PRINCIPLES OF VENTILATION

INSTRUCTOR'S MANUAL

99-72-52

Prepared by George M. Hama

1.a

50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO.

2.

3. Recipient's Accession No. PB84 156272

4. Title and Subtitle

Principles of Ventilation--Instructor's Manual

1972

5. Report Date

6.

7. Author(s) Hama, G.

Hama, G. M.

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

NIOSH
4676 Columbia Parkway
Cincinnati, Ohio 45226

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.

(C) 099-72-0052

(G)

12. Sponsoring Organization Name and Address

NIOSH
4676 Columbia Parkway
Cincinnati, Ohio 45226

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This is an instructor's manual for two series of lectures, the first entitled Principles of Ventilation, and the second, Ventilation Measurements. Topics in the first include: characteristics of contaminants and their sources and modes of dissemination: the types, design and operation of hoods in local exhaust systems; pressures and pressure losses in local exhaust systems; the flow of air in industrial local exhaust duct work systems; industrial ventilating fans, industrial exhaust system air cleaning devices, and methods of trouble shooting an exhaust system. Topics in the Ventilation Measurements series include: purpose of making such measurements; importance of evaluating a system in its effectiveness to control contaminants; types of systems to be measured; types of measurements to be made; the general types of instruments used; the use of the pitot tube to measure air flow; various air meters; how to make measurements of air velocity at hood openings; practical methods of measuring general ventilation; criteria on standards and good practice for industrial ventilation. Laboratory exercises for ventilation measurements are provided. (Contract No. 99-72-52)

17. Document Analysis a. Descriptors

Ventilation-systems, Environment, Ventilation-ducts, Ventilation-equipment, Analytical-methods, Air-quality-measurement, Dusts, Fumes, Smokes, Workplaces, Workrooms, Mists, Particulates,

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement:

19. Security Class (This Report)

20. Security Class (This Page)

21. No. of Pages 153

22. Price

PRINCIPLES OF VENTILATION

LECTURE I

INSTRUCTOR'S MANUAL

Lecture Outline	
	The trainees and the Instructor should be provided with Industrial Ventilation 12th Edition 1972, American Conference of Governmental Industrial Hygienists. Committee on Industrial Ventilation, P. O. Box 453, Lansing, Michigan 48903, price $5. 00 single copy, $3. 75 - 15 copies or more. This reference text is valuable to all engineers and technicians measuring or evaluating industrial ventilation systems. It is complete as to necessary references and charts.
I	A good reference on the subject of dusts is: Industrial Dust by Drinker and Hatch Plant and Process Ventilation by W. C. L. Hemeon
I-C	Settling rate depends not only on size of particle, but also on shape of particle and density of material.
I-D	Threshold Limit Values are helpful in evaluating the relative toxicity of dusts.
I-E-4-5	Note visual aid comparison table
II-E-2	On structural work and arc welding on large objects, it is not practical to provide local exhaust at all welding points which are varied and many. A custom shop may not repeat the same manufacturing job.
II-E-3	Inertial collectors, cyclones or low pressure drop wet collectors are ineffective for fume removal.
III	A number of plating solutions cause adverse exposures by virtue of mist dissemination rather than vaporization. Generation of mists on high amperage "strike solutions" can be very active; this must be considered in prescribing ventilation rates.
III-A	Cutting oils are used in machining operations, the insoluble type becomes heated in the operation and through vaporization and condensation produces oil mist of small particle size.

IV-A Carbon monoxide is the most commonly encountered toxic gas. Propane and gasoline fueled lift trucks are a common industrial source.

IV-A Diesel vehicles and engines produce considerable oxides of nitrogen gas and comparatively little carbon monoxide.

IV-C (a) Because certain gases in pure state are heavier than air does not mean they will be found near the floor when diffused with the work room air. In most cases, the density of hygienic significant mixtures of toxic gases is very little different than the density of air.

V-C-6 A problem is to be assigned to the trainees using this equation. This equation and further information on Threshold Limit Values of a mixture of solvents is given in THRESHOLD LIMIT VALUES FOR 1970, American Conference of Governmental Industrial Hygienists, pages 21 to 25.

V-E-1 Flammability information for Flash points and lower Explosive Limit Values (LEL) is available for solvents. LEL is the lower limit of flammability of a gas at ordinary ambient temperatures expressed as per cent of gas or vapor by volume in the air. Flash point is the temperature the gas will flash at specified conditions.

V-E-3-6 Very few ventilation systems for dilution approach perfect mixing. This should be stressed to trainees.

V-E-5 Unfortunately, there needs to be more practical investigation to establish "K" values. At the moment, they are used to impress the designer that perfect dilution with exact calculated air quantities does not occur practically -- and a safety factor must be used.

VI-C In this equation "P" is available draft pressure, with a flow of air up a stack or chimney, part of the pressure is converted to velocity pressure to effect the air flow movement.

VI-E Natural ventilation from thermal effects can be of fair magnitude. It should not be ignored as a means of effecting general ventilation if necessary conditions are present -- that is sizeable temperature differentials between indoors and outdoors and large building height.

VI-E-6 This and further information on natural ventilation can be obtained from ASHRAE Guide and Data Book 1961 Fundementals and Equipment pages 429 - 431.

VI-E-8 Example problem can be omitted if time does not permit using it.

PRINCIPLES OF VENTILATION

LECTURE II

INSTRUCTOR'S MANUAL

Lecture Outline	
	Instructors should read and become familiar with terms, definitions and concepts in section 4, Hood Design, Industrial Ventilation.
II-A	Highly toxic material such as benzene, lead dust and fumes, beryllium dust and fumes cannot be controlled by dilution ventilation. The exposure limits are so low on these materials that the dilution rates become impractical.
II-B	This is an important consideration. All air exhausted must be replaced with make-up air, which must be heated in winter for worker comfort. Air cleaning equipment and operational costs are high and vary nearly directly with cfm. Air cleaning equipment can be the principle expense in a ventilation system.
III	Effective design of the hood is not "vacuum cleaning", removing the product from the process, it is the prevention of the escape of contaminated air. Also, a well engineered hood does not exhaust more air than is necessary.
IV-C	The enclosing hood design is to be preferred over an exterior hood.
IV-C	The trainee should be warned to look for man cooler fans, they are a common and important cause of hood failure.
IV-C-4	The selection of the correct capture velocity is probably the most difficult judgement factor in hood design. If possible, data from a similar existing satisfactory hood is the best guide.
IV-F-1-2-3	This is the main reason for making a hood face traverse.
IV-G-3	It is not uncommon to find a centrifugal fan rotating in reverse, the result is low air flow, 25 to 40% of rated flow.
V-C	There is a tendency to work beyond the range of these hoods, at which point they become ineffective.

V A good reference on exterior hoods is: Dalla Valle, J. M., Exhaust Hoods, 2nd Edition 1952, Industrial Press, 148 Lafayette Street, New York, N. Y'

V-D-3 Canopy hoods are really similar to square opening hoods, they should be normally only applied to hot operation. The thermal currents bring the contaminated air within the range of exhaust currents.

VI-B-3 At distances greater than 1 1/2 diameters the air flow drops off more slowly than the equation given indicates. At distances greater than 2 diameters the equation becomes $Q = V \ (4.45 x^2 + A)$ for unflanged hoods.

VI-B-4 A flange of four inches or more around the hood is satisfactory.

VI-C Exterior hoods are commonly applied to arc welding, stone cutting and certain table operations.

VII-B-4 If a blowing slot is applied, care must be taken not to blow too great an air volume. Air is entrained by the primary air supplied. On a 20' throw the primary supply air is increased about twenty fold.

VII-B-7 A table or tank with slot against the wall is well baffled and takes less air for control than a table or tank in middle or the room.

VIII To be effective, these hoods should be placed as close as possible to the operation. Generally speaking, they should be used as a last resort. On open tanks, a slot hood is to be preferred as contaminant does not move by workers breathing zone. They should not be applied to toxic materials.

PRINCIPLES OF VENTILATION

LECTURE III

INSTRUCTOR'S MANUAL

Lecture Outline

The instructor should read Section 1 and 4, Industrial Ventilation and familiarize himself with diagrams, equations and concepts of pressure and flow.

I-B Velocity Pressure can be defined as the kinetic pressure in direction of flow necessary to cause a fluid at rest to flow at a given velocity.

I-B-3 From equation: $v = \sqrt{2\,gh}$

if we substitute $\frac{V}{60}$ for v $\quad$ V = fpm

$\frac{VP\ 62.5}{12\ \ .075}$ for h

VP = inches wg

equation becomes

$$V = 60\sqrt{\frac{2 \times 32.2}{12} \times \frac{62.5}{.075}\ VP}$$

$$V = 60\sqrt{4472 \times VP} = 4005\sqrt{VP}$$

I-B-6 A pitot tube measures velocity by subtracting static pressure from total pressure

TP = SP + VP

VP = TP - SP

TP is impact or total pressure measured at the nose of the pitot tube. SP is measured through fine holes around circumference of the tube. Each pressure is connected through pitot tube connections and rubber tubing to an opposite leg of a liquid manometer, thus working against each other.

I-B-6 The trainee should be made aware of Velocity - Velocity pressure tables (see Industrial Ventilation pp. 6-33)

I-C-4 When manometer liquid moves toward duct the pressure
I-D-3 is negative.

I-E-2 It is assumed that TP and SP are measured at same point in air stream.

I-E-2 On the exhaust side of fan SP is always the largest
I-E-3 numerical value. On the supply or pressure side TP is always the largest numerical value. This may be a confusing matter, but it can be cleared by statement E-2C and E-3-b

II-A This pressure is the SP at the hood.

II-B For practical purposes, friction through a round duct varies directly as length, inversely as the diameter and directly as the square of the velocity.

II-C-4 It is important that correct signs be used. On exhaust side of fan +VP -SP -TP on pressure or discharge side of fan +VP +SP +TP

II-C-7 This may appear simple and obvious but some persons do not get it. There is a convertion of pressures so TP remains constant. Actually there are friction and turbulence losses, the conversion back and forth is therefore less than 100%.

III-A-2 This is one reason it is better to measure SP a short distance from hood.

III-A-4 The largest loss is VP to SP.

III-8-c For a perfect no loss streamline hood $C_e = 1$, this is theoretical.

III-8-d Hood C_e value are given on pp. 6-26 Industrial Ventilation. It is important that the hood and duct are clean and not blocked if this method is to be used for estimation of air flow.

III-9 Be sure trainee can differentiate between C_e and h_e. C_e is a ratio, h_e is actual inches wg loss.

III-9-c h_e values are given in Industrial Ventilation pp. 6-26 and in each plate of the Specific Operations Section. They vary from 1.78 VP for a sharp edged orifice to .04 VP for a streamlined entry.

III-9-f Losses in a ventilating system are calculated as SP. Note diagram page 1-4, Industrial Ventilation to get concept of pressures in a local exhaust system.

PRINCIPLES OF VENTILATION

LECTURE IV

INSTRUCTOR'S MANUAL

Lecture Outline	
	A rather simple, easy to follow reference on fluid flow is, Alden, John L., and Kane, John M., Design of Industrial Exhaust Systems, 4th Edition 1970. Industrial Press Inc. Chapter 1.
II-B	Reynolds' number (R_e) can be applied to any fluid, oil, water or air gas. It is a useful fool in the field of fluid flow; it has reduced much empirical data to a rational basis.
II-B-5	To get in the laminar flow range, velocities must be very low, for example with an R_e = 3000, the velocities are as follows:

Pipe diameter	V (fpm)
3"	120
12"	30
36"	10

III-B	(f) varies with roughness or smoothness of duct. Relationship of R_e and f is not a straight line relationship in turbulent flow. In laminar flow it is a straight line relationship ($f = \frac{64}{R_e}$)
IV-A	For friction charts see page 6-31 and 6-32 Industrial Ventilation. Friction charts are for clean round, galvanized duct having approximately 40 joints per 100 ft.
IV-B	Correction factors vary from 0.6, for very smooth duct, to 2.3 for very rough duct. Factor varies with diameter, duct roughness and velocity. See page 6-30 Industrial Ventilation.
IV-C	Corrections are normally not applied for small variation in temperature and pressure. Usually temperature variations of $\pm 30^\circ$F are allowable without correction.
V-B-5	A sharp mitered elbow has a loss of about 1 VP. The loss increases in elbows with radius of curvature greater than 2.5 diameters radius.
V-C-1	90° entries with a "boot" have a high loss.

V-D-3 These losses can be calculated and equations are given in Industrial Ventilation 12th Edition, page 6-12.

V-E Weather cap losses are given in Industrial Ventilation 12th Edition, page 6-29.

V-F Certain collectors, such as fabric collectors, can increase in resistance to flow; this can be improved by proper c aning. See Industrial Ventilation 12th Edition, page 11-4.

VII-A Required cfm for control is first ascertained for the hood; this is required Q. Minimum transport velocity V is selected to prevent settling out in duct. Transport velocity for various material and processes can be obtained from Industrial Ventilation 12th Edition, Section V. Specific Operations.

VII-A If we put the equation Q = AV, in the form (to solve for A) $A = \frac{Q}{V}$. "A" can be determined in square feet as Q and V are known. From the duct area, the duct diameter can be determined. Duct diameter should be selected in sizes commercially available. (see section VII-A-5) The largest available size duct that will meet the minimum transport velocity with the required cfm should be selected. Industrial Ventilation 12th Edition, Fig. 6-18 page 6-35 gives areas from duct diameters.

VII-A-5 Patterns for elbow, and other duct work accessories are not normally available for other increments of duct size.

VII-B-1-f In Industrial Ventilation 12th Edition, transport velocities are given with processes and operations in the Specific Operations Section 5. Also see Alden, J., Design of Industrial Exhaust Systems, page 81.

VII-B-1-g Pressures SP, TP, increase directly as the square of the velocity for same size duct. Horsepower varies directly as the pressure (TP).

VII-C-1 Usually velocities in the range of 2000 to 3000 fpm are selected on basis of power cost and capital cost based amortization of system over a long period of time.

VII-C-2-a Low pressure, low cost fans can be employed, however high pressure, higher cost fans may be required.

VIII-A Hood design including hood cfm is the beginning point of a system layout.

IX The instructor should read Industrial Ventilation 12th Ed., Section 7, to be familiar with make-up air.

IX-C-2-a In plants with lack of make-up air, the periphery around the walls, windows and doors may be cold while the center of the plant where heaters are present may be excessively hot.

IX-C-2-b Short natural draft stacks often work on a small draft pressure which if it is less than the negative pressure in the building may reverse the flow of air.

IX-C-2-c This is a serious condition which has caused illness and death.

IX-C-2-d Low pressure fan systems are the most vulnerable to negative pressures.

IX-C-2-e This may result in a safety hazard.

IX-D-1 Large quantities of air relative to available crack or air inlet area will result in negative pressures which are corrected by providing make-up air. Small volumes of exhausted air in large plants may not create a negative pressure problem.

IX-F The fan and thermostatically controlled heat source is essentialy for make-up heaters used in cold climates.

PRINCIPLES OF VENTILATION

LECTURE V

INSTRUCTOR'S MANUAL

Lecture Outline

Reference reading on this section as follows:

Industrial Ventilation 12th Edition, Section 10 and 11.

I-A-1 For natural draft systems there must be sufficient stack height and a source of heat. The building must not be under negative presure.

I-A-2 Air ejector systems are expensive to operate as they are very inefficient. Generally speaking, they can be applied only to low pressure systems. The main advantage of ejectors is the contaminant does not contact a moving fan blade. This reduces clogging and fire hazards.

II-A-1-2-3 These fans cannot be applied as air movers on medium to high pressure local exhaust systems.

II-B-4 There is space saving not only because of size, but because of their straight line flow through design.

III-A This is the popular low cost fan used in heating, ventilating and air conditioning work.

III-B Besides being of heavy construction, these fan blades because of their simple shape can be readily coated with corrosion resistant materials.

III-C-5 In a centrifugal fan running at constant speed as the resistance is decreased, air flow and horsepower increase. With a backwardly curve blade fan this increase in horsepower is small as compared with forward curved and radial blade fans. This is the reason for the term "non-overloading" applied to this fan. Small variation in pressure do not greatly change the horsepower required.

V When one point of operation of a local exhaust system is known, that is cfm and SP, a complete curve can be drawn. This can be accomplished by assuming a series of new cfms' and calculating the corresponding new SPs' from equation

$$SP_2 = \frac{Q_2^2}{Q_1^2} \times SP_1$$

V-B Ratings under specified certified testing conditions are conducted with straight duct runs at fan inlet and outlet. Operating conditions of systems with elbow at fan inlet and reverse elbows at fan outlet will not give the specified rating even if fan static pressure is correctly calculated.

V-C A few fan manufacturers give their fan ratings in Fan total pressure. Example is American Air Filter Co. Inc.

These fan laws are useful in anticipating cfm and horsepower when a fan rpm is increased. It should be stressed the horsepower increases rapidly with increased rpm and in most cases is the governing limit for the maximum fan rpm on a specific system.

There are other fan laws relating to fan size, air density and other factors.

VII-2 It can be seen from equation that horsepower varies directly with TP. For this reason a good designer designs with lowest pressure and cfm possible.

X-A Because of the high cost of collectors for fine particles, for dusts with larger size particles lower cost collectors with good efficiency on these larger size particles are used. For example, with very coarse wood dust, a conventional low cost cyclone collector is used satisfactorily.

X-B If efficiency figures are given for a collectors the size range of particles should also be given. A collector may have good efficiency on large particles but poor efficiency on fine particles.

XII The impractical large required size of a settling chamber excludes its use as a means of collection except on very large particles.

"Chip traps" are located at the hood to prevent large pieces of material from clogging the duct.

XIII-A-B Separating effect of a cyclone collector varies as: $S = \frac{v^2}{gr}$

where
S = separating coefficient
v = tangential velocity, fps
r = radius of rotation, ft.
g = gravitational constant

For settling chamber S would equal 1

XIII-B-1 It can be seen from the equation the smaller the diameter and the greater the velocity the greater the separation factor.

XIII-B These collectors are composed of a number of these small cyclones connected together in parallel. One make is known as "Multiclone".

XIII-C This collector is available from American Air Filter, Inc. It is known as "Rotoclone". Its' collection efficiency is similar to small diameter cyclones.

XIV-A There are a number of makes of fabric collectors. They are highly efficient. Cotton, wool, synthetic and glass fabrics are used.

XIV-B Furnace filters would clog very quickly with industrial dust. They have a very small area, up to 350 cfm per a sq. ft. of filter area.

XIV-B-3 A reverse air flow is sometimes combined with rapping and vibrating.

XIV-C-1 There is also one reverse jet collector that uses compressed air pulses to effect a reverse flow.

XV-A-5 Highly flammable dusts such as magnesium should be collected only in wet collectors.

XVI-A-4 Cost of electrical equipment is very high.

XVII This chart VA-18 should be reviewed by the instructor so he is able to discuss comparative features of each collector.

XVIII This discussion is to assist in trouble shooting a system.

PRINCIPLES OF VENTILATION

LESSON PLAN

PROBLEMS

STUDENT TEST

Prepared by George M. Hama

PRINCIPLES OF VENTILATION

LECTURE I

LESSON PLAN

Specific Aim

To familiarize the trainee with the characteristics of contaminants and their source and mode of dissemination into the work room atmosphere, so that the trainee can intelligently understand the application of ventilation for their control.

General Aim

To acquaint the trainee with dusts, fumes, mists, gases, smokes and vapors.

To give the trainee some knowledge of the common industrial sources of these materials.

To instruct the trainee in methods of estimating dilution ventilation.

To give the trainee basic information of the nature and magnitude of thermal ventilation.

Procedure and Content

The trainee is expected to know how dusts are generated and disseminated and to know their physical characteristics.

Instruction is given to the trainee, in a general way, as to type of ventilation to be applied to dusts.

The trainee is expected to know what fumes and mists are and how they are generated.

In a general way, the trainee is instructed as to what type of ventilation is applied to fumes and mists.

The trainee is expected to know the major sources of industrial gas exposures. Instruction is given on characteristics and behavior of gases as related to the application of ventilation.

The trainee is expected to know characteristics of vapors. He is expected to know the relation of vapor pressure of solvents to work room exposure and dissemination rates.

The trainee is expected to know how to make a dilution calculation for solvent vapors.

The trainee is expected to know and understand factors and relationships affecting thermal heads in hot processes.

The trainee is expected to estimate through calculations the natural ventilation rates in industrial buildings through thermal effects.

The following subjects are presented:

Dusts

Fumes and Smokes

Mists

Gases

Vapors

Equations are given for determining:

1. Vapor pressures of each component in a mixture of solvents

2. Threshold Limit Value of a mixed solvent

3. Volume rate of air for effecting dilution of a solvent vapor

4. Density of air when temperature is known

5. Draft pressure from thermal effects

6. Velocity of heated air

7. Natural ventilation rates in buildings from thermal effects. Example problems are given for dilution ventilation calculations and for natural ventilation rates for thermal effects. Lectures are to be assisted by visual aid materials

Activities

Visual aid projection* material is used as indicated on lecture outline Visual aid material include:

(Table on mean particle sizes
VA-1 (Table on distance traveled by spherical particles
(Diagram of positioning of hood for high velocity particles

VA-2 Diagram illustrating good and poor distribution

Give students list of References on Industrial Ventilation

Student test can be given

Assignments

Problem 1

Reference Reading

Section 1 and 2 Industrial Ventilation

VA-2 reprinted from Industrial Ventilation 12th Edition, American Conference of Governmental Industrial Hygienists with permission of the Committee on Industrial Ventilation, American Conference of Governmental Industrial Hygienists

*A 3-M Overhead projector, or equivalent is needed for projection of visual aid material.

REFERENCES ON INDUSTRIAL VENTILATION

1. Industrial Ventilation - A Manual of Recommended Practice. A. C. G. I. H., Committee on Industrial Ventilation, P. O. Box 453, Lansing, Michigan. Twelth Edition, 1972.

2. Plant and Process Ventilation, W. C. L. Hemeon. The Industrial Press, New York 13, N. Y. First Edition, 1955.

3. Design of Industrial Exhaust Systems, J. I. Alden and John M. Kane. The Industrial Press, New York, N. Y. 10016. Fourth Edition, 1970.

4. Ashrae Guide and Data Book, Am. Soc. Heat. & Air Conditioning Eng., Inc., 62 Worth St., New York, N. Y.

5. Fan Engineering, R. D. Madison, Editor. Buffalo Forge Co., Buffalo, N. Y.

6. Industrial Health Engineering, A. D. Brandt, John Wiley & Sons, Inc., New York, 1947.

7. Industrial Dust. P. Drinker and T. Hatch. McGraw-Hill Book Co. Inc., New York, 1954.

8. Flow and Fan. C. H. Berry. The Industrial Press, New York 13, N. Y., 1954.

9. Exhaust Hoods. J. M. DallaValle. The Industrial Press, New York 13, N. Y. Second Edition, 1952.

10. Encyclopedia of Instrumentation for Industrial Hygiene. C. D. Yaffe, D. H. Byers, A. D. Hosey, Technical Editors. University of Mich. Institute of Industrial Health, Ann Arbor, Michigan, 1956.

11. Engineering Manual for Control of In-Plant Environment in Foundries. Am. Foundrymen's Soc., Inc., Des Plaines, Illinois, 1956.

12. The Industrial Environment----Its Evaluation and Control. U. S. Dept. of Health Education and Welfare, Public Health Service. (2. 75)

13. Heating and Cooling for Man in Industry. American Industrial Hygiene Association. Publications Manager, 210 Haddon Ave. Westmount, N. J. 08108.

14. Federal Register Sat. May 29, 1971, Washington, D.C. Vol. 36, No. 105. Dept. of Labor Occupational Safety and Health Admin.

15. Ower, E. and Pankhurst, R. C., The Measurement of Air Flow. Pergamon Press, Ltd. Headington Hill Hall, Oxford 4 & 5 Fitzroy Square, London W1 England.

16. Operating Instructions for Alnor Series 6000-P Velometer. Form 6270 Alnor Instrument Co., 420 N. LaSalle St., Chicago, Ill. 60610.

17. Testing and Balancing Manual, Ventilating and Air Conditioning Contractors Assoc. of Chicago., 228 N. LaSalle Street, Chicago, Ill.

PRINCIPLES OF VENTILATION

LECTURE I

Student Test

1. Explain how fumes are generated and how they differ from dusts.

2. What type of ventilation is generally applied to plating tanks for the control of mists?

3. 4 gallons of Methyl Ethyl Ketone are used in 8 hours. If a "K" factor of 6 is assumed for distribution, calculate the volume rate (cfm) required to dilute the solvent to the Threshold Limit Value of 100 ppm.

   Sp. Gr. .803   MW 72.06

PRINCIPLES OF VENTILATION

LECTURE I

ANSWER TO TEST

1. See Lecture Outline II A, B, C.

2. See Lecture Outline III C, 1, 2.

3. See Secture Outline V-E-4

$$\frac{403 \times 4 \times 8 \times .803 \times 6 \times 1000000}{72.06 \times 8 \qquad\qquad 100} \times \frac{1}{60} = 18000 \text{ cfm}$$

PRINCIPLES OF VENTILATION

Lecture I

Problem

1. Calculate the Threshold Limit Value of a half solution value of Trichlorethylene and Methyl Chloroform from a reservoir of solvent mixture where composition does not change appreciably by evaporation.

	M. W.	Sp. Gr.	TLV	Vapor Pressure
Trichlorethylene	131.4	1.46	100	73 mm Hg
Methyl Chloroform	133.42	1.33	350	125 mm Hg

Lecture I

1. SOLUTION TO PROBLEM

Methylene Chloride $\frac{50 \times 1.46}{131.4} = .555$ mols

Methyl Chloroform $\frac{50 \times 1.33}{133.42} = .495$ mols

$$1.050$$

Methylene Chloride $\frac{.555}{1.050} = .527$ mol fraction

Methyl Chloroform $\frac{.495}{1.050} = .473$ mol fraction

Methylene Chloride $P_a = FP_a = .527 \times 73 = 38.2$

Methyl Chloroform $P_a = FP_a = .473 \times 125 = 59.2$

$$TLV = \frac{38.2 + 59.2}{\frac{38.2}{100} + \frac{59.2}{350}} = 177 \text{ ppm}$$

PRINCIPLES OF VENTILATION

LECTURE II

LESSON PLAN

Specific Aim

To familiarize the trainee with the types, design and operation of hoods used in industrial local exhaust systems.

General Aim

To instruct the trainee in the operation of a local exhaust system and its advantages.

To instruct the trainee in basic data and equations used to design hoods and calculate their air flow.

To familiarize the trainee with factors that must be considered in effective hood operation and design, operation, air movement, drafts, ventilating and mancooler fans.

Procedure

The trainee is expected to be familiar with the local exhaust system.

The trainee is expected to know the types of hoods and their application.

The trainee is expected to know how to calculate the air flow needed for enclosing hoods and exterior hoods.

Methods of calculating flow and equations are given for:

1. Enclosing hoods
2. Exterior square or round hood openings
3. Slot hoods
4. Overhead canopy hoods

Example problems are presented for:

1. Exterior round flanged opening hood air flow calculation
2. Canopy hood calculation

Diagrams of hoods are presented through visual aid material.

Activities

Transparent visual aid material* to be presented includes:

VA-3 Diagrams of different types of hoods

VA-4 Enclosing hoods

VA-5 Capture velocity

VA-6 Exterior hoods - square hoods, canopy hoods, round hoods

Student test can be given.

Assignment

Problems 1, 2.

Reference reading

Industrial Ventilation, Sections 1 and 2

VA-4, 5, 6, visual aid material, is from Industrial Ventilation 12th Edition, American Conference of Governmental Industrial Hygienists and is reprinted by permission of the Committee on Industrial Ventilation, American Conference of Governmental Industrial Hygienists.

*A 3-M Overhead Projector or equivalent is needed for projection of visual aid material

PRINCIPLES OF VENTILATION

LECTURE II

Student Test

1. Give two advantages of local exhaust ventilation systems as compared with dilution ventilation.

2. Describe an enclosing hood. How would you calculate the air flow?

3. What is meant by capture velocity?

   What would be a good figure for capture velocity in fpm for a quiet operation with very little cross draft or process air motion?

4. Calculate the air flow for a canopy hood 3' from a hot process tank 4' x 4' surface area. A capture velocity of 150 fpm is needed.

PRINCIPLES OF VENTILATION

LECTURE II

ANSWER TO TEST

1. See lecture outline II A & B

2. See lecture outline IV A, B, C, E.

3. See lecture outline IV B-1 and IV C-4-a

4. Q = 1.4 PDV

   P = 16'   D = 3'

   Q = 1.4 x 3 x 16 x 150 = 10100 cfm

PRINCIPLES OF VENTILATION

LECTURE II

PROBLEMS

1. An acid pickling tank is 20" wide and 36" long. It is ventilated by a slot on the long side of the tank. The tank is placed along the wall and the slot is against the wall. A capture velocity of 125 ft. per minute is needed. What is required air flow in cfm?

2. A flanged round open hood 6" in diameter is located 8" away from an arc welding operation. If a capture velocity of 200 ft. per a minute is required, what is the required air flow in cfm?

LECTURE II

Answers to problems

1. $Q = 2.8\ LXV$

   $Q = 2.8 \times \frac{20}{12} \times \frac{36}{12} \times 125$

   $Q = 2.8 \times 1.67 \times 3 \times 125 = 1753.5$

   $Q = 1753.5$ cfm

2. $Q = .75V\left(10x^{2} + A\right)$

   $Q = .75 \times 200\left(10\left(\frac{8}{12}\right)^{2} + .1964\right)$

   $Q = 696.$ cfm

   $A = 3.1416\ r^{2} = 3.1416 \times \left(\frac{6}{2 \times 12}\right)^{2} = .1964$

PRINCIPLES OF VENTILATION

LECTURE III

LESSON PLAN

Specific Aim

To familiarize the trainees with pressures and pressure losses in a local exhaust system.

General Aim

To define the pressures used, velocity pressure, static pressure and total pressure and to instruct the trainee in their relationships to each other, both on the inlet side of the fan and the discharge side of the fan.

To instruct the trainee how to calculate velocity from velocity pressure.

To familiarize the trainee with the losses in local exhaust systems and their expression in pressures.

To give the trainee a concept of the conservation of energy in a local exhaust system through the mutual exchange of energy of one pressure to the other.

To familiarize the trainee with constants and factors relating to pressure losses from air entering a hood and to instruct the trainee how to compute hood losses.

Procedure and Content

The trainee is expected to be familiar with SP, VP and TP, and to know how they are measured.

The trainee is expected to know how to calculate velocity in fpm from VP and vice versa.

Visual aid material is used to indicate SP, VP and TP, on the inlet and on the outlet side of the fan.

Visual aid material is used to show hood vena contracta and the pressures at a hood opening.

Instruction is given the trainee on how to estimate air flow from a hood static pressure readings.

Equation are presented for:

1. Calculating velocity from Velocity Pressure
2. Calculating Velocity Pressure from Velocity
3. Relationships of TP, SP and VP
4. Calculating coefficient of entry of a hood
5. For calculating Q (cfm) at a hood when the coefficient of entry and hood static pressure are known
6. For calculating the hood SP when the entry loss factor and the velocity at the hood are known
7. Calculating the coefficient of entry from the hood SP and VP

Example problems are given for calculating air flow (Q) from hood SP and the coefficient of entry and for calculating hood SP from hood entry loss factor F and the velocity of air in the hood duct.

Activities

Visual aid transparent projection* material will be used to present

VA-7
(Pressures in a pipe above atmospheric pressure with air flowing through it.
(Pressures in a pipe below atmospheric pressure with air flowing through it.
(Pressures in a local exhaust system equipped with a defined hood

VA-8
(Air flow at vena contracta
(Pressure losses in an exhaust system

VA-9
(Coefficient of entry (C_e) and entry loss (h_e) for several different hood shapes

Assignment

Problems 1 and 2

Reference Reading

Industrial Ventilation, sections 6 and 7

Student test is provided.

Visual aid material is from Industrial Ventilation 12th Edition, American Conference of Governmental Industrial Hygienists. It is reprinted by permission of the Committee on Industrial Ventilation, American Conference of Governmental Industrial Hygienists

*A 3-M Overhead Projector or equivalent is needed

PRINCIPLES OF VENTILATION

LECTURE III

Student Test

1. A hood connected to a 14" diameter duct has a SP reading of 4" wg at the duct connection to the hood. If the hood has a velocity of 5000 fpm in the duct, calculate

   (a) Coefficient of entry (C_e)

   (b) Hood entry loss (h_e)

   (c) Hood entry loss factor

2. A hood connected to a 10" diameter duct has an SP at the hood throat of 3" wg. From the shape of the hood the hood entry loss factor is .25. What is the quantity cfm of air flowing thru the hood?

PRINCIPLES OF VENTILATION

LECTURE III

ANSWER TO TEST

1. Calculate VP $VP = \frac{5000^2}{4005^2} = 1.56'' \text{ wg}$

(a) Coef. of entry $C_e \sqrt{\frac{VP}{SP}} = \sqrt{\frac{1.56}{4.00}} = \sqrt{.39} = .625$

$SP = VP + h_e$

(b) Entry loss $h_e = SP - VP = 4. - 1.56 = 2.44 \text{ wg}$

(c) Entry loss factor F

$h_e = FVP$

$F = \frac{h_e}{VP} = \frac{2.44}{1.56} = 1.56$

2. 10'' diameter 0.5454 sq. ft. cross section area

$SP = VP + h_e = VP + FVP = VP + .25\ VP$

$SP = 1.25\ VP$

$VP = \frac{SP}{1.25} = \frac{3}{1.25} = 2.4'' \text{ wg}$

$V = 4005 \sqrt{VP} = 4005 \sqrt{2.4}$

$V = 6205 \text{ fpm}$

$Q = 6205 \times .5454 = 3380 \text{ cfm}$

PRINCIPLES OF VENTILATION

LECTURE III

Problems

1. If a pitot tube measurement indicates a velocity pressure of 4.2" wg, calculate equivalent velocity in fpm.

2. A round tapered hood has a hood entry (h_e) loss of .2 VP. If 3000 fpm is the duct velocity, what is the hood static pressure and the coefficient of entry (Ce) for the hood?

PRINCIPLES OF VENTILATION

LECTURE III

Answers to problems

1. $V = 4005\sqrt{VP}$

   $V \quad 4005\sqrt{4.2} = 4005 \times 2.05$

   $V = 8200$ fpm

2. $VP = \dfrac{V^2}{4005^2} \qquad \dfrac{3000^2}{4005^2}$

   $VP = .56$

   $SP_h = VP + he = .56 + .2 \times .56 = .56 + .112 = .672$

   $Ce \cdot \sqrt{\dfrac{VP}{SP}} = \sqrt{\dfrac{.56}{.67}}$

   $Ce = \sqrt{.835} = .915$

PRINCIPLES OF VENTILATION

LECTURE IV

LESSON PLAN

Specific Aim

1. To familiarize the trainee with the flow of air in industrial local exhaust duct work systems.

2. To familiarize the trainee with industrial make-up air systems.

General Aim

1. To familiarize the trainees with the fundamentals of fluid flow as it pertains to air flow in duct systems.

2. To instruct the trainee in the selection of proper duct sizes in local exhaust systems.

3. To instruct the trainee in methods of calculating pressure losses in ducts and elbows.

4. To instruct the trainee in methods of calculating pressure losses in a single branch local exhaust system.

5. To define to the trainee what make-up air is and why it is necessary for local and general exhaust ventilation systems.

6. To provide the trainee with information on the components of a make-up air systems and the different types of heating equipment available.

7. To inform the trainee on adverse effects which result from lack of or insufficient make-up air.

Procedure and Content

Information on laminar and turbulent flow is given.

Reynolds' number is discussed and the equation for calculation is given.

The friction loss equation is given.

Friction loss charts and their use is presented.

Dynamic losses are discussed.

Instruction on sizing ducts is given.

Instruction for calculating pressures for a single branch local exhaust system is presented.

The need and use of make-up air is discussed.

Adverse effects of negative pressures are given.

Instruction on selecting make-up heater size is provided.

The necessary components and types of heaters used for heating make-up air are given.

Information is presented on the best location of make-up air heaters.

Activities

Transparent projection* material is used to project charts and diagrams as follows:

VA-10 Friction loss chart and correction chart.

VA-11 Elbow losses - Weather cap losses - entry losses.

VA-12 (Losses in local exhaust systems and Adverse effects of negative (pressures.

Student test is provided.

*A 3-M overhead projector, or equivalent is needed for projection of visual aid material

Assignments

Read sections 10, Fans, and Section 11, Air Cleaning Devices, in Industrial Ventilation, 12th Edition.

Problems 1, 2, 3, to be worked.

Visual Aid material is from Industrial Ventilation, 12th Edition, American Conference of Governmental Industrial Hygienists. It is reprinted by permission of the Committee on Industrial Ventilation, American Conference of Governmental Industrial Hygienists.

PRINCIPLES OF VENTILATION

Lecture Outline IV

Student Test

1. Describe how laminar or turbulent flow can be predicted in a duct system.

2. What is minimum transport velocity, where is it used?

3. What factors govern the selection of duct size in system where only gases and vapors are handled?

4. What causes negative pressures within buildings? Give four adverse effects of negative pressures.

5. The winter design temperature in Detroit is $-10^{o}F$. A gas direct fired make-up air heater is to be used to supply 10000 cfm with an outlet air discharge temperature of $75^{o}F$. Calculate the required BTU output for the heater.

ANSWER TO TEST

1. See lecture outline II-B
2. " " " VII-B-1
3. " " " VII-C-1, 2, 3.
4. " " " IX-C-1, 2.
5. BTU output $= \dfrac{Q \times 1.08 \times (t_i - t_o)}{E}$

   $E = .90$

   $t_i = 75$

   $t_o = -10$

   $Q = 10000$

$$\text{BTU's} = 10,000 \times 1.08 \left(\frac{75 - (-10)}{.9}\right) = 1020000 \text{ BTU / hour}$$

PRINCIPLES OF VENTILATION

Lecture Outline IV

Problems

1. An air flow of 400 cfm is flowing through a 10" diameter duct. What is the Reynolds' number? Is the air flow laminar or turbulent?

2. A local exhaust system in which wood dust is being exhausted requires an air flow of 600 cfm. If the minimum transport velocity is 3500 fpm, what would be the best available duct size to use in this system?

3. Calculate the SP at the fan for a local exhaust system which consists of a hood, (h_e = .15 VP) 100 ft. of straight duct, 1-90° elbow (2-D radius of curvature). Use 6" diameter duct. 800 cfm is exhausted through system.

ANSWER TO PROBLEMS

1. $R_e = 8.4\ dv = 8.4 \times 10 \times 734 = 61500$

$$V = \frac{Q}{A} = \frac{400}{.5454} = 734 \text{ fpm}$$

A for 10" diameter duct = .5454 sq. ft.

Flow is turbulent

2. $A = \frac{Q}{V} = \frac{600}{3500} = .171$ sq. ft.

5 1/2 diameter .165 sq. ft.

6" diameter .1964 sq. ft.

use 5 1/2" $V = \frac{600}{.1650} = 3640$ fpm

3. For 6", A = .196

$V = \frac{800}{.196} = 4080$ fpm   V = 1.04" wg

Hood SP

$VP + h_e = 1.15 \times 1.04$	1.2
1 Elbow .27 x 1.04	.28
100' duct 4.4	4.4
SP at fan	5.88"

PRINCIPLES OF VENTILATION

LECTURE V

LESSON PLAN

Specific Aim

The specific aim of this lecture is to familiarize the trainee with

1. Industrial ventilating fans
2. Industrial exhaust system air cleaning devices
3. Methods of trouble shooting an exhaust system

General Aim

To give the trainee necessary information on fans and air moving equipment so he will be knowledgeable as to types of fans, methods of rating fans, efficiencies of fans and performance characteristics for fans with changes in cfm, pressure and rpm.

To give the trainee information so that he will be knowledgeable as to the correct application of air cleaning devices to contaminated air material of various characteristics such as particle size, temperature, moisture and flammability.

Procedure and Content

The trainee is expected to know the different types and characteristics of both axial flow fans and centrifugal fans.

He is expected to know what a fan performance curve is and its relation to a local exhaust system curve.

He is expected to understand the use of a fan manufacturers multirating table.

Fan laws for variations of cfm, pressure and horsepower with rpm are given.

Equation for calculating fan brake horsepower is given.

The trainee is expected to know the various factors affecting the selection of dust collectors.

He is expected to be familiar with the characteristics and application of the following types of collectors:

1. Centrifugal and inertia
2. Filters
3. Wet collectors
4. Electrostatic precipitators

If the information on the contaminant is given, the trainee is expected to have some knowledge as to which collector can be best applied.

The trainee is expected to know what to look for in an industrial ventilating system if it fails to give control.

<u>Activities</u>

Transparent projection* material is to be used in this lecture. This material includes diagrams and tables as follows:

VA-13	Axial flow fans with performance curves
VA-14	Centrifugal fans with performance curves
VA-15	System curve and performance curves - Fan multirating table
VA-16	Fabric collectors
VA-17	Wet collectors - Centrifugal collectors
VA-18	Table comparison of collectors

<u>Assignments</u>

Problems 1 and 2

Visual aid material is from <u>Industrial Ventilation</u>, 12th Edition, American Conference of Governmental Industrial Hygienists. It is reprinted by permission of the Committee on Industrial Ventilation, American Conference of Governmental Industrial Hygienists.

Student test is provided.

*A 3-M Overhead Projector, or equivalent, is needed for projection of visual aid material.

PRINCIPLES OF VENTILATION

Lecture V

Student Test

1. Name three types of centrifugal fans. Give one advantage and one disadvantage of each type. Diagram the fan wheel configuration for each type.

2. A local exhaust system has the following design data

Fan inlet SP	-8.4
Fan outlet SP	+1.6
Velocity at fan inlet and outlet	5665 fpm

Determine the Fan static pressure.

3. Give the best choice of collector for the following types of contaminated air.

(a) Cement Dust .5 to 5 microns
$400^{\circ}F$, 600,000 cfm

(b) Wood dust 50 to 10 microns
$70^{\circ}F$, 2,000 cfm

(c) Magnesium dust 2 to 5 microns
$70^{\circ}F$, 3,000 cfm

PRINCIPLES OF VENTILATION

LECTURE V

Problems

1. A centrifugal fan running at 500 rpm is exhausting 3600 cfm thru a local exhaust system, the SP at the fan is 2" and the B. Hp is 1.9. It is desired to increase the air flow to 4000 cfm by speeding up the fan.

   Calculate

   (a) Fan rpm

   (b) New SP

   (c) New B. Hp

2. A local exhaust system is designed to handle 10000 cfm, at a TP of 5.5" wg. If it is estimated that a fan with a mechanical efficiency of 60% is to be used, calculate the Brake Horsepower required.

LECTURE V

ANSWERS TO PROBLEMS

1. New rpm varies directly as cfm

$$\frac{rpm_2}{rpm_1} = \frac{Q_2}{Q_1} = \frac{rpm_2}{500} = \frac{4000}{3600}$$

$$rpm_2 = 500 \times \frac{4000}{3600} = 555.5$$

SP varies as square of rpm

$$\frac{SP_2}{SP_1} = \frac{rpm_2^2}{rpm_1^2} = \frac{SP_2}{2''} = \frac{555.5^2}{500^2}$$

$$SP_2 = \frac{2 \times 555.5^2}{500^2} = 2.47$$

Hp varies as cube of rpm

$$\frac{Hp_2}{Hp_1} \quad \frac{rpm_2^3}{rpm_1^3} = \frac{Hp_2}{1.9} \times \frac{555.5^3}{500^3}$$

$$Hp_2 = 1.9 \times \frac{555.5^3}{500^3} = 2.605$$

2. $$B.H_p = \frac{cfm \times TP}{6356 \times ME} = \frac{10000 \times 5.5}{6356 \times .60} = 14.4$$

VENTILATION MEASUREMENTS
INSTRUCTOR'S MANUAL

Prepared by George M. Hama

VENTILATION MEASUREMENTS

LECTURE I

INSTRUCTOR'S MANUAL

Lecture Outline	
I	It is assumed the trainee is unfamiliar with industrial ventilation systems. This lecture should reach the trainees as to the prime purpose of industrial ventilation. The principle reference for this course is <u>INDUSTRIAL VENTILATION</u> 12th Edition. Committee on Industrial Ventilation, P. O. Box 453, Lansing, Michigan 48902. USA. $5.00 Sections 9-1 should be read by the instructor for this lecture.
II-A	A simple example of ultimate goal should be given, similar to this: In foundry work the shaking out of poured castings from their sand molds produces an exposure of silica dust to the workers. The dust may be controlled by a side draft hood (see INDUSTRIAL VENTILATION print VS-10). This hood controls dust laden air by virtue of definite air currents which move the contaminated air into the hood by means of a fan and suitable duct work. Certain standards of air flow rate and hood structure enter into the effective design. It should be emphasized to the student that end result is that the system control the dust so the exposure to the worker is removed and no adverse condition is present.
II-B	It is important to note on the data sheet damage, corrosion, clogging or improper operation of a system. A common failure on slot hoods for welding is that the workers operate the welding at points beyond the range of the ventilation system. The system may function properly if used as designed. Mancooler fans produce a high velocity cross draft that will ruin the capture velocity of a hood.

II-C-1 Federal Regulations as presented in Federal Register under U.S. Dept. of Labor are expected, in time, to supersede local codes and regulations.

II-C-2 This is a good reason to check a system. Failure to correctly install and design a system can be determined by measurement. The check should be made before contractor leaves the installation.

II -C-3 Adding hoods to a system without ascertaining if system has ample reserve capacity will end up in a botched up job.

II-C-4 An existing system operating satisfactorily provides the best criteria of design for a similar future system

II-C-5 Local exhaust systems deteriorate quickly. Periodically scheduled tests are important in determining the need of maintenance.

III-A The trainee is probably not familiar with a local exhaust system. It should be discussed in some detail.

III-B The mixing or distribution of air is important. Dilution will be discussed in detail later.

Some operations cannot be controlled by local ventilation. For example, gasoline fueled industrial lift trucks emit exhaust gases which cannot be controlled by local exhaust ventilation because the lift truck moves from place to place.

III-C The provision of make-up air systems is greatly neglected for industrial ventilation systems by designers and contractors.

IV The terms, velocity and volume rate (cubic ft. per a min.) are often confused by students.

Use several examples, i.e., velocity is speed like the speed of a river flowing, it might be 3 miles per hour, while volume rate is so many gallons per hour. The difference is hard to get across. Be sure they understand it.

Also, the quantity rate in a fixed system does not change, but velocity may change as it becomes lower at large cross-sectional areas and higher at smaller cross sectional areas.

Smoke tubes, because of their simplicity, are often ignored. It should be stressed that they are very useful both in demonstrating hood capture and in determining adverse cross draft effects.

IV-E Standard air is dry air at 70^{o}F and 29.92" Hg Barometer. This is substantially equivalent to a density of .075 lbs. per cubic ft.

In this course, standard air is discussed. However, in the section on measurements and use of instruments for determining air flow, corrections for densities other than standard air is given.

V-B Time does not permit a discussion of these meters.

VENTILATION MEASUREMENTS

LECTURE II

INSTRUCTOR'S MANUAL

Lecture Reference

I-A-1

The standard pitot tube in U. S. A. is made according to Air Moving and Conditioning Association standards specified on the visual aid diagram. There are other designs which include certain British specifications. The AMCA design can be recognized by the round hemispherical nose.

It can be made of many different materials. Materials suitable for high temperatures and resistant to corrosive atmospheres can be used.

If a liquid manometer is used there is no need for calibration. An aneroid manometer requires calibration.

I-A-2

It takes considerably more time to set up an inclined manometer, drill a hole in the duct and make a pitot traverse than to measure a hood face with an air meter.

I-B-1

At 800 fpm the velocity pressure measured on the manometer is .04" wg. This means all readings from zero to 800 fpm must be read on a scale indicating values between 0 to .04" wg. An inclined manometer can be read to ± .005" wg. Measurement below 800 fpm have a large ± error.

I-B-2-b

The horizontal section of the standard pitot tube is approximately 7 1/2" long. The distance between the SP holes and TP opening is 2 1/2". A uniform air stream at least 2 1/2" long is therefore needed for any type of measurement with standard pitot.

I-C

<u>Visual Aid Diagram</u>. This is AMCA (Air Moving and Conditioning Association) standard pitot tube.

Other sizes may be scaled to geometric proportions to a minimum stem diameter of .10 inch. The small 1/8" stem pitot commercially available meets AMCA standards.

I-C-6 Equation is derived from falling body equation: $v = \sqrt{2\,gh}$ There is a change in units, V in equation 3 is fpm, v in original equation is fps. h in equation 3 is inches of water as compared with h in original equation which is ft. of fluid (air).

I-D-1 Certain field measurements sometimes because of difficult conditions exclude the use of an inclined manometer.

I-D-3-a The magnehelic gage is manufactured by the F. W. Dwyer Co.

I-D-4-b The instructor if, possible should use an inclined manometer to demonstrate its actual use.

I-E-2 A standard pitot tube is too large in diameter to be positioned in outer diameter traverse points in a small duct, it cannot be placed close enough.

I-F-7 In general, centerline readings for determining average velocities are not satisfactory. The 0.9 factor is somewhat an ideal figure, it cannot be expected to be precise in field conditions.

I-G-2 Hole sizes for standard pitot tube should be 3/8" diameter and for the small pitot tube 3/16" diameter.

Contrary to what persons may think, industrial establishments do not object to hole drilling in ducts.

If plastic coated duct is drilled, the hole edges should be sprayed with plastic to prevent corrosion at metal edges.

I-G-9 If readings are all the same, the hose should be examined for pinching.

VENTILATION MEASUREMENTS

LECTURE III

INSTRUCTOR'S MANUAL

Lecture Reference

The instructor should have the following instruments present:

Alnor Velometer 6000 P Series
Alnor Jr. Velometer
Alnor Thermoanemometer
Dwyer Air Meter
Rotating Vane Anemometer
Smoke Tubes

Instructor should point out components, meter box and probes so trainees can recognize the working parts of the instrument. The instructor should demonstrate how to operate the meters.

I-A — The velometer is the most popular direct reading air meter. It's most common application is measuring hood face velocities.

I-A — Series 6000 P Velometer is the currently available instrument. The older models use a different probe arrangement.

I-B-1 — Although the scale readings go down to 30 fpm, the reliability and accuracy is not satisfactory below 50 fpm. At lower velocities the thermoanemometer is more reliable.

I-C-1-c — The diffuser probe is specifically designed to measure flow through diffusers. If the probe is positioned according to manufacturers' recommendations,measurement can be simplified by making only four reading. A "K" factor applied to readings gives actual air flow.

Reference on "K" factor for diffusers:

Testing & Balancing Manual for Ventilating & Air Conditioning Systems

Ventilating & Air Conditioning Contractors Assoc. of Chicago, 228 N. LaSalle St., Chicago, Illinois

I-C-1-b In stack and ducts where velocity is low a velometer with a long probe can be used for a traverse. Long probes are available upon special request.

I-C-1-d Normally a liquid manometer would be preferred over velometer probes for measuring static pressure. The manometer has no mechanism to malfunction.

I-C-1-b The velometer probe diameter is large, 1/2" in diameter. Generally speaking the probe does not introduce significant error where the duct diameter is 30 times or more the probe diameter. For ducts smaller than 15" in diameter an instrument with a smaller probe such as a Thermoanemometer should be used.

II Alnor Velometer, Jr. is a low priced meter.

III There are a number of other satisfactory heated thermocouple instruments on the market. The Alnor Thermoanemometer is one of several satisfactory makes.

III The Anemotherm although it operates on a different principle is a popular instrument for similar use to the Thermoanemometer. It can be used for low air flows.

III-C If probe sensing element is damaged replacement is expensive. It takes considerable time to get service on this instrument. Care should be exercised in using probe.

IV <u>Rotating Vane Anemometer</u>: This instrument is seldom used in industrial ventilation measurements. It is an older instrument which was used before the advent of the Velometer and Thermoanemometer, to measure air flow in the range below the pitot. It has been applied to measure large opening air flows.

IV-A-6 The one minute or timed interval of measurement averages variations in flow, so that a more representative reading is obtained than instant reading meters.

IV-E Because of the friction of gear train the meter is designed to read low at low ranges and high at higher ranges. The corrections are an inherent part of the instrument design and must be used.

IV-E The large size of the instrument causes considerable blockage to flow.

IV-E Normally, the rotating vane anemometer would not be exposed to high temperatures, however, if corrections need to be made for medium high temperatures the following equation can be used:

$$\text{True Velocity} = \text{Velocity Read} \sqrt{\frac{1}{d}}$$

$$\text{True Velocity} = \text{Velocity Read} \sqrt{\frac{460 + t}{530}}$$

where d = density factor

t = temperature of ambient air ^{o}F

V For a low cost device the Dwyer air meter is a valuable well designed instrument.

V-B The low scale range 260 to 1200 fpm measures a range difficult to read accurately on the Velometer.

V-C It is important the U-tube be held vertically when instrument is used.

V-E-1-c The range of the instrument is well suited to Heating, Ventilating and Air Conditioning work.

VI The most popular smoke tubes are throw-away sealed glass tube type sold by Mines Safety Appliance Co. A rubber squeeze bulb is used to actuate air flow through tube.

VI-C-2-d The titanium tetrachloride smoke is irritating and corrosive. Open tubes if carried with air meters may corrode mechanisms.

An experienced investigator with smoke tubes alone can quickly ascertain if hoods are effecting capture.

There are some powder aspirating devices on the market for giving visible "smoke" or powder puffs.

Because of the fire hazard cigars, cigarettes and combustion smoke methods should not be used as an indicating smoke source.

VIII This summarizes characteristics of each air meter.

VENTILATION MEASUREMENTS

LECTURE IV

INSTRUCTOR'S MANUAL

Lecture Reference	
I-A	If the trainees get the concept of the variations in flow at an opening, they will realize the inaccuracy of random or single measurements at hoods faces. Also, a concept of the type of flow and poor uniformity at hood openings emphasizes the advantage of a pitot measurement within the duct, which even at poor locations is superior to a hood opening measurement.
I-A-4	Variation across diameter of duct vary as shown in table from authors' own measurements across the diameter of a plain duct opening (6")

Distance from Edge	Velocity fpm
1/8"	1720
7/8"	1324
2"	1225
Centerline	1170

I-A-5	The variation of velocity in and out of a plain duct opening in line of flow varies as follows from measurements made by the author:

Distance in and out of Duct	Velocity fpm
1/2" out	970
0	1170
1" in	1350
2"	1600

I-B-1-c	It is very difficult to make an accurate measurement of average velocity at a plain duct opening. However, at tapered openings, a much better measurement can be made.

II-A	On measurements involving a complete study of a system, a pitot traverse is used to get a precise air flow measurement. Hood measurements which are also made can be used for only ascertaining face velocity uniformity.
II-B-2	The velometer for hood face measurements is the more popular meter. If the meter box probe is used it is easier to position and less fragile than the thermoanemometer.
II-B-2	To assist in circular opening traverses, two strings 90° apart can be taped across diameter.
II-B-3	It is important that the hood and duct are clean with no blockage, if hood static pressures are used for future reference in rechecks.
III-A-4	At certain specialized hoods, such as grinding, buffing, if a pitot traverse is not made, it may be necessary to open the hood door and measure at hood throat with door open to get a satisfactory measurement.
III-B-2-c	It is important to traverse the full slot length, as slots tend to vary in velocity along the long dimension.
III-B-2-g	Actually the measurements less than the average hood face velocity are most significant variations as these areas may be the point of contaminant escape.
III-B-2-j	When checking with smoke, the process should be in full operation, as the process itself may create cross drafts and adverse velocities.
III-C-2-c	The trainees should be warned to use care in electroplating slot measurements so that he doesn't short circuit electrodes with the metal probe.
III-D-2-b	Slots on foundry side draft hoods, sometimes have adjustable opening so that the desired distribution can be provided.
III-E-2-a	On grinding, buffing and polishing wheels pitot traverses should be preferably made in ducts. A hood velocity measurement may be inaccurate.

III-E-2-c The main purpose of this ventilation is to attain good visibility. However, it is imperative the booth be under negative pressure to prevent leaks outward.

III-E-2-c-5 A careful check for leaks must be made. If sand is used as an abrasive, even very small leaks may cause an adverse free silica dust exposure.

VENTILATION MEASUREMENTS

LECTURE V

INSTRUCTOR'S MANUAL

Lecture Reference	
II-C	The instructor may be hard pressed to cover all the material in this lecture in detail.
	To shorten the lecture, if this seems necessary, it is suggested that in II-C open surface tank criteria C-1, a, b, c, d, be presented and C-2, a, b, c, d, e, f be omitted. This section can then be taken on by the trainees and the method learned by solving the problem assigned. A copy of the example problem should be given the trainees as a guide.
	Some necessary data for determining required open surface tank ventilation can be found in Industrial Ventilation ACGIH. This includes Threshold Limit Values, evolution rates, evaporation rates and process solution temperatures.
I-D-4-a-h	It is assumed that the principles of ventilation lectures will precede the Ventilation Measurements section or be given concurrently with the Ventilation Measurements lectures. If either of these assumptions is correct omit the lecture section D-4-a through h.
I-C-1	The tremendous turbulence at the propeller fan face makes it nearly impossible to even get a satisfactory estimate.
I-C-2	If the probe is held against grill, the higher velocity in the smaller net area opening will be measured and not the average velocity going through the gross grille area.
	It is possible to carefully measure the net opening and get the area and measure the velocity with the probe in the net openings (if it is large enough) and use this area and velocity in the equation $Q = AV$

I-C-3 The "K" factors and measurement points are available from the reference:

Testing and Balancing Manual
Ventilating and Air Conditioning
Contractors Association of Chicago
228 N. LaSalle Street
Chicago, Illinois price $10.00

Another method for checking these diffusers is to build a round tube large enough to enclose the diffuser. This is held tightly against the ceiling and a traverse of the air discharged through the bottom opening is made.

I-C-7 The most important consideration in make-up air installations is to determine if there is sufficient make-up air. Insufficient make-up air means negative pressures. A quick and satisfactory method is to check inflow or outflow of air in door openings. To estimate or measure each source of supply or exhaust separately, does not always safely give the correct results, as the error in measurements can be large enough so that a negative pressure might exist, even if computations show otherwise.

To add up rated air flows of make-up air units is not safe as most package make-up units are overated, in some cases, as much as 25% to 35%.

I-D-4 If this has already been covered in the Principles of Ventilation lecture, omit it.

II-A-B-C-D Federal Dept. of Labor Standards are given in Federal Register Part II, Saturday May 29, 1971, Vol. 36, No. 105 pages 10506 to 10518 and page 10667.

II-C This method is given also in Industrial Ventilation, 12th Edition pages 5-60 to 5-66.

III A discussion of multibranch systems and their balancing has not been included in this course. Therefore, this is not included in the discussion.

Also, fan testing has not been included. However, normally certain fan data might be included such as rpm, horsepower load, etc.

III-B It may seem a duplication of effort, but for reliable results, a pitot tube traverse of the duct and a hood face traverse with an air meter are both necessary.

III-B-3 The measurement of SP at the hood along with cfm at the hood is an excellent means of establishing future quick reference points. If the hoods are clean, future checks by SP only can be used as a quick estimate of air flow.

III-B-4 Fabric collectors are quite vulnerable to plugging. This will result, if the SP drop increases, in a low air flow at the hoods.

III-B-5 Very often the fan is undersized or running at too low a speed. These SP checks are important in judging the fan performance.

III-B-5-c Fan RPM should not be increased unless it is ascertained the motor has sufficient capacity so that it is not over loaded by the increased RPM. A wattmeter test should be made on motor. Calculation of increased Horsepower can be made from Fan Laws given in the Principles of Ventilation lectures.

IV-7 It is not necessary to use a weather cap on a continuous running system. A weather cap design with no resistance is presented in Industrial Ventilation, 12th Edition page 8-5.

IV-9 Another serious matter which is the result of negative pressure is that flues and chimneys may reverse in flow and discharge products of combustion into room. This may cause a serious carbon monoxide exposure.

VENTILATION MEASUREMENTS

LESSON PLAN

PROBLEMS

STUDENT TEST

Prepared by George M. Hama

VENTILATION MEASUREMENTS

LECTURE I

LESSON PLAN

Specific Aim

The aim of this lecture is to inform the trainee of the:

1. Purpose of making measurements.

2. The importance of evaluating a system in its effectiveness to control contaminants.

3. The types of systems to be measured.

4. The types of measurements that are to be made.

5. The general types of instruments used.

General Aim

It is assumed the trainee may know nothing about industrial ventilation systems that he is to check, or the type of measurements and observations he is to make. The general aim is in some degree to make the trainee knowledgeable of what measurements will be made and how and where they are done.

Content

The trainee is expected to know:

(a) Why the ventilation is provided.

(b) Why measurements are made.

(c) The basic measurements of velocity and pressure, and how air volume rates are calculated.

(d) How to apply corrections for high temperatures and variations in pressure for abnormal air conditions.

(e) The types of systems that are to be checked and how they operate.

(f) The use of simple flow equations and the knowledge of common terms used in measurements.

Procedure

The material is to be presented on the basis that the trainee should be able to go out into the workroom environment and be able to measure and evaluate a system.

It must be assumed that the trainee has no experience in this field. Practical details should be provided with just enough theoretical material to understand what he is doing.

Activities

The lecture is to include visual aid material.

Transparent projection* diagrams and aid material will include:

VA-19 Diagram of local exhaust system and components.

VA-20 (Sketch of General or Dilution ventilation system
(Sketch of make-up air systems

VA-21 (Illustration of system of flow and velocity change with changes in cross sectional areas
(Diagram of static pressure measurement

Student test is provided.

Assignment

Problems 1, 2 and 3 for next period.

Reading Reference:

Industrial Ventilation, ACGIH, Section 9, page 9-1 to 9-8

*A 3-M Overhead projector or equivalent is needed for projection of visual aid material.

VENTILATION MEASUREMENTS

LECTURE I

Student Test

1. Give 3 reasons for making measurements on ventilation systems.

2. Describe a local exhaust system. Make a diagram of such a system and name components.

3. What are measurements generally made on ventilating systems? How is air volume rate determined?

4. A local exhaust system is exhausting 2000 cfm. What is the average velocity through a 4 ft. x 4 ft. booth opening?

5. An air flow of 3000 cfm is measured in a local exhaust system, a static pressure measurement made at the hood throat is 2" wg. If at a later date the static pressure is 1.5" wg in a clean hood and duct system, what is the air flow rate in cfm?

VENTILATION MEASUREMENTS

LECTURE I

Student Test

ANSWERS

1, 2, 3 read lecture outline.

4. $Q = AV = 2000 = (4 \times 4)^2$

$$V = \frac{2000}{4 \times 4} = 125 \text{ fpm}$$

5. $$\frac{Q_1}{Q_2} = \sqrt{\frac{SP_1}{SP_2}} = \frac{3000}{Q_2} = \sqrt{\frac{2}{1.5}}$$

$$Q_2 = 3000\sqrt{\frac{1.5}{2_1}} = 3000\sqrt{.75} = 3000 \times .865 = 2600 \text{ cfm}$$

VENTILATION MEASUREMENTS

LECTURE I

PROBLEMS

1. A spray booth has a face opening of 6' x 6'. It is exhausted through a 20" diameter duct connected to a fan. If an average velocity of 2000 fpm is measured in the duct, what is the average face velocity in fpm across booth opening?

2. On the same booth, a static pressure of .15" wg is measured in the 20" diameter duct near the hood connection. If the velocity drops to 1500 fpm in the duct, what is the new static pressure in the duct?

3. Air exhausted from a hood over a heat treat furnace has a temperature of 300°F. The operation is at sea level (Barometric Pressure 29.92" Hg). What is the air density of the 300°F air in pounds per cubic ft.?

VENTILATION MEASUREMENT

Lecture I

Answer to Problems

1. $Q = A.V.$

$A = 2.182$ Sq. ft. 20'' duct

$$A = \frac{3.14 \times 10^2}{144} = 2.182$$

$Q = 2.182 \times 2000 = 4364$ cfm

$Q = A_1 V_1 = A_2 V_2$

$A_2 = 6' \times 6' = 36$

$Q = 4364 = 36' \times V$

$V = 121.2$ fpm

2. $$\frac{Q_1}{Q_2} = \sqrt{\frac{SP_1}{SP_2}}$$

$$\sqrt{SP_2} = \frac{Q_2}{Q_1}\sqrt{SP_1} = \frac{1500 \times 2.182}{2000 \times 2.182}\sqrt{.15}$$

$$SP_2 = \left(\frac{1500}{2000}\right)^2 \times .15 = .0844''$$

3. $$d = \frac{530}{460+t} \times \frac{B}{29.92} = \frac{530}{460+300} \times \frac{29.92}{29.92}$$

$$d = \frac{530}{760}$$

Density of air $= \frac{530}{760} \times .075 = .0523$

Density = .0523 pounds per Cu. Ft.

VENTILATION MEASUREMENTS

LECTURE II

LESSON PLAN

Specific Aim

To instruct the student in the use of the pitot tube to measure air flow.

General Aim

To impress the student that pitot tube measurements are the most reliable of all portable air meter measurements.

To explain the principle of operation.

To describe where it can be used.

To acquaint the student with mathematical relationship of velocity pressure measured by pitot tube and velocity.

To acquaint the student with manometers and their use for measuring pressure..

To acquaint the student with special types of pitot tubes.

To give the student some knowledge of the accuracy of measurements.

To give detailed instructions as to making traverses and measurements.

To present equations to correct pitot measurements made at abnormal pressures and temperatures so the actual air flow rates can be determined.

Content

The trainee is expected to know how to set up and make accurate measurements with pitot tube, to calculate velocity from velocity pressure with standard air and with air at abnormal conditions and to have some knowledge as to the accuracy of the readings.

The trainee is expected to know where and where not measurements can be made.

Procedure

Stress that in locations and conditions where the pitot can be used it is first choice of all instruments.

In describing the instrument, a diagram of the pitot should be projected with the transparent projection aids.

Point out on diagram:

1. Static pressure measurement holes.

2. Total pressure probe section.

3. How velocity pressure is the resultant reading.

4. How to connect the manometer to the pitot tube.

Activities

The lecture is to include visual aid material.

Transparent projection diagrams and tables include:

VA-22 (Standard pitot tube - "S" pitot tube
(Traverse points - Use of pitot tube

VA-23 (Inclined, vertical, and aneroid manometers

VA-24 (% Errors in pitot measurements

Student test is provided

Assignment

Problems 1, 2 and 3 for next period

Reading Reference: Industrial Ventilation ACGIH, Section 9, 9-8 to 9-14

Diagram VA-22 reprinted from Industrial Ventilation, 12th Edition, American Conference of Governmental Industrial Hygienists, with permission of Committee on Industrial Ventilation, American Conference of Governmental Industrial Hygienists.

VENTILATION MEASUREMENTS

Lecture II

Student Test

1. Describe pitot tube and give its principle of measurement.
2. A pitot tube measurement in standard air is .25" wg. What is the velocity at point of measurement?
3. Give two modifications that are used to increase the accuracy of a liquid in an anometer.
4. Give four advantages in the use of a pitot tube.

VENTILATION MEASUREMENTS

Lecture II

ANSWERS TO TEST

1. See lecture outline C-1

2. $V = 4005\sqrt{VP} = 4005\sqrt{.25}$

   $V = 4005 \times .5 = 2002$ fpm

3. Lengthening the scale by using a liquid lighter than water (oil 0.8 Sp. Gr.) and inclining one of the vertical tubes.

4. See section A-1 lecture outline

VENTILATION MEASUREMENTS

LECTURE II

PROBLEMS

1. A pitot tube measurement of a duct air stream at temperature of 150° F with a standard pitot tube gives a velocity pressure of 0.5" wg (at standard barometric pressure). What is the velocity of the air stream in fpm?

2. If the velocity in a duct is 3000 fpm at 70° F and standard barometric pressure, calculate the velocity pressure. (show calculations).

3. A six point traverse of a 5" diameter duct gave the following velocity pressures:

   .39" wg
   .40
   .41
   .42
   .40
   .38

   What is the volume rate in cfm (air is at standard conditions)

VENTILATION MEASUREMENTS

LECTURE II

Answer to Problems

1. $d = \frac{530}{460 + 150} = 0.87$

$V = 1096\sqrt{\frac{.5}{.075 \times .87}} = 1096\sqrt{7.65}$

$V = 3030$ fpm

2. $VP = \frac{3000^2}{4000^2} = 0.562$

3.

VP	V
.39	2501
.40	2533
.41	2563
.42	2595
.40	2533
.38	2469
	15194

$\frac{15194}{6} = 2532.3$

Area = 0.1364 sq. ft. for 5" duct

$.1364 \times 2532.33 = 345.41$

VENTILATION MEASUREMENTS

LECTURE III

LESSON PLAN

Specific Aim

To familiarize the student with the following air meters

1. Alnor Velometer
2. Alnor Thermoanemometer
3. Rotating Vane Anemometer
4. Dwyer Air Meter
5. Smoke Tubes

General Aim

To teach the student the use and application of each of the air meters.

To explain the principle of operation of each instrument.

To give the range of air flow measured.

To present to the trainee the application of each instrument and some information on accuracy of the meter.

Content

Each instrument is discussed separately and the following information is presented.

1. Principles of operations
2. Velocity range measured
3. Use of appurtenances and probes
4. Manufacturers' information on correction for temperature and pressure
5. Advantages and disadvantages of each instrument

6. Recommended use

7. Maintenance and care

Procedure

The instructor will have each instrument present. The trainee is to observe the components and features of each instrument.

The characteristic and features of each instrument will be presented. At the end of the discussion a comparison is to be given in a visual aid table which presents application, range, and precision of each instrument.

Activities

The instructor should have available all air meters discussed for demonstration to the trainees.

Transparent projection tables and diagrams will include:

VA-25 Comparison table of characteristics of air meters

Student test is provided

Assignment

Problems 1, 2, 3.

Reading Reference

Industrial Ventilation ACGIH 9-22 to 9-29

VENTILATION MEASUREMENTS

Lecture III

Student Test

1. State which instrument you would select for best velocity measurement in the following conditions:

    (a) Drafts on workers

    (b) Velocity measurements at spray booth face opening, velocity above 100 fpm.

    (c) Air flow measurement at a circular diffuser

    (d) Air velocity in 8" diameter round duct, velocity is below 600 fpm

2. Describe principle of operation of the rotating vane anemometer, state where it can be used.

3. Give the range of air velocities measured by the following instruments:

    Alnor Velometer

    Alnor Thermoanemometer

    Pitot Tube

    Smoke Tubes

4. A velocity reading of 1500 fpm is made in a heated air stream (300 ^{o}F) with an Alnor Velometer. What is the true velocity?

VENTILATION MEASUREMENTS

Lecture III

ANSWERS TO TEST

1. (a) Alnor Thermoanemometer

   (b) Alnor Velometer, other choices; Velometer Jr., Thermoanemometer

   (c) Alnor Velometer with diffuser probe

   (d) Thermoanemometer

2. See Lecture discussion of rotating van anemometer.

   It can be used in clean air for measuring velocities 200 to 2000 fpm in large openings.

3.

Alnor Velometer	50 to 10000 fpm
Thermoanemometer	10 to 2000 fpm
Pitot tube	800 to 10000 and above
Smoke tubes	50 to 150 fpm

4. True Velocity = Velocity Read $\sqrt{\frac{460 + t}{530}}$

$$= 1500\sqrt{\frac{460 + 300}{530}} = 1500\sqrt{1.43}$$

$$= 1500 \times 1.195 = 1800 \text{ fpm}$$

VENTILATION MEASUREMENTS

Lecture III

PROBLEMS

1. A measurement of air flow with an Alnor Velometer gives a reading of 2000 fpm. The air measured is heated dry air at a temperature of 200^{o}F. What is the true velocity of the air?

2. A measurement of air flow with an Alnor Velometer gives a reading of 1000 fpm. The measurement is made at an altitude of 5000 ft., at which the Barometric pressure is 24.9" of mercury. The air temperature is 70^{o}F. What is the true velocity of the air?

ANSWER TO PROBLEMS

1. True Velocity = Velocity read $\sqrt{\frac{460 + t}{530}}$

$$V = 2000\sqrt{\frac{460 + 200}{530}} = 2000\sqrt{\frac{660}{530}}$$

$$= 2000\sqrt{1.24} = 2000 \times 1.11 = 2220 \text{ fpm}$$

2. True Velocity = Velocity read $\sqrt{\frac{1}{d}}$

$$d = \frac{530}{460 + t} \times \frac{B}{29.92} = \frac{24.9}{29.92} = 0.831$$

$$V = 1000\sqrt{\frac{1}{.831}} = 1000\sqrt{1.205} = 1000 \times 1.1 = 1100 \text{ fpm}$$

VENTILATION MEASUREMENTS

LECTURE IV

LESSON PLAN

Specific Aim

To teach trainee how to make measurements of air velocity at hood openings.

General Aim

To familiarize the trainee with the character of air flow at various hood openings.

To instruct the trainee on proper instrumentation for measuring high and low velocity at hoods.

To familiarize the trainee with a number of different process hoods and instruct him in their measurement.

To instruct the trainee on process criteria on which ventilation rates are based.

To instruct the trainee in the measurement of Static Pressures at hoods and their interpretation.

Procedure and Content

The trainee is expected to know how to proceed in measuring an industrial exhaust hood.

He is expected to know what air meter he should use to measure a specific hood or air flow.

Method of measuring static pressure is given. Equation for calculating air flow from static pressure is given.

Methods of traversing hood faces are given.

The use of smoke tubes for ascertaining capture is given.

Hoods discussed for ventilation measurements include:

Large opening hoods

Side draft hoods

Slot hoods

Grinding wheel hoods

Wood working equipment hoods

Abrasive blasting booths

Dimensions and criteria for certain processes on which air flow rates are based are presented.

Activities

Transparent projection diagrams and tables include:

VA-26 Pattern of air flow at hood openings and in ducts is given.

VA-27 Velometer measurements - use of smoke tubes.

VA-28 Measurement at large hood face.

VA-29 Measurement at slot hoods.

Student Test

Assignment

Problem 1 and 2

Read Industrial Ventilation, 12th Edition, Section 9 and Section 5, pages 5-59 to 5-67.

VENTILATION MEASUREMENTS

LECTURE IV

Student Test

1. Describe how you would make a measurement of air flow at a spray booth 12' x 8' in cross sectional opening. Give your choice of air meters you would use.

2. Give the procedure for checking a slot hood on a muriatic acid pickling tank. State necessary information you would record so you can evaluate air flow requirements.

VENTILATION MEASUREMENTS

LECTURE IV

ANSWER TO STUDENT TEST

1. See Lecture Outline IV, Section III-B-1, 2

2. See Lecture Outline IV, Section III-C-1, 2

VENTILATION MEASUREMENTS

LECTURE IV

PROBLEMS

1. A static pressure measurement made in an untapered duct connection to a spray booth shows .66" wg. static pressure, if the duct is a 14" diameter duct, calculate the air flow (in cfm) exhausted from the hood.

2. A hood face velocity traverse shows the following velocities:

150	140	160
120	110	120
110	120	110
130	150	120

What is the greatest plus or minus percent variation at hood face?

ANSWERS TO PROBLEMS

1. $V = 4005\, C_e \sqrt{SP}$

$Q = 4005\, A\, C_e \sqrt{SP}$

$C_e = .82$

$Q = 4005 \times 1.07 \times .82 \times \sqrt{.66} = 4005 \times 1.07 \times .82 \times .812 = 2880$

2. $\frac{1540}{12} = 128$ av. velocity

$\left(\frac{128 - 110}{128}\right) \times 100 = \frac{18}{128} = -14.1\ \%$

$\left(\frac{160 - 128}{128}\right) \times 100 = \frac{32}{128} = +25\%$

VENTILATION MEASUREMENTS

LECTURE V

LESSON PLAN

Specific Aim

To familiarize the trainee with practical methods of measuring general ventilation.

To give the trainee an understanding of measurements by presenting criteria on standards, and good practice for industrial ventilation.

To instruct the trainee in trouble shooting an exhaust system.

General Aim

To instruct the trainee in methods of measuring ventilation at grilles, diffusers and make-up air heaters.

To instruct the trainee on procedure for making a routine ventilation evaluation of a local exhaust system.

To familiarize the trainee with criteria data and some of its sources.

To point out to trainees the points of failure in a system where measurements and observations indicate it is not functioning satisfactorily.

Content

The trainee is expected to know, after this lecture, how to measure general ventilation, adequacy of make-up air, and flow of air at grilles, louvers, and diffusers.

The trainee is expected to be able to express general ventilation in terms of air changes per hour, cfm per sq. ft. and dilution rates where solvent rate use is known.

The lecture presents to the trainee criteria data for evaluation of common operations. Two sources emphasized are U.S. Dept. of Labor Standards and the manual Industrial Ventilation ACGIH.

Actual required ventilation rates for paint booths, grinding, buffing and polishing, open surface tanks and welding are presented.

A detailed procedure for measurement of an exhaust system is given.

Instructions for trouble shooting a ventilation system. This includes both operational and design failure.

Activities

Visual aid material is to be presented which includes transparent projection material as follows:

VA-30
(Correction factor for velometer when measuring air flow at grill
(openings.
(Correction factor for rotating vane anemometer at pressure and
(suction opening.
(Example of "K" factors and use of Velometer for measuring air
(at diffusers.

VA-31 Criteria on requirements from U.S. Dept. of Labor for paint booths.

VA-32
(Criteria for grinding buffing polishing wheels from U.S. Dept. of
(Labor

VA-33 Criteria for welding and cutting from U.S. Dept. of Labor

Student test is provided.

Information sheet to hand out to trainees on:

1. Criteria for open surface tanks

2. Example problem open surface tank ventilation rates

Assignments

Problems 1 and 2 are to be assigned to students

Reading Reference

1. Federal Register Part II, Sat. May 29, 1971. Vol. 36 No. 105 pp. 10506 - 10518 and p. 10667.

2. Industrial Ventilation, 12th Edition, page 5-60 - 5-66

3. Testing and Balancing Manual, Ventilation and Air Conditioning Contractors Association of Chicago, Ill.

CRITERIA FOR OPEN SURFACE TANKS

TABLE 1–DETERMINATION OF HAZARD POTENTIAL

HAZARD POTENTIAL	HYGIENIC STANDARDS		FLASH POINT (See Appendix)
	Gas and Vapor (See Appendix)	Mist (See Appendix)	
A	0-10 ppm	0-.1 mg/M^3	–
B	11-100 ppm	.11-1.0 mg/M^3	Under 100 F
C	101-500 ppm	1.1-10 mg/M^3	100-200 F
D	Over 500 ppm	Over 10 mg/M^3	Over 200 F

TABLE 2–DETERMINATION OF RATE OF GAS, VAPOR OR MIST EVOLUTION

Rate	Liquid Temperature °F	Degrees Below Boiling Point	Relative Evaporation (Time for 100% Evaporation)	Gassing
1	Over 200	0-20	Fast (0-3 hours)	High
2	150-200	21-50	Medium (3-12 hours)	Medium
3	94-149	51-100	Slow (12-50 hours)	Low
4	Under 94	Over 100	Nil (Over 50 hours)	Nil

TABLE 3–MINIMUM CONTROL VELOCITY (FPM) FOR UNDISTURBED LOCATIONS

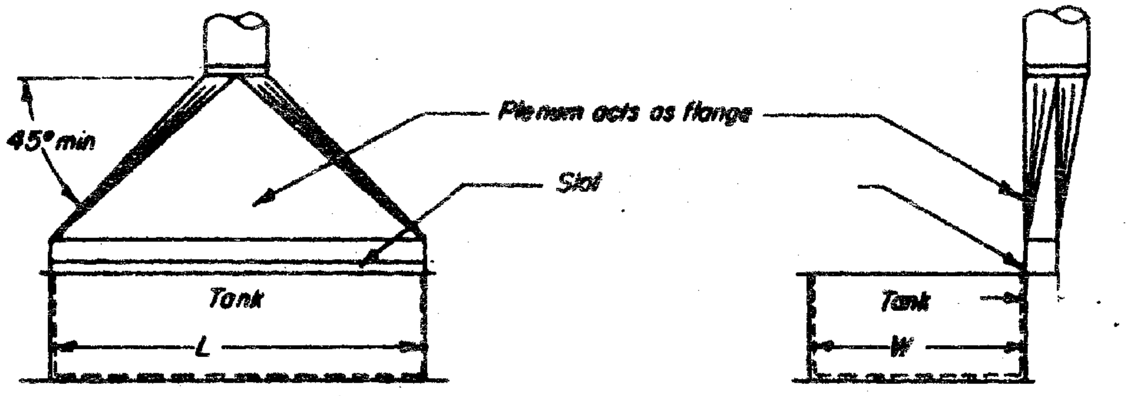
Class (See Tables 5-5-1 and 5-5-2)	Enclosing Hood		Lateral Exhaust (See VS-503-504) (Note 1)	Canopy Hoods (See Fig. 4-14 & VS-903)	
	One Open Sides	Two Open Sides		Three Open Sides	Four Open Sides
A-1, and A-2 (Note 2)	100	150	150	Do not use	Do not use
A-3 (Note 2), B-1, B-2 and C-1	75	100	100	125	175
B-3, C-2, and D-1 (Note 3)	65	90	75	100	150
A-4 (Note 2), C-3, and D-2 (Note 3)	50	75	50	75	125
B-4, C-4, D-3 (Note 3), and D-4 ADEQUATE GENERAL ROOM VENTILATION REQUIRED (See Sec. 2)					

Notes: 1. Use aspect ratio to determine air volume, see Table 4 for computation.
2. Do not use canopy hood for Hazard Potential A processes.
3. Where complete control of hot water is desired, design as next highest class.

TABLE 4–MINIMUM RATE, CFM PER SQUARE FOOT OF TANK AREA FOR LATERAL EXHAUST

Required Minimum Control Velocity, fpm (From Table 5-5-3)	Cfm per sq ft to maintain required minimum control velocities at following $\frac{\text{tank width}}{\text{tank length}}\left(\frac{W}{L}\right)$ ratios.				
	0.0-0.09	0.1-0.24	0.25-0.49	0.5-0.99	1.0-2.0
Hood along one side or two parallel sides of tank* when one hood is against a wall or baffle. Also for a manifold along tank centerline.*					
50	50	60	75	90	100
75	75	90	110	130	150
100	100	125	150	175	200
150	150	190	225	260	300
Hood Along one side or two parallel sides of free standing tank not against wall or baffle					
50	75	90	100	110	125
75	110	130	150	170	190
100	150	175	200	225	250
150	225	260	300	340	375

VENTILATION MEASUREMENTS V
EXAMPLE PROBLEM
OPEN SURFACE TANK.



A. UPWARD PLENUM

Example Problem:

Given: Chrome Plating Tank 6' × 2.5'.
High production decorative chrome.
Free standing in room.
No cross drafts.

a. Tank Hood. . Use hood "A" along 6' side. Hood acts as baffle.
W = 2.5'
L = 6.0'
W/L = 0.42

b. Component - Chromic Acid

Hazard potential: A (From Table 1; From Appendix: TLV = 0.1 mg/m^3
Flash point = Negligible)

Rate of Evolution: 1 (From Table 2; Gassing rate = high)

Class: A-1
Control Velocity = 150 fpm (From Table 3)

Minimum Exhaust Rate = 225 cfm/ft^2 (From Table 4; Baffled tank, $\frac{W}{L}$ = 0.42)

Minimum Exhaust Volume = 225 × 15 sq ft = 3375 cfm

VENTILATION MEASUREMENTS

Lecture V

Student Test

1. A plant with ten roof exhausters and two make-up air heaters would like to know how much make-up air they are short, so they can order the correct size make-up heater to overcome the negative pressure. Describe a method of measurement to determine the required cfm.

2. Describe where Static Pressure readings should be made in evaluating a local exhaust system with a dust collector.

3. After making measurements at a foundry shake out hood, you find the air flow is approximately 60% of design air flow, state what you would look for as a cause of low air flow.

4. Describe how you would measure air flow at an Anemostat Diffuser. State instrument you would use.

ANSWERS TO TEST

1. Lecture V I-C

2. " III-B-3, 4, 5.

3. " IV-A

4. " I-C-3, -a, b, c, d.

VENTILATION MEASUREMENTS

LECTURE V

PROBLEMS

1. Given:

   Sulfuric Acid Tank 8' x 1.5' for a Steel pickling process using a hot solution, with single slot hood against wall, slot is located on long side of tank. Rate of gassing is high,

   Calculate:

   Minimum exhaust rate cfm/sq. ft.

   Minimum exhaust volume, cfm.

2. A window fan is exhausting 2000 cfm from a room 12 ft. high 20 ft. wide, 40 ft. long. Calculate:

   (a) Air changes per hour

   (b) cfm per sq. ft.

PROBLEMS

Solution:

1. Hazard potential B

   Rate of Evolution 1

   Class B-1

   Minimum Control Velocity 100

   Tank W/L = $\frac{1.5}{8}$ = .19

   Tank against wall

   Minimum Rate 125 cfm per sq. ft.

   Minimum Exhaust Volume 8 x 1.5 x 125 = 1500 cfm

2. Air changes per hour = $\frac{Q \times 60}{P} = \frac{2000 \times 60}{12 \times 20 \times 40} = 12.5$

   cfm per a sq. ft. = $\frac{2000}{20 \times 40} = 2.5$

LABORATORY EXERCISES

VENTILATION MEASUREMENTS

PROCEDURES
DATA SHEETS
PROBLEM SHEETS

Prepared by George M. Hama

LABORATORY EXERCISE I

PROCEDURE

Hood and Duct Air Flow Measurement

OBJECT

1. To become familiar with the use of pitot tube and procedures used to determine average velocity and cfm in a duct.

2. To become familiar with the use of air velocity meters and procedures to determine average hood face velocity, face velocity variations and cfm at a rectangular hood and a round hood openings.

3. To compare accuracy of measurements of several different air meters with pitot tube measurements.

4. To determine ratio of centerline duct velocity to average duct velocity.

THEORY

Continuous air flow through a single fixed system has the same volume rate through all cross sections of flow. Velocity varies with change in area of cross section, according to relationship in the equation.

$$Q\ (\text{cfm}) = A_1V_1 = A_2V_2 = A_3V_3$$

where:

A_1, A_2, A_3, = Area in square ft. at various flow sections

V_1, V_2, V_3, = Corresponding velocity, fpm through sections

Therefore, if hood area is known, and average velocity, velocity can be calculated in connecting duct of known cross sectional area.

Pitot tube measures velocity pressure (VP) in inches of water on inclined or vertical manometer.

For standard air (.075 pounds per cubic ft. density, essentially dry air at 70° F and 29.92" Hg Barometric Pressure) the relationship of velocity (V) fpm to velocity pressure (VP) is: $V = 4005\sqrt{VP}$

Velocity in hood face openings and duct cross sections is non-uniform. A single velocity reading may have considerable variance from average velocity across hood opening. It is necessary, therefore, to divide hood face opening or duct cross section into a number of equal areas and measure velocity in the center of each area. These points are called traverse points.

Where velocity pressure readings are made, the corresponding velocities should be averaged, not the velocity pressures.

For round duct and round hood openings, traverse points are usually selected in the centers of equal concentric areas. Traverse point measurements for most round duct sizes are available from tables. Two traverses 90° apart are made across the diameter of round ducts and round hood openings. The centerline reading for average velocity estimation can be taken in sections where the velocity profile has reached equilibrium, average velocity is 0.9 times centerline reading at this point. The centerline reading should not be averaged with traverse points.

In the case of rectangular openings, areas should be sized so the centers are less than 6" apart and at least 16 traverse points are available.

EQUIPMENT

1. Small pitot tube
2. Inclined manometer
3. Alnor Velometer
4. Alnor thermoanemometer
5. Dwyer air meter
6. Rotating Vane anemometer with rod holder
7. Stop watch
8. Wax pencil and ruler
9. Rectangular hood
10. Round opening hood
11. At least ten diameters of round duct
12. Centrifugal fan
13. Adjustable damper

PROCEDURE

1. Measure duct diameter. Record on Data Sheet 1.
2. Mark 10 point traverse points on pitot tube

3. Level and zero manometer

4. Make 2 - 10 point traverses 90° apart at a point at least 7.5 diameters from hood.

5. Make centerline reading

6. Record readings on Data Sheet 1, calculate velocities and average traverse point readings

7. Divide rectangular hood into 36 equal areas. See Data Sheet 1

8. With each air meter measure velocity at traverse points; average readings - be sure to apply any correction factors. Record readings on Data Sheet 1.

9. With rotating vane anemometer, time each reading one minute

10. Do not obstruct opening with hands, body or clothing during measurements

11. Make pitot traverse after each air meter traverse. Variations in line voltage may vary fan speed and velocity.

12. Remove rectangular hood and replace with round hood

13. Mark off traverse points for round hood. Use Data Sheet 2.

14. Repeat previous procedure for rectangular hood

15. Record pitot traverse on round hood on Data Sheet 3.

CALCULATIONS AND COMPARISON OF DATA

1. For each set of traverses with pitot tube, velocities should be calculated from velocity pressures and averaged.

2. The centerline ratio should be calculated by dividing the centerline velocity by the average duct velocity.

3. The cfm for the duct should be calculated by multiplying duct area by average velocity.

4. Average velocity and cfm for each hood measurement should be similarly calculated.

5. Calculate ± % variation in face velocity.

6. Tabulate cfm measurement made with air meters so that corresponding pitot tube duct readings can be compared on same line.

7. Corresponding pitot readings are the average of the traverses made just before and after each air meter traverse reading.

8. Assuming the pitot readings to be the true cfm measurement, calculate the plus or minus error for each air meter cfm measurement.

LABORATORY EXERCISE I

PROBLEM SHEET

From data obtained in this exercise, calculate the following:

1. Calculate Velocities from Velocity pressures

   $V = 4005\sqrt{VP}$

2. Average velocities (do not include centerline measurement)

   $$\text{av. } V = \sum \frac{(V_1 \quad V_2 \quad V_3 \ldots)}{n}$$

   n = number of traverse readings

3. Cfm from pitot traverse

   Duct Area (A_d) $= \pi R^2$ (calculate area in sq. ft.)

   A_d =

   Q_p (cfm) = AV =

   V = av. Velocity pitot tube

   $$\text{Centerline Ratio} = \frac{\text{Centerline Velocity}}{\text{Av. Velocity}} =$$

4. Hood Traverse

   Hood area = WL Calculate in sq. ft.

   A_H =

   Q_H (cfm) = $A_H \times V$ =

   V = average velocity for each instrument

   Calculate Q_H using average velocity determined by each instrument.

   (Alnor Velometer, Alnor Thermoanemometer, Dwyer air memter, Rotating Van Anemometer)

   Compare with corresponding pitot traverse cfm.

87

5. Accuracy of Instrument

Calculate percent variation. Assume pitot tube readings to be correct and the true readings. Calculate for each instrument percent plus or minus error.

$$\% \pm \text{ error} = \frac{\text{Difference between true cfm and meter cfm}}{\text{true cfm}}$$

Tabulate Data

Meter	Cfm	Pitot Cfm	% ± Error
Velometer			
Thermoanemometer			
Rotating Vane Anemometer			
Dwyer air meter			

6. For each hood face velocity traverse, calculate % variation below average velocity

$$\% \text{ Variation} = \frac{\text{average V - minimum V}}{\text{average V}} \times 100$$

V = velocity measured at hood face.

LABORATORY EXERCISES

DATA SHEET

PITOT TUBE TRAVERSES

Duct Size ______ ______								TEST RESULTS ______				
	(1) Air Temp ______ S.P. ______				(2) Air Temp ______ S.P. ______				(3) Air Temp ______ S.P. ______			
	VP	VEL	VP	VEL	VP	VEL	VP	VEL	VP	VEL	VP	VEL
1	.		.		.		.		.		.	
2	.		.		.		.		.		.	
3	.		.		.		.		.		.	
4	.		.		.		.		.		.	
5	.		.		.		.		.		.	
6	.		.		.		.		.		.	
7	.		.		.		.		.		.	
8	.		.		.		.		.		.	
9	.		.		.		.		.		.	
10	.		.		.		.		.		.	
	Total											
V = Average Velocity												
A = Duct Area												
Q_a = Volume												
Q_s = Volume												

Calculations: Q = AV (Average Velocity × Duct Area)

Q_a = Actual Volume of Air (A cfm)

A = Area (Sq. Ft.)

Duct Size ______ ______								TEST RESULTS ______				
	(1) Air Temp ______ S.P. ______				(2) Air Temp ______ S.P. ______				(3) Air Temp ______ S.P. ______			
	VP	VEL	VP	VEL	VP	VEL	VP	VEL	VP	VEL	VP	VEL
1	.		.		.		.		.		.	
2	.		.		.		.		.		.	
3	.		.		.		.		.		.	
4	.		.		.		.		.		.	
5	.		.		.		.		.		.	
6	.		.		.		.		.		.	
7	.		.		.		.		.		.	
8	.		.		.		.		.		.	
9	.		.		.		.		.		.	
10	.		.		.		.		.		.	
	Total											
V = Average Velocity												
A = Duct Area												
Q_a = Volume												
Q_s = Volume												

Calculations: Q = AV (Average Velocity × Duct Area)

Q_a = Actual Volume of Air (A cfm)

A = Area (Sq. Ft.)

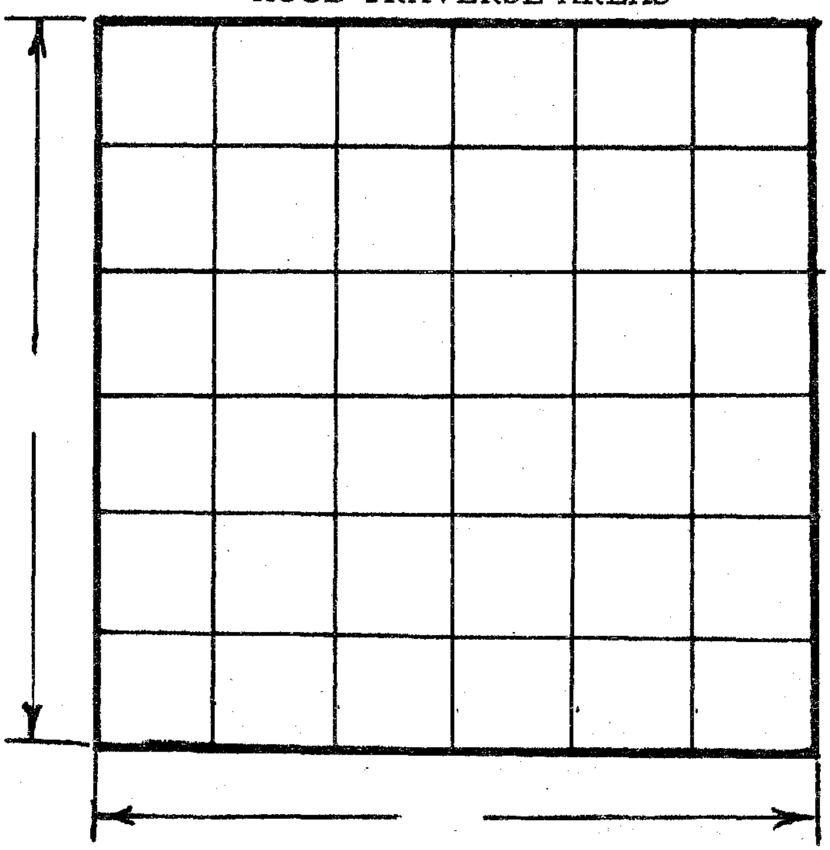
LABORATORY EXERCISE I
DATA SHEET

PITOT DUCT TRAVERSE

Duct Size ______ ______			TEST RESULTS									
	(1) Air Temp ______ S.P. ______				(2) Air Temp ______ S.P. ______				(3) Air Temp ______ S.P. ______			
	VP	VEL	VP	VEL	VP	VEL	VP	VEL	VP	VEL	VP	VEL
1	.		.		.		.		.		.	
2	.		.		.		.		.		.	
3	.		.		.		.		.		.	
4	.		.		.		.		.		.	
5	.		.		.		.		.		.	
6	.		.		.		.		.		.	
7	.		.		.		.		.		.	
8	.		.		.		.		.		.	
9	.		.		.		.		.		.	
10	.		.		.		.		.		.	
	Total											
V = Average Velocity												
A = Duct Area												
Q_a = Volume												
Q_s = Volume												

Calculations: Q = AV (Average Velocity × Duct Area) V = Average Vel

HOOD TRAVERSE AREAS



VELOCITIES fpm

LABORATORY EXERCISE I

DATA SHEET

ROUND HOOD OPENING

TRAVERSE READINGS

	Velometer				Dwyer Air Meter				Thermoanemometer			
	VP	**VEL**	**VP**	**VEL**	**VP**	**VEL**	**VP**	**VEL**	**VP**	**VEL**	**VP**	**VEL**
1	.		.		.		.		.		.	
2	.		.		.		.		.		.	
3	.		.		.		.		.		.	
4	.		.		.		.		.		.	
5	.		.		.		.		.		.	
6	.		.		.		.		.		.	
7	.		.		.		.		.		.	
8	.		.		.		.		.		.	
9	.		.		.		.		.		.	
10	.		.		.		.		.		.	
	Total											
V = Average Velocity												
A = Duct Area												
Q_a = Volume												
Q_s = Volume												

Calculations: Q = AV (Average Velocity × Duct Area)

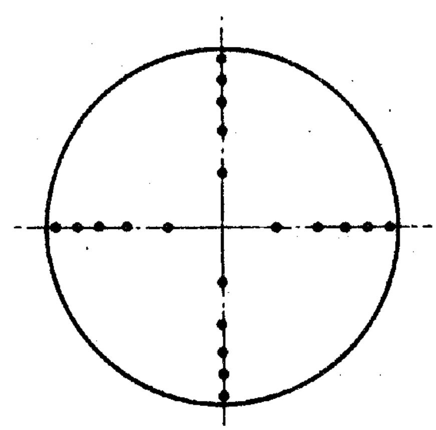
Q_a = Actual Volume of Air (A cfm)

A = Area (Sq. Ft.)

DISTANCE FROM WALL OF ROUND PIPE TO POINT OF READING (NEAREST 1/8 INCH) FOR 10-POINT TRAVERSE.

DUCT DIA	R_1 0.026 DIA	R_2 0.082 DIA	R_3 0.146 DIA	R_4 0.226 DIA	R_5 0.342 DIA	R_6 0.658 DIA	R_7 0.774 DIA	R_8 0.854 DIA	R_9 0.918 DIA	R_{10} 0.974 DIA
4	1/8	3/8	5/8	7/8	1 3/8	2 5/8	3 1/8	3 3/8	3 5/8	3 7/8
4 1/2	1/8	3/8	5/8	1	1 1/2	3	3 1/2	3 7/8	4 1/8	4 3/8
5	1/8	3/8	3/4	1 1/8	1 3/4	3 1/4	3 7/8	4 1/4	4 5/8	4 7/8
5 1/2	1/8	1/2	3/4	1 1/4	1 7/8	3 5/8	4 1/4	4 3/4	5	5 3/8
6	1/8	1/2	7/8	1 3/8	2	4	4 5/8	5 1/8	5 1/2	5 7/8
7	1/8	5/8	1	1 5/8	2 3/8	4 5/8	5 3/8	6	6 3/8	6 7/8
8	1/4	5/8	1 1/8	1 3/4	2 3/4	5 1/4	6 1/4	6 7/8	7 3/8	7 3/4
9	1/4	3/4	1 1/4	2	3 1/8	5 7/8	7	7 3/4	8 1/4	8 3/4
10	1/4	7/8	1 1/2	2 1/4	3 3/8	6 5/8	7 3/4	8 1/2	9 1/8	9 3/4
11	1/4	7/8	1 5/8	2 1/2	3 3/4	7 1/4	8 1/2	9 3/8	10 1/8	10 3/4
12	3/8	1	1 3/4	2 3/4	4 1/8	7 7/8	9 1/4	10 1/4	11	11 5/8
13	3/8	1	1 7/8	2 7/8	4 1/2	8 1/2	10 1/8	11 1/8	12	12 5/8
14	3/8	1 1/8	2	3 1/8	4 3/4	9 1/4	10 7/8	12	12 7/8	13 5/8
15	3/8	1 1/4	2 1/4	3 3/8	5 1/8	9 7/8	11 5/8	12 3/4	13 3/4	14 5/8
16	3/8	1 1/4	2 3/8	3 5/8	5 1/2	10 1/2	12 3/8	13 5/8	14 3/4	15 5/8

TRAVERSE POINTS



Pitot traverse points in a circular duct. 10 or 20 locations in centers of equal annular area.*

** 6 or 12 locations for small ducts*

LABORATORY EXERCISE II

PROCEDURE

To determine hood flow contours for a round hood and a slot hood

OBJECT

1. To determine flow contours of

    (a) Round hood under suction
    (b) Slot hood under suction

2. To compare measurements of velocity at various centerline distances from a round hood and a slot hood with their equations of flow.

THEORY

Air moves in all directions towards openings under suction. By definition, flow contours are lines of equal velocity in front of a hood. Similarly, streamlines are lines perpendicular to velocity contours which indicate direction of flow. The equation of flow before free hanging round hoods, and rectangular hood which are essentially square has been determined empirically, and is

$$V = \frac{Q}{10\,x^2 + A}$$

where:

V = Centerline velocity at X distance from hood, fpm

X = Distance outward along axis in ft.

Q = Air flow, cfm

A = Area of hood opening in square feet

The equation of flow before free hanging slot hoods (Width/Length ratio .2 or less) is: $Q = 3.7\ LVX$

where:

V = Centerline velocity X distance from hood, perpendicular to hood opening, fpm.

L = Length of slot in ft.

X = Distance outward, perpendicular to slot opening in ft.

EQUIPMENT

1. Small pitot tube
2. Inclined manometer
3. Alnor thermoanemometer
4. Wax pencil
5. Ruler
6. Rectilinear graph paper (20 x 20 to inch)
7. Round hood opening
8. Slot hood opening
9. Wire frame grid with wires at 0", 2", 6", 8", 10", 12", 14", horizontal and 0", 2", 4", 6", 12", up from centerline. One for slot hood, one for round hood
10. Fan connected to hood with at least 10 diameters of round duct.

PROCEDURE

1. Place round hood checking grid on fan duct fan system
2. Hoods and equipment must be located in a draft free area; doors and windows must be closed.
3. Determine cfm going thru duct with 2-10 point pitot tube traverses. Record on data sheet.
4. With Alnor thermoanemometer measure velocities at points indicated on cross wire on grill 0", 2", 4", 6", 8", 10", 12" and 14 inches out along centerline, and repeat readings at 2", 4", 6", 10", and 12" up from centerline. Record in exact position on data sheet.
5. Measurement must be taken in quiet air, walking and body movements will disturb air flow. Care must be taken not to obstruct air flow with body or hands.

PROCESSING DATA AND CALCULATIONS

1. Separate calculations and graphical plots should be made for the round hoods and for the slot hoods.

2. From pitot traverses of duct, calculate average velocity at face of hood.

3. Calculate all meter reading taken before hood in percent of average velocity at face of hood opening.

4. Prepare graph paper for plotting by marking percent (between 0 to 100%) velocity as ordinate and distance from opening in inches as abscissae.

5. Plot separate curves as shown in example for reading at 0", 2", 4", 6", 8", 10", 12" up from centerline axis on graph paper prepared.

6. Make final plot of contour lines by plotting point of equal velocity taken from previously made graph with inches up from centerline as ordinate and inches out from hood as abscissae. Each point of equal velocity should be plotted in its exact position up from centerline and out from hood and connected to make an equal velocity contour.

7. Streamlines can be sketched in by connecting points at which the streamline will be perpendicular to the contour lines at all points.

8. It should be noted from velocity measurement and contours how rapidly the velocity falls off a very short distance from the hood opening.

9. Calculate velocity at 2", 4", 6", 8", 10", and 14" out from hood using equations of flow for round or rectangular hood and slot hood.

10. Summarize and tabulate results using 4 columns, distance, inches from hood, measured velocity, calculated velocity and percent difference.

LABORATORY EXERCISE II

PROBLEM SHEET

1. Solve for Q

$Q = AV =$

$A = 3.1416\ R^2$ R = Radius in ft.

2. Solve for V From Equation

Where:

$X = 2'' = \frac{2}{12} =$

$$V = \frac{Q}{10\ X^2 + A}$$

$X = 4'' =$

and for slot hood

$X = 6'' =$

$X = 8'' =$

$$V = \frac{Q}{3.7\ LX}$$

$X = 10'' =$

$X = 12'' =$

$X = 14'' \doteq$

X inches	V calculated	V measured	% diff.
2"			
4"			
6"			
8"			
10"			
12"			
14"			

3. Calculate all meter reading taken before hood in percent of average velocity at face of hood opening.

4. Prepare graph paper for plotting by marking percent (between 0 to 100%) velocity as ordinate and distance from opening in inches as abscissa.

5. Plot separate curves as shown in example for reading at 0", 2", 4", 6", 8", 10", 12" up from centerline axis on graph paper prepared.

6. Make final plot of a half section of contour lines by plotting point of equal velocity taken from previously made graph with inches up from centerline as ordinate and inches out from hood as abscissa. Each point of equal velocity should be plotted in its exact position up from centerline and out from hood and connected to make an equal velocity contour.

7. Streamlines can be sketched in by connecting points at which the streamline will be perpendicular to the contour lines at all points.

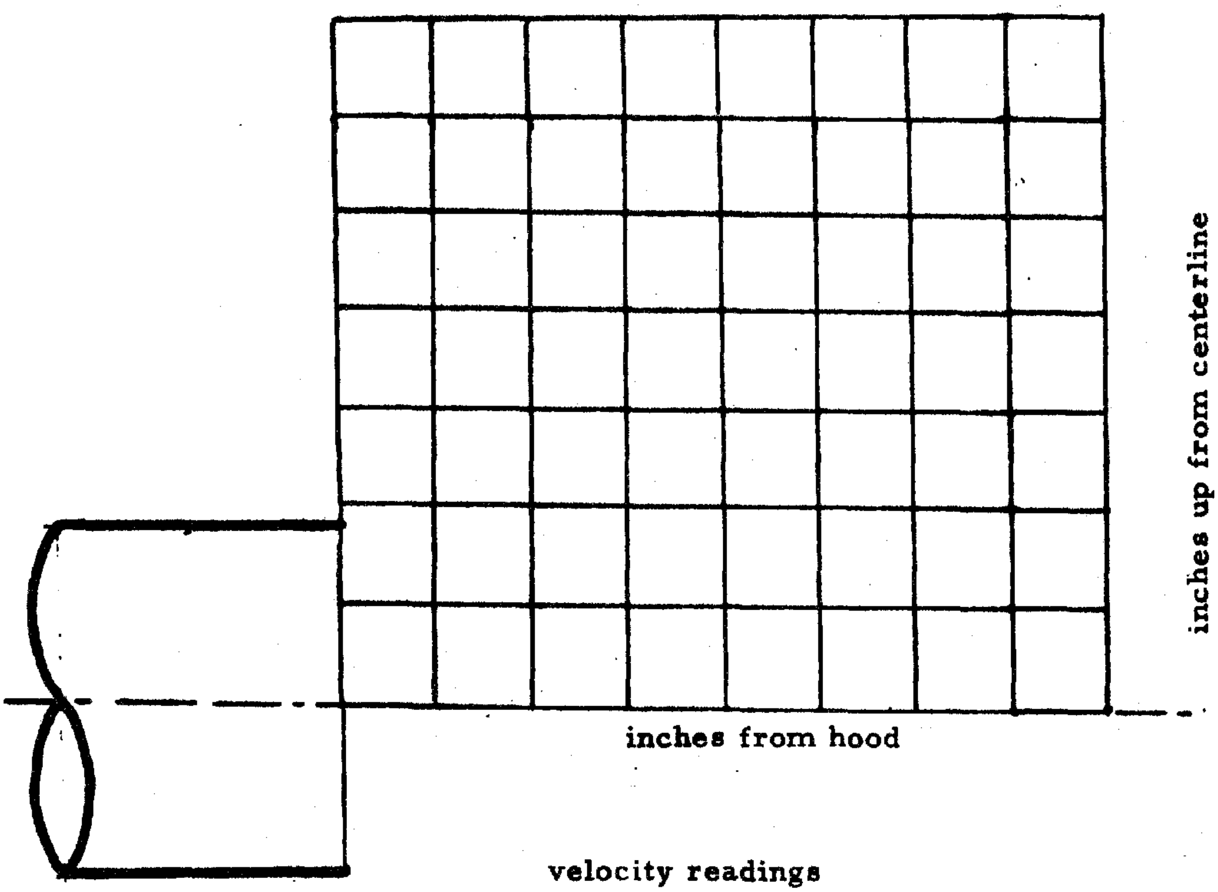
LABORATORY EXERCISE II

LABORATORY DATA SHEET

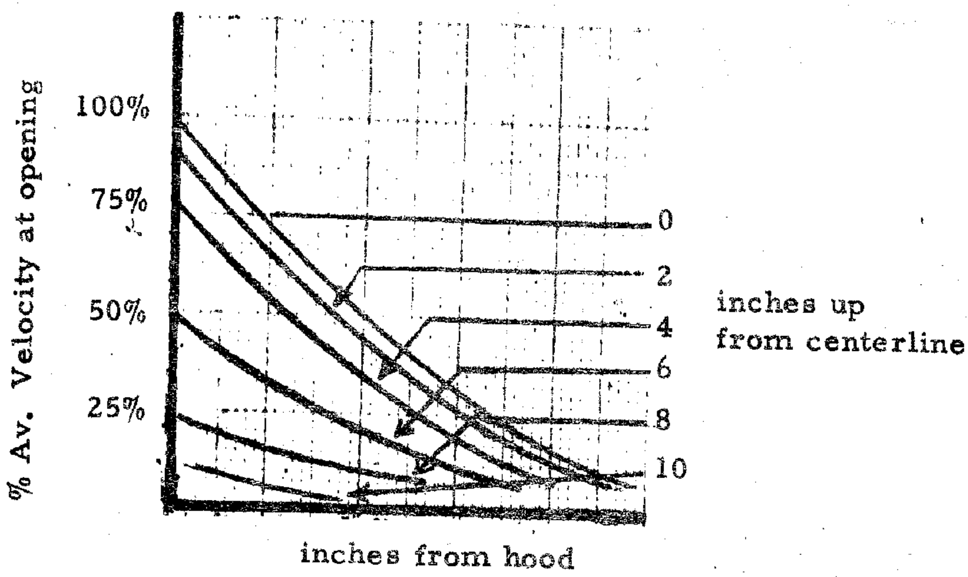
PITOT DUCT TRAVERSE

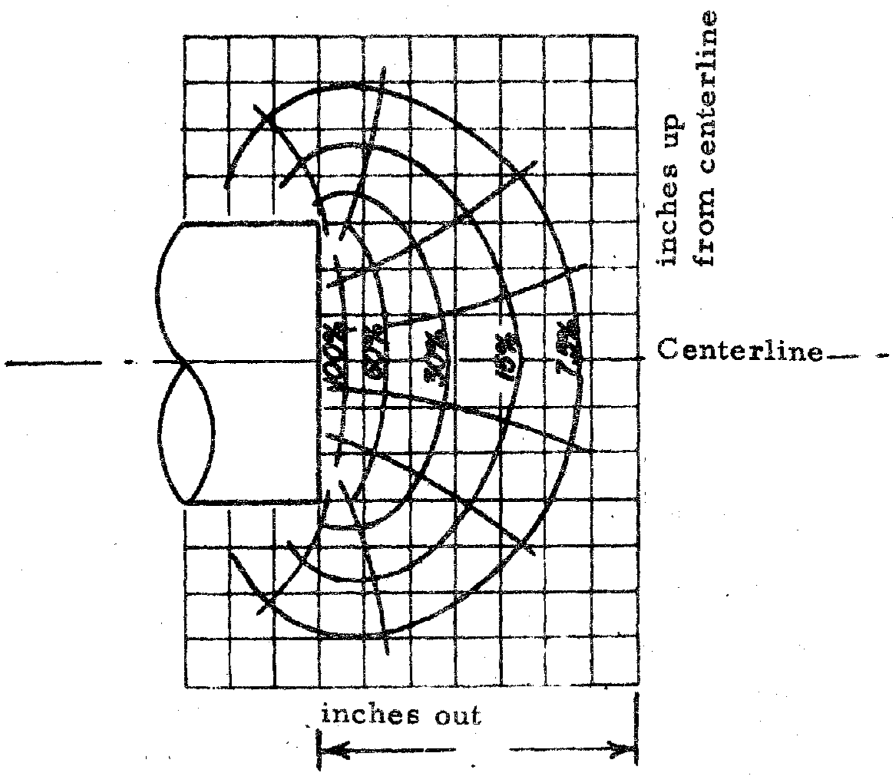
Duct Size						TEST RESULTS						
	(1) Air Temp		S.P.		(2) Air Temp		S.P.		(3) Air Temp		S.P.	
	VP	VEL	VP	VEL	VP	VEL	VP	VEL	VP	VEL	VP	VEL
1	.		.		.		.		.		.	
2	.		.		.		.		.		.	
3	.		.		.		.		.		.	
4	.		.		.		.		.		.	
5	.		.		.		.		.		.	
6	.		.		.		.		.		.	
7	.		.		.		.		.		.	
8	.		.		.		.		.		.	
9	.		.		.		.		.		.	
10	.		.		.		.		.		.	
	Total											
V = Average Velocity												
A = Duct Area												

GRID TRAVERSE V

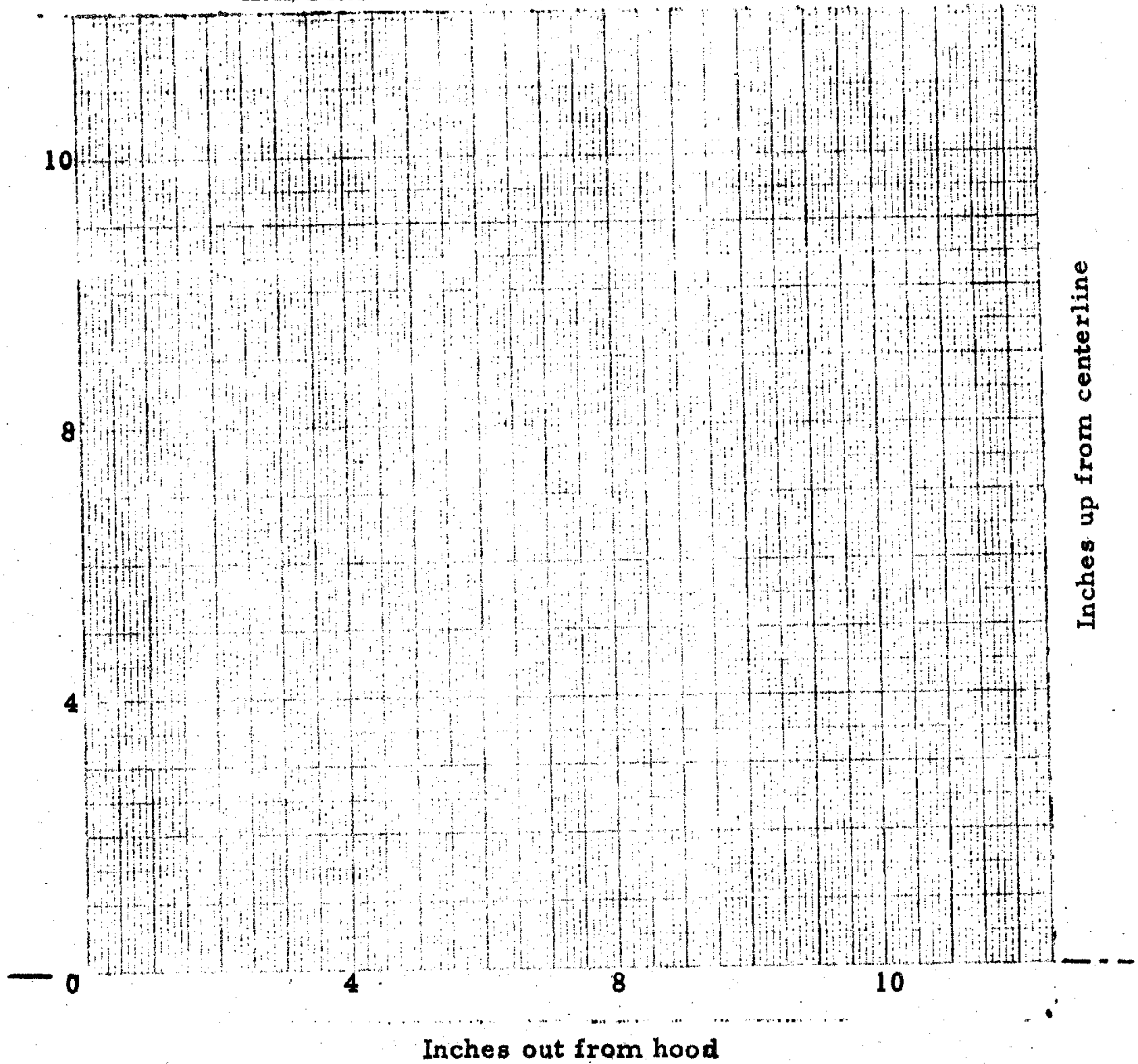


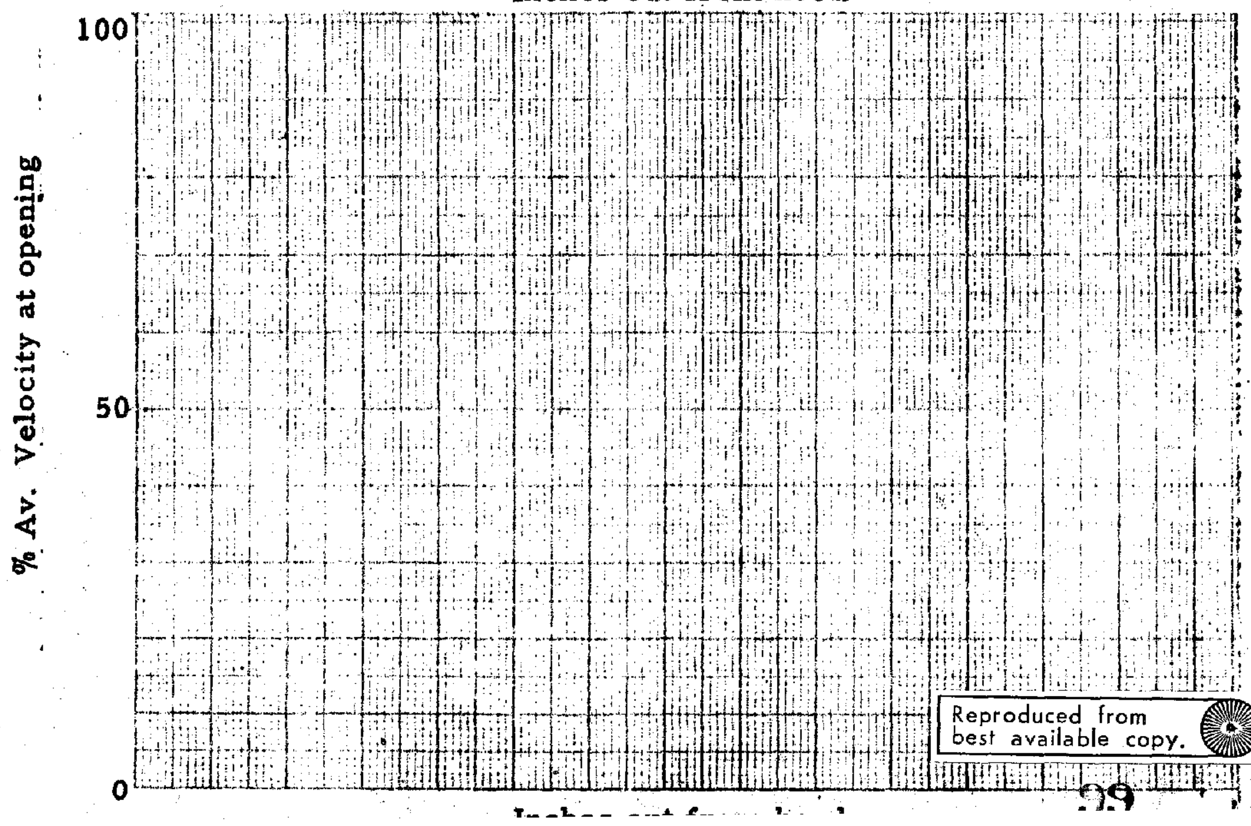
velocity readings


100%
75%
50%
25%
% Av. Velocity at opening
0
2
4
6
8
10
inches up
from centerline
inches from hood


inches up
from centerline
Centerline
inches out

LABORATORY EXERCISE II DATA SHEET





LABORATORY EXERCISE III

PROCEDURE

DETERMINATION OF HOOD ENTRY LOSSES

OBJECT

1. To determine entry losses for several different hood shapes. These losses include coefficient of entry (C_e), hood entry loss (h_e) and hood static pressure.

2. To measure static pressure by several different methods, (1) external static pressure by measurement with a liquid manometer, (2) external static pressure with a Velometer probe and (3) static pressure using a pitot tube within the duct.

THEORY

Air entering a duct, or hood comes from all directions and converges in the duct a short distance from the entry so that a contracted air stream or vena contracta is formed. As the air continues to flow into the duct the air stream expands and fills the duct. The contraction requires the conversion of SP to VP, the expansion involves the conversion of VP to SP, in these exchanges there is some pressure loss which cannot be recovered. The shape of the hood affects the loss. The greatest loss is a sharp edged orifice loss. Other hood losses decrease successively as follows: plain duct openings, flanged openings, tapered openings and streamline bell shaped openings.

Hood SP includes VP, the pressure necessary to accelerate the air from rest to duct velocity and hood entry loss, h_e, the pressure necessary to overcome losses of air entering the hood. This is expressed as, in equation form:

$$SP = VP + h_e$$

h_e can be expressed in terms of a factor F times VP, in equation form:

$$h_e = FVP$$

F depends on hood shape

The coefficient of entry (C_e) indicates decreased flow from air entry loss. C_e is defined as the ratio of actual rate of flow from a given static pressure to theoretical flow if the static pressure could convert to velocity pressure with 100% efficiency.

100

Equation is:

$$C_e = \sqrt{\frac{VP}{SP}}$$

The coefficient of entry (C_e) and the hood entry loss (h_e) can be determined by measuring the air flowing through hood and at the same time measuring the static pressure at the duct connection to the hood.

Because of the high turbulence at the hood connection to the duct, the measurement is made a short distance from the duct connection. A correction is made for friction in the short duct.

Static pressure can be measured with a pitot tube within the duct by using only the static pressure connection to the pitot tube.

Static pressure can also be measured with the static pressure probes on an Alnor Velometer. The Velometer requires a hole 1/4" or larger in diameter. The Dwyer Air meter can measure static pressure in a limited range up to 1"wg. These devices are not as reliable as inclined liquid manometers which have no moving parts or mechanisms to get out of order.

To get accurate results using a liquid manometer 4 small holes should be used as measurement point 90° apart. The holes should be preferably as small as 1/16" diameter and drilled clean so there are no burrs or projections present. A punched hole is not satisfactory.

EQUIPMENT

1. Small pitot tube
2. Inclined - vertical manometer
3. Rubber tubing
4. Duct tape
5. Alnor Velometer
6. Plain duct opening hood
7. Flanged duct opening hood
8. Tapered duct opening hood
9. Slot hood
10. Ruler

PROCEDURE

1. There are several hood shapes to be checked; follow the same procedure for each hood with the exception that the slot hood requires additional measurements. Each hood is checked separately by connecting to fan system.

2. At a position three diameters from the hood, drill 4 holes 90° apart with a 1/16" diameter drill. The drill should be run in the hole to clear it of burrs and projections.

3. At the same in-line position, drill four 1/4" holes 90° apart, 45° off from the 1/16" holes, so that on the circumference of the duct there are 8 holes 45° apart, alternately a 1/4" hole and 1/16" hole. The holes should be covered with duct tape when not in use. When measuring SP, only the hole measured should be uncovered.

4. Measure round duct diameter.

5. Measure air flow in duct with two pitot tube traverses 90° apart at least 7.5 diameters downstream from the hood. Calculate average velocity. Each hood measured requires a separate pitot tube measurement in the duct.

6. Level and zero liquid manometer. Connect rubber tubing to right port, wet tip of the other end of the rubber tubing and press it firmly over the 1/16" hole so a positive seal is made, at the same time noting and recording the reading on the manometer. Measure all 4 holes and average readings.

7. Connect small pitot tube static pressure connection to rubber tubing and manometer. The static pressure connection is at right angles to the long tube. Make static pressure readings by traversing duct at this point. The 1/4" hole will admit the small pitot tube. Manometer should be leveled and zero'd. Traverse in 2 holes 90° apart.

8. Connect static pressure probe to Alnor Velometer, press rubber cup over 1/4" hole so a positive seal is made, record reading. Make readings at all 4 holes, and average readings.

9. On slot hood measure length and width of slot opening so area of opening in square ft. can be obtained.

10. Measure slot velocity with Alnor Velometer by dividing slot into equal areas and measuring the velocity in the center of each area.

11. Measure length and width of taper both on the slot hood and on the tapered hood so the included angle of taper can be calculated.

12. Measure distance from static pressure holes to hood. Record measurement in feet.

LABORATORY EXERCISE III

PROBLEM SHEET

1. Calculate average velocity going into duct. From average velocity, calculate corresponding velocity pressure.

2. Average the four static pressure measurements made by each method. Tabulate results so they can be compared.

3. Correct static pressure for friction loss in duct. From average fpm measured and duct size obtain friction loss in inches of water per 100 ft. from duct friction chart.

   Get friction loss in distance (d) in ft. from SP holes to hood using equation:

   $$\frac{d}{100} \times \text{friction loss per 100 ft.} = \text{loss for (d) ft. "wg}$$

   Subtract this loss from measured SP

   $$SP - \left[\frac{d}{100} \times (\text{friction per 100 ft.})\right] = \text{Corrected } SP_c$$

   SP_c is static pressure of hood only

4. Calculate coefficient of entry, C_e, for each hood type

   $$C_e = \sqrt{\frac{VP}{SP_c}}$$

5. Calculate hood entry loss, h_e, for each hood type

   $$h_e = SP_c - VP$$

6. Calculate F factor for each hood type

   $$h_e = FVP$$

7. Calculate SP loss for slot hood

Equation for sharp edged slot loss (h_e) and tapered transition hood to duct

h_e = 1.78 slot VP + F duct VP

slot VP = Velocity pressure corresponding to average slot velocity

F = decimal factor depending on angle of transition, as follows:

For 45° F = .15

For 90° F = .25

For 180° F = .65

VP = Velocity Pressure corresponding to average duct velocity

Slot hood SP is: SP = 1.78 slot VP + F duct VP + VP

Calculate angle of transition from measurements on taper, estimate F.

Calculate slot hood SP

Compare calculation with measured SP on slot hood.

104

LABORATORY EXERCISES

DATA SHEET

PITOT TUBE TRAVERSES

Duct Size ____________ ____________ TEST RESULTS ____________

	(1) Air Temp ______ S.P. ______				(2) Air Temp ______ S.P. ______				(3) Air Temp ______ S.P. ______			
	VP	VEL	VP	VEL	VP	VEL	VP	VEL	VP	VEL	VP	VEL
1	.		.		.		.		.		.	
2	.		.		.		.		.		.	
3	.		.		.		.		.		.	
4	.		.		.		.		.		.	
5	.		.		.		.		.		.	
6	.		.		.		.		.		.	
7	.		.		.		.		.		.	
8	.		.		.		.		.		.	
9	.		.		.		.		.		.	
10	.		.		.		.		.		.	
	Total											
V = Average Velocity												
A = Duct Area												
Q_a = Volume												
Q_s = Volume												

Calculations: Q = AV (Average Velocity × Duct Area)

Q_s = Actual Volume of Air (A cfm)

A = Area (Sq. Ft.)

Duct Size ____________ ____________ TEST RESULTS ____________

	(1) Air Temp ______ S.P. ______				(2) Air Temp ______ S.P. ______				(3) Air Temp ______ S.P. ______			
	VP	VEL	VP	VEL	VP	VEL	VP	VEL	VP	VEL	VP	VEL
1	.		.		.		.		.		.	
2	.		.		.		.		.		.	
3	.		.		.		.		.		.	
4	.		.		.		.		.		.	
5	.		.		.		.		.		.	
6	.		.		.		.		.		.	
7	.		.		.		.		.		.	
8	.		.		.		.		.		.	
9	.		.		.		.		.		.	
10	.		.		.		.		.		.	
	Total											
V = Average Velocity												
A = Duct Area												
Q_a = Volume												
Q_s = Volume												

Calculations: Q = AV (Average Velocity × Duct Area)

Q_s = Actual Volume of Air (A cfm)

A = Area (Sq. Ft.)

LABORATORY EXERCISE III

DATA SHEET

TYPE OF HOOD	SP "wg Exterior Holes	Velom.	Pitot	Friction Loss "wg	Net SP SP-Friction Loss	VP	C_e	h_e	F
PLAIN DUCT									
OPENING									
Average									
FLANGED									
OPENING									
Average									
TAPERED									
HOOD									
Average									
SLOT									
HOOD									
A[illegible]ge									

LABORATORY EXERCISE IV

PROCEDURE

MEASUREMENTS ON A LOCAL EXHAUST SYSTEM

OBJECT

To measure and evaluate a local exhaust system.

To determine required capture velocity and maximum effective control distance of an exterior slot hood.

To determine and become familiar with pressure losses in a local exhaust system.

To understand the relationship of pressure and air flow and to calculate and plot a system curve for a local exhaust system.

To determine loss factors for

(a) 90° sharp turn miter elbow

(b) 90° long radius elbow

EQUIPMENT

1. Smoke tube
2. Rule
3. Thermoanemometer
4. Velometer
5. Inclined-vertical manometer
6. Pitot tube
7. Local exhaust system

   (a) Slot hood

   (b) Ductwork

   (c) 1 - 90° mitered elbow "O" radius of curvature

(d) 1 - 90° Elbow 2-D radius of curvature

(e) Centrifugal fan

(f) Ductwork and damper on discharge side of fan

8. Small table or flat surface (2' x 2') or larger can be placed against slot opening. The surface should be at same level as bottom of slot.

9. Smoke tubes and squeeze bulb.

THEORY

Capture velocity for an exterior hood is the velocity at a point in front of the hood, which overcomes opposing air currents and captures the contaminated air and causes it to flow into the hood.

A point at the maximum distance away where satisfactory control is just effected is the maximum effective working distance of the hood. This can be determined by a visual observation with smoke.

The air velocity at the maximum distance from the hood where control is just effected is the capture velocity.

A system curve represents points of performance of a local exhaust system under all operational conditions of pressure and air flow.

The system pressure is plotted against system cfm. If one point of performance is known, that is the point where measured values of cfm and SP are obtained, the system curve can be drawn. Points for the curve can be calculated by assuming values for cfm and solving for SP according to the equation:

$$SP_2 = \frac{cfm_2^2}{cfm_1^2} \times SP_1$$

where:

cfm_1 is known air flow

SP_1 is known static pressure

108

Static pressure at the hood taken at the same time as the cfm measurement is made can in a clean hood system be used as a quick check of the air flow. Variations in the SP can be used to estimate variations in cfm in the equation:

$$\frac{cfm_2}{cfm_1} = \sqrt{\frac{SP_2}{SP_1}}$$

If SP_1 and cfm_1 are initial measurements and SP_2 is a different reading made at a later date, cfm_2 can be determined from the equation:

$$cfm_2 = cfm_1 \sqrt{\frac{SP_2}{SP_1}}$$

The intersection of the system curve and the fan pressure-volume curve is the point where the system will operate.

Air moving in a duct downstream towards the fan will be marked by increasing static and total pressure. The pressure represents the energy required to overcome the upstream resistance. This resistance includes entrance of air into hood, frictional resistance of ductwork, turning losses in elbows and other losses.

Air moving from outlet of fan into discharge duct and stack is marked by a decreasing static and total pressure in direction of fan to outlet. The pressure represents the energy required to overcome the duct frictional and dynamic losses from the fan or point of measurement to the outlet discharge.

Air passing through an elbow is marked by losses and flow disturbances in the region of the elbow throat. The loss is greatest with sharp turn elbows and lowest in long radius of curvature elbows, (up to 2.5 diameter radius of curvature). Elbow losses are expressed in terms of a factor multiplied by velocity pressure. The loss factor can be determined if the static pressure drop across the elbow is known and the velocity of the air flowing through the elbow.

PROCEDURE

1. TO EVALUATE SLOT HOOD

Measure open slot area. Divide slot into equal areas so a traverse can be made. Traverse opening with a velometer probe. Record on Data Sheet 1. Calculate average velocity and cfm. Calculate variance in velocity.

With a smoke tube, puff smoke along flat surface in front of hood and note if definite capture of smoke takes place. Gradually increase distance of smoke puffs from slot until complete capture does not take place. Move into the range where complete definite capture just takes place. Measure the distance to the hood and mark the point or points. Record distance in ft. This will be the working range of the hood for quiet operations. With the thermoanemometer measure the velocity at the point marked. Record velocity. This will be the required capture velocity for the space air movement conditions.

2. TO MEASURE PRESSURE LOSSES FOR ELBOWS, HOOD AND FAN

A. Drill four 1/16" diameter holes 90° apart at the following positions:

1. In duct 1 1/2 diameters from entrance into hood transition
2. At a point just before long radius elbow
3. At a point just after long radius elbow
4. At a point just before "O" radius of curvature mitered elbow
5. At a point 1 1/2 diameters after mitered elbow
6. At a point 1 1/2 diameters before fan inlet opening
7. At a point 1 1/2 diameters after the fan discharge opening.

B. Run fan at a fixed damper setting

1. Measure air flow with 2-90° duct pitot tube traverses. Obtain and compute average velocity and cfm. Record on Data Sheet 3.
2. Measure static pressure with manometer and rubber tubing at points where 1/16" holes were drilled. Average readings at each measurement location.
3. Record readings on Data Sheet 1.

3. FOR SYSTEM CURVE AND HOOD SP

A. Change damper setting

1. Measure air flow with pitot tube traverse. Record on Data Sheet 3.
2. Re-check static pressures at hood, fan inlet and fan outlet
3. Record readings on Data Sheet 1

4. Calculate system curve. See Problem Sheet item 2. Plot on Data Sheet 2.

5. Plot Graphical representation of pressures in systems on Data Sheet 2.

111

LABORATORY EXERCISE IV

PROBLEM SHEET

1. SLOT HOOD EVALUATION

Using the equation for a flanged exterior slot calculate capture velocity (V) from measured cfm and range of hood distance obtained experimentally. Flange slot equation is: $V = 2.8 \ LXV$

where:

$V =$ Capture velocity, fpm, at distance X

$X =$ Distance, feet, furthest point of control

$L =$ Length, feet, of slot

Compare with slot velocity measured.

2. SYSTEM CURVE CALCULATION

In a fixed local exhaust system, SP and TP at same point in system vary as volume rate, Q and velocity V squared.

$$\frac{SP_1}{SP_2} = \frac{Q_1^2}{Q_2^2}$$

Calculate a series of points for curve by assuming values for cfm and solving for SP using equation:

$$SP_2 = \frac{cfm_2^2}{cfm_1^2} \times SP_1$$

where:

cfm_1 is measured flow (cfm)

SP_1 is measured SP

Plot system curve on Data Sheet 2, use Fan inlet and outlet SP as ordinate and cfm as abscissa.

112

From two different measurements of cfm and Fan inlet and outlet SP from different damper settings compare measurements with system curve.

3. GRAPHICAL REPRESENTATION OF PRESSURES IN SYSTEM

Average each set of SP's measured. Calculate TP at each point of SP measurement. The duct velocity measured can be used to obtain corresponding VP. From VP and SP, TP can be calculated.

Equation $TP = VP + SP$

Graphically represent pressures in system at relative position of each dynamic or friction loss in system starting with hood and finishing with stack discharge. Plot cumulative pressures in inches wg as ordinate, relative positions in line of flow in system as abscissa. Use Data Sheet 3.

4. ELBOW LOSS FACTOR

Calculate the difference in SP measurements before and after each elbow to obtain the pressure loss in the elbow. The VP of average velocity flow through elbow has been computed. The loss factor, F, can be computed for each elbow from the equation:

$$SP_e = F\ VP$$

where:

SP_e is SP pressure loss in elbow. Compare with book values for each elbow.

Book values are:

O Radius mitered elbow = 1. VP

1.5 Diameters centerline radius elbow 0.39 VP

2. " " " " 0.27 VP

2.5 " " " " 0.22 VP

Record F factors and elbow data on Data Sheet 1.

113

LABORATORY EXERCISES

DATA SHEET

PITOT TUBE TRAVERSES

Duct Size					TEST RESULTS							
	(1) Air Temp ______ S.P. ______				(2) Air Temp ______ S.P. ______				(3) Air Temp ______ S.P. ______			
	VP	VEL	VP	VEL	VP	VEL	VP	VEL	VP	VEL	VP	VEL
1	.		.		.		.		.		.	
2	.		.		.		.		.		.	
3	.		.		.		.		.		.	
4	.		.		.		.		.		.	
5	.		.		.		.		.		.	
6	.		.		.		.		.		.	
7	.		.		.		.		.		.	
8	.		.		.		.		.		.	
9	.		.		.		.		.		.	
10	.		.		.		.		.		.	
	Total											
V = Average Velocity												
A = Duct Area												
Q_a = Volume												
Q_s = Volume												

Calculations: Q = AV (Average Velocity × Duct Area)

Q_a = Actual Volume of Air (A cfm)

A = Area (Sq. Ft.)

Duct Size					TEST RESULTS							
	(1) Air Temp ______ S.P. ______				(2) Air Temp ______ S.P. ______				(3) Air Temp ______ S.P. ______			
	VP	VEL	VP	VEL	VP	VEL	VP	VEL	VP	VEL	VP	VEL
1	.		.		.		.		.		.	
2	.		.		.		.		.		.	
3	.		.		.		.		.		.	
4	.		.		.		.		.		.	
5	.		.		.		.		.		.	
6	.		.		.		.		.		.	
7	.		.		.		.		.		.	
8	.		.		.		.		.		.	
9	.		.		.		.		.		.	
10	.		.		.		.		.		.	
	Total											
V = Average Velocity												
A = Duct Area												
Q_a = Volume												
Q_s = Volume												

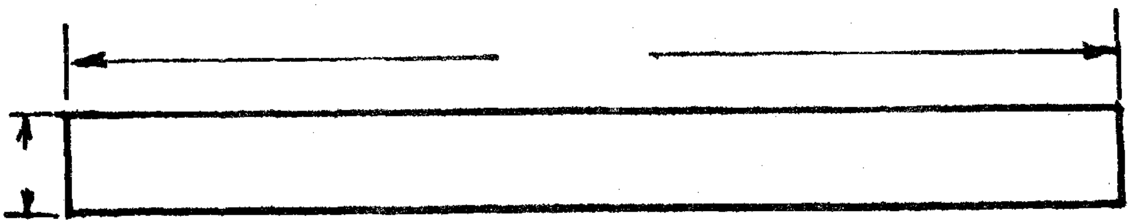
Calculations: Q = AV (Average Velocity × Duct Area)

Q_a = Actual Volume of Air (A cfm)

A = Area (Sq. Ft.)

LABORATORY EXERCISE IV

DATA SHEET



TRAVERSE AREAS FOR SLOT
SLOT VELOCITIES

Run 1

Hood SP	VP	Fan Inlet SP	Fan Outlet SP
Av.			

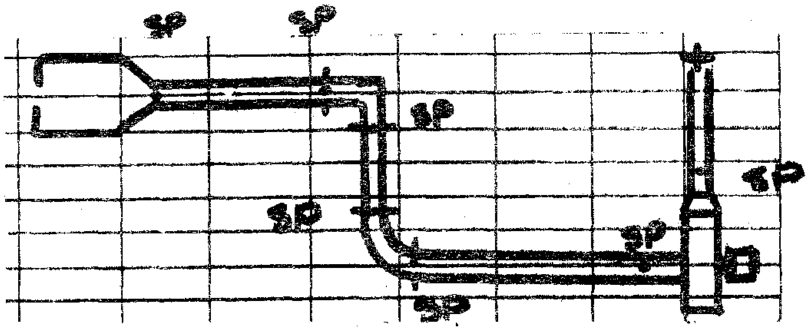
Run 2

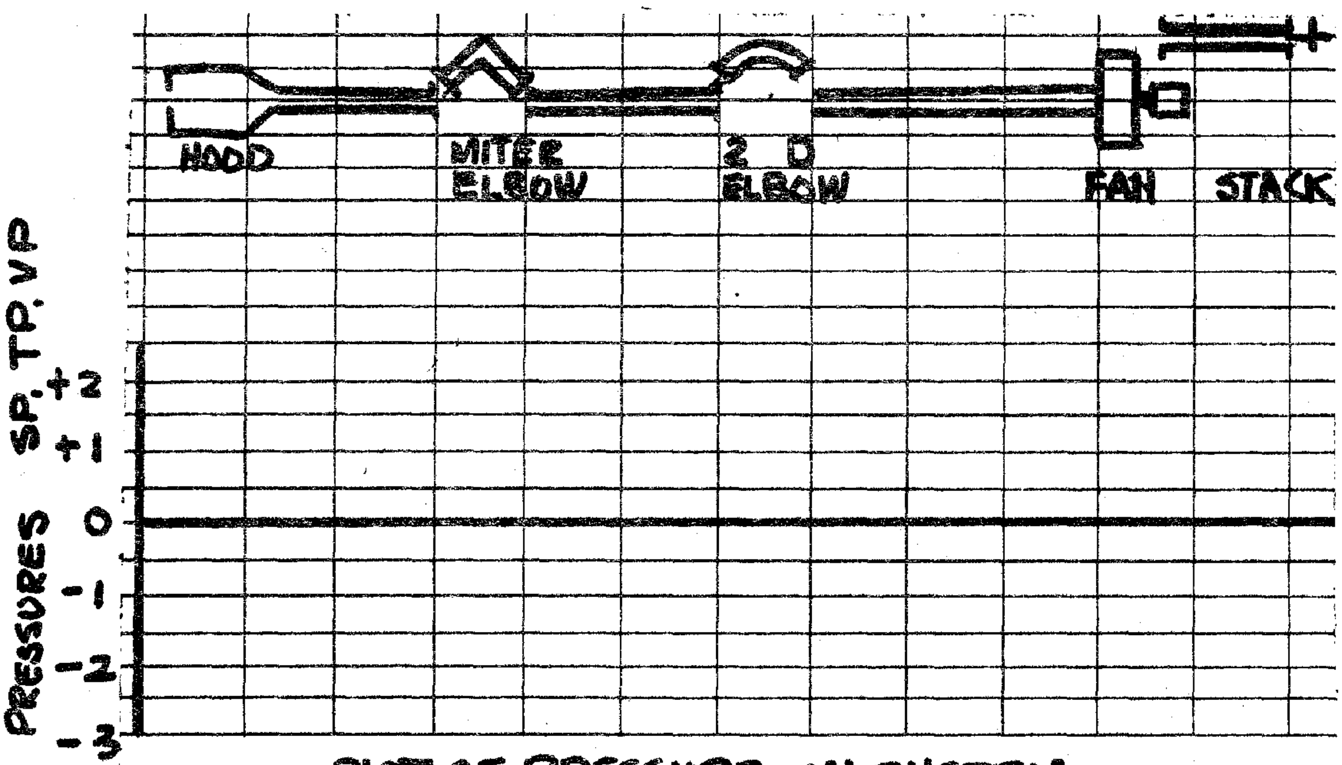
Hood SP	VP	Fan Inlet SP	Fan Outlet SP
Av.			

	SP_1	SP_o	$SP_o - SP_1$	VP	F
Sharp					
Turn					
Mitered					
Elbow					
Av.					

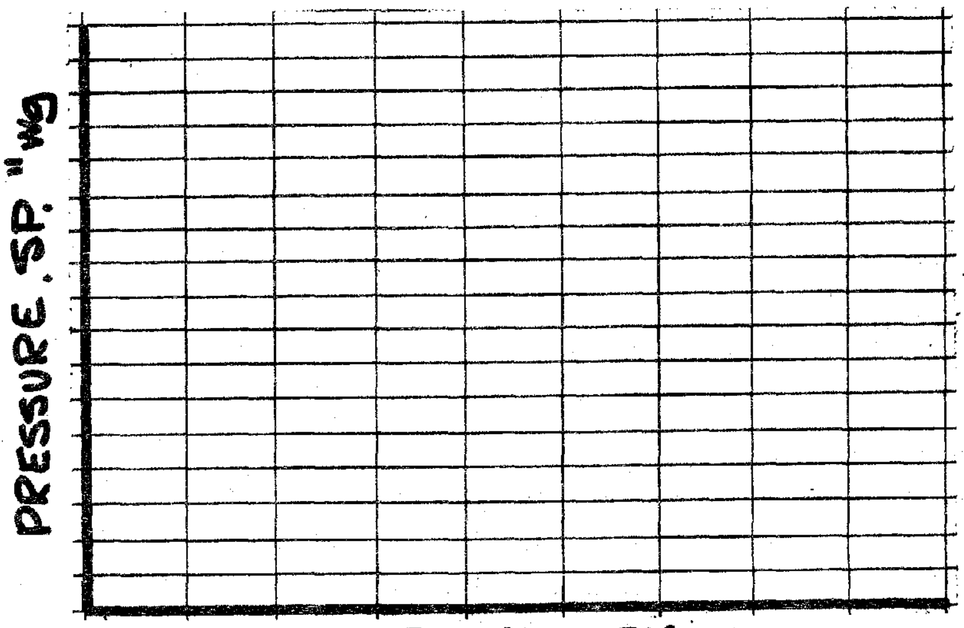
	SP_1	SP_o	$SP_o - SP_1$	VP	F
Long					
Radius					
2 - D					
Elbow					
Av.					

LABORATORY EXERCISE 4
DATA SHEET 2





PLOT OF PRESSURE IN SYSTEM



AIR FLOW CFM

SYSTEM CURVE

LABORATORY EXERCISES

VENTILATION MEASUREMENTS

INSTRUCTOR'S MANUAL

Prepared by George M. Hama

LABORATORY EXERCISES

INSTRUCTOR'S MANUAL

EQUIPMENT FOR LABORATORY

Necessary equipment for laboratory includes a fan, ductwork, straight duct and elbows, several different types of hoods, and a damper system for regulation flow. Fittings should be constructed with flanged connections so different combinations of duct, hoods, and elbows can be used.

Ductwork should be round, preferably 7" diameter size. Smaller sizes are difficult for beginners to traverse accurately. Larger sizes require larger fan and higher air flows. Hoods, straight duct and elbows should all have 7" diameter flanged connections.

DUCTWORK

Ductwork should be constructed of galvanized sheet steel preferably of 24 U.S. Standard gauge or heavier. If light weight material is needed, aluminum duct can be used preferably not lighter than B & S gauge 22.

Ductwork and fittings should be constructed in a permanent and workmanship manner. Hoods and elbows must be free of sharp edges and burrs.

The following fittings and sections of ductwork are needed:

2 sections of 7" diameter round duct approximately 48" long.

7" diameter round transition to 7 1/2" round with collar for fan inlet connection.

Rectangular 8 3/16" x 6" transition to 7" diameter round for fan outlet connection.

1 - 24" length 7" diameter round for fan outlet.

This section should be provided with an adjustable screw damper (see diagram).

Rectangular opening hood 18" x 18" opening with tapered connection to 7" diameter duct (see diagram).

Slot arrangement to place over above hood (see diagram).

Plain duct opening hood 7" diameter, 24" long.

Flanged duct opening hood, 6" flange, 7" diameter, 24" long.

Slot hood, 18" x 2" slot, tapered transition to 7" diameter duct (see diagram).

Sharp mitered elbow, 7" diameter duct.

Long radius elbow, 2 diameters radius of curvature, preferably 7 section construction, 7" diameter duct.

Plain duct opening 10" diameter 24" length, tapered to 7" diameter, round duct.

MISCELLANEOUS EQUIPMENT

Grids for positioning air flow measurement for determining contours at round and slot openings can be constructed from 1/8" metal frames. Holes should be placed 2" apart on the vertical and horizontal dimension of the frame. Wires are strung through the holes to form squares. Measurements are made at intersection of wires. The frames can be made 14" x 14" in size. Grids should be made to fit on tapered slot hood and 10" diameter plain duct hood.

Traverse area for rectangular opening hood 18" x 18" can be marked out with wires on an 18" x 18" frame. Wires should be strung at 3" intervals so 36, 3" square traverse areas are marked out.

A rigid table with solid floor contact should be provided for mounting the inclined vertical manometer.

The laboratory room should not be too small. A room at least 25' x 25' is recommended.

INSTRUMENTS

The following air flow meters and equipment is needed:

1 - 12" or longer Standard Pitot tube
1 - 12" 1/8" Pitot tube (scaled to AMCA code)

Two coils 3/16" rubber tubing

1 - Inclined/vertical manometer
0 - 5", inclined section .01, 0-1" wg,
vertical section .1, 1-5" wg

1 - Dwyer Air Meter
Dwyer Instruments Co.
Michigan City, Indiana 46360

1 - Alnor Thermoanemometer Type 8500
Alnor Instrument Co.
420 N. La Salle Street
Chicago, Ill. 60610

1 - Alnor Velometer, 6006 AP Series
Alnor Instrument Co.
420 N. La Salle Street
Chicago, Ill. 60610

1 - Rotating Vane Anemometer (preferably 3" diameter)
These are available at several sources, one source is:
E. Vernon Hill, Incorporated
P.O. Box 14248
San Francisco, Cal. 94114

Ventilation Smoke Tubes
Aspirator bulb
Mines Safety Appliance Co.
201 N. Braddock Ave.
Pittsburgh, Pa.

Stop Watch

Marking pencils

Rules

Manometer oil

FAN

A forward curved centrifugal fan is the least expensive of centrifugal fan types. A number of fan manufacturers provide this fan in packaged deal or "utility set" which includes fan, motor, drive arrangement and base. A belt drive has some advantage as with a variable pitch pulley, there can be some adjustment in fan speed. A direct drive may be unnecessarily noisy. With a belt drive the fan can be adjusted as low as possible in speed and at the same time providing what is needed in static pressure and air flow to meet the conditions of the experiment, thus keeping the noise at a minimum. The fan recommended for the laboratory set-up is, American Standard Sirocco, utility set, size 75 or equivalent from any AMCA certified fan manufacturer. With American Standard Fan 3/4 Hp motor, S75EL is recommended.

The catalogue rating for this fan is given in the following American Standard Multirating table.

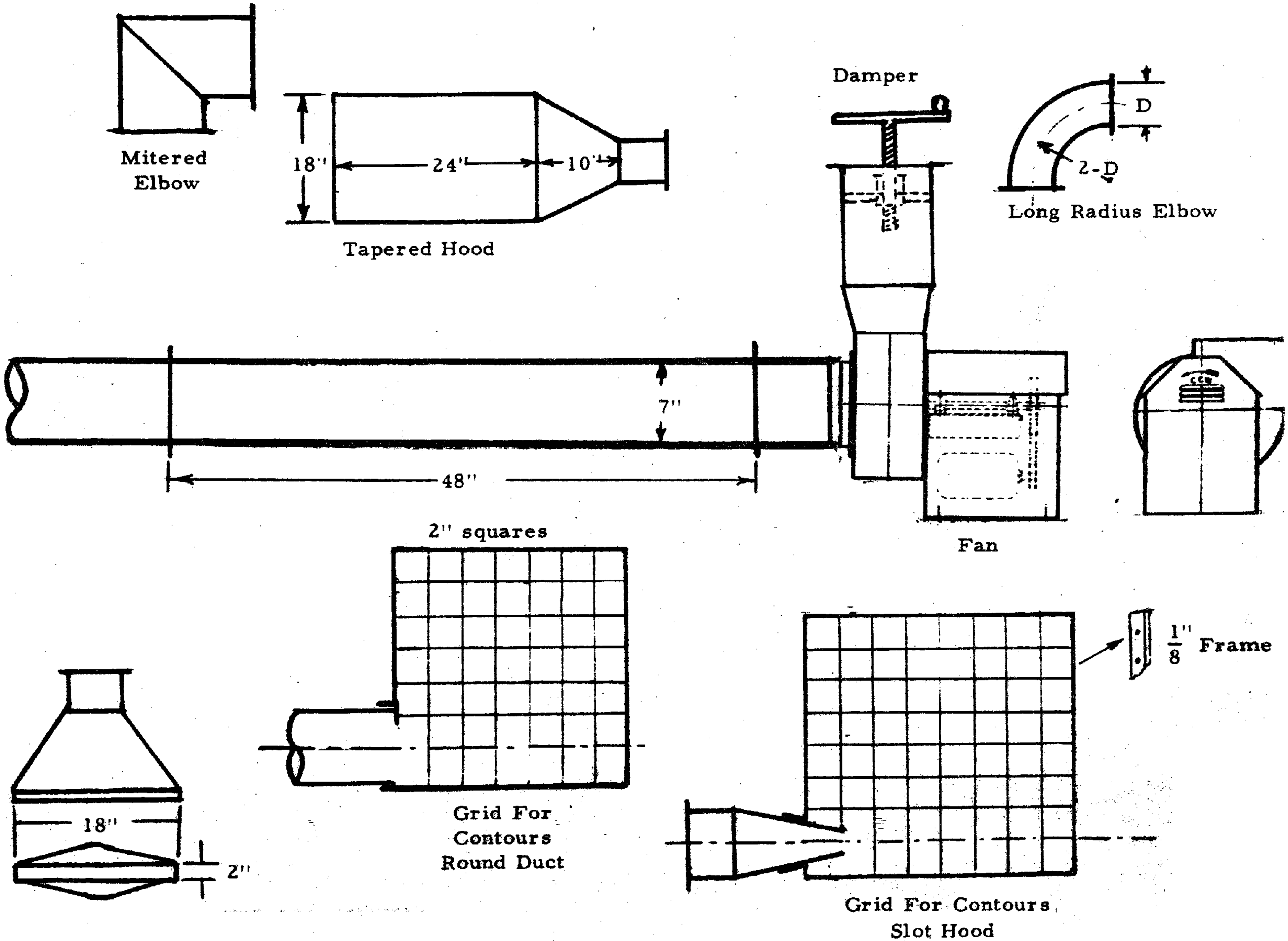
SIZE S75 OUTLET | 8³⁄₁₆" x 6" outside, area 0.330 sq. ft. inside — WHEEL | 7½" diameter, 1.964 ft. circumference — INLET | 7½" diameter outside, area 0.277 sq. ft. inside

CFM	Outlet Velocity	¼" S.P.		⅜" S.P.		½" S.P.		⅝" S.P.		¾" S.P.		⅞" S.P.		1" S.P.		1¼" S.P.	
		RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP
335	1000	916	.02	1033	.02	1142	.05	1246	.06	1351	.06	1453	.06	.....	.....	.....	.....
369	1100	960	.03	1072	.03	1170	.06	1268	.08	1365	.08	1460	.08	1552	.09	.....	.....
402	1200	1000	.05	1111	.05	1206	.08	1298	.09	1386	.09	1475	.11	1568	.11	1736	.13
436	1300	1036	.06	1150	.06	1244	.09	1335	.11	1420	.11	1498	.13	1592	.13	1744	[illegible]
469	1400	1072	.08	1190	.08	1284	.11	1373	.13	1455	.13	1527	.14	1616	.14	1762	[illegible]
503	1500	1108	.09	1229	.09	1329	.13	1411	.14	1490	.14	1565	.16	1640	.16	1780	[illegible]
536	1600	1152	.11	1266	.11	1374	.14	1455	.16	1524	.16	1602	.17	1672	.17	1806	.21
570	1700	1200	.13	1307	.13	1414	.16	1500	.17	1566	.17	1640	.19	1712	.19	1834	.23
603	1800	1248	.14	1346	.14	1464	.17	1544	.19	1607	.19	1678	.20	1752	.20	1870	.26
637	1900	1308	.16	1386	.16	1497	.19	1581	.20	1649	.21	1722	.22	1792	.23	1905	[illegible]
670	2000	1364	.17	1430	.17	1522	.20	1620	.22	1690	.23	1767	.25	1832	.26	1941	.31
704	2100	1420	.19	1474	.20	1555	.22	1656	.23	1732	.25	1812	.28	1872	.30	1986	[illegible]
737	2200	1460	.21	1527	.23	1601	.25	1698	.25	1774	.28	1850	.31	1920	.33	2030	.34
771	2300	1540	.23	1582	.25	1646	.28	1734	.30	1815	.31	1887	.33	1960	.36	2075	.39
804	2400	1600	.26	1640	.28	1697	.31	1772	.33	1857	.34	1925	.36	2000	.39	2120	.44
838	2500	1660	.30	1699	.31	1748	.34	1810	.36	1891	.38	1962	.39	2040	.42	2165	[illegible]
871	2600	1720	.33	1762	.34	1804	.38	1854	.39	1919	.42	1999	.44	2072	.47	2200	[illegible]
905	2700	1780	.36	1822	.38	1861	.41	1898	.44	1961	.45	2037	.47	2104	.52	2236	.56
938	2800	1840	.41	1876	.42	1918	.44	1949	.47	2009	.52	2074	.53	2144	.55	2272	.61
972	2900	1900	.45	1934	.47	1974	.49	2006	.52	2050	.55	2119	.58	2184	.59	2307	.66
1005	3000	1960	.50	1993	.52	2030	.53	2063	.56	2092	.59	2157	.63	2224	.64	2343	.7[illegible]
1039	3100	2020	.55	2056	.56	2087	.58	2120	.61	2154	.63	2202	.67	2264	.69	2379	.7[illegible]
1072	3200	2080	.59	2115	.61	2144	.63	2177	.66	2210	.69	2254	.74	2304	.75	.....	.....
1106	3300	2140	.66	2174	.67	2200	.69	2234	.72	2266	.74	.....	.....	.....	.....	.....	.....
1139	3400	2200	.70	2233	.72	2262	.74	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

CFM	Outlet Velocity	1½" S.P.		1¾" S.P.		2" S.P.		2¼" S.P.		2½" S.P.	
		RPM	BHP	RMP	BHP	RPM	BHP	RPM	BHP	RPM	BHP
536	1600	1935	.26	2074	.30	2194	.26	....	....	....	....
570	1700	1960	.28	2085	.33	2217	.31	....	....	....	....
603	1800	1990	.31	2106	.36	2229	.36	2352	.31	....	....
637	1900	2019	.34	2138	.39	2251	.39	2364	.38	2479	.44
670	2000	2048	.38	2170	.44	2274	.44	2388	.42	2492	.50
704	2100	2078	.41	2212	.47	2308	49	2412	.47	2517	.56
737	2200	2128	.44	2244	.50	2342	.53	2436	.53	2530	.63
771	2300	2176	.46	2278	.55	2375	.58	2472	.58	2567	.67
804	2400	2225	.49	2318	.58	2421	.63	2506	.64	2593	.74
838	2500	2274	.52	2360	.61	2454	.66	2544	.69	2643	.80
871	2600	2313	.57	2392	.66	2489	.70	2550	.74	.....	.....
905	2700	2352	.61	2453	.69	2534	.75	.....	.....	.....	.....
938	2800	2391	.66	2487	.72	.....	.....	.....	.....	.....	.....
972	2900	2430	.69	.....	.....	.....	.....	.....	.....	.....	.....

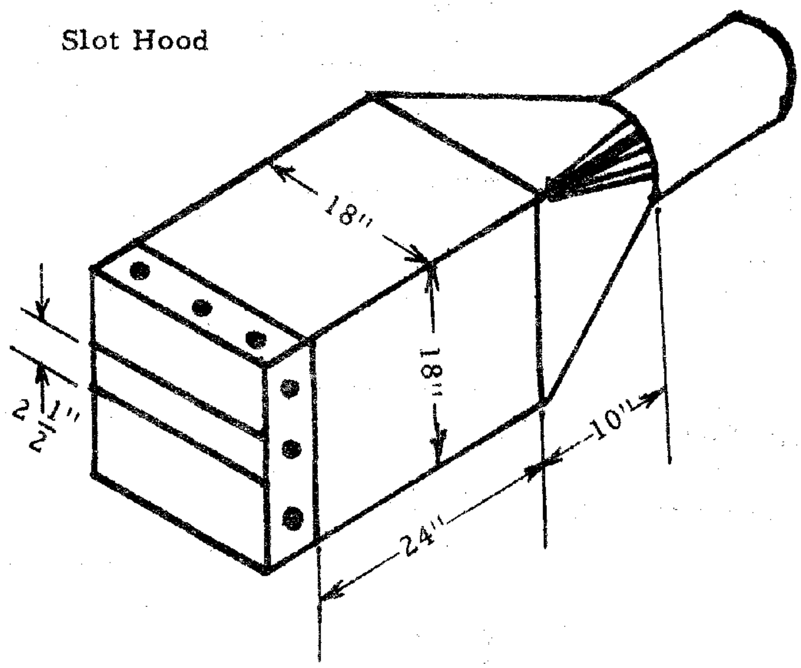
CATALOG NUMBER	MOTOR HP	FAN RPM MIN-MAX
S75AT	1/6	916-13
S75AS	1/6	1295-17
S75BR	1/4	1308-1834
S75CQ	1/3	1600-2040
S75CP	1/3	1920-22
S75DO	1/2	1748-21
S75DN	1/2	2022-24
S75EM	3/4	1993-2390
S75EL	3/4	2210-2593

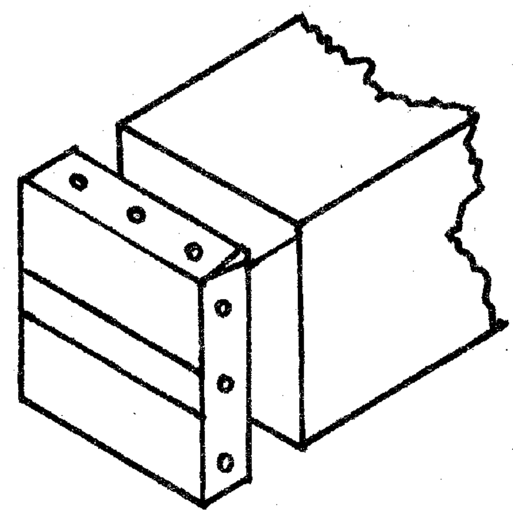
121



Mitered Elbow
18''
24''
10''
Tapered Hood
Damper
D
2-D
Long Radius Elbow
7''
48''
Fan
2'' squares
Grid For Contours Round Duct
1/8'' Frame
18''
2''
Grid For Contours Slot Hood

Slot Hood





MAKE SLOT SO IT CAN BE PLACED ON TAPERED HOOD

LABORATORY EXERCISE I

INSTRUCTOR'S MANUAL

OBJECT

1. To familiarize students with air meters and pitot tube by making actual measurements.

2. To teach the students how to make a precise measurement of air flow with a pitot tube in a duct, by means of a duct traverse.

3. To instruct the students on how to measure a hood face velocity measurement with several different meters by means of traverse of the hood face.

TEST SET UP

1. Fan and ductwork are connected to a rectangular opening hood 18" x 18", with traverse areas marked off by wires in 3" squares (see diagram).

2. Air flow is measured with pitot tube in the round duct connecting the hood to fan at two measuring holes, 90^{o} apart at least 7 1/2 diameters from hood.

3. Air flow is measured at rectangular hood with each instrument. A 36 point traverse should be used.

4. Rectangular duct is replaced by round duct and procedure repeated. Use 2-10 point traverses on round duct.

5. Rotating vane anemometer is not used on round duct, as it is too large in area.

6. Two threads or thin wires 90^{o} apart can be placed across diameter of round hood opening to facilitate locating traverse points.

TEST PROCEDURE

The instructor should point out that the air velocity varies at the hood face and in the duct and is not uniform. The air flow varies both in and out of hood face and also across face opening. The inaccuracy of taking one or two "hit and miss" readings should be stressed.

The damper in the system should be opened so that the rectangular and round hood face velocity is in excess of 200 fpm.

The students should be instructed not to block hood opening in any degree with hands or body.

Probes for air meter should be kept at plane of opening and not inserted in hood or placed outside of hood face.

The instructor should discuss in detail each instrument before starting and demonstrate its use and procedure for operation.

On the Velometer it is highly important the student reads the correct scale with the equivalent probe and air flow setting.

On the Thermoanemometer it is important that the instrument be constantly checked and readjusted for battery fading. Extreme care should be taken not to damage fine wires in probes.

The correction factors on the rotating vane anemometer are inherent to this type of instrument and are provided to correct for friction in gear train and propeller bearing. Generally they are plus at low velocities and increasingly minus at high velocities. This should be pointed out to stress importance of always considering them. Usually a rod or holder is provided so the hands can be kept out of hood opening. The clutch arrangement should be pointed out. Some instruments have an arrangement for setting dials to zero, other instruments the cumulative dial reading is used for zero setting. The reading of these dials should be discussed. Extreme care should be exercised not to drop this instrument, as it is fragile.

The Dwyer air meter tubes must be occasionally cleaned. There are some pipe cleaners provided for this purpose. If the float sticks in one place cleaning may be necessary.

The data should be recorded on worksheet provided.

Students should alternate on pitot measurement so that all get experience in its actual use.

The instructor should assist in marking traverse points on pitot tube. To assist easy reading the mark should be ringed around tube with wax pencil.

Traverse points are available in Industrial Ventilation and on data sheet.

Instructor should go over detailed instruction in the section 2 of the measurement lecture outline. Points of importance are:

(a) The manometer should be checked for proper level several times during measurement.

(b) The zero setting should be obtained with rubber hose disconnected. Time should be allowed for manometer fluid to run down.

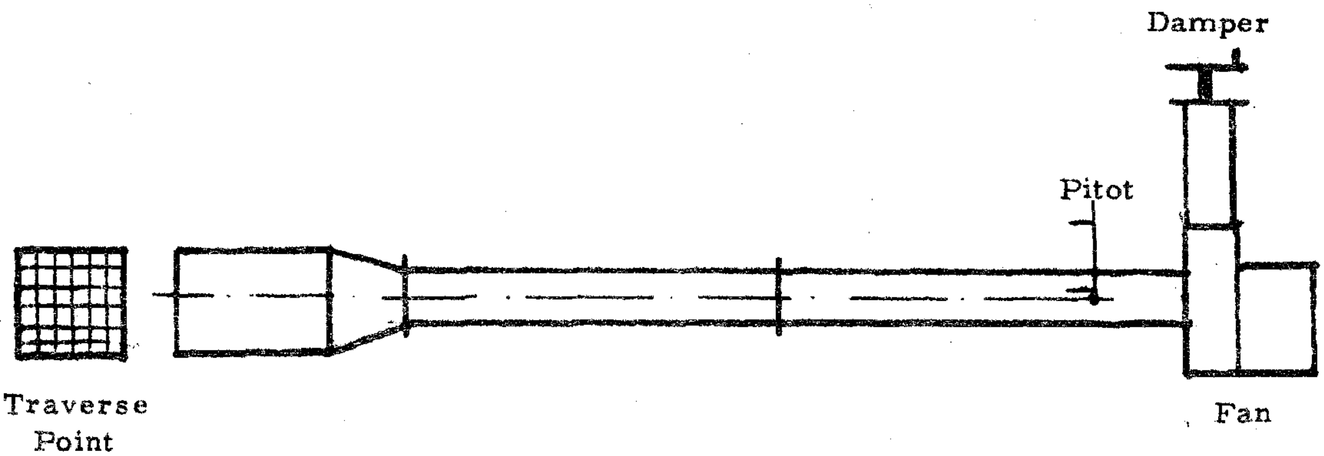
(c) Check for pinched hoses from time to time.

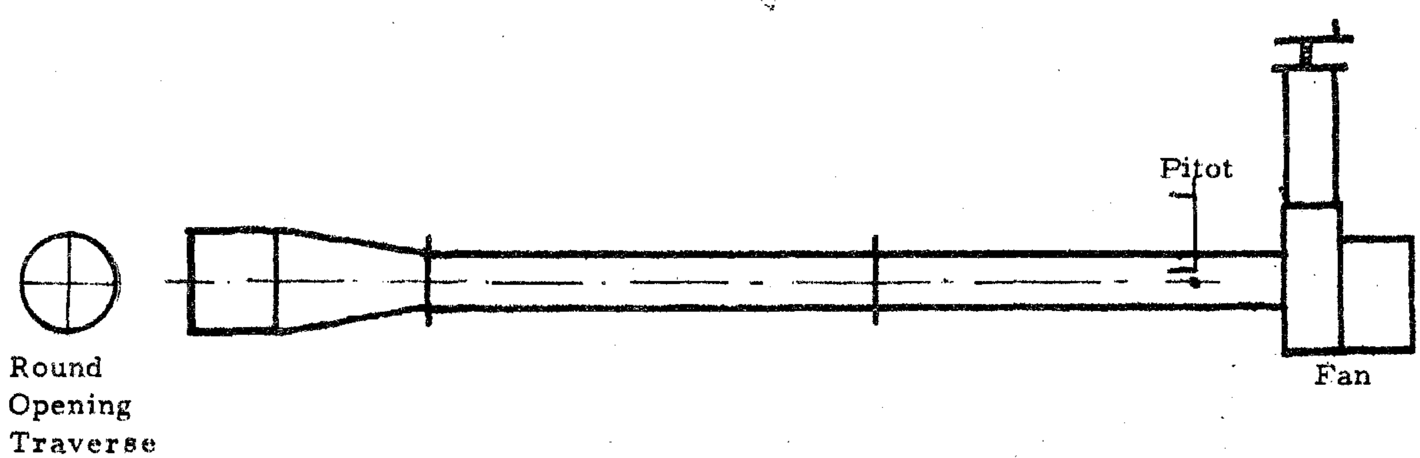
(d) Avoid parallax in reading fluid meniscus.

(e) Students with adequate instructions should make reading within 2 to 3% error.

LABORATORY EXERCISE I

Diagram of Test Set Up





LABORATORY EXERCISE II

INSTRUCTOR'S MANUAL

PURPOSE

1. To give the student experience in measuring low velocities outside of ducts and hoods.

2. To impress the student through observation with the rapid fall off of velocity short distances from the hood opening.

3. To give the student through actual observation the concept that air comes from all direction into hood openings under suction.

4. To have the student confirm the validity of the empirical equations of flow for slot hood and round or essentially square hoods.

PROCEDURE

The instructor should familiarize himself with velocity contours and streamlines as shown in diagram so that he can discuss this with the student.

It should be explained to the students that one of the objectives of the exercise is to construct such a diagram.

The method used is the one described in Dalla Valle, J.M., Exhaust Hoods pages 8 - 11. A series of readings are made with the Thermónemometer at regular intervals along the centerline and up from the centerline. The average velocity across the hood opening is obtained from the pitot tube traverse. The air flows are recorded in proper position using the data sheet provided. The exact position of each measurement can be positioned by the use of a frame and cross wires which provide 2" squares up to 14" away from opening and 2" square up from centerline to 14".

The reading is converted to % of average hood face reading. They then are plotted in a series of curves, each curve represents velocities in percent, a distance up from centerline. On the curve, % velocity is plotted against distance out in inches (see worksheet). From this graph, a one-half diagram of flow contours can be constructed each contour line representing a line of equal velocity or percent equal velocity in its actual position relative to the suction open.

The students should be provided with rectilinear graph paper.

For best results the damper on fan should be wide open to provide measureable air flows.

The thermoanemometer or similar heated thermocouple devices is the instrument of choice because it is sensitive to low velocities. Because the battery tends to drop in voltage, frequent checks and necessary adjustments should be made.

References

1. Dalla Valle, J. M., Exhaust Hoods 2nd Edition 1945. The Industrial Press, 148 Lafayette Street, New York, N. Y. Chapter 2, page 8.

2. Industrial Ventilation 12th Edition 1972, Committee on Industrial Ventilation, P. O. 453, Lansing, Michigan. Section 4, Hood Design 2-1

TEST SET UP

1. A round plain duct is connected to fan and ductwork providing with grid for position velocity measurements

2. Air flows are measured exterior to the hood at measured points in front of hood and up from centerline. See data sheet.

3. A pitot traverse is made at same time to determine average velocity.

4. Same procedure is repeated with a slot hood. Used tapered slot hood and grid.

5. Data should be recorded on data sheet in exact position taken.

LABORATORY EXERCISE III

INSTRUCTOR'S MANUAL

OBJECT

1. To give the student experience in measuring static pressure by several different methods.

2. To give the student some concept of pressure losses in different hood shapes.

TEST SET UP

1. Four different hoods are separately connected to fan and duct work (see diagram).

2. Each hood is connected to duct work which includes sufficient duct for a pitot traverse 7.5 diameter or more from hood.

3. Static pressure is measured by three different methods at the duct just above hood.

4. The air flow is determined at the same time with a pitot tube traverse.

The instructor should familiarize himself with the theoretical considerations involved in air entering a duct. He should have a clear understanding of coefficient of entry, C_e, hood entry loss, h_e, and hood static pressure, SP. He should also have a clear concept of what causes certain types of hoods to have low entry losses and others high entry losses.

The method using a liquid inclined vertical manometer with rubber tubing and exterior drill holes can be accepted as the usual standard for checking SP's in a local exhaust system. The same care in setting up and zeroing the manometer as for pitot traverses should be exercised. It should be pointed out a small hole has less disturbance than a large hole and gives a more precise reading. Four holes 90° apart are used to average out variances in the duct. Also, it can be mentioned piezometer rings are used sometimes to connect all the holes together so the four readings are averaged and one average measurement can be made by connecting manometer to ring.

The pitot tube method may give slightly different readings than the exterior hole method. This measurement is possibly more representative of the over-all static pressure in the air stream, but it is less frequently used, possibly because it is more time consuming. Variances internally across the diameter are measured by this method.

The velometer probes require a 1/4" hole or larger, if smaller holes are used, low readings will result. The readings are not as reliable as liquid manometer readings.

The measurement is made a short distance from the hood throat (3 diameters). This assures that the high VP from vena contracta closer to hood, with temporary high SP is not measured, but the more stable SP at a point beyond the vena contracta is measured. This SP will include the conversion losses of SP to VP and VP to SP. On tapered connections it is possible to measure as close as 1 1/2 diameters and get stable SP reading. The friction loss in the short section of duct (hood to drill holes) should be subtracted from measured SP to give corrected SP.

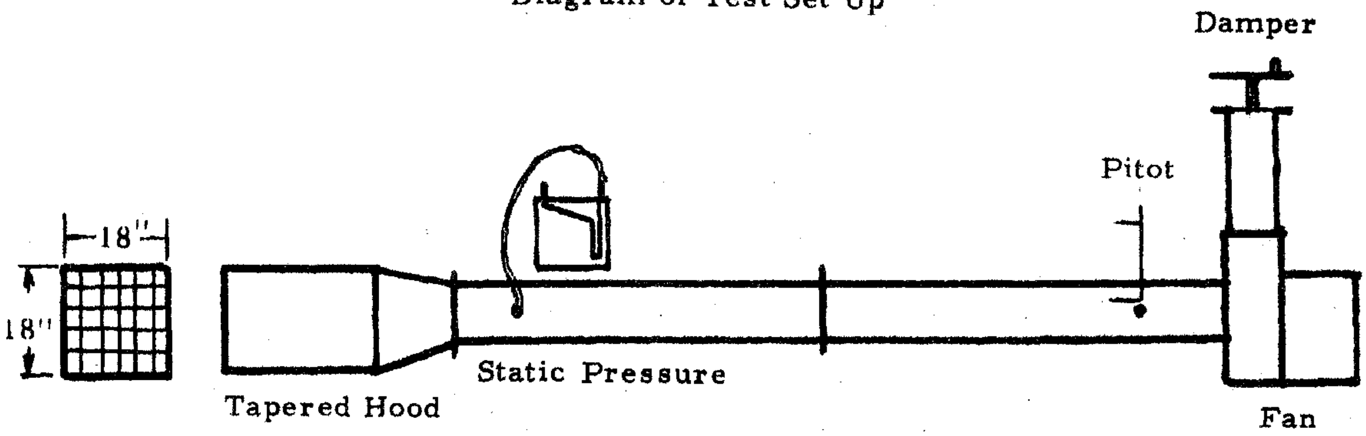
It should be pointed out in the slot hood two losses occur. First, the air entering the slot, this is based on slot, not duct velocity, and for a sharp edged orifice is 1.78 slot VP, the second loss is from hood to duct and depends on the angle of transition hood to duct. In general, if the slot velocity is lower at the slot only VP needs to be added to the h_e losses to give duct SP. Tapered and other losses can be estimated from diagrams and charts given on page 6-26 Industrial Ventilation ACGH.

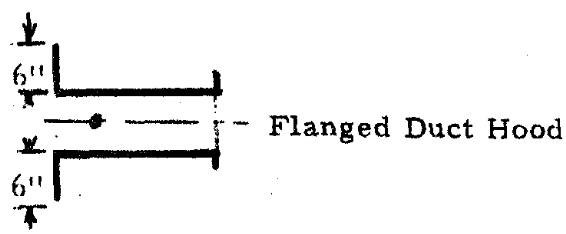
In this exercise higher air flows will give more satisfactory results. Hoods should be tested in open areas, care should be exercised not to block opening with body or objects.

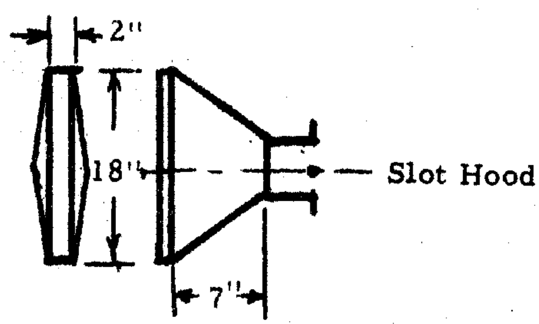
131

LABORATORY EXERCISE III

Diagram of Test Set Up







LABORATORY EXERCISE IV

INSTRUCTOR'S MANUAL

OBJECT

1. To give the student practice in checking out a local exhaust system.

2. To, by measuring velocity and checking capture in front of an exterior local exhaust hood, impress the student with the rapid decrease in velocity a short distance from an exterior hood opening.

3. To give the student an understanding of pressures throughout a local exhaust system.

4. To, by testing SP losses in elbows, understand the value of long radius of curvature elbows as compared with sharp turn elbows.

5. To help the student understand the relationship of airflow to pressures in a system, by constructing a system curve.

The evaluation of the hood gives opportunity to emphasize that air blown from a small opening retains its velocity and directional effect for some distance. However, an exhaust opening handling the same volume of air loses its directional effect and becomes completely non-directional and its range of measurable velocity influence is greatly reduced (see figure 2). It should be emphasized that local exhaust hoods should not be contemplated for any process which cannot be conducted in immediate vicinity of the hood.

The pressure measurements should be plotted on data sheet as illustrated in figure 1.

Some discussion of good and poor elbow should be given. On the mitered elbow the SP is measured 1 1/2 diameters away to get a better measurement in a less turbulent area.

It can be pointed out that if a system is checked out with clean hoods, a hood SP can be used in the future as a quick easier evaluation of hood air flow.

The testing of fans was purposely omitted from laboratory exercises. It can be pointed out, however, that where the system curve crosses the fan curve it is the point of system operation.

Reference: Industrial Ventilation 12th Edition, ACGIH section 9 - 1.

In setting up the exercise the air flows should be kept high as all measurements will have a greater degree of accuracy.

133

TEST SET UP

Test set up is to be assembled as shown in diagram at the top of Data Sheet 2. First, a slot hood as shown in accompanying diagram is connected to a straight section of duct, this is followed by a mitered elbow, another straight section of duct follows, this is then connected to a round 2-diameter radius elbow, another section of straight duct follows, this is connected to the fan. A straight section of duct is connected to the fan. The damper is placed on the discharge of this duct.

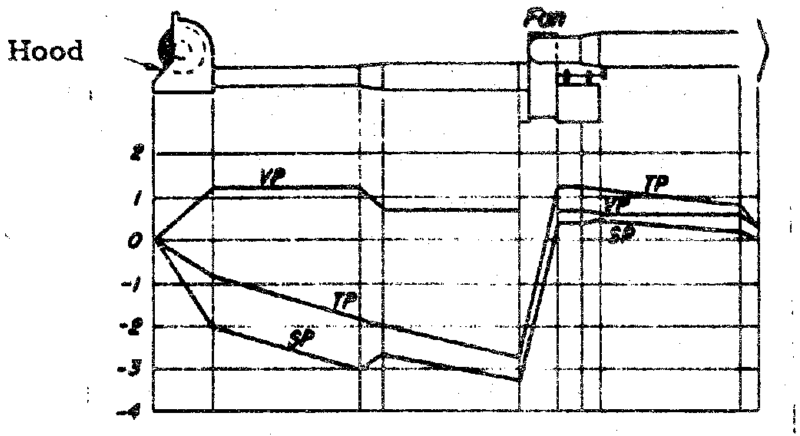
Static pressure holes are drilled in the positions indicated in the Procedure item 2.

A small table or flat surface should be placed at the same level as the lower edge of slot at hood.

Examine data sheets and instruct trainees on their use.

System curve should look like accompanying diagram, Fig. 1.

Fig. 2 emphasizes the difference between blowing and exhausting.



SYSTEM PRESSURES
Fig. 1

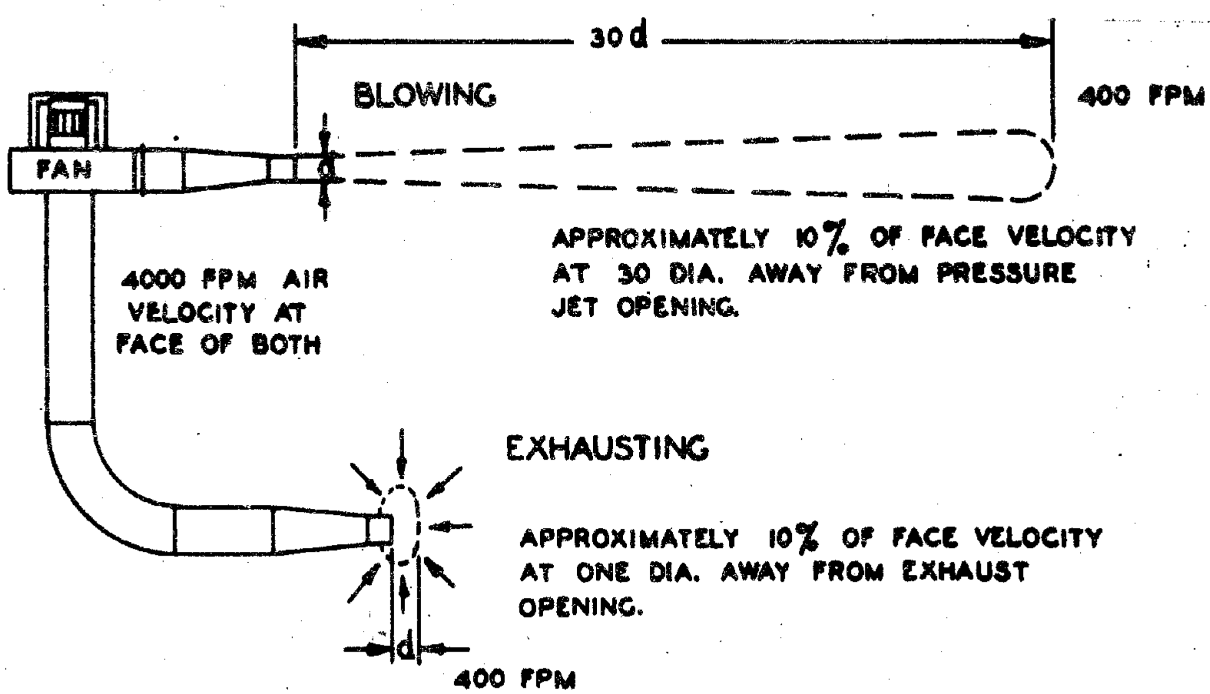


Fig. 2