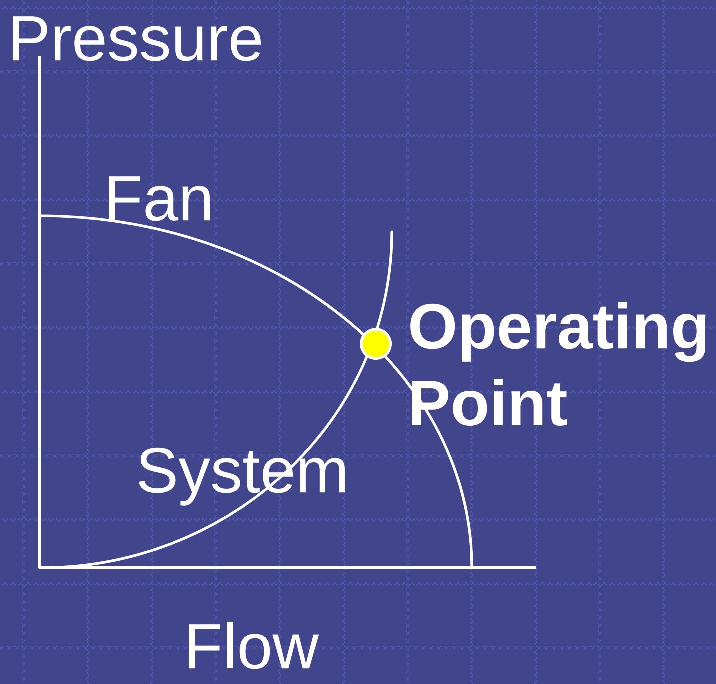
Backward Inclined: higher energy efficiency

Fan aerodynamic performance

- Fan shaft speed
- Excessive clearance between impeller and housing
- Buildup on impeller
- Erosion on impeller
- Fan control method
- Inlet and outlet duct design – fan system effect like centrifugal pump NPSH loss

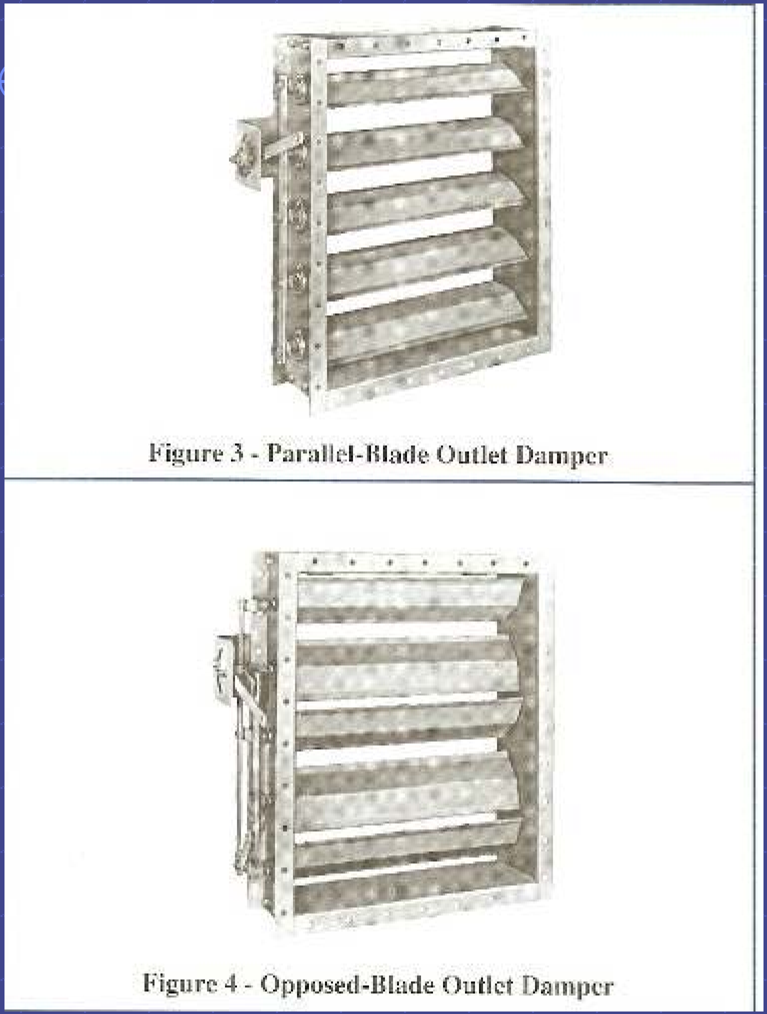
Fan Design Operating Point

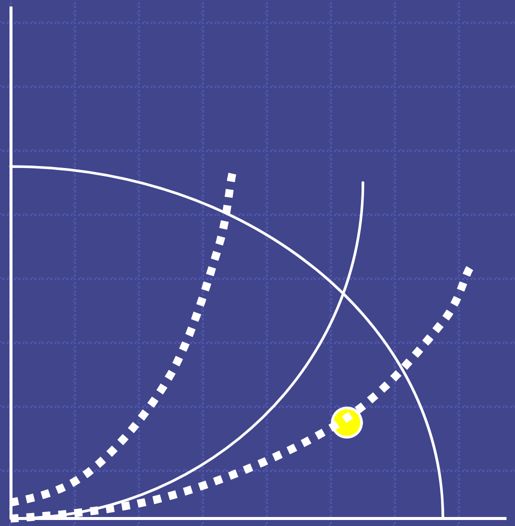
- Combine curves



- System balance calculations determine fan requirement
- Fan Performance Tables locate the vendor's fan that can deliver requirement

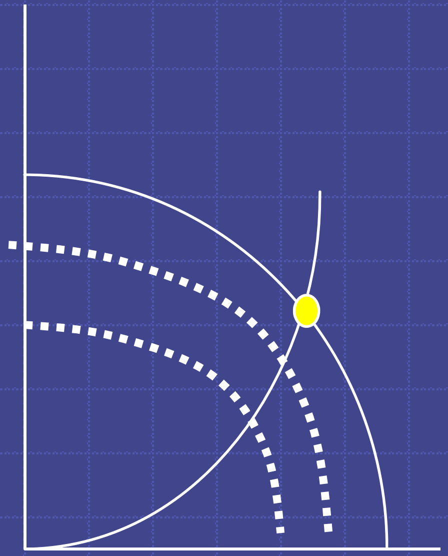
Fan Control



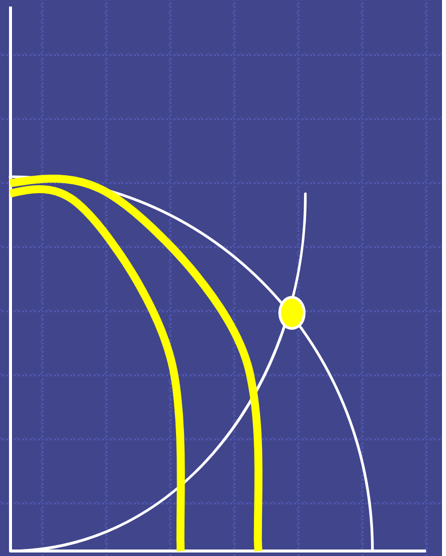


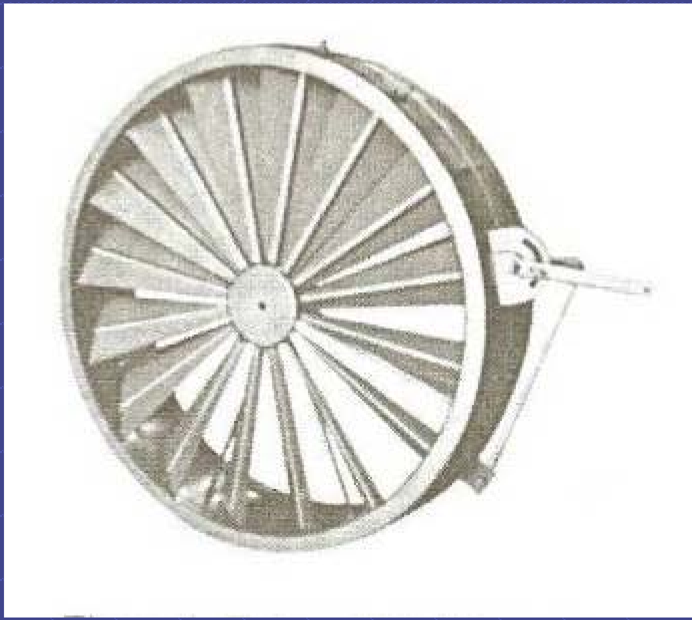
Outlet Dampers – add resistance and change fan curve shape

Fan Control



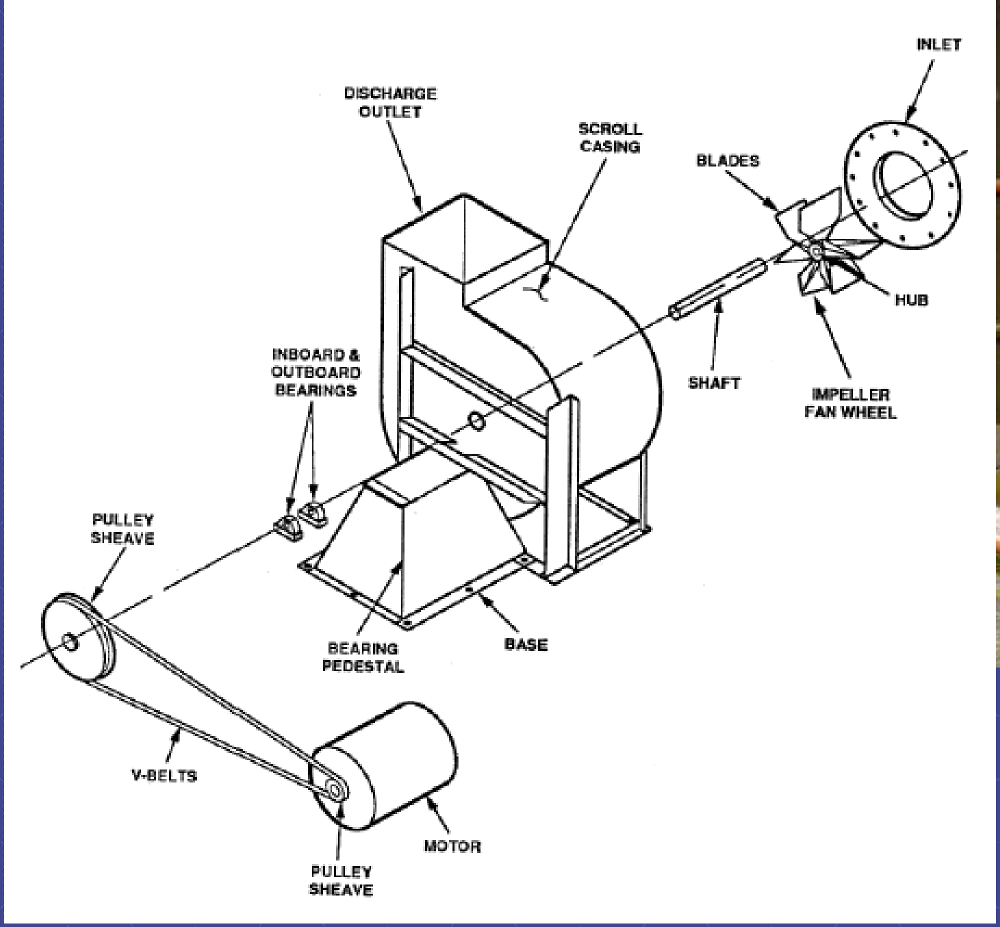
Inlet Damper – “bends” fan curve

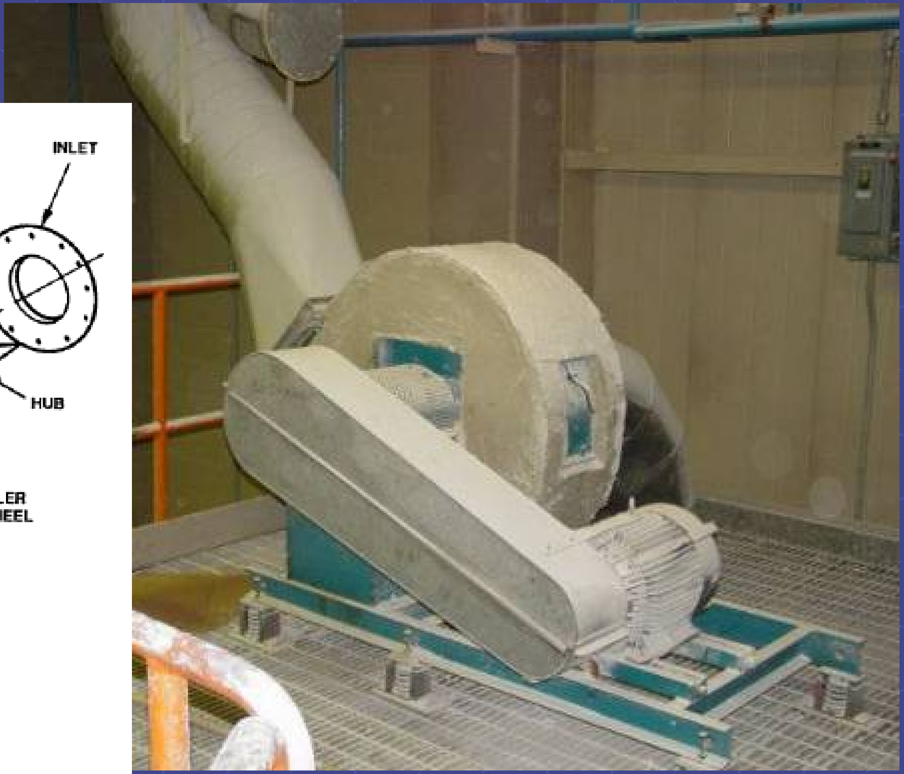




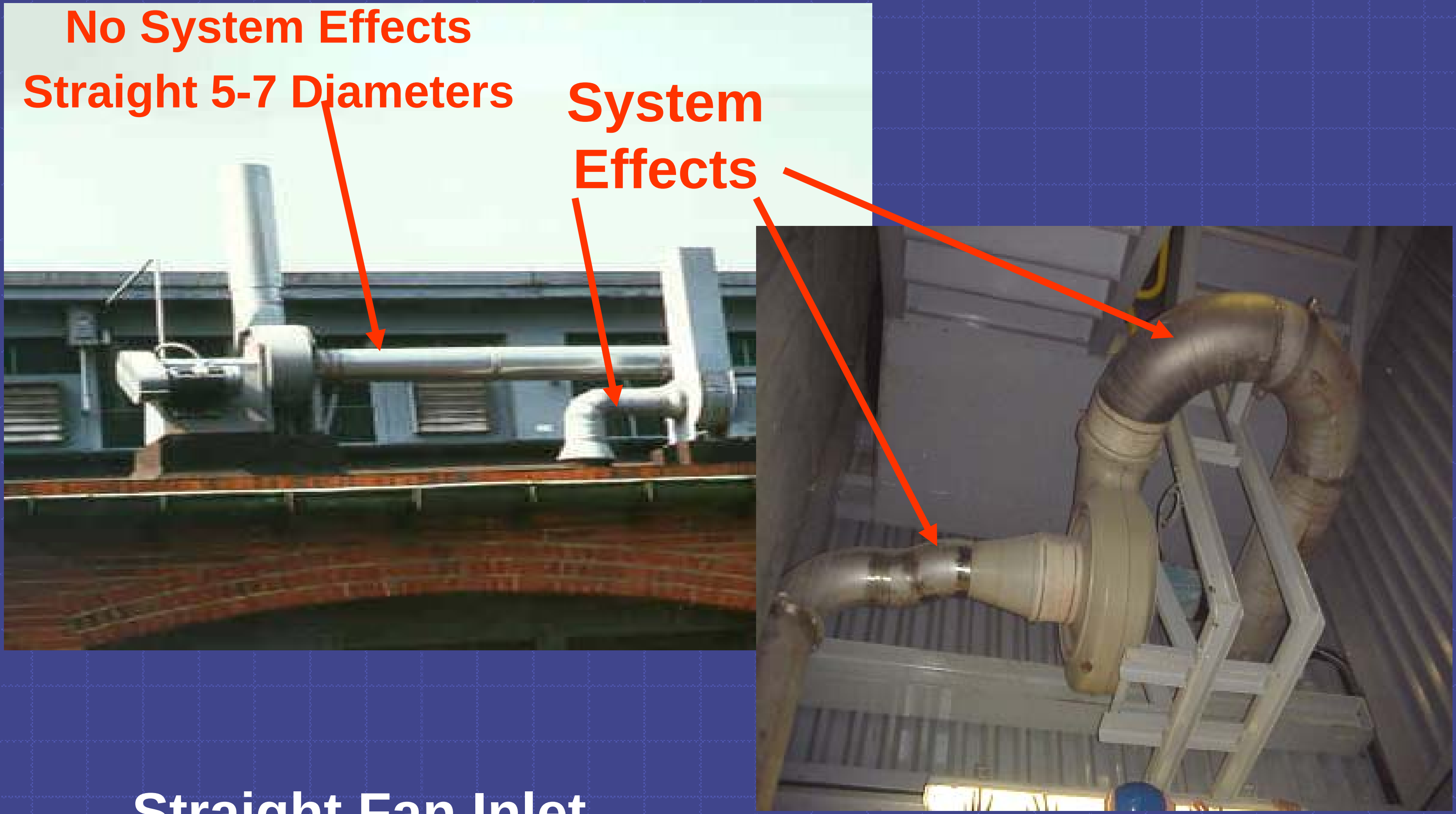
VFD-Variable Frequency Drive – develops family of curves

Fan Drives: Pulley belts & sheaves: ease of speed change





Fan Inlets - Avoid System Effects and fan performance loss!

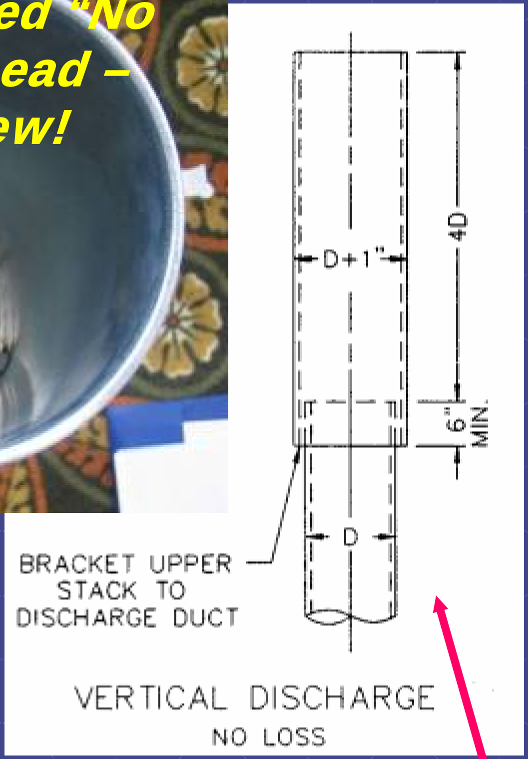


Straight Fan Inlet

IVS Exhaust Stacks Issues

- Purposes for stack placement
  - Escape the building envelope so plume not drawn into building
  - Sufficient dispersion so plume contact with ground does not cause a problem
- Designs to disperse emissions
- Impact of airflow patterns around a building

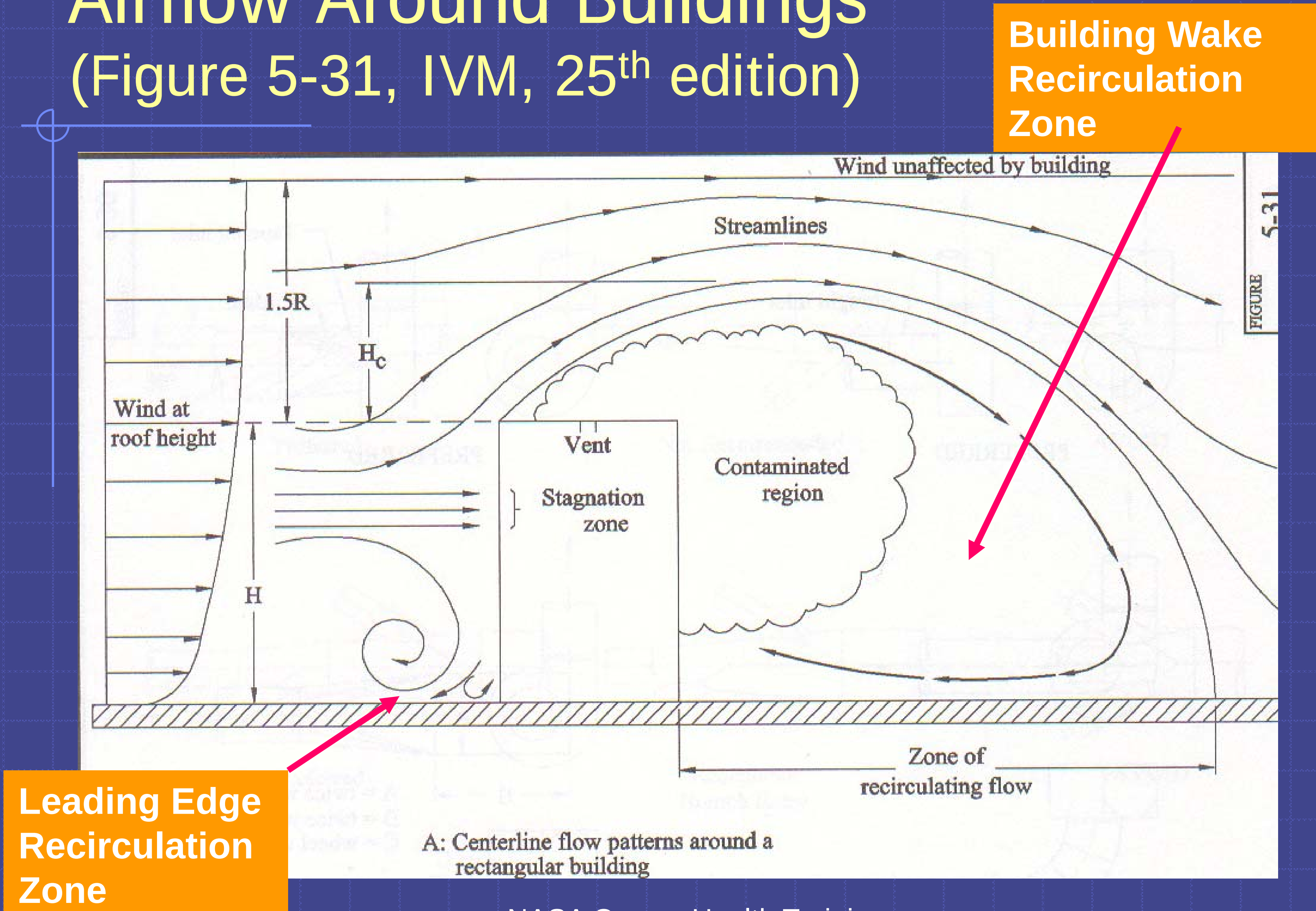
Fan Stack Weather Head



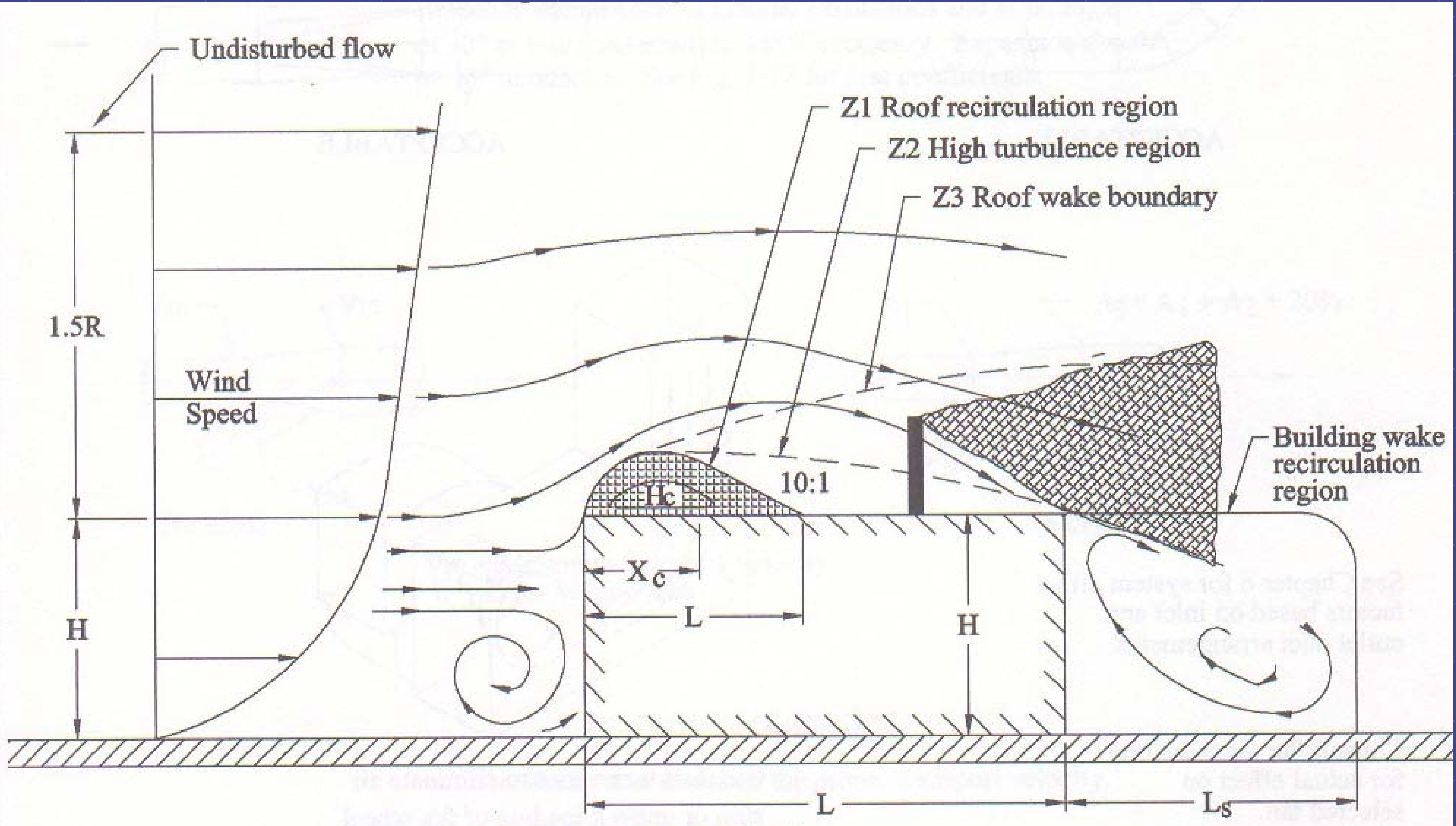
DON'T USE THESE!

Fig.5-18: From American Conference of Governmental Industrial Hygienists (ACGIH®), Industrial Ventilation: A Manual of Recommended Practice for Design, 26th Edition. Copyright 2007. Reprinted with permission.

Airflow Around Buildings
(Figure 5-31, IVM, 25th edition)



Building Recirculation Cavities
(Figure 5-16, IVM, 26th edition)



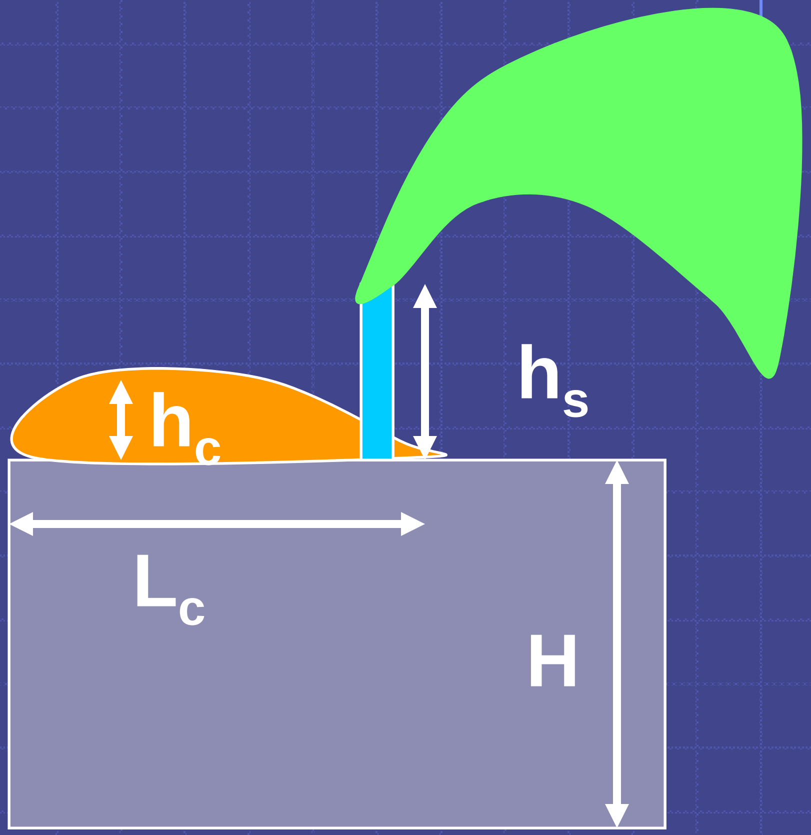
B: Building Recirculation Cavities

Stack Design Considerations

- Wind speed affects attainable dilution
- Stack temperature and velocity influence effective stack height
- 3000 ft/min stack velocity prevents downwash up to 22 mph, higher velocity is better dilution
- To avoid entrainment of exhaust into the wake, stacks must terminate above the recirculation cavity
- ASHRAE Fundamentals – "Airflow Around Buildings" – screening dispersion model

ASHRAE scaling length method

- Stack – exhaust above the orange bubble
- Find L_c and h_s
- Scaling length
  - $R=B_S^{0.67} \times B_L^{0.33}$
  - Bs = smaller of H or W
  - BL = larger of H or W
  - H_c estimate = 0.22R
  - L_c estimate = 0.9R



W – bldg width facing flow

Stack Design Considerations

- Separate building air intakes from exhaust points to increase dilution – 50 feet minimum
- Bring several small exhaust ducts to one stack for increased dilution
- Put stacks on building high points, if possible
- Avoid rain caps on stacks
- Avoid use of architectural screen – interference

Fan Measurements

Courtesy
Sticht Co.

Shaft speed: (check against fan curve)

hand held mechanical tachometer or strobotach

Fan motor current: (rough estimate of total airflow) Clamp on ammeter

Vibration analysis

Courtesy
Tiger Tek

Fan Maintenance

- Visual
  - Overheated bearings?
  - Unusual noises or vibrations (belts aligned?, impeller out of balance-erosion/buildup?)
  - Air leaks on flexible connections?
  - Fan inlet damper changed?
- Routine Maintenance
  - Lubricate shaft bearings – fan, motor
  - Check mechanical components (belts, bearings, fan impellor & housing clean)
  - Check vibration isolators
  - Vibration analysis
  - Motor condition & electrical current draw

Fan Troubleshooting

- Air Moving and Conditioning Association (AMCA)
  - Publication 201 – Fans & Systems
  - Publication 202 – Troubleshooting Fans
- ACGIH
  - Industrial Ventilation, A Manual of Recommended Practice for Design, 26th edition
  - Industrial Ventilation, A Manual of Recommended Practice for Operation and Maintenance, 1st edition
- Your Fan Manufacturer's literature

Key Performance Issues for Any Collector

- Meet environmental emission permit
  - contaminant collection efficiency
  - collected contaminant recycle or disposal
- Operating the collector within its design differential pressure (DP) range
  - DP high –
    - acts like a damper & reduces airflow in rest of system
  - DP low –
    - bypassing of collector and IV System?
    - cause higher than desired airflow in IV System?

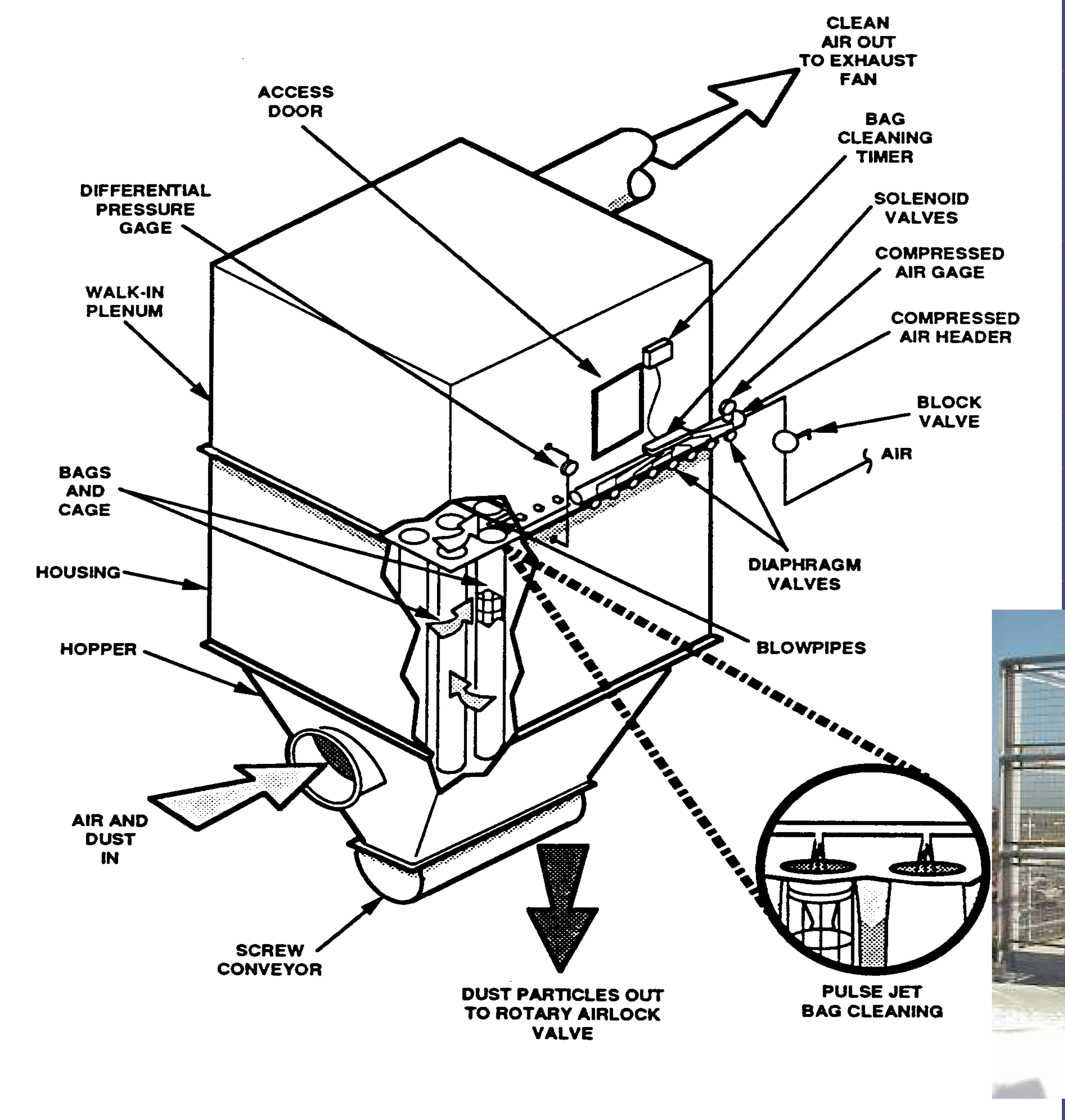
Types of Collectors

PARTICULATE

- **Fabric Filters (Baghouses)**
- **Inertial Separators (Cyclones)**
- **Wet Collectors (Scrubbers)**
- Electrostatic Precipitators
- Mist Eliminators

NON-PARTICULATE

- Gas Absorbing Scrubbers
- Bio Filters & Scrubbers
- Thermal & Catalytic Oxidizers
- Adsorbing Filters
- Condensing and Solvent Recovery



Fabric Filter Components & Features

Tubular

Cartridge

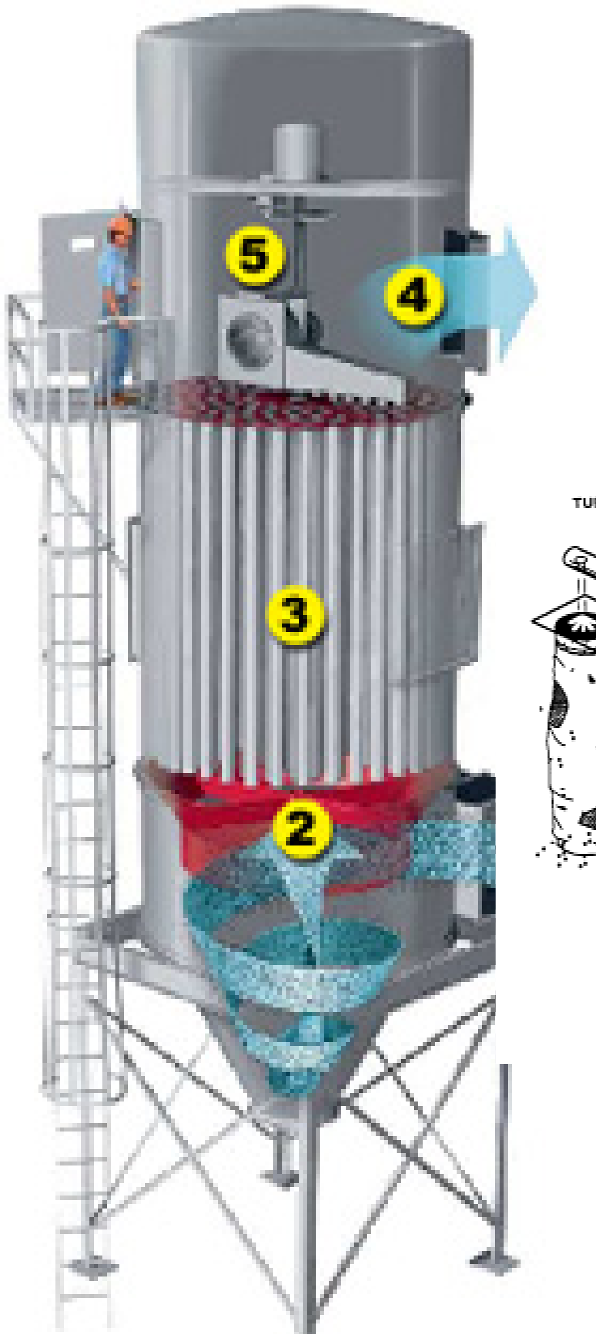
Star

or pleated

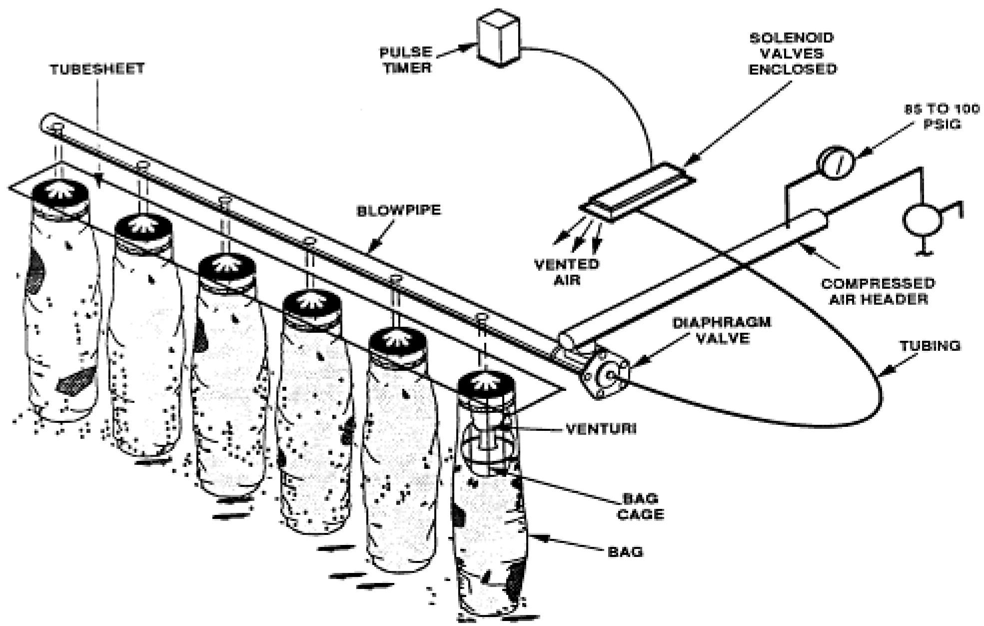
Envelope

Types of Filter Elements

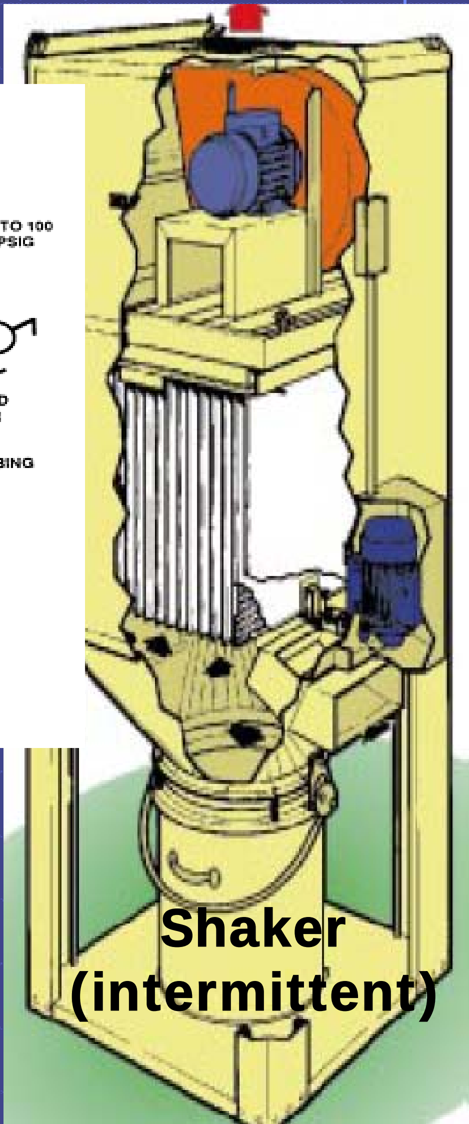
Bag Cleaning Method



Reverse Air



Reverse Pulse Jet



Shaker (intermittent)

Integrated Baghouse Controls

Inductive leak detector – Courtesy FilterSense

Non-clogging diff. pressure sensor - Courtesy FilterSense

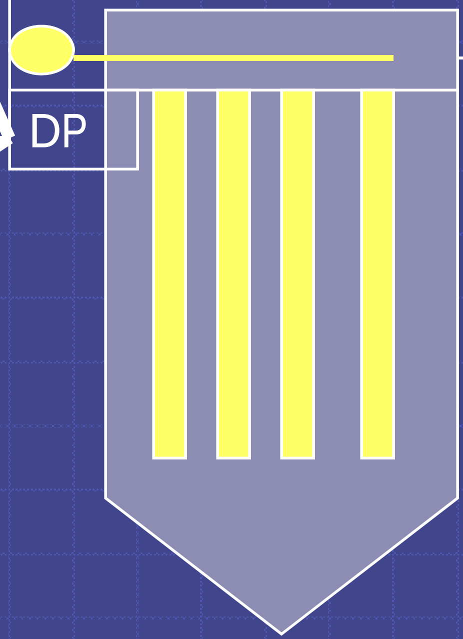


Photo-helic diff. press. – courtesy Dwyer

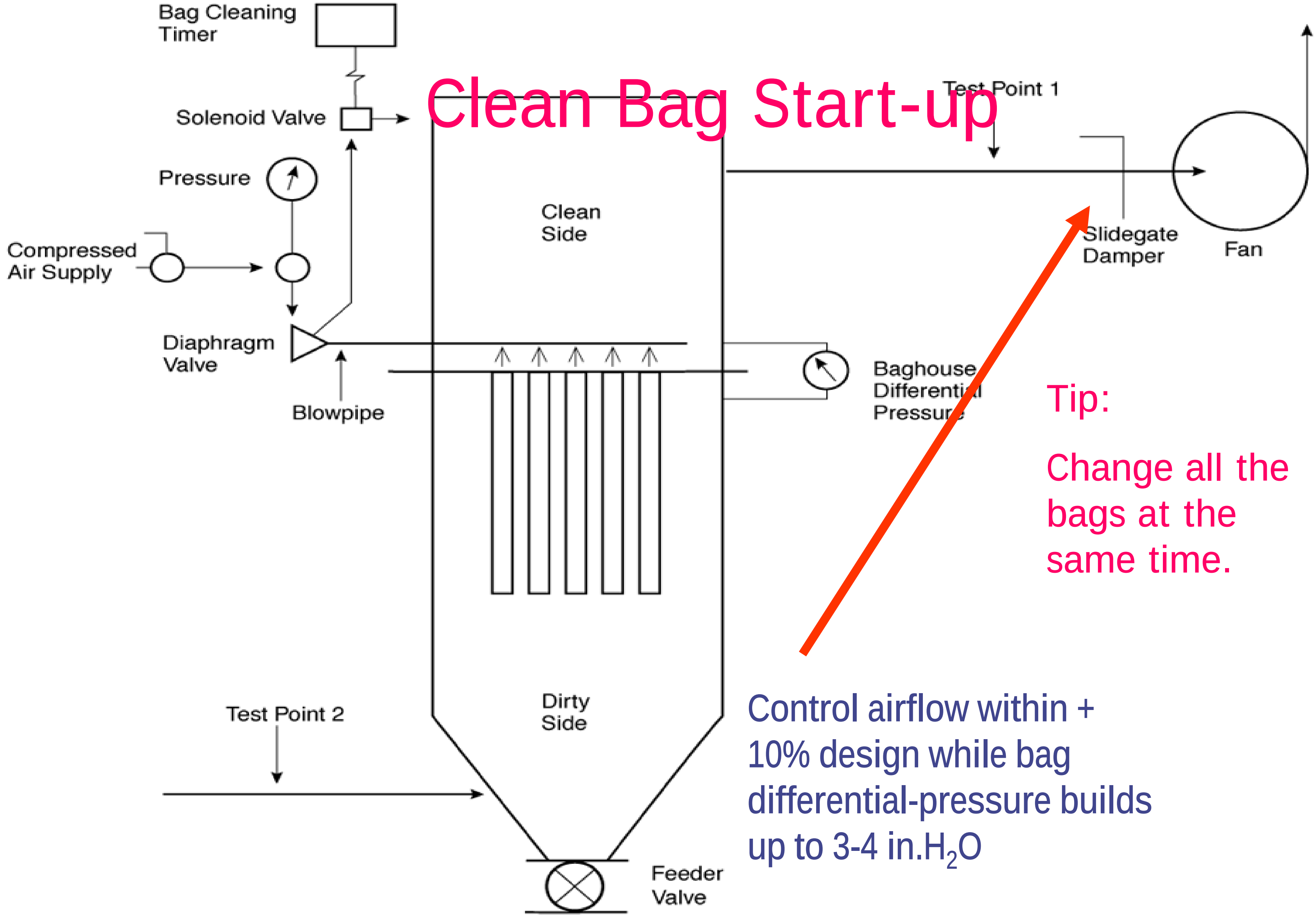
Integrated controller – Courtesy FilterSense

Possible Causes of Visible Emissions

Bag Leak Detection System gives warning for pinhole leaks.

- Bag fabric torn or damaged: burned, erosion, chemical?
- Bag not sealed to tubesheet? – look on clean side for signs of dust buildup at some bags
- Bag venturi not sealed to tubesheet?
- Broken bag detector malfunction?
- Loose bag clamps?

Clean Bag Start-up



Tip:

Change all the bags at the same time.

Control airflow within + 10% design while bag differential-pressure builds up to 3-4 in.H_2O

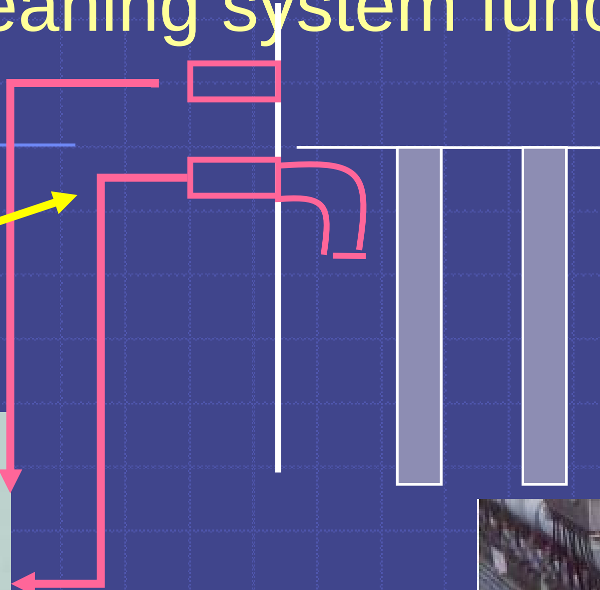
Cartridge filter dust collector

Fabric Filters: Daily Recommended Monitoring
Visual

- Record bag differential pressure, upward trend?
- Record bag cleaning compressed air pressure
- Audible air leaks at baghouse?
- Air lock valves apparently operating?
- No apparent backup in filter hopper? – thump it to listen for hollow, drum sound
- No apparent backup in dust disposal container under filter hopper?
- Visible stack emissions?

Baghouse Monitoring - Weekly Check
bag cleaning system function

Provide access to poke through



Down turned elbow prevents plugging

Investigate increasing differential pressure trend

When a row of bags is being cleaned, you will see:

DP – level or needle quiver/jump

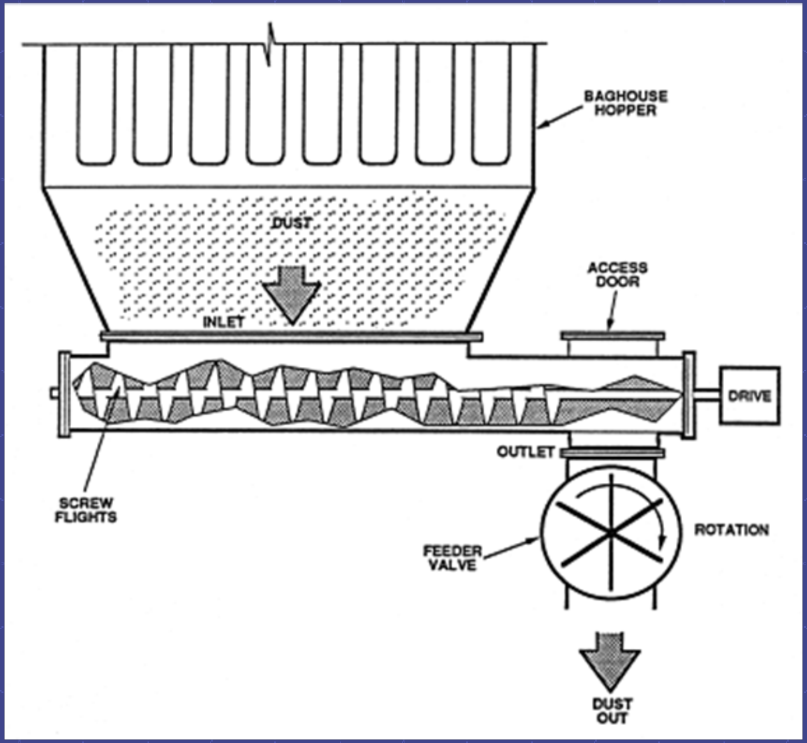
CAP – drop 20 psig

Baghouse Monitoring - Weekly
Check dust removal system function

- Filter hopper paint looking beat up?
- Air lock valve discharging expected amount?
- No apparent metal to metal sounds?
- No apparent signs of air in-leakage around air lock?
- Visual check of rotary valve pocket plugging if a problem experienced with your dust

Dust Removal - Rotary Valve, Screw Conveyor

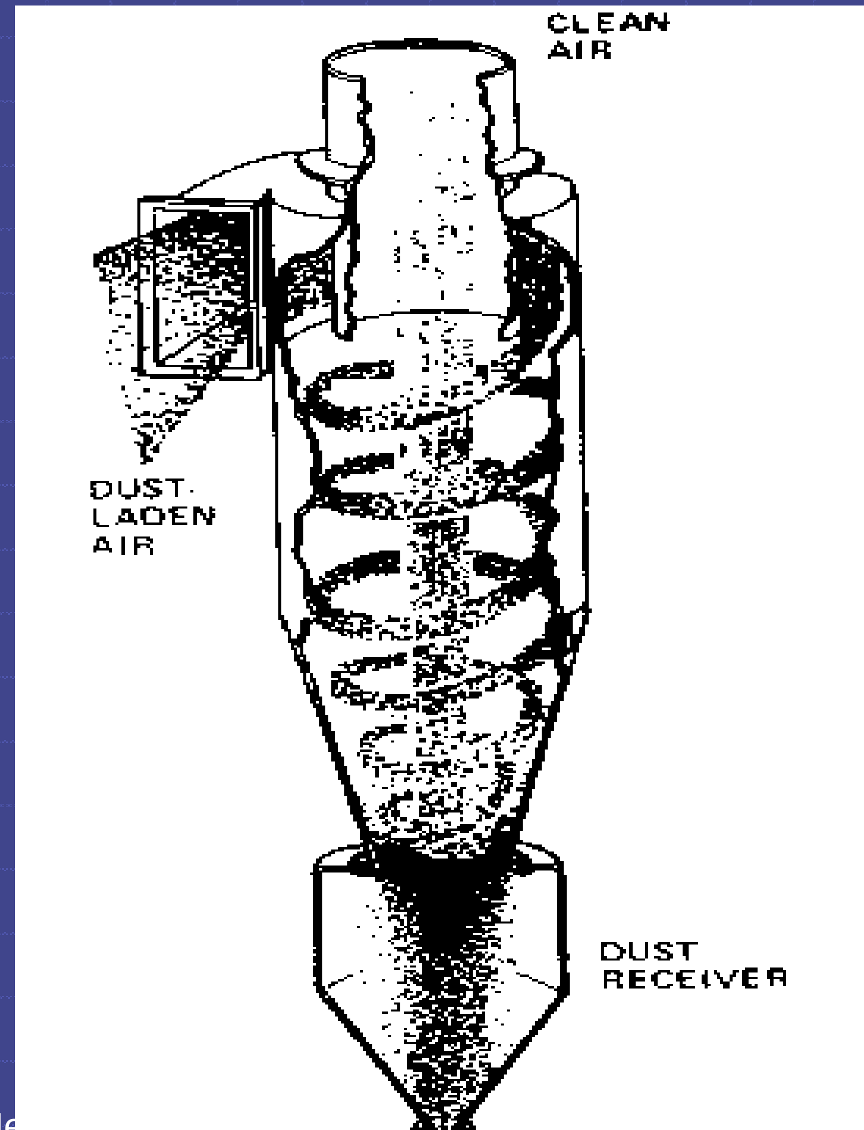
- Continuously empty hopper- **don't use hopper as surge bin.**
- Provides a seal between dust collector and chute to bin.
  - **Dust collector under negative pressure (vacuum)**
  - **Chute is at ambient pressure**
- Rotor-to-housing clearance must be maintained to keep valve from leaking air INTO filter and disrupting dust removal.



Troubleshooting Fabric Filters

- **High differential pressure causes**
  - Fabric "blinding" by dust
    - Too high air to cloth?
    - Bag cleaning failure?
    - Process moisture?
    - Dust removal failure?
  - Wrong fabric?
  - Higher airflow?
- **Low differential pressure causes**
  - Low bag resistance to airflow
    - New fabric not yet conditioned?
    - Bags cleaned too often?
    - Missing bags?
  - Low system airflow?
    - Duct network plugged?
    - Filter access door open – bypassing?
    - Combustible dust device open or leaking?
    - Fan shaft speed low?

Cyclones –Centrifugal Force at Work



Actual Cyclone Dust Vortex

Variables that Affect Collection Efficiency - Limit Flexibility for Changes

- Flowrate (d/p approx. v^2)
  - Efficiency increases as v increases , then efficiency drops from re-entrainment from turbulence *(10-20% changes in airflow ok)*
- Gas physical properties
  - Temperature
  - Viscosity incr. as temp, efficiency decreases
  - Density- dust much denser
- Dust particle properties
  - Particle size smaller, efficiency decreases
  - Particle density greater, efficiency increases
  - Settling velocity smaller, efficiency increases
- Dust Loading Increase
  - d/p decreases & efficiency increases
  - Total mass out increases

Operating Tips and Monitoring

- Cyclone Differential Pressure
  - Early indication of internal buildup and loss of collection efficiency
  - Air leakage
- Keep design backpressure on cyclone - elbow or cap
  - Efficiently converts vortex velocity pressure to static pressure.
- Monitor Cyclone Discharge for Emissions
  - Cyclone dirty?
  - Process changes? – Monitor key variables

Cyclone Upsets Are Messy!

One more tip: Continuously run cyclone discharge bin empty

Buildup into bottom of cyclone will disrupt vortex with full flow of dust loading to atmosphere

Troubleshooting Cyclones

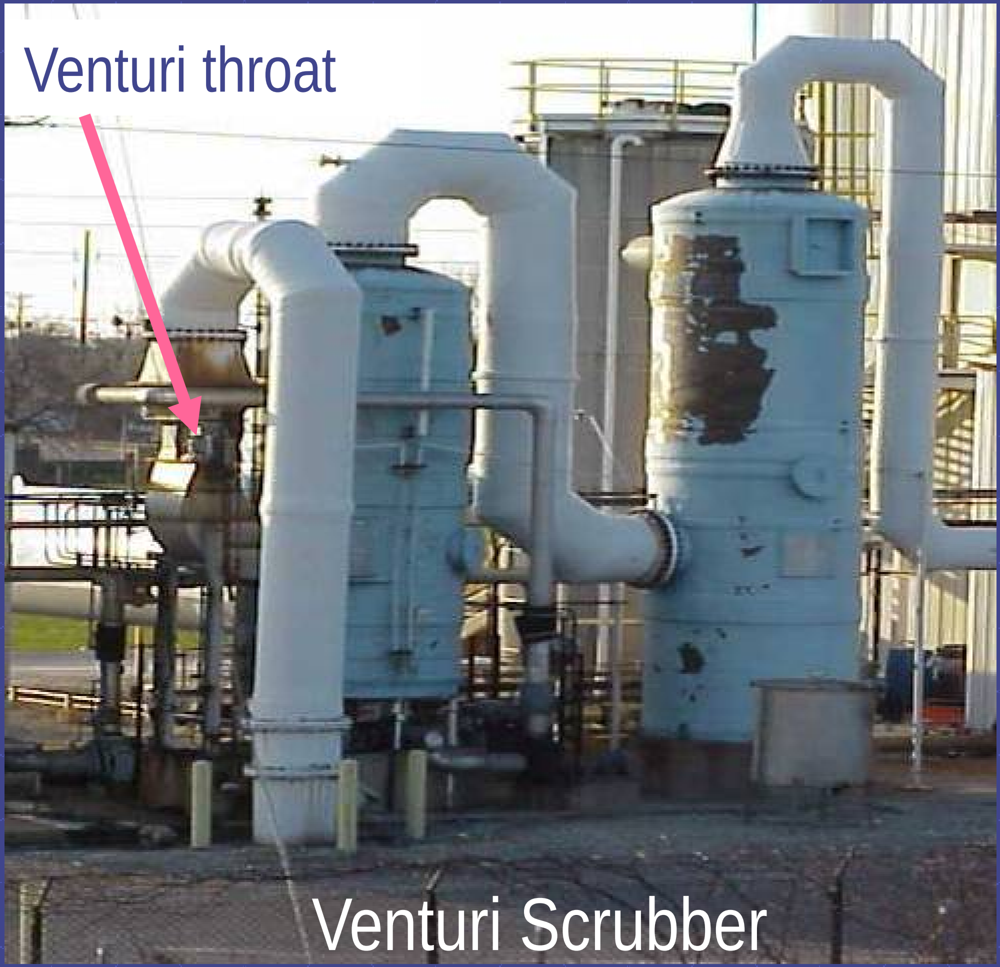
- **High differential pressure causes**
  - Higher than design airflow?
    - Duct cleanout door open?
    - Fan shaft speed high?
  - Dust buildup on cyclone internal walls?
  - Dust hopper backup?
  - Proper design?

- **Low differential pressure causes**
  - Low system airflow?
    - Duct network plugged?
    - Fan shaft speed low?
  - Air leakage into cyclone?
    - Cyclone access door open?
    - Dust hopper access door open?

Particulate Scrubbers

Most collection by particle impaction with water surface in many particle/droplet collisions

Venturi:
-Many droplets at venturi throat from high differential pressure
- Throat opening adjusted for max. efficiency



Particulate Scrubbers

AAF Type W Roto-Clone (combined fan and wet scrubber)

Packed Bed Scrubber

Fisher-Klosterman
– particles + absorbable gases
- Complex surfaces of packed bed create many collisions

Application Issues

- Mist elimination separation tank may be needed to
  - Knock down droplets
  - Collect wet sludge for disposal by treatment system (extra process steps)
- Wet collectors chosen if:
  - Concern for fires
  - Desire for gas quenching
  - Desire to also remove gases
- *No wet collector exhaust recirculation – humidity buildup within building*

Variables That Impact Collection Efficiency

- Scrubbing liquid
  - Flow rate (sludge pump)
  - Worn spray nozzles
  - Sludge loading in liquid
  - Concentration of additives for absorption, if used
  - Changes in ratio of gas to liquid
- Internal scrubber wear
- Dust loading
  - Increased loading
  - Smaller particle sizes
- Mist eliminator carryover
  - Excessive airflow or water flow
  - Cleanliness
  - Drain backup
- Backup in sludge separation tank that floods scrubbing zone

Monitoring & Maintenance

- Scrubbing liquid flow rate and pressure
- Gas flow rate and pressure drop across scrubber and mist eliminator
- Feed and bleed of scrubbing liquid to maintain proper sludge concentration
- pH of scrubbing water
- Spray nozzle pattern
- Monitor for contaminant buildup on collecting surfaces that interferes with water-particulate collisions, mist elimination, or sludge drainage

Troubleshooting Scrubbers

- High differential pressure causes
  - Throttling orifice opening too small?
  - Dust buildup on scrubber internal walls?
  - Sludge hopper backup?
  - Higher than design water flow?
  - Higher than design airflow?
    - Duct cleanout door open?
    - Fan shaft speed high?
- Low differential pressure causes
  - Scrubber water low flow?
  - Low system airflow?
    - Duct network plugged?
    - Fan shaft speed low?
    - Fan running backward?
  - Bypassing
    - Scrubber access door open?
    - Sludge hopper access door open?

Summary

- IV Systems – 4 functions
  - Capture
  - Contain
  - Convey
  - Collect
- All parts are connected by airflow – changes in one part can be measured in other parts – potential negative impact!
- Make sure that your IVS are BASELINED!

IVS Troubleshooting - Where Do You Start?

- Broadly, system problems due to
  - Original design?
  - System modified without redesign?
  - Poor operating practice? (ie, adjusting blast gates)
  - Little or no system monitoring & maintenance?
- Getting started
  - Define the problem areas & symptoms
  - Gather visual and measurement data on system

Defining the Problem

- Observable Symptoms?
  - Accumulation of combustible dusts
  - Qualitative (visible, olfactory, etc.)
  - Quantitative symptoms (air samples)
  - Operator complaints
- Specific locations affected?
  - Reasons, frequency of equipment entry?
  - One hood/enclosure?
  - Multiple hoods/enclosures?
  - Nowhere near a hood/enclosure?

Data Gathering - Qualitative

- Original system design work as intended?
  - Design basis for each hood/enclosure
  - System layout and schematic
  - System Baseline airflows and static pressures
  - System IH Evaluation at startup
  - Problem area data today?

Data Gathering – Qual. 2

- System modification without redesign?
  - Site have a Change Management System with IVS knowledgeable people part of the process?
  - Compare original schematic to as installed
  - Visual clues if no documentation
  - Problem area data today

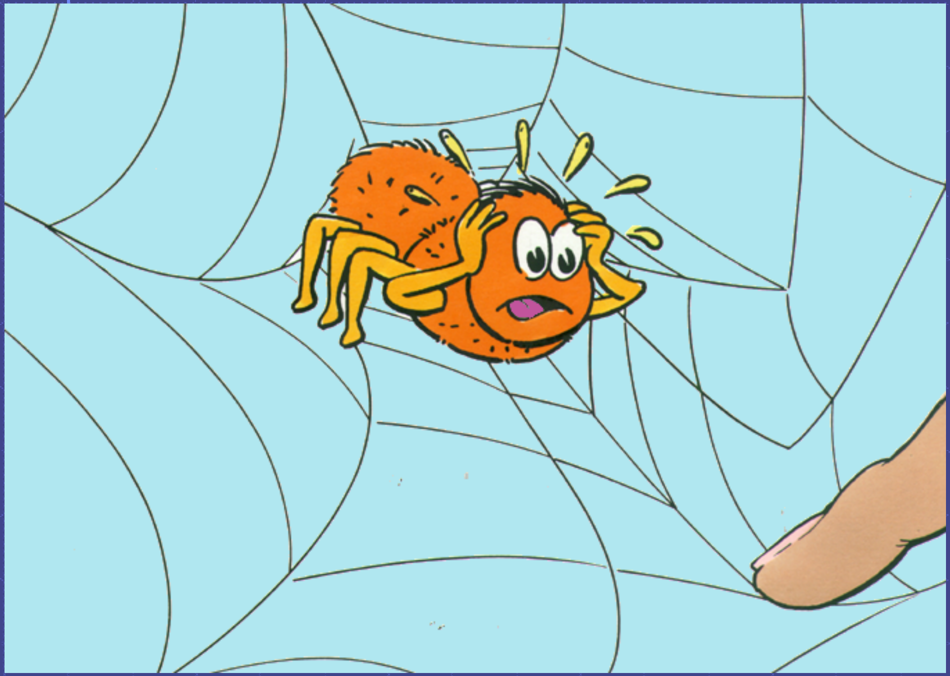
Data Gathering – Qual. 3

- Operating practices?
  - Designated system owner
  - Operators (line and IVS) trained
  - Blast gates locked or adjusted whenever anyone wants
- Monitoring & Maintenance?
  - System Baseline Documentation available as reference for M&M
  - Installed monitoring devices or routine system wide data gathering
  - Breakdown or predictive maintenance
  - Recent maintenance on system

Troubleshooting Approaches

- Visual observations
- Data based troubleshooting approaches – BASELINE data needed -Baseline Deviation Method
- What if there is no Baseline or Design data?

A Change Affects All Parts of System

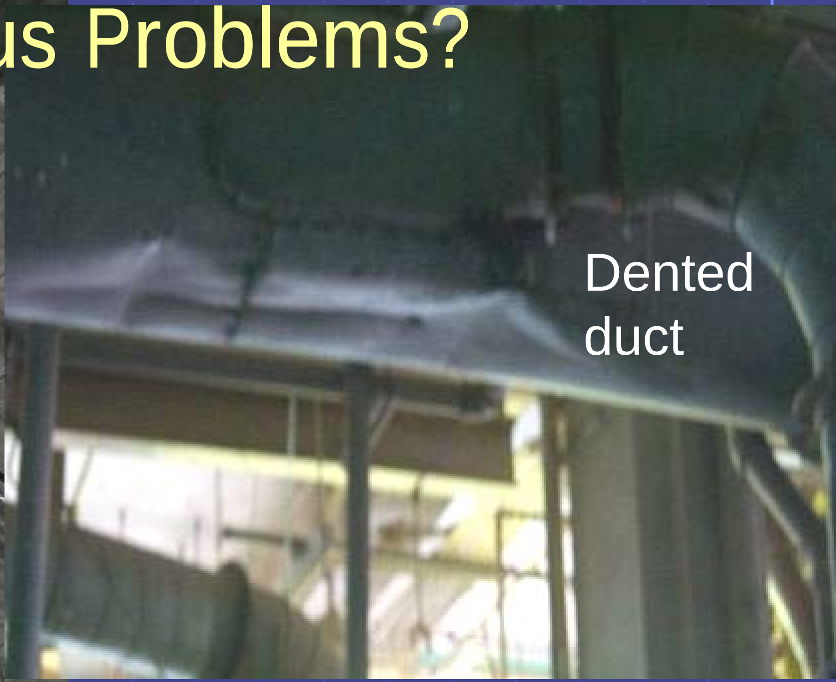


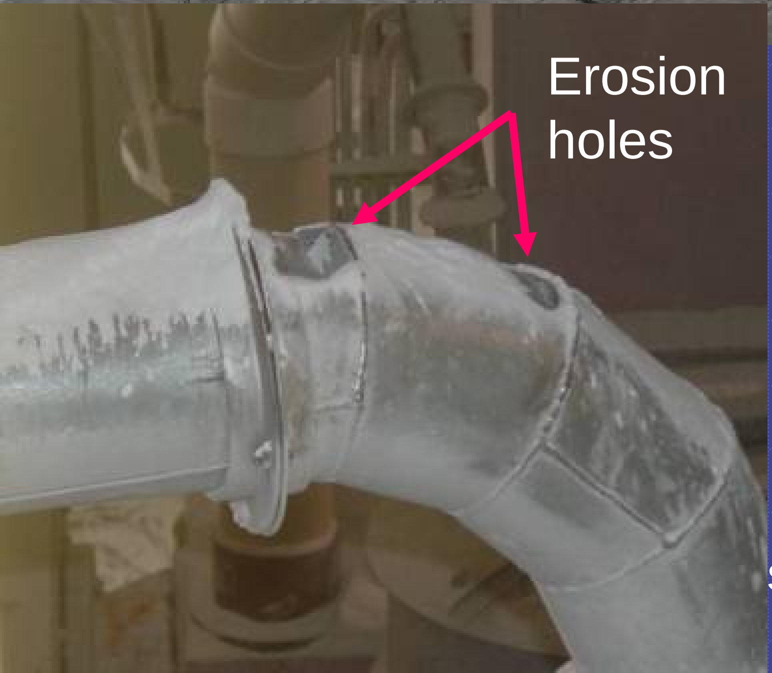
- Problems fall into 2 general categories
  - Duct Network Problem?
    - One spot causes both high & low SP/Q in other ducts
    - General causes (plugged or bypassed ducts)
  - Change seen throughout system?
    - Collector high or low differential pressure
    - Exhaust fan problems
- More than one problem likely with infrequent maintenance

Step 1: Visual Observation

- Contaminants billowing out of the enclosure/hood?
- Hoods pulling in air?
- Obvious problems with the hood including exhaust vent/slot clogging, damage to opening?
- Open or leaking cleanout/inspection doors?
- Obvious changes to the ventilation system (i.e. additional branches/hoods)?
- Ductwork damaged (dents, holes, rust)?
- Ducts cut off and covered with blanking flanges?
- Dampers/blast gates positions been altered?
- Unusual sounds?
- Obvious process or ingredients changes?

Troubleshooting – Obvious Problems?





Troubleshooting: Baseline Deviation Method

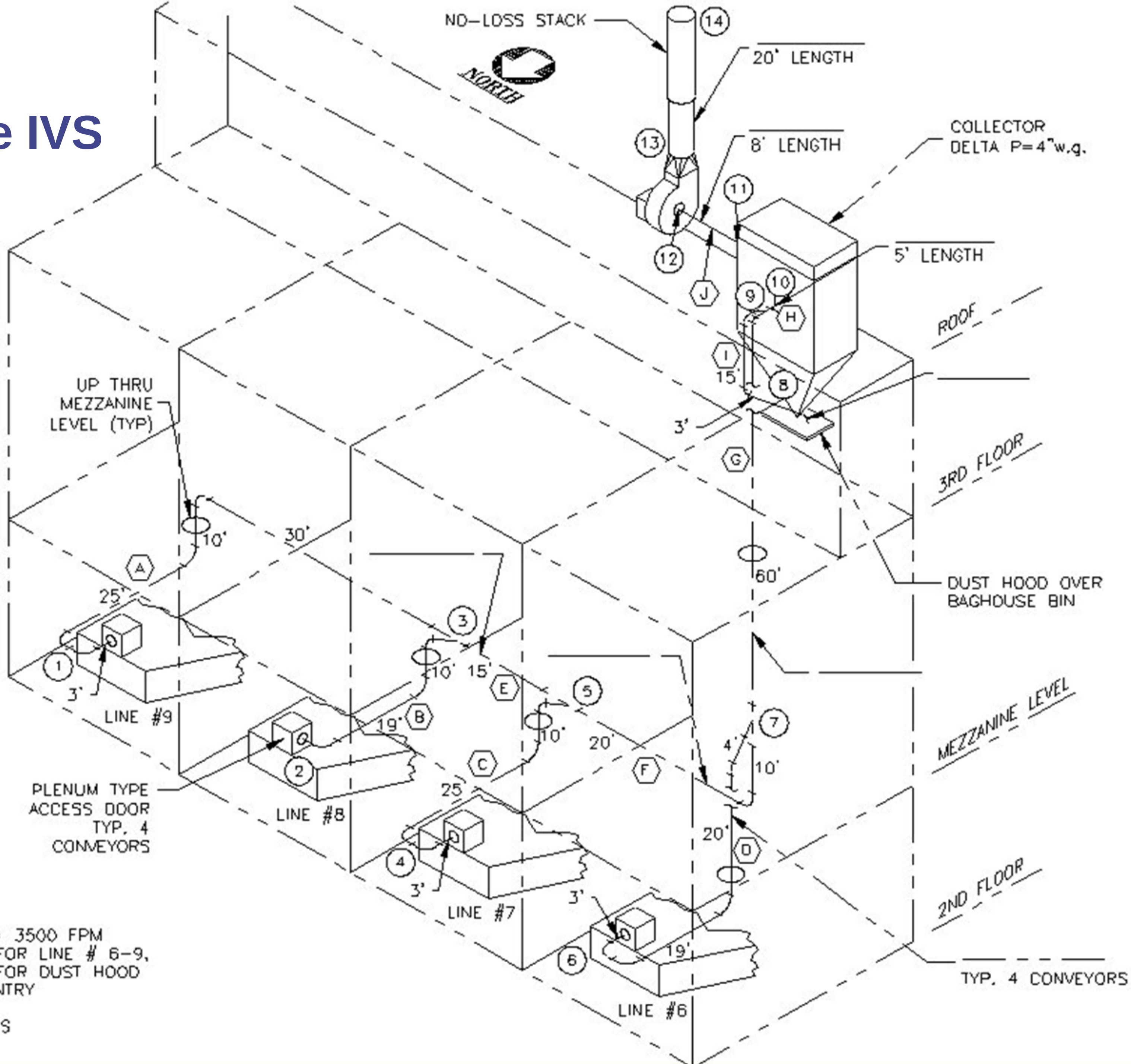
Start with Static Pressures

- Remember Baseline Specifications
  - Airflow: $\pm$ 10% design
  - Static Pressure: $\pm$ 20% Baseline
- For a measured SP, calculate % Baseline:

$$\%\text{ of Baseline} = \frac{\text{measured SP} - \text{baseline SP}}{\text{baseline SP}} \times 100$$

For example, (120 - 140)/(140) x 100 = - 16.7 %

Example IVS



NOTES:

1) MINIMUM DUCT VELOCITY = 3500 FPM
2) HOOD LOSS = 0.25 VPd FOR LINE # 6-9.
3) HOOD LOSS = 0.49 VPd FOR DUST HOOD
4) ALL "WYE" FITTINGS 45° ENTRY
5) ALL ELBOWS 2.0D RADIUS
6) BALANCE WITH BLAST GATES
7) FAN HAS 17"ø INLET

Example Problem Data Table

Test Point	Predicted Static Pressure	Problem 1 Measured SP	Problem 3 Measured SP
A	2.26	1.58	1.36
B	4.54	3.27	2.59
C	4.87	3.41	3.16
D	5.64	7.22	3.44
E	5.35	3.69	3.53
F	5.77	7.21	3.75
G	7.35	9.26	4.85
H	7.81	9.76	5.31
I	7.00	8.75	4.55
J	11.83	14.32	7.81

Problem # 1

Calculate the % Baseline for all test ports -is the system operating as per predicted SP? Use the example problem data table (from system drawing.) Is it OK? If not, where would you suggest to start looking for the problem?

Test Port	SP Reading	Predicted SP	% Baseline = (Reading - Predicted) x 100 / Predicted	% Baseline	HI or LO?
A	________	________	________	________	____
B	________	________	________	________	____
C	________	________	________	________	____
D	________	________	________	________	____
E	________	________	________	________	____
F	________	________	________	________	____
G	________	________	________	________	____
H	________	________	________	________	____
I	________	________	________	________	____
J	________	________	________	________	____

Answers to Example Problem #1

Test Port	SP Reading	Predicted SP	% Baseline = (Reading - Predicted) x 100 / Predicted	% Baseline	HI or LO?
A	1.58	2.26	(1.58 - 2.26)/2.26x100 =	-30.1	LO
B	3.27	4.54	(3.27 - 4/54)/4.54x100 =	-28.0	LO
C	3.41	4.87	(3.41 - 4.87)/4.87x100 =	-30.0	LO
D	7.22	5.64	(7.22 - 5.64)/5.64x100 =	28.0	HI
E	3.69	5.35	(3.69 - 5.35)/5.35x100 =	-31.0	LO
F	7.21	5.77	(7.21 - 5.77)/5.77x100 =	25.0	HI
G	9.26	7.35	(9.26 - 7.35)/7.35x100 =	26.0	HI
H	9.76	7.81	(9.76 - 7.81)/7.81x100 =	25.0	HI
I	8.75	7.00	(8.75 - 7.00)/7.00x100 =	25.0	HI
J	14.32	11.83	(14.32 - 11.83)/11.83x100 =	21.0	HI

Problem # 1
Graphical analysis:
Look at the arrow direction change between port F & ports C & E.

A reversal indicates something has happened in that area.

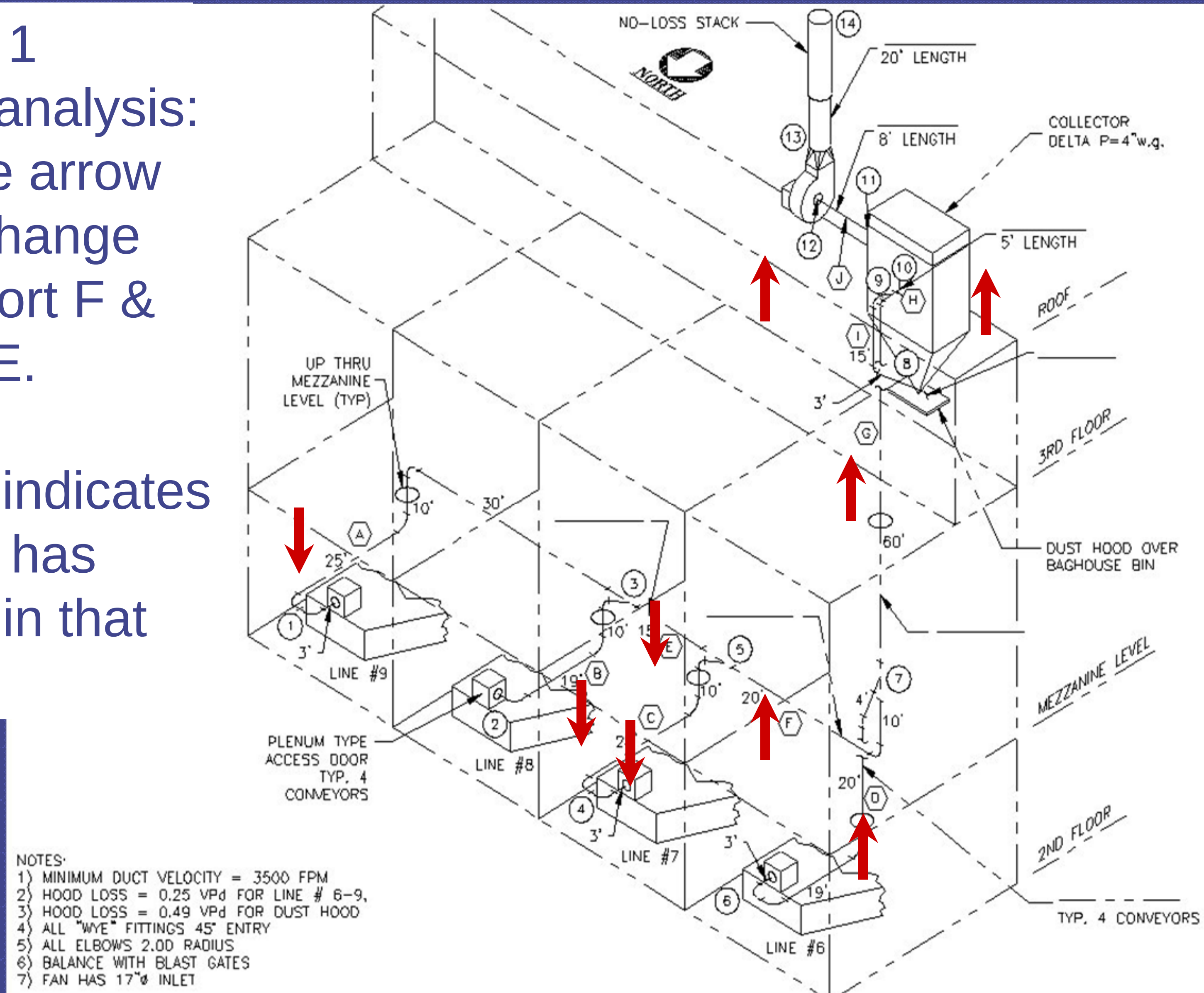


Fig.7-2: From American Conference of Governmental Industrial Hygienists (ACGIH®), Industrial Ventilation: A Manual of Recommended Practice for Operation & Maintenance, 1st Edition. Copyright 2007. Reprinted with permission.

Why Pressures Switch: HI to LO (or LO to HI)

- Pressures switch because airflow has changed
- Fan delivers airflow on its curve that matches available system resistance

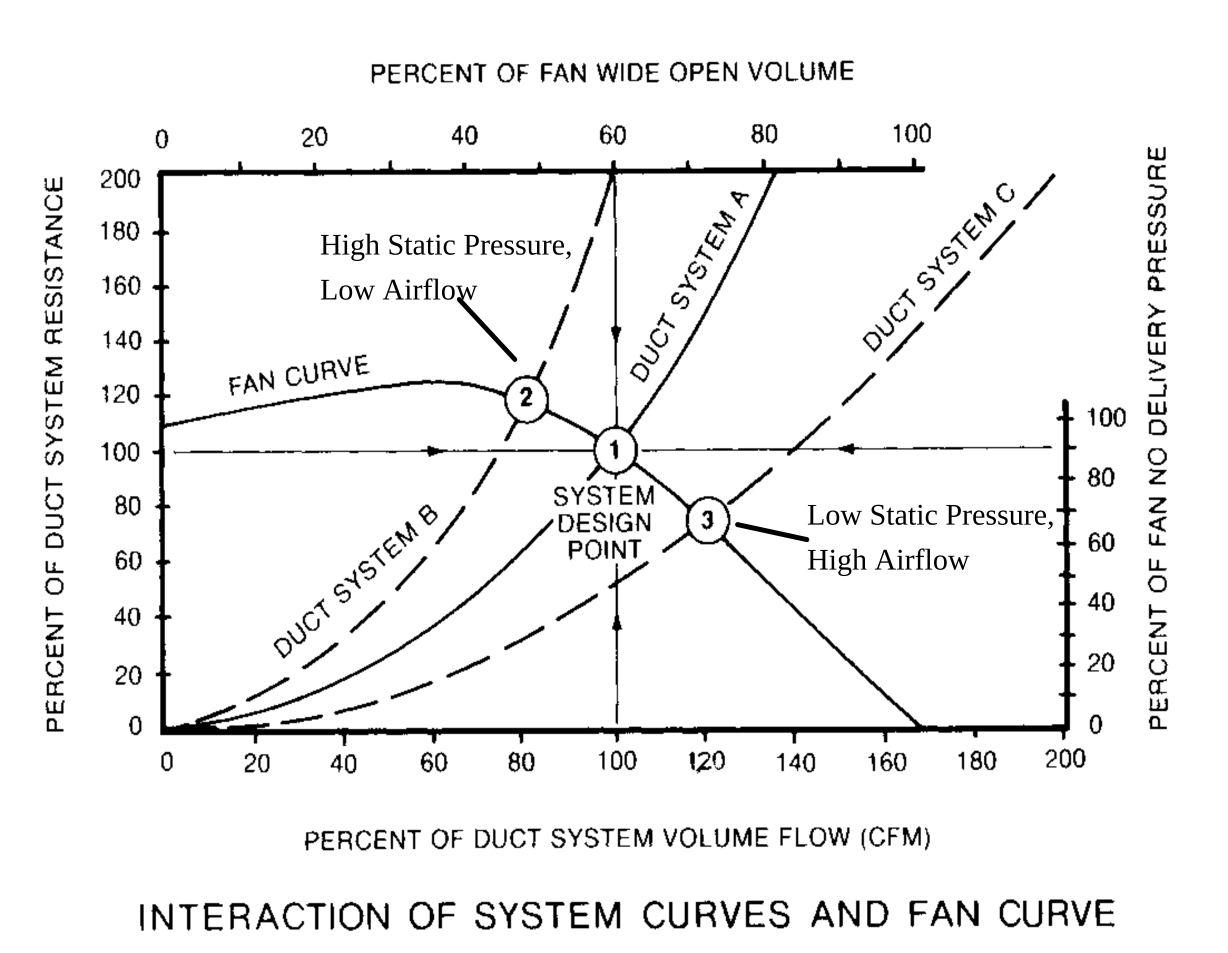


Fig.7-3: From American Conference of Governmental Industrial Hygienists (ACGIH®), Industrial Ventilation: A Manual of Recommended Practice for Operation & Maintenance, 1st Edition. Copyright 2007. Reprinted with permission.

DCS Troubleshooting Guide

- For analysis at a single point, possible causes :

	HIGH STATIC PRESSURE	LOW STATIC PRESSURE
HIGH AIRFLOW OR VELOCITY	1. Branch airflow > design due to restrictions in an adjacent duct branch: - Duct plugged? - Orifice too small? - Blast gate closed too far? - Air bleed blocked? 2. Total system airflow > design: - Fan inlet slide gate open too far? - Fan/Rotoclone speed too high? - Belt pulley diameter? - Fan motor speed? - Filter differential pressure low? - Pressure indicator ok? - Bag cleaning too often?	1. Branch airflow > design due to duct branch resistance < design between duct branch air inlet and test point: - Duct access door open? - Orifice missing? - Orifice too large? - Blast gate open too far?

Look at points F & C/E – which causes fit SP data best?

Table 7-4: From American Conference of Governmental Industrial Hygienists (ACGIH®), Industrial Ventilation: A Manual of Recommended Practice for Operation & Maintenance, 1st Edition. Copyright 2007. Reprinted with permission.

DCS Troubleshooting Guide (cont'd)

	HIGH STATIC PRESSURE	LOW STATIC PRESSURE
LOW AIRFLOW OR VELOCITY	1. Branch airflow < design due to restrictions between duct branch air inlet and test point: - Duct plugged? - Poorly cut flange gasket partially blocking duct? - Orifice too small? - Blast gate closed too far? - Air bleed blocked?	1. Branch airflow < design due to restrictions between the test point and the system fan: - Duct plugged? - Poorly cut flange gasket partially blocking duct? 2. Openings in other parts of system allow airflow to bypass test point duct branch: - Duct access door open? - Filter inspection door open? - Missing orifice? - Blast gate opened too far? 3. Total system airflow < design: - Fan/Rotoclone performance? - Fan rotation incorrect? - Loose belts? - Small pulley diameter? - Wrong fan motor speed? - Filter differential pressure high? - Pressure indicator ok? - Bag cleaning ok? - Moisture, bags blinded? - Fan damper closed too far?

Table 7-4: From American Conference of Governmental Industrial Hygienists (ACGIH®), Industrial Ventilation: A Manual of Recommended Practice for Operation & Maintenance, 1st Edition. Copyright 2007. Reprinted with permission.

DCS Troubleshooting Guide

Recommendations:

- **Walk the system with a system schematic - everything look OK ?**
- **Take static pressures at all test points and compare to Baseline static pressures.**
- **Part of the system - reversal or switch between low values and high values?**
  - High SP ? ("High? Look Low towards the air inlets")
  - Low SP ? ("Low? Look High towards the exhaust fan")
- **Take airflows in the area of the switch to locate the problem.**

Problem # 3

Again, take the data from the drawing, calculate % Baseline, and determine if and where the problem might be.

Test Port	SP Reading	Predicted SP	% Baseline = (Reading - Predicted) x 100 / Predicted	% Baseline	HI or LO?
A	______	______	______	______	______
B	______	______	______	______	______
C	______	______	______	______	______
D	______	______	______	______	______
E	______	______	______	______	______
F	______	______	______	______	______
G	______	______	______	______	______
H	______	______	______	______	______
I	______	______	______	______	______
J	______	______	______	______	______

Answer to Problem # 3

Test Port	SP Reading	Predicted SP	% Baseline = (Reading - Predicted) x 100 / Predicted	% Baseline	HI or LO?
A	1.36	2.26	(1.36-2.26)/2.26*100 =	-39.8	LO
B	2.59	4.54	(2.59-4.54)/4.54*100 =	-43.0	LO
C	3.16	4.87	(3.16-4.87)/4.87*100 =	-35.1	LO
D	3.44	5.64	(3.44-5.64)/5.64*100 =	-39.0	LO
E	3.53	5.35	(3.53-5.35)/5.35*100 =	-34.0	LO
F	3.75	5.77	(3.75-5.77)/5.77*100 =	-35.0	LO
G	4.85	7.35	(4.85-7.35)/7.35*100 =	-34.0	LO
H ←	5.31	7.81	(5.31-7.81)/7.81*100 =	-32.0	LO
I	4.55	7.00	(4.55-7.00)/7.00*100 =	-35.0	LO
J ←	7.81	11.83	(7.81-11.83)/11.83*100 =	-34.0	LO

Problem # 3 Graphical Analysis:

Look how all the SP's are low - a system wide problem. Since baghouse differential pressure is not high with a high SP at the fan inlet (J), then the fan is the problem - wrong rotation.

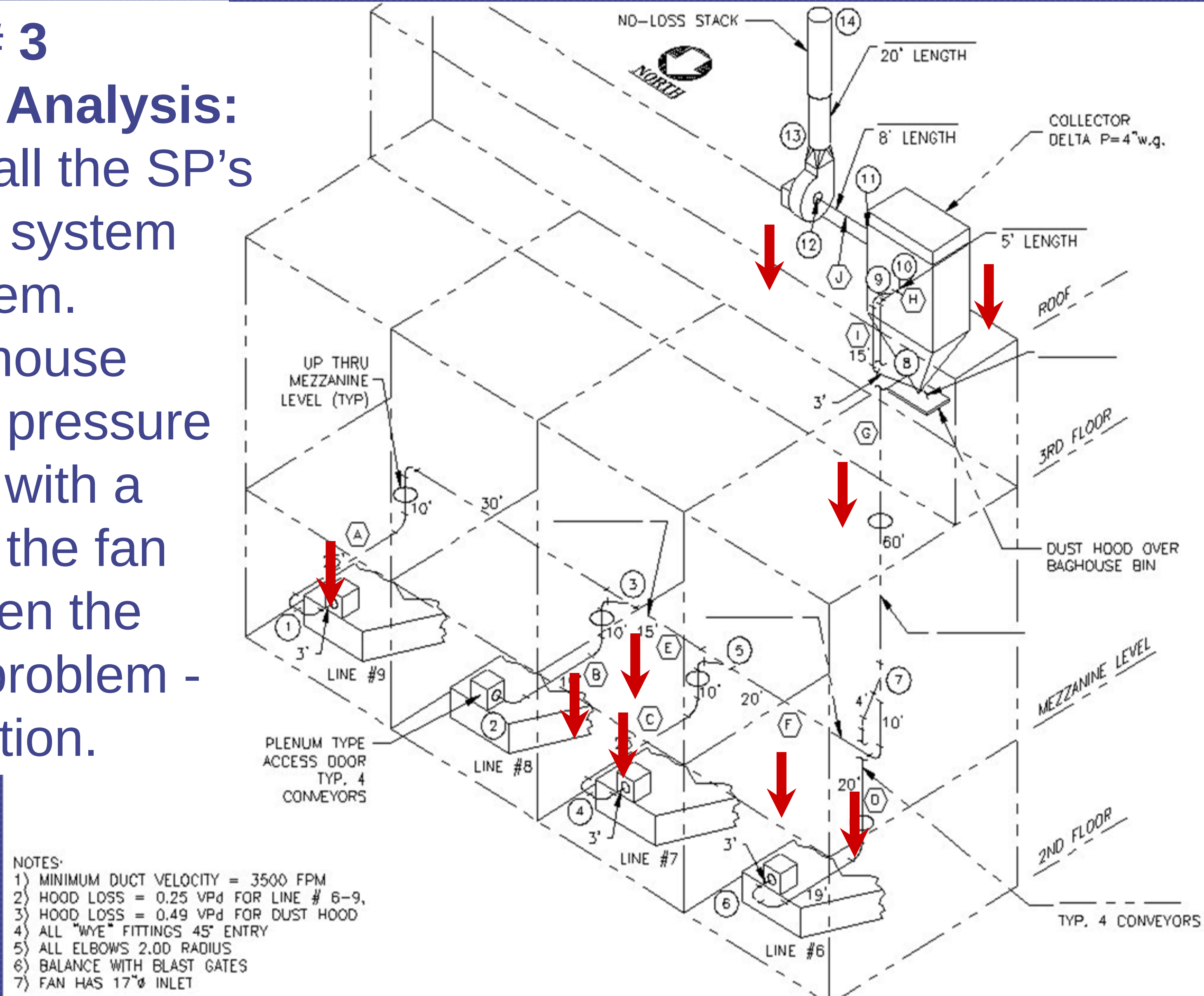


Fig.7-4: From American Conference of Governmental Industrial Hygienists (ACGIH®), Industrial Ventilation: A Manual of Recommended Practice for Operation & Maintenance, 1st Edition, Copyright 2007. Reprinted with permission.

DCS Troubleshooting Guide

- For analysis at a single point, possible causes :

	HIGH	LOW
	STATIC PRESSURE	**STATIC PRESSURE**
HIGH AIRFLOW OR VELOCITY	1. Branch airflow > design due to restrictions in an adjacent duct branch: - Duct plugged? - Orifice too small? - Blast gate closed too far? - Air bleed blocked? 2. Total system airflow > design: - Fan inlet slide gate open too far? - Fan/Rotoclone speed too high? - Belt pulley diameter? - Fan motor speed? - Filter differential pressure low? - Pressure indicator ok? - Bag cleaning too often?	1. Branch airflow > design due to duct branch resistance < design between duct branch air inlet and test point: - Duct access door open? - Orifice missing? - Orifice too large? - Blast gate open too far?

Why are all SP's low?

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DCS Troubleshooting Guide (cont'd)

	HIGH STATIC PRESSURE	LOW STATIC PRESSURE
LOW AIRFLOW OR VELOCITY	1. Branch airflow < design due to restrictions between duct branch air inlet and test point: - Duct plugged? - Poorly cut flange gasket partially blocking duct? - Orifice too small? - Blast gate closed too far? - Air bleed blocked?	1. Branch airflow < design due to restrictions between the test point and the system fan: - Duct plugged? - Poorly cut flange gasket partially blocking duct? 2. Openings in other parts of system allow airflow to bypass test point duct branch: - Duct access door open? - Filter inspection door open? - Missing orifice? - Blast gate opened too far? 3. Total system airflow < design: - Fan/Rotoclone performance? - Fan rotation incorrect? - Loose belts? - Small pulley diameter? - Wrong fan motor speed? - Filter differential pressure high? - Pressure indicator ok? - Bag cleaning ok? - Moisture, bags blinded? - Fan damper closed too far?

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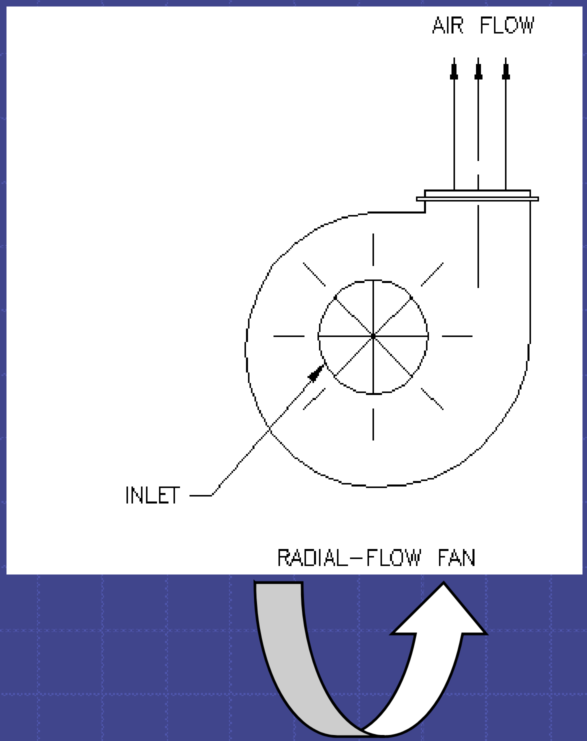
Good Baghouse D/P = Low Air Flow?

HIGH DIFFERENTIAL	PRESSURE
1. Bag blinding, bridging	A. Bag cleaning system B. Dust removal system C. Moisture D. Static electricity
2. High airflow through baghouse	A. Fan speed B. Fan throttling damper C. Open inspection doors
3. Bag fabric problem	A. Fabric not vendor spec B. Correct fabric for service
LOW DIFFERENTIAL	**PRESSURE**
1. Low bag resistance	A. Inadequate precoat B. Bags cleaned too often C. Bag installation
2. Low system airflow	A. Major pluggage in network B. Fan performance? C. Baghouse bypassing?

Fans Deliver Air Rotating Backwards!



Correct impeller rotation (looking from air inlet end)

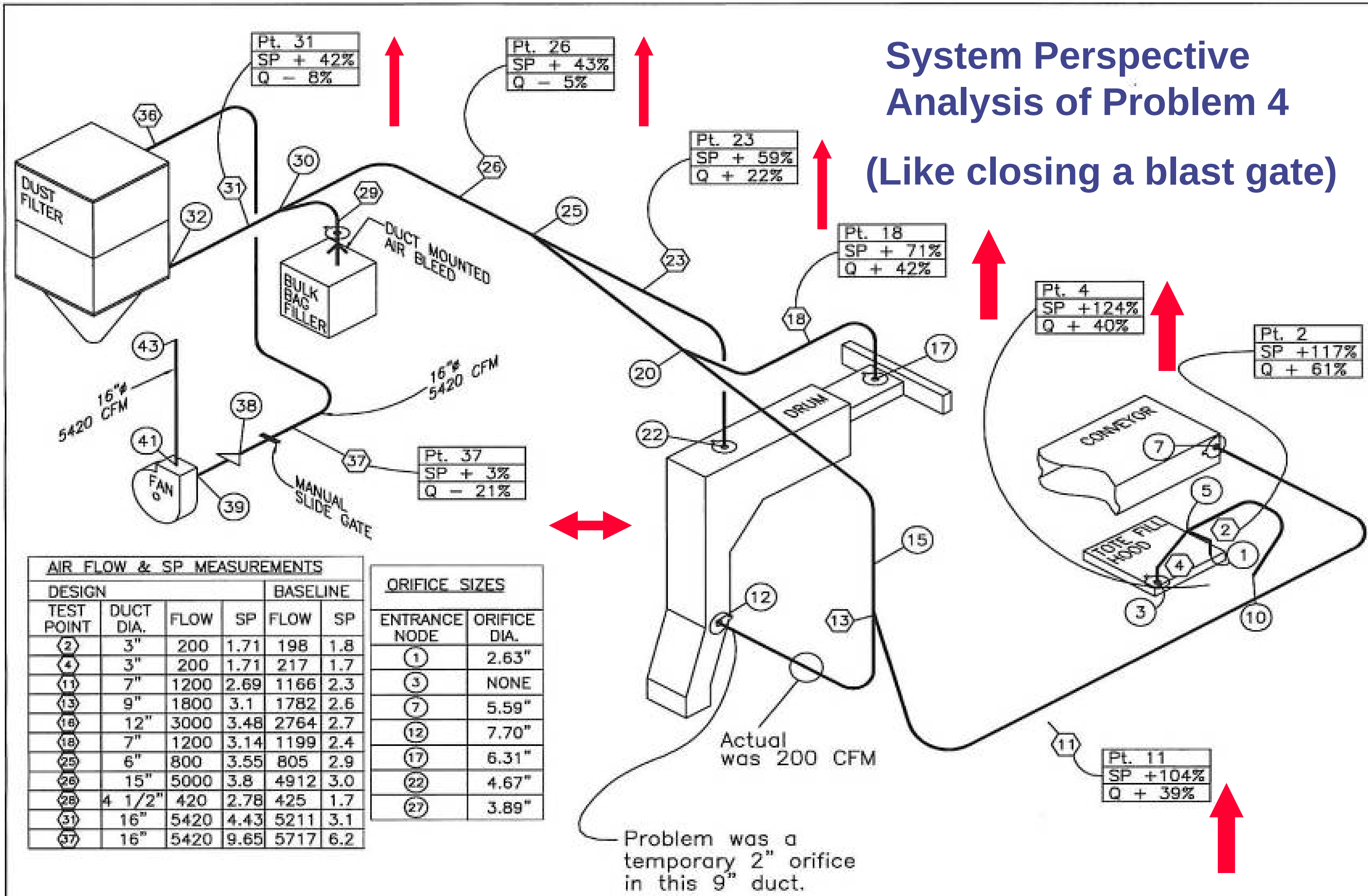
Even with backwards rotation

- 50-60% airflow
- 25% static pressure

Correct by reversing two of three electric motor leads

System Perspective Analysis of Problem 4

(Like closing a blast gate)



AIR FLOW & SP MEASUREMENTS					
DESIGN				BASELINE	
TEST POINT	DUCT DIA.	FLOW	SP	FLOW	SP
2	3"	200	1.71	198	1.8
4	3"	200	1.71	217	1.7
11	7"	1200	2.69	1166	2.3
13	9"	1800	3.1	1782	2.6
16	12"	3000	3.48	2764	2.7
18	7"	1200	3.14	1199	2.4
25	6"	800	3.55	805	2.9
26	15"	5000	3.8	4912	3.0
28	4 1/2"	420	2.78	425	1.7
31	16"	5420	4.43	5211	3.1
37	16"	5420	9.65	5717	6.2

ORIFICE SIZES	
ENTRANCE NODE	ORIFICE DIA.
1	2.63"
3	NONE
7	5.59"
12	7.70"
17	6.31"
22	4.67"
27	3.89"

Fig.7-5: From American Conference of Governmental Industrial Hygienists (ACGIH®), Industrial Ventilation: A Manual of Recommended Practice for Operation & Maintenance, 1st Edition. Copyright 2007. Reprinted with permission.

Troubleshooting with No Design or Baseline Data Available

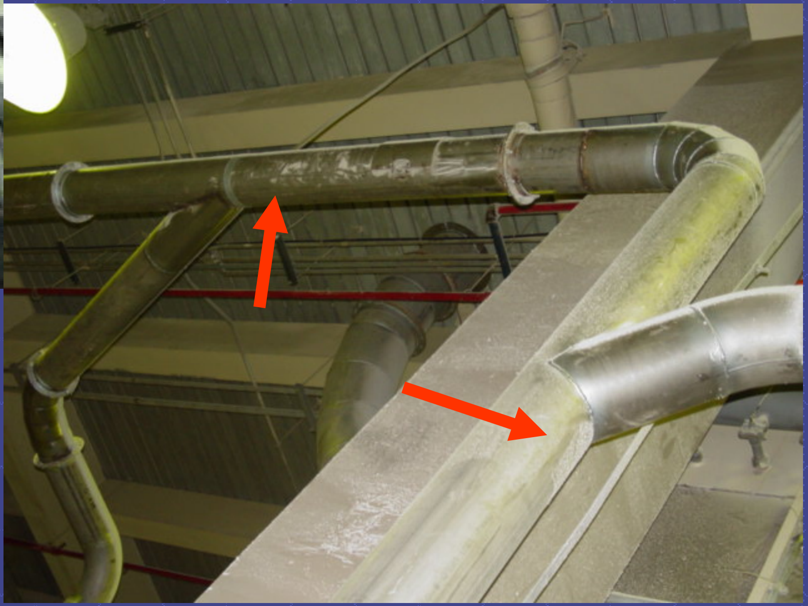
- With system analysis and cleaning, a new BASELINE can be established
- Airflow requirements for each hood & enclosure
- Adequacy of duct conveying velocities
- Reasonableness of Air Cleaning Device differential pressure
- Fan operation on its performance curve
- Adequacy of fan to deliver total airflow for all hoods through the existing duct network

Potential Sources of Comparison Information

- Existing drawings
- Existing design calculations
- Recommended approaches such as IVM
- Permit Applications or Title V submissions
- Walk through the system to determine the required ventilation at each potential exposure point and estimate the needs of the system

Troubleshooting, No Design Data – obvious change?

Branch blanked off?



Duct diameter unchanged after several tie-ins?

Compare to Existing Drawings or Make a System Sketch to Show

- Hood opening sizes (width and length)
- Plugged or dirty screens at hood openings
- Diameter of duct connected to hood
- Locations of blast gates and gate approximate percent open
- Lengths and locations of flexible hoses
- Damaged ducts (dented, holes or other audible airleaks)
- Angle of branch duct entry into the sub-main or main. “Y” shapes are recommended practice, not “T” shapes.
- Ducts removed and sealed with a blank flange or similar device

Compare to Existing Drawings or Make a System Sketch to Show

- Ducts added (branches joining main header and duct afterwards does not get larger in diameter for the extra airflow)
- Sudden expansions or contractions in duct diameter without an addition of a branch to explain it.
- Air cleaning device differential pressure measuring points
- Unusual fan sounds
- Estimate number of duct diameters of straight duct into and out of the fan
- Visible emissions on the roof by the exhaust stack

Troubleshooting:
No Design Data Available

- Engineering study to gather system data to assess possible system capability
  - Process problems due to LEV
  - Hood/enclosure airflow estimates
  - Duct network dimensions
  - Collector and fan nameplate information
- Perform calculations - Industrial Ventilation, A Manual of Recommended Practice for Design
- Recommend system changes

Summary

- Walk the system to check for obvious changes
- Has there been recent maintenance on system?
- Take SP data at strategic test points
- Use some airflow data to clarify unclear SP data
- System wide problem or confined to part of duct network?
- There can be more than one cause of the problem
- A new BASELINE can be established on old systems for ongoing maintenance

IVS Maintenance Risk Assessment
The Big Questions

- How often should I be monitoring the system to keep it working within design parameters, a *before the fact* measure?
- How do I justify the maintenance and operating resources to support the right monitoring frequency?
- How do I get out of a “breakdown” maintenance mentality into a “predictive” mode?

Maintenance Risk Analysis

- How bad would the consequences be if the IVS failed?
- Consider the risk of rapid IVS degradation due to contaminant and other risks
- Consider yours and your industry's specific experience
- Set frequency based on holistic analysis
- See handout worksheet "Risk Factors for Increased IVS Monitoring"

Protect Against These Risks

- Consequences of Contaminant Peak Exposures
  - Inherent Contaminant Hazards to: Health, Fire, Explosion, Reactivity
- Risk Factors Leading to Rapid IVS System Degradation
  - Contaminant Characteristics
  - IVS system design
  - IVS system operability

Also Consider These Risks from IVS Malfunction

- Compliance with legal or regulatory limits
- Product formulation and quality
- Buildup of combustible materials
- Equipment reliability from contaminants fouling
- Appearance and cleanup

Endpoint of the Risk Analysis Risk Based initial frequency for:

- ALERT Monitoring
  - Provide warning of rapid changes that could potentially hurt IVS performance (ie, fan failure, plastic bag, etc.)
  - Change to long term frequency based on monitoring data and experience

ALERT:

Visual Indication or Automatic Alarms

Endpoint of the Risk Analysis

Risk Based initial frequency for

- DEGRADATION Monitoring
  - Establish on-going degradation and trend monitoring of the IVS System to:
  - Identify the places where and when the system routinely begins to degrade, helpful for troubleshooting, and
  - Provide confidence that the ALERT monitoring locations give adequate early warning
- Change to long term frequency based on monitoring data and experience

Contaminant Inherent Risk Factors

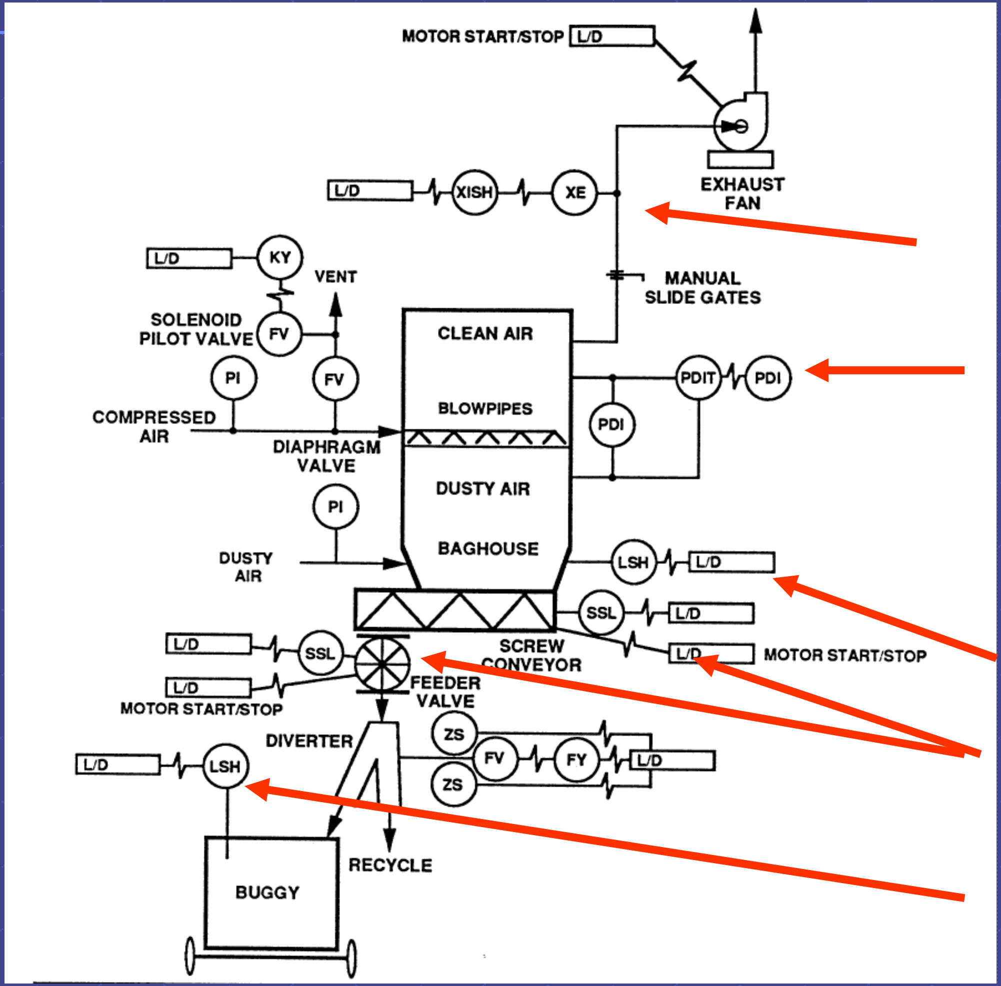
- Some materials have a severe hazard in one or more of the hazard categories (Health, Flammability, and Physical/Reactivity Hazard.)
- Using Professional Judgment, select category that best describes the overall hazard of the contaminant mixture being controlled by the IVS
- ***How long would you be ok with the IVS being out of limits? – set ALERT frequency***
  - **Severe** (Automatic or shiftly)
  - **High** (Daily)
  - **Moderate** (Weekly)
  - **Low** (Monthly)

NASA Example – Toxic & Comb. Gases Full enclosures with exhaust vent.

Continuous Monitors, Alarms

Hazards both from combustible gases and toxic gases

Other Possible IVS Alarms



Bag Leak Detection System

High differential pressure

Dust Removal System

-Filter Hopper high level

-Screw conveyor & rotary airlock rotation

-Disposal buggy high level

Problem Particulate Contaminants Cause more rapid IVS degradation

- Sticky, smearing dust (e.g. detergents, wet clay, ore after floatation)
- Hygroscopic dust (readily absorbs moisture) & ambient humidity is high enough to cause sticky or adherent dust problems
- High humidity in intake air & possible approach to the dew point that can cause sticky or adherent dust problems
- Combustible dust – avoid duct accumulations
- Heavy dust such as lead or large granule sand
- Abrasive dust that wears elbows rapidly
- Lightweight, low density dust such as paper dust
- Fibrous dust such as fiberglass fluff which can tangle and form mats in the duct

Problem Non-particulate (Vapor/Gas) Contaminants

- Contaminant change from a vapor or fine mist in the duct network to
  - A solid (by drying or precipitation or freezing)
  - Condense continuously
  - Condensing conditions possible in range of operation
- Contaminant is corrosive
  - pH <2 or >12
  - pH 2-5 or 9-12
- Contaminant has NFPA flammability rating of (closed cup flash point, F)
  - Class I (<100 F)
  - Class II (100-140 F)
  - Class IIIA (140–200 F)
- Contaminant is flammable and could exceed 25% of Lower Explosive Limit in IVS if out of balance
- Contaminant is reactive if exposed to ambient air or moisture

Contaminant Characteristics IVS Design Impact

- Particulate IVS - more attention to details than vapor/gas IVS
- Key parameter maintain conveying velocity:
  - In all duct branches with static pressure balance scheme
  - In duct junctions or Y’s (maintain conveying through transition of two air streams)
  - More gradual turn elbows and Y’s for stickier particulates
  - Abrasives erode holes in duct

Impact of Contaminant Characteristics

Impact of Combustible Dust

- Accumulation of CD in workplace > NFPA (1/32 to 1/16")?
  - Aggressive housekeeping
  - Better dust control design
- Prevent ignition (electrostatic, embers, sparks, open flame)
- Explosion hazards addressed
  - Venting, suppression, isolation, inerting

Dust Loading Makes a Difference

- < 1 gr/DSCF (dry standard cubic foot)
- 1 – 10 gr/DSCF
- > 10 gr/DSCF
- Pneumatic conveying on some branches (> 0.5 # solids/ # air)

Pneumatic conveying into dust control at quality check station

Particulate Duct Construction Contributions to Rapid Degradation

- **Flexible hoses >3 ft long (twice resistance/ft, rough surface easily forms coating)**
- **Elbows**
  - **Tight radius <2.0 D**
  - **Sequential elbows w/i 5 D**
  - **Welded elbows**
- **Y's: Branch ducts join main headers at these angles**
  - **15 – 30 degrees**
  - **31 - 45 degrees**
  - **46 – 90 degrees or Tee**
  - **> 90 degree turn (reverse direction)**
- Y's: Branch does not enter main in a tapered section
- Y's: Branch enters main at the bottom
- Y's: Blank flanges on branch instead of air bleed
- Branch adds > 10% more air to main and downstream duct not larger diameter and conveying velocity problem
- Sudden enlargement or contraction in duct diameter
- Mist systems do not have low point drains on duct network
- No intake to permit air entry at duct on sealed equipment

Maintenance Access?

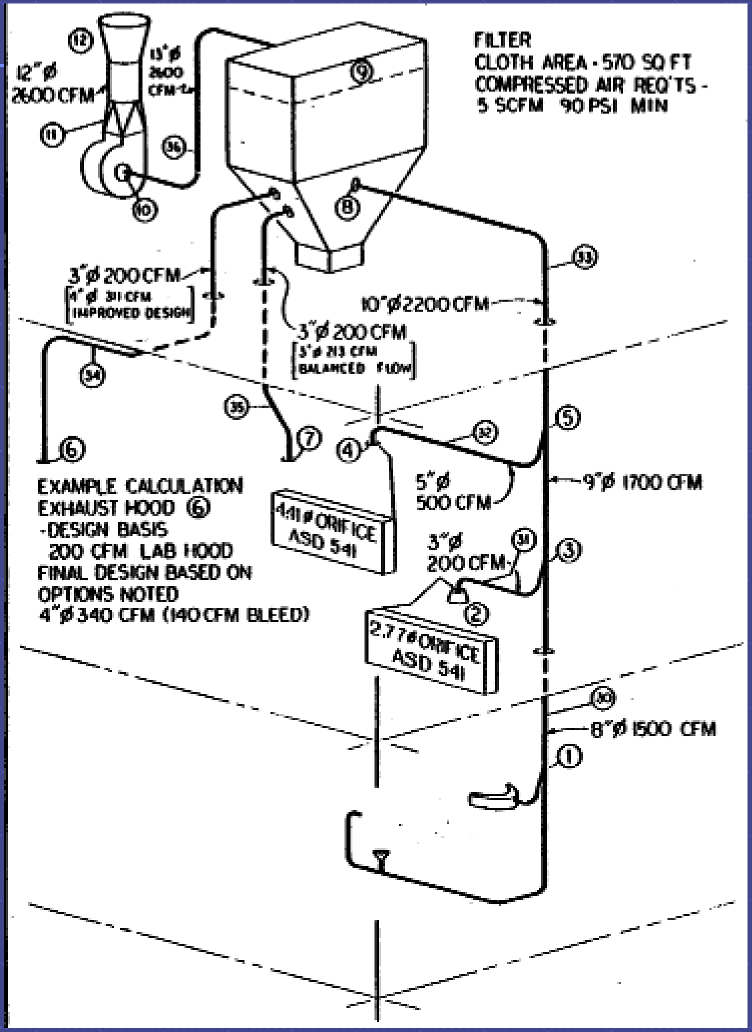
Particulate IVS Air Cleaning Device Contribution to Rapid Degradation

- ACD Differential Pressure
  - Automatic and tight control of DP within 2 in.w.c. (ie, demand bag cleaning on fabric filter)
  - Automatic control of DP (ie, timer bag cleaning on fabric filter)
  - ACD - cleaned off line
  - Problem particulates plug device requiring frequent (> 1x/month) manual cleaning
- ACD and Fan Access
  - Installed access platforms, ladders for routinely inspections (ie, bag cleaning system on fabric filter)
  - Find a ladder to gain access for routine inspections
  - Located within a short, 2-3 minute, walk from the dust controlled process equipment it serves
  - Very remote from process equipment served

Reduce Capital, Increase Admin.

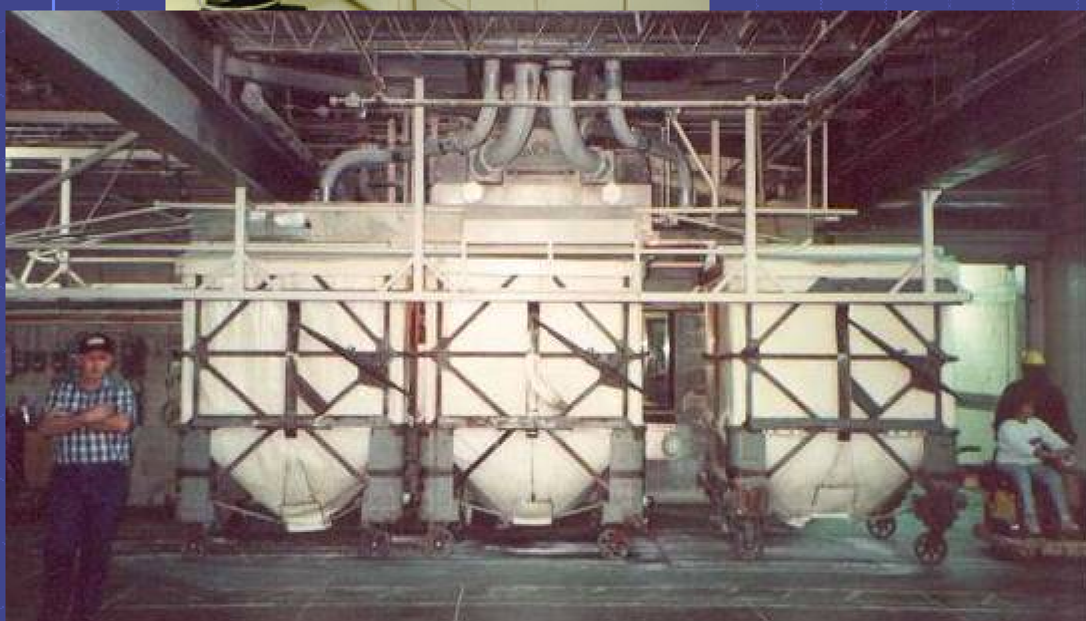
- Air Cleaning Device Dust Removal
  - Automated, continous dust removal system
  - Administrative controls to remove dust from system
  - ACD used as dust surge bin

IVS Balance & Documentation



- System balancing approach
  - Balance by Design as per IVM
  - Balance with plate orifices or locked blast gates
  - Balance by un-locked blast gates
  - Huh? What is IVS Balance?
- System Baseline Documentation
  - Documentation complete, < 1 year old
  - Documentation complete, < 2 years old
  - Documentation exists but > 2 years old and not checked for accuracy
  - No documentation exists

IVS Complexity



- IVS Complexity
  - Single hood: (lab hood or unit filter)
  - Simple: 2- 5 dust pickup points
  - Moderate: 5 – 15 dust pickup points
  - Complex: > 15 dust pickup points
  - Very complex: Interaction between process air exhausts and dust control exhausts with varying conditions

Before the Fact Detection

- How does the operator know of a dust control system problem?
  - Action limits on locally installed indicators
  - Routine system monitoring by trained operators
  - Dust blows out of dust pickups
- Downtime availability for IVS maintenance for known problem spots in system
  - As needed
  - Within > 1 week
  - Within > 1 month
  - Once/year

Gas/Vapor IVS Capability Contribution to Rapid Degradation

- IVS depends on dilution with fresh air to keep flam. conc. < 25% LEL
- Flexible hoses >3 ft long in any branch
- For condensing vapors & oil mists, ducts not sloped to low point drains
- Duct liquid drains do not have an effective trap to prevent air entry
- IVS materials not corrosion resistant
- ACD: Varying differential pressure and system-wide airflow
- IVS shutdown does not automatically shut down process
- Same IV System Wide Issues as Particulate
  - Maintenance access
  - Balance
  - Baseline Documentation
  - Operator Warning
  - IVS Complexity

Inherent Risk Profile – What is Your Assessment of Overall Rating?

Impact **Hazard** **Risk Categories**

Health		**Low**	**Moderate**	**High**	**Severe**
Flammability, Comb. Dust		**Low**	**Moderate**	**High**	**Severe**
Reactivity Physical		**Low**	**Moderate**	**High**	**Severe**
Quality		**Low**	**Moderate**	**High**	**Severe**
House-keeping		**Low**	**Moderate**	**High**	**Severe**
Other?		**Low**	**Moderate**	**High**	**Severe**

Risk of Rapid Degradation Profile
What is Your Overall Rating?

Contaminants		Risk	Categ	ories	
Particulates + your experience		Low	Moderate	High	Severe
Non-particulates (Gas/Vapor) + your experience		Low	Moderate	High	Severe

Deciding ALERT and DEGRADATION Monitoring

	ALERT	Your analysis?	DEGRA-DATION	Your analysis?
Severe	Auto or shiftly		Weekly	
High	Daily		Monthly	
Moderate	Weekly		Quarterly	
Low	Monthly		Semi-Annual	

Contaminant Impact on IVS Example: Detergent with Enzymes

- Particulate: sticky, hygroscopic, smears high velocity, drops out low velocity
- IVS Rapid Degradation Risks
  - Low limit (< 1 mg/m^3)
  - Duct makeup – dictated design approach
  - IVS was balanced and documented
  - Trained operators at site with time to do work
- Degradation Monitoring – Severe
  - Started: weekly checks
  - Long term: Monthly checks & scheduled cleaning of known problem spots

Inherent Risk Profile Example: Powder Detergent with Granulated Enzymes

Impact	Hazard	Risk Categories			
Health	Irritant 1mg/m^3 Resp.Sensit. ng/m^3	Low	Moderate	High	Severe
Flammability	Burns with right conditions	Low	Moderate	High	Severe
Reactivity Physical	Minor ingredient - oxidizer	Low	Moderate	High	Severe
Quality	Consumer product- appearance, formula	Low	Moderate	High	Severe
House- keeping	Spills & fugitive emissions	Low	Moderate	High	Severe
Regulatory	Enzymes: 60 ng/m^3	Low	Moderate	High	Severe

Inherent Risk Profile Example: Powder Detergent with Granulated Enzymes

Impact	Hazard	Risk Categories			
Health	**Irritant 1mg/m^3** **Resp.Sensit. ng/m^3**	Low	Moderate	High	Severe
Flammability	**Burns with right conditions**	Low	Moderate	High	Severe
Reactivity Physical	**Minor ingredient - oxidizer**	Low	Moderate	High	Severe
Quality	**Consumer product-appearance, formula**	Low	Moderate	High	Severe
House-keeping	**Spills & fugitive emissions**	Low	Moderate	High	Severe
Regulatory	**Enzymes: 60 ng/m^3**	Low	Moderate	High	Severe

Example: Detergent w/Enzymes ALERT, DEGRADATION Monitoring

	ALERT	Your analysis?	DEGRA-DATION	Your analysis?
Severe	Auto or shiftly		Weekly	Start
High	Daily	Start	Monthly	Long-term
Moderate	Weekly	Long-term	Quarterly	
Low	Monthly		Semi-Annual	

Changing Frequency Based on Data and Experience

1. Startup Learning Period (3 mo)
2. Transition to Strategic Test Points & Visual Controls
3. Reducing Strategic Test Point Frequency
4. What about system modifications?

1 Startup Learning Period

- Initial data base
  - Weekly static pressure readings all test points
  - Weekly airflows at strategic test points (roughly 25% of test points)
- Parts of system will go out of Baseline
- Take corrective action and show by measurement that it fixes problem

2 Transition to Strategic Test Points & Visual Controls

- Biweekly SP data and Monthly Airflows
- **Strategic test points** (20-25% of total test points) - locations
  - where data shows blockages occur
  - that provide the earliest warning of problems

Guidance on Selecting Strategic Test Points (20-25% all test points)

- Branches with
  - Heavy dust loading
  - Multiple elbows in quick succession.
  - Incorrect airflow paths through the connected equipment can get powder airborne and pull excessive amounts into the IVS. This has a negative impact on product quality (for example, Loss In Weight feeders.)
  - That may "inadvertently" pick up lightweight objects, such as gloves, wipe rags, drink cans, , etc.
- Each duct branch that enters the Air Cleaning Device
- Fan inlet and outlet
- No reduction in test point monitoring at the areas known to be more frequent risk.

Reducing Strategic Test Point Frequency

- Scheduled elbow cleanout inspections
- Document the common causes of deviation
  - this elbows plugs every third week, this air bleed screen gets dirty, difference in measurements is known between filler door open and closed
- Design modifications as appropriate - extend the length of time for deviations to develop
  - larger mesh air bleed screens, longer radius elbows, reduce the source of dust so less it carried into the IVS
- Visual controls (i.e., Magnehelic gauges or other static pressure indicators with action limits indicated) on the branches with routine deviations.
- The length of time for problems to develop undetected is longer than the new monitoring frequency for each test point.

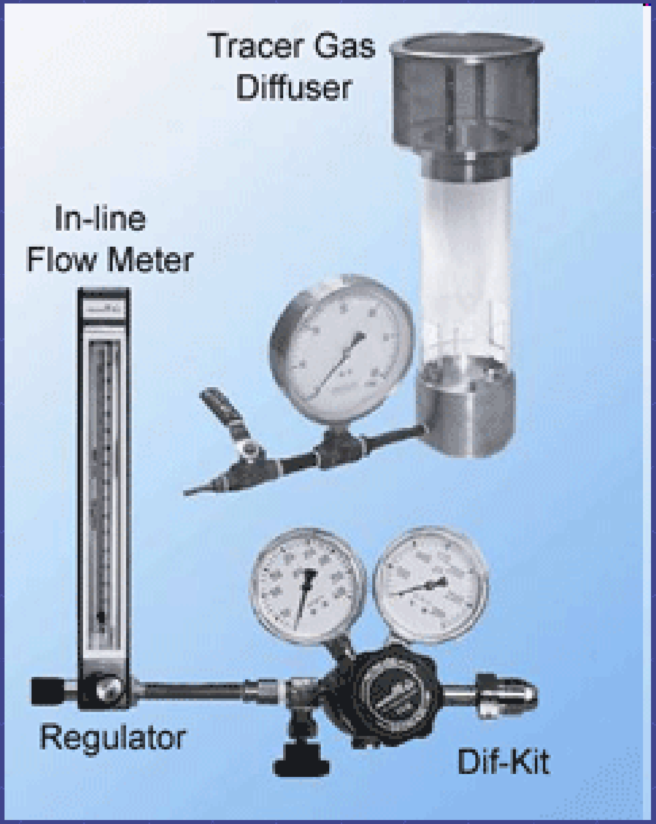
Risk Assessment Summary

- Maintenance Risk Assessment
  - Contaminant inherent risks?
  - Likelihood of rapid IVS degradation due to contaminant characteristics and existing design capability and operability
- Key question for monitoring: ***HOW LONG ARE YOU COMFORTABLE WITH POOR IVS OPERATION?***
- Set ALERT & DEGRADATION frequencies based on holistic assessment and experience
- Adjust monitoring frequency so it remains value added over the long term
- Assess the risk and staff for on-going maintenance success

Lab Hood Commissioning

- Sulfur hexafluoride testing
- Factors that impact hood performance

ANSI/ASHRAE Standard 110-1995 Sulfur hexafluoride tracer gas setup



Courtesy Kanomax

Factors that affect lab hood performance? Face velocity alone may not be enough to prove performance

Factors that affect lab hood performance

- Hood design – tested at manufacturer?
- Environment around hood?
  - Supply air outlets
  - Multiple thermostat zones
  - Room air supply/exhaust balance
  - Room air controls
  - Proximity to doors
  - Pedestal or other local cooling fans
- Standards
  - ANSI Z9.5 Laboratory Hoods
  - ANSI/ASHRAE Standard 110-1995 Sulfur hexafluoride tracer gas testing

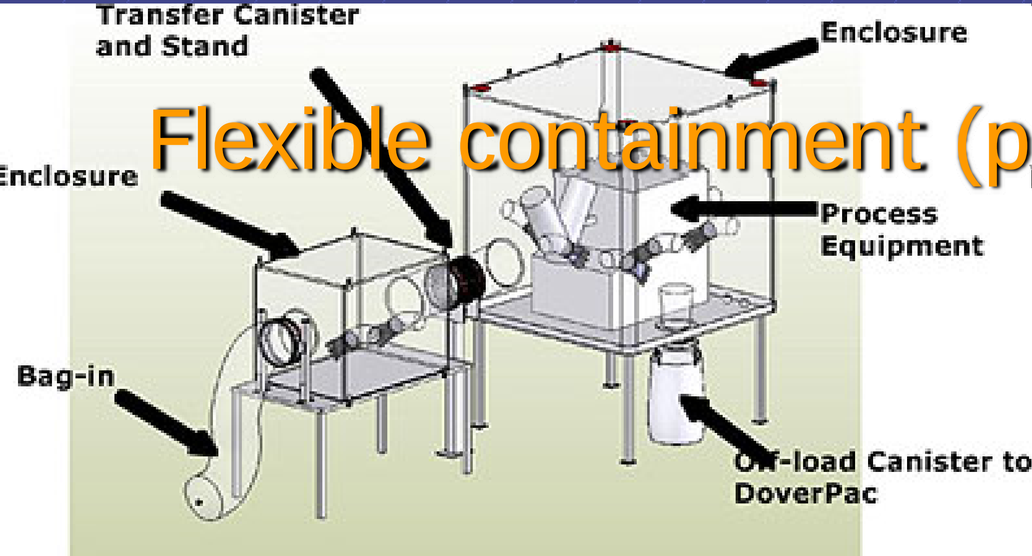
ASHRAE 110 – Recommends versus mandates hood testing - rationale for testing

- High risk materials in hood?
  - Nanoparticles
  - Toxic or radioactive gases
- High interference potential?
  - Room supply/exhaust problems
  - Noticeable drafts
  - Proximity to doors
  - High energy lab operations
- Representative locations? (Test one of each type of hood in representative locations – Perhaps 20% of hoods)
  - Center of row of hoods
  - Ends of row of hoods

Emerging Technology Issue – Nanoparticles

- Strategy – very limited exposure or health effect data available
  - Local exhaust ventilation
  - Flexible containment
- NIOSH Information
  - "Approaches to Safe Nanotechnology" www.cdc/niosh/docs/2009-125/
  - **Current Intelligence Bulletin 60: Interim Guidance for Medical Screening and Hazard Surveillance for Workers Potentially Exposed to Engineered Nanoparticles – Feb. 2009**

Flexible containment (pharma reapplic.)



Tablet press (Fabohio)

Reactor charging (Fabohio)

Drum transfer (ILC Dover)

Thank You For Your Questions and Now for Some Answers

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