

INDUSTRIAL VENTILATION

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Revised: September, 2005

DAY ONE AGENDA

INDUSTRIAL HYGIENE VENTILATION

8:30AM – 10:30AM	INTRODUCTION AND ORIENTATION AIR SUPPLY AND EXHAUST INDUSTRIAL HYGIENE ROUTES OF ENTRY EXPOSURE LIMITS
10:30AM – 10:40AM	BREAK
10:40AM – 11:30AM	PROBLEM CHARACTERIZATION AIR CAPTURE CHARACTERISTICS INTERACTION WITH EMPLOYEES GROUP EXERCISE
11:30AM – 12:30PM	LUNCH
12:30PM-1:00PM	AIR BEHAVIOR STATIC PRESSURE VELOCITY PRESSURE
1:00PM – 1:45PM 1:45PM – 2:20PM	USE OF THE SCIENTIFIC CALCULATOR INSTRUMENTATION
2:20PM – 2:30PM	BREAK
2:30PM – 4:30PM	LAB
DISMISS	

DAY TWO AGENDA

INDUSTRIAL HYGIENE VENTILATION

8:30AM – 10:20AM	BURTON CHAPTER 4 – DILUTION VENTILATION
10:20AM – 10:30AM	BREAK
10:30AM – 11:00AM	BURTON CHAPTER 11 – MAKE UP AIR REENTRAINMENT
11:00AM – 11:10AM	BURTON CHAPTER 14 – STACK HEIGHT
11:10AM – 11:30AM	BURTON CHAPTER 12 – RECIRCULATING EXHAUST AIR
11:30AM – 12:30PM	LUNCH
12:30PM – 2:30PM	BURTON CHAPTER 5 – LOCAL EXHAUST VENTILATION SYSTEM COMPONENTS TYPES OF LOSSES
2:30PM – 2:40PM	BREAK
2:40PM – 4:30PM	BURTON CHAPTER 6 – HOOD SELECTION AND DESIGN HOOD EFFICIENCY TYPES OF HOODS HOOD ENTRY LOSS

DISMISS

DAY THREE AGENDA

INDUSTRIAL HYGIENE VENTILATION

8:30AM – 10:25AM	BURTON CHAPTER 6 – HOOD EVALUATION BURTON CHAPTER 7 – DUCTWORK FRICTION LOSSES STATIC PRESSURE LOSSES
10:25AM – 10:35AM	BREAK
10:35AM – 11:30AM	TYPES OF DUCTWORK EXPANSION AND CONTRACTION LOSSES BURTON CHAPTER 8 – FAN SELECTION AND OPERATION FAN TOTAL PRESSURE FAN STATIC PRESSURE
11:30AM – 12:30PM	LUNCH
12:30PM – 1:30PM	EXERCISES POWER NEEDS
1:30 – 1:40PM	BREAK
1:40PM – 3:30PM	DESIGN EXERCISES
DISMISS	

Course Objectives

Upon completion, participants will be able to:

- Know elementary physics of air.
- Comfortably discuss technical topics related to industrial ventilation such as local exhaust systems, dilution ventilation, etc.
- Participate in identification and elimination of health problems by the use of industrial ventilation.
- Perform routine evaluations to maintain ventilation systems.
- Participate in simple design of industrial ventilation systems and its components.
- Expand your expertise in this field through self-study.

Industrial Ventilation

Follow-up Activities

- Analyzed the ventilation system in the workplace and offered suggestions for low-cost modifications.
- Incorporated this knowledge into a monitoring interval for the operation of such equipment.
- Explained to the staff, the operation of the equipment to include limitations and safeguards.

Activity Plan

	Activity	Other people involved	Target Deadline
□			
□			
□			
□			
□			
□			
□			
□			

Resources Available from the Division of Safety & Hygiene (DSH) Libraries

(800) 644-6292 (614) 466-7388

library@bwc.state.oh.us

www.ohiobwc.com

Safety training:

- Safety talks, outlines and scripts - DSH Safety leader's discussion guide, Training Center's One-hour safety presentations, reference books, web resources
- Videos – hundreds of safety and health topics
- Books and articles on training techniques

Machine and equipment safety:

- Safety standards (ANSI, NFPA, CGA)
- Books and articles on power presses, material handling equipment, lockout/tagout, etc.

Sample written programs:

- DSH program profiles and sample written programs
- Reference books
- Internet resources

Illness and injury statistics:

- Statistics from the U.S. Bureau of Labor Statistics
- National Safety Council's *Injury Facts*
- National Institute of Occupational Safety & Health (NIOSH) studies

Hazard communication and chemical safety:

- Chemical safety information
- Material safety data sheets (MSDSs)
- Sample written programs
- Videos
- Internet resources

Safety standards

- American National Standards Institute (ANSI) standards (including standards for construction, machinery and equipment, personal protective equipment)
- National Fire Protection Association (NFPA) fire codes (including the Life Safety Code and the National Electrical Code)
- Compressed Gas Association (CGA) standards

Other topics of interest (books, articles, magazines, videos and standards):

- Confined spaces
- Electrical safety
- Job safety analysis
- New employee orientation
- Powered industrial trucks
- Respiratory protection
- Scaffolds
- Spill response

Directories and lists of vendors of safety equipment

Occupational Safety & Health Administration (OSHA) regulations

Manual of Uniform Traffic Control Devices (MUTCD)

Recommendations of useful Internet sites

BWC publications

Saving You Time and Research

Requests for copies of OSHA standards, information on starting a safety committee, a video on accident investigation techniques -- these are some of the thousands of inquiries BWC's Division of Safety & Hygiene (DSH) libraries receive each year.

DSH has two libraries to serve you:

- The central library in the William Green Building in downtown Columbus;
- The resource center and video library located at the Ohio Center for Occupational Safety and Health (OCOSH) in Pickerington.

Both libraries are open 8 a.m. to 4:45 p.m., Monday through Friday. Your need for information does not require a visit to the library. You can phone, fax, or e-mail your requests and receive a quick response.

The central library provides free information services on the topics of occupational safety and health, workers' compensation and rehabilitation.

The OCOSH resource center provides similar services for those who visit OCOSH for meetings and training center classes.

The video library offers an extensive collection of videotapes to supplement your organization's safety and health training program. It is a convenient and popular source for Ohio employers to borrow quality occupational safety- and health-related training aids.

Visit our Web site at **www.ohiobwc.com**.

Central library
30 W. Spring St., Third Floor
Columbus OH 43215-2256
1-800-OHIOBWC
(614) 466-7388
(614) 644-9634 (fax)
library@bwc.state.oh.us

OCOSH resource center
13430 Yarmouth Drive
Pickerington OH 43147
1-800-OHIOBWC
Resource center (614) 728-6464
Video library (614) 644-0018

**INTERNET WEB SITES
FOR
OCCUPATIONAL SAFETY & HEALTH INFORMATION
April 2005**

GENERAL

NATIONAL SAFETY COUNCIL (NSC)

<http://www.nsc.org/>

The NSC has a user friendly web site for innovative and current information on home, farm and community, on the road and workplace safety and as well statistical data and charts.

NORTH DAKOTA WORKFORCE SAFETY & INSURANCE

<http://www.workforcesafety.com/>

For workplace safety, North Dakota's WSI site puts forth their "safe operating procedures" page where they give information on accident and near miss reports, substance abuse, material handling and storage, walking and working surfaces, and safety program development and orientation.

OCCUPATIONAL & INDUSTRIAL SAFETY RESOURCES

<http://www.khake.com/page59.html>

Maintained by a Vocational Information Center, this web site provides links to occupational and industrial safety with lists of directories, national centers, hotlines and help lines as well as specific area coverage such as emergency, disaster and natural hazards, and tool, machine and equipment safety options.

OKLAHOMA STATE UNIVERSITY

<http://www.pp.okstate.edu/ehs/>

The Department of Environmental Health & Safety at OSU offers an online safety resource library that is constantly being updated with topics from A-Z including specific areas of safety such as fire, construction, HAZCOM and training. Go to the "Links Library" option.

SAFETY DIRECTORY

<http://www.safetydirectory.com/>

Safety Directory.com is an Internet gateway to occupational health & safety sites. This web site is indexed with information on industry specific topics, training, illness and injury, as well as safety publications and resources.

FEDERAL GOVERNMENT

CENTERS FOR DISEASE CONTROL & PREVENTION (CDC)

<http://www.cdc.gov/>

The CDC is always a good resource for current medical issues throughout the United States. Health topics from A-Z give an in-depth look at most communicable diseases as well as topics such as safe driving, violence, and air pollution, and workplace safety and health topics.

FEDERAL EMERGENCY MANAGEMENT ASSOCIATION (FEMA)

<http://www.fema.gov/>

For up-to-date information on active disasters and emergencies nationwide access this web site first. Publications include options for emergency preparedness and prevention, response and recovery, disaster fact sheets, and public awareness information.

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY & HEALTH (NIOSH)

<http://www.cdc.gov/niosh/homepage.html>

NIOSH's web site provides current information on many services as well as safety research, including ergonomics programs, respirators, and mining safety. At the chemical page you will find databases and other helpful resources, information on personal protective equipment, as well as government agency web sites of interest.

OCCUPATIONAL SAFETY & HEALTH ADMINISTRATION (OSHA)

<http://www.osha.gov>

OSHA'S official web site includes media releases, online publications, statistics, standards & directives, "Technical Links," training center courses, "hot topics," and "what's new" as well a very useful A-Z index page.

INTERNATIONAL RESOURCES

HEALTH & SAFETY EXECUTIVE (HSE)

<http://www.hse.gov.uk/>

The United Kingdom has an international safety web site with a good deal to offer on occupational safety & health. Drop down boxes offer A-Z industry information, health and safety topics, tools, research, as well as publications and statistics.

ERGNET

<http://www.sunderland.ac.uk/~ts0qli/ergnet.htm>

The University of Sunderland in the UK is an international web site directory of "places for ergonomics and human factors". Featuring lists of sources such as societies, organizations, government bodies, institutes, centers and laboratories, this site also gives links to journals, a research database and other general ergonomic sites.

OHIO

OHIO EPA (OEPA)

<http://www.epa.state.oh.us>

At the official web site for Ohio's Environmental Protection Agency; use the "Topic Index" to find regulations and information on permits, hazardous waste, pollution prevention, wastewater, wetlands, and much more.

OHIO STATE LIBRARY/OHIOLINK

<http://winslo.state.oh.us>

At **OhioLink**, a statewide library and information network, you can search the State Library of Ohio's collection for the BWC's Division of Safety & Hygiene library books as well as other Ohio College and university library collections. Also available at this web site are searchable versions of Ohio Administrative laws and rules, electronic databases, and other Ohio library directories.

SPECIFIC (BY SUBJECT)

CONSTRUCTION

<http://www.cdc.gov/elcosh/index.html>

CDC's **eLCOSH** is a comprehensive library of construction-related safety information presented in both English and Spanish with items listed under trade, hazard, job site, and others. Also see: The Construction Industry Safety Council, a Center to Protect Workers' Rights resource center at <http://www.buildsafe.org/RSC.htm> for OSHA publications in PDF and hazard alerts.

ERGONOMICS

<http://www.ergoweb.com>

ERGOWEB provides current information on ergonomics and human factor science. Offered are: research, case studies, reference material and a forum for questions, answers and discussion.

LABORATORY SAFETY

<http://safety.science.tamu.edu/>

Texas A&M University College of Science is an optional choice for safety in the laboratory information. From hazard identification to waste disposal this web site offers thorough coverage of laboratory safe practices.

MATERIAL SAFETY SHEETS

<http://www.ilpi.com/msds/index.html>

This web site offers many solutions for finding MSDS (100 free sites) as well as chemical manufacturers and suppliers, pesticides including fertilizers, government sites, and other miscellaneous locations for chemical data. Also check any toxicological effects at <http://www.atsdr.cdc.gov/toxprofiles/> and health and safety information on household chemical ingredients at <http://householdproducts.nlm.nih.gov/>.

<http://www.fmcsa.dot.gov/safetyprogs/saftprogs.htm>

The Federal Motor Carrier Safety Administration (FMCSA), an administration within the U.S. Department of Transportation, regulates and supports the Nation's interstate commercial carrier industry. The FMCSA web page offers several safety programs in PDF format such as brake safety, fatigue, HAZMAT safety, speed management, sharing the road safely, and other insurance and licensing information.

RADIATION

<http://www.physics.isu.edu/radinf/>

The Radiation Information Network offers a web site that is in-depth with information on radiation topics and issues. In addition to what's new in the field and general information there are regulatory, organizational and society links as well as research and educational resources available to access.

SAFETY STATISTICS

<http://stats.bls.gov/>

Occupational health and safety statistics by industry and occupation can be researched for injuries, illnesses, and fatality data at this web site starting with the "Overview of BLS Statistics on Worker Safety and Health" page.

SAFETY BRIEFINGS, MANUALS, PRODUCTS & PROGRAMS

OSHA POWERPOINT SAFETY PRESENTATIONS

<http://esf.uvm.edu/siript/powerpt.html>

An extensive safety PowerPoint presentation library is available at this web site featuring A-Z topics such as accident investigations, bomb threats, chemical spills, construction, electrical, hand tools, emergency response, fire safety, forklifts, JSA, laser, OSHA compliance, PPE, razor knife safety, safe lifting, and many more.

SAFETY PUBLICATIONS & VIDEO RESOURCES

<http://www.cbs.state.or.us/external/osha/standards/pub.htm>

A valuable resource for safety resources, the Oregon State's Department of Consumer and Business Publications web site is packed with downloadable information. Areas covered are agriculture, asbestos abatement, occupational exposures, HAZCOM, HAZMAT, HAZWOPER, safety practices, writing manuals and programs, tools of the trade, workers' compensation and ergonomics.

Ohio Bureau of Workers' Compensation, Div. of Safety & Hygiene Library
30 W. Spring St., L-3, Columbus, OH 43215-2256
(800) 644-6292, press option 2 - 2
(614) 466-7388/ (614) 644-9634 (fax)
E-Mail: library@bwc.state.oh.us

Instructors

Don Bentley, PE, CIH is the Industrial Hygiene Technical Advisor for the Division of Safety and Hygiene. Don has been with the Division since 1982. During that time, Don has worked as an industrial hygienist, an ergonomist, and as an industrial hygiene supervisor. His area of specialization is occupational exposure control assessment. Don has a Bachelor of Science degree in civil engineering from Ohio University. He has worked in private industry and consulting from which he has established a solid foundation of practical experience. He is a Professional Engineer (PE), registered by the Ohio Board of Registration for Professional Engineers and Surveyors, and a Certified Industrial Hygienist (CIH), certified by the American Board of Industrial Hygienists (ABIH) in 1990.

Jim Scholl is a Field Consultant with the Division of Safety and Hygiene with our Columbus office. He has been with the Division since 1993. Jim received a Bachelor of Science degree from Bowling Green State University. This was followed by a Master of Business Administration degree from Xavier University. In 1997, the American Board of Industrial Hygiene certified Jim in the Comprehensive Practice of Industrial Hygiene.

Participant Introduction

1. Name?
2. What is your position with the company? How long?
3. What type of product or service does your company provide?
4. How many employees are there in your company?
5. What involvement do you have with industrial ventilation at your facility?
6. Specifically what do you hope to gain by attending this seminar?
7. What are your expectations of this class?
8. Describe an air quality problem you may have had in your facility. What part did ventilation play?

Introduction to Industrial Ventilation

Industrial Ventilation (IV) is the supply and exhaust of air to control airborne contaminants. The theory is to bring clean air into the facility and exhaust bad air from the location where it is generated.

Heating, ventilating, and air-conditioning (HVAC) can also be called general ventilation. General ventilation is used for comfort or for dilution. For dilution, we call it general ventilation or dilution ventilation. For comfort, we call it HVAC. HVAC systems provide indoor comfort by:

- A. Heating, cooling/dehumidifying, and filtering air to maintain comfortable temperature and humidity conditions
- B. Circulating air to reduce temperature and humidity stratification and reduce drafts and the feeling of stuffiness.
- C. By introducing a sufficient amount of outside air into a building and exhausting an equal amount of indoor air, thus reducing air contaminants.

Due to conservation of mass, ventilation flow rate into a building must equal the flow rate out of a building.

Ventilation Control in HVAC is a means of diluting and exchanging the air in the occupied space with outside air. ASHRAE Standard 62.1-2004, Ventilation for Acceptable Indoor Air Quality, specifies both minimum and recommended outside air flow rates to obtain acceptable IAQ for a variety of indoor spaces. Since humans give off carbon dioxide (CO₂) when exhaling, its concentration in the air provides a good indication of the quality of air circulation and how effective the ventilation system is in diluting and removing contaminants from the air. Standard 62.1-2004 establishes a CO₂ concentration of outside air concentration plus 700 ppm (typically 1050 – 1200 ppm) as the acceptable limit correlation to 15 cfm of outside air per person for occupied spaces. Carbon dioxide sensing is particularly effective when used as a surrogate “indicator” of indoor air quality to determine whether or not the building’s ventilation system is properly removing the indoor air pollutants.

Indoor Air Quality (IAQ) has become a big problem in the last few years. Since the majority of IAQ problems are due to the HVAC system, solving IAQ problems generally requires an understanding of HVAC. For more information on HVAC and IAQ we offer a class on IAQ for the non-industrial environment.

Industrial Ventilation is used to control indoor air quality problems in the industrial setting. The IAQ problem involves controlling particulates, gases and vapors to keep employee exposures at safe levels. It is also used to keep concentration of dust or vapor from exploding or causing fire.

Episodes of poor indoor air quality in the industrial setting abound. What situations have you faced? What part did ventilation play?

Industrial Hygiene

The field of industrial hygiene involves the anticipation, recognition, evaluation and control of workplace hazards. Exposures to chemical contaminants and physical contaminants abound in the workplace. The determination of whether the exposures are excessive is the job of the industrial hygienist. There is a level of chemical exposure below which most individuals will not have an adverse health effect. The industrial hygienist can monitor to determine the extent of exposure. If an overexposure occurs, this will be identified by the IH and will probably be supported by health effects that workers are starting to recognize to some extent.

Routes of entry. Chemical exposures in the workplace get into the body by ingestion, absorption, or inhalation. Inhalation is the primary route of entry for most chemicals and so it becomes the main route for evaluation purposes.

There are acceptable exposures to many chemicals. The acceptable exposures can be found in a booklet, which contains Threshold Limit Values (TLV's). These values are established by the American Conference of Governmental Industrial Hygienists (ACGIH). Another control limit would be those enforced by the Occupational Safety and Health Administration (OSHA). These limits are called the Permissible Exposure Limits (PEL's). These values, while not as protective as the TLV's, do carry the weight of the law. The TLV's do carry more weight with regard to injuries or illnesses the worker sustains as a result of being overexposed to workplace hazards.

The PEL's and the TLV's are in terms of parts per million (ppm) and milligrams per cubic meter (mg/M^3). They are also exposures for an entire workday. This is called a time-weighted-average exposure. This exposure assumes that the worker works 8 hours and gets a 16-hour break before required to work another 8 hours.

Industrial Hygiene aspects of industrial ventilation

Industrial hygienists know that if a problem with airborne contaminants is identified, industrial ventilation is just one of many options that need to be considered to reduce employee exposure.

How does an industrial hygienist know? Sampling is performed using pumps, filters, and other instrumentation. Once the extent of the problem is identified, then control options need to be considered.

There are six types of controls that we will take a look at. These options are considered following a priority order. If changing the process is possible, that is the most desirable option. In order of priority type, types of controls include:

- 1) Process change
- 2) Substitution -- <http://clean.rti.org>
- 3) Isolation
- 4) Ventilation
- 5) Administrative controls
- 6) Personal protection

Note that ventilation, while not the first option, is not the last either. When taking on an exposure problem, start at the top of the list and try to come up with the best exposure control means for the situation that presents itself.

As an example, solve this problem using the priority list from above.

Exercise 1-3 (Burton's manual Chapter 1-3): Suppose a worker is cleaning metal parts by hand with perchloroethylene and a small rag. Sampling suggests overexposure. You are called upon to suggest potential controls. What alternatives can you think of?

Teamwork is required for effective control of industrial hygiene problems.

Teamwork is required for effective control of industrial hygiene problems. To get the best control option, the team needs to understand the extent of the problem. They must also know about the physical properties, toxicity, and the behavior of the chemical hazards to be controlled.

Problem Characterization

Emission Source

Air Movement

Worker Interaction

Calculator Exercise

If you will be performing industrial ventilation system design calculations in the future you will want to either have a programmable calculator or a computer program. However, for this class any scientific calculator will work just fine.

The following functions on your scientific calculator will be needed:

Arithmetic's + , - , x , / , ÷ , +/- , 1/x

Log & Ln

(()))

Y^X , X^2 , X^3 , $\sqrt[3]{Y}$, $\sqrt{\quad}$, $\sqrt[3]{\quad}$

Math Review

1) Order of performing calculations:

$$3 \times 2 + (8 \div (9 - (2 - 3))) \quad = 1.9?$$
$$\quad \quad \quad \quad \quad \quad \quad \quad \quad \quad = 6.8?$$

2) $\text{Log } 25 =$ $10^{1.4} =$

$\ln 326 =$ $e^{5.786} =$

3) $3.2^{8.6} =$

$16^2 =$

$8^3 =$

$\sqrt[2]{256} =$

$\sqrt[3]{512} =$

$\sqrt[5]{8679} =$

4) Area of a circle

$$A = \pi \times D^2/4 \text{ or } \pi \times r^2$$

$$D = 14''$$

$$A = ? \text{ (in square feet)}$$

Area of a rectangle

$$A = a \times b$$

$$a = 8'' ; b = 5''$$

$$A = ? \text{ (in square feet)}$$

Industrial Ventilation Exercises

MEASUREMENT LOCATION:

Option 1- At least 4 duct diameters from hood. If possible, 6 duct diameters is ideal. Pitot traverse normally performed (6 and 10 point traverses are common.)

Option 2 - Take 90% of centerline velocity or .81 of centerline VP.

The first thing you must do is to determine the area of the duct.

A) Area

1) Measure circumference $C = 2 * \pi * r$

Then $A = C * C / 4 * \pi$

2) Area 3" diameter duct $A = \pi * r^2 = \pi * d^2 / 4 = \underline{\hspace{2cm}}$
Area 4" diameter duct $A = \underline{\hspace{2cm}}$

After you have the area, you can start to take measurements. Depending on the instrument, you will be able to take readings in velocity or velocity pressure.

- 1) Velocity: This is easy, just read off the instrument
- 2) Velocity Pressure: This is also read off the instrument. However, it must now be converted to velocity to work with it.

$$\text{Calculate velocity: } V = 4005 * \sqrt{VP}$$

Once you have the area and the velocity, you can calculate how much air is moved by the blower. This is called volumetric flow rate, and is given the term Q.

1) Calculate Volumetric flow rate: $Q = V * A$

With this information, we can now begin to take measurements of a duct system in various arrangements and see how the system (ductwork) affects the ability of the blower to do its job.

Say according to the Industrial Ventilation Manual, we needed 500 cfm to exhaust a process. We must run duct from the process to the blower. Will the 532 cfm blower be sufficient to do the job?

Let's look at different arrangements and see the effect on the blower.

- | | | |
|----|-----------------------------------|--|
| 1) | Blower with 3' of 3" duct | $VP_{CL} - \text{_____} \text{''wg} \Rightarrow VP_d - \text{_____} \text{''wg} \Rightarrow$
$V - \text{_____} \text{ fpm} \Rightarrow Q - \text{_____} \text{ cfm}$
$SP - \text{_____} \text{''wg}$ |
| 2) | 7' of 3" duct | $VP_{CL} - \text{_____} \text{''wg} \Rightarrow VP_d - \text{_____} \text{''wg} \Rightarrow$
$V - \text{_____} \text{ fpm} \Rightarrow Q - \text{_____} \text{ cfm}$
$SP - \text{_____} \text{''wg}$ |
| 3) | Add flanged hood to plain opening | $VP_{CL} - \text{_____} \text{''wg} \Rightarrow VP_d - \text{_____} \text{''wg} \Rightarrow$
$V - \text{_____} \text{ fpm} \Rightarrow Q - \text{_____} \text{ cfm}$
$SP - \text{_____} \text{''wg}$ |
| 4) | 3" straight duct | What is the capture velocity \Rightarrow _____ fpm |
| 5) | With flange | What is the capture velocity \Rightarrow _____ fpm |
| 6) | Blower with 3' of 4" duct | $VP_{CL} - \text{_____} \text{''wg} \Rightarrow VP_d - \text{_____} \text{''wg} \Rightarrow$
$V - \text{_____} \text{ fpm} \Rightarrow Q - \text{_____} \text{ cfm}$
$SP - \text{_____} \text{''wg}$ |

- 7) 7.5' of 4" duct
 VP_{CL} - _____ "wg \Rightarrow VP_d - _____ "wg \Rightarrow
 V - _____ fpm \Rightarrow Q - _____ cfm
 SP - _____ "wg
- 8) 13' of 4" PVC duct
 VP_{CL} - _____ "wg \Rightarrow VP_d - _____ "wg \Rightarrow
 V - _____ fpm \Rightarrow Q - _____ cfm
 SP - _____ "wg
- 9) 4" straight duct
 What is the capture velocity \Rightarrow _____ fpm
- 10) 3' of 4" PVC and
 10' of 4" flex duct
 VP_{CL} - _____ "wg \Rightarrow VP_d - _____ "wg \Rightarrow
 V - _____ fpm \Rightarrow Q - _____ cfm
 SP - _____ "wg
- 11) Bend 4" flex duct
 one sharp turn (90°)
 VP_{CL} - _____ "wg \Rightarrow VP_d - _____ "wg \Rightarrow
 V - _____ fpm \Rightarrow Q - _____ cfm
 SP - _____ "wg
- 12) Bend 4" flex duct
 several times (8-90's)
 VP_{CL} - _____ "wg \Rightarrow VP_d - _____ "wg \Rightarrow
 V - _____ fpm \Rightarrow Q - _____ cfm
 SP - _____ "wg
- 13) Suction vs. Push
 Velocity on suction side \Rightarrow _____ fpm
 Velocity on push side \Rightarrow _____ fpm