

CHAPTER 6

INDUSTRIAL VENTILATION

1. **GENERAL.** Ventilation is the process of supplying and removing air by natural or mechanical means to or from any space. It is used for heating, cooling, and controlling airborne contaminants which affect employees and the general environment. Industrial ventilation emphasizes the control of toxic and/or flammable contaminants.

2. **DEFINITIONS.**

a. Baffle - a surface which provides a barrier to unwanted airflow from the front or sides of a hood.

b. Blast gate - a sliding valve used in ducts to create additional pressure loss in the duct and restrict flow.

c. Capture velocity - the air velocity at any point in front of the hood or at the hood opening necessary to overcome opposing air currents and to capture the contaminated air at that point by causing it to flow into the hood.

d. Coefficient of entry - the actual rate of flow caused by a given hood static pressure compared to the theoretical flow which would result if the static pressure could be converted to velocity pressure with 100% efficiency. The ratio of actual to theoretical flow.

e. Entry loss - loss in pressure caused by air flowing into a duct or hood.

f. Fan - a mechanical device which physically moves air by creating a pressure differential.

g. Flange - a surface at and parallel to the hood face which provides a barrier to unwanted air flow from behind the hood.

h. Hood - a shaped inlet designed to capture contaminated air and conduct it into the exhaust duct system.

i. Lower explosive limit - the lower limit of flammability or explosibility of a gas or vapor at ordinary ambient temperatures expressed in percent of the gas or vapor in air by volume. This limit is assumed constant for temperatures up to 250° F. Above these temperatures, it should be decreased by a

factor of 0.7 since explosibility increases with higher temperatures.

j. Plenum - pressure equalizing chamber.

k. Replacement (make-up) air - the volume of outdoor air intentionally supplied to a building to replace air being exhausted.

l. Static pressure - the potential pressure exerted in all directions by a fluid at rest; the tendency to either burst or collapse a pipe. For a fluid in motion, it is measured in a direction normal (perpendicular) to the direction of flow. It is usually expressed in inches of water gauge (" w.g.) and may be positive or negative.

m. Total pressure - the algebraic sum of the velocity pressure and the static pressure. May be positive or negative.

n. Velocity pressure - the kinetic pressure in the direction of flow necessary to cause a fluid at rest to flow at a given velocity. Usually expressed in inches of water gauge, it is always positive.

3. INSTRUMENTATION.

a. Manometer and Pitot tube.

(1) The manometer is an instrument, which is a primary standard, for the measurement of pressure. The simplest type of manometer is the U-tube, partially filled with liquid (usually water, mercury, or light oil). The inclined manometer is more accurate, but more difficult to use. The amount of liquid displaced indicates the amount of pressure exerted on the instrument.

(2) The Pitot tube is a tube within a tube. The inner tube has a port that points directly into the airstream and measures total (impact) pressure. The outer tube has a ring of ports that are perpendicular to the airstream and measures static pressure.

(3) When both tubes of the Pitot Tube are connected to a manometer, the velocity pressure is measured.

(4) The manometer and Pitot tube combination is simple to operate, inexpensive, and the most legally credible air velocity measurement system. The one disadvantage is that it cannot measure velocity less than 600 feet per minute.

b. Thermal (heated wire/element) anemometer.

(1) When air moves across the electrically heated wire/element, the wire cools and the resistance changes. The resistance change provides an electrical signal which is proportional to the air velocity and is displayed on either a digital or analog meter.

(2) The probe can be used directly to measure air velocity in open spaces and at air exhaust and supply openings.

(3) Attachments are available to measure static pressure.

(4) Due to the small diameter of the probe, measurements can be made directly inside ducts using the measurement techniques described for Pitot traverses in sections 4.b. and 4.c. of this chapter.

(5) Battery charging and maintenance are extremely important and the battery voltage must be checked prior to instrument use.

(6) Minimum velocity ranges vary depending on the manufacturer, but are generally 50-100 feet per minute.

(7) Initial and periodic calibration are required.

CAUTION: Thermal anemometers should not be used in explosive atmospheres because they may provide an ignition source.

c. Swinging vane anemometer (velometer).

(1) Indicates air velocity as a function of the pressure exerted by the air stream on a swinging vane which is under tension and calibrated.

(2) Includes a variety of fittings which can be used to measure static pressure and a wide range of linear velocities.

(3) Perform "zero check" prior to use by holding it horizontal and covering both ports so that no air can flow through. If the pointer does not come to rest at zero, the zero ("Z") adjustment must be turned to make the necessary correction.

(4) Dust, moisture, or corrosive material in the atmosphere present a problem since air passes through the meter.

(5) The minimum velocity is 50 feet per minute unless adapted for a lower range.

(6) The instrument requires initial and periodic calibration.

d. Aneroid gauge.

(1) Gauge operates without liquid to measure pressure. The best known type is the "Magnehelic" gauge.

(2) Advantages:

- (a) Easy to read;
- (b) Greater range of response than manometers;
- (c) Portable (small and lightweight);
- (d) Less maintenance due to absence of fluid; and
- (e) Can mount and use in any position without loss of accuracy.

(3) Disadvantages:

- (a) Subject to mechanical failure; and
- (b) Requires periodic calibration checks and occasional recalibration.
- (c) Change of mounting position (e.g., from vertical to horizontal) requires rezeroing.

4. **GENERAL METHODS FOR EVALUATION OF INDUSTRIAL VENTILATION SYSTEMS**. See Reference 6-1 for a complete discussion on where to take measurements, the number of readings required, etc.

a. Face velocity traverse method.

(1) Determine the area of the open face of the booth or hood.

(2) Measure air velocity at several points across the face of the booth or hood and calculate the average velocity. This should be accomplished by forming a grid of equal area rectangles across the face and taking a velocity measurement in the center of each rectangle.

(3) Calculate total volumetric flow rate using Equation 6-1.

$$Q=VA$$

Equation 6-1

Where:

Q = volumetric flow rate (ft³/min)

V = average air velocity across face (ft/min)

A = area of booth or hood face (ft²)

b. Pitot tube traverse method for round ducts.

(1) Make two traverses across the diameter of the duct at right angles to each other.

(a) Holes made for the Pitot tube should be drilled, not punched, to avoid projections or burrs inside the duct which may add to air turbulence and alter readings.

(b) Whenever possible, the traverse should be made 7½ duct diameters or more downstream and 2½ duct diameters or more upstream from any major air disturbance (e.g., elbow, hood, branch entry).

(2) Measure velocity pressure at the center of annular rings of equal area.

(3) For ducts with a diameter less than or equal to 6 inches, at least 6 traverse points should be measured. For ducts with diameters greater than 6 inches, at least 10 traverse points should be used. For very large ducts (approximately 40 inches in diameter or larger) or for ducts with a wide variation in velocity from point to point, 20 traverse points should be used. The location of the traverse points should be documented.

If the minimum distances from disturbances cannot be satisfied, a traverse should be taken at a second location. If the average reading from the two locations agree within 10%, an average of all readings may be used. If variation exceeds 10%, readings should be taken from a third location and average of the two readings in closest agreement may be used.

(4) Convert all velocity pressure measurements to velocity using Equation 6-2.

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

Equation 6-2

Where:

V = velocity (ft/min)

VP = velocity pressure (inches of water gauge)

This equation is for dry air at standard temperature (25° C) and pressure (760 mm Hg). Otherwise, corrections must be made for temperature, moisture and pressure. Consult Reference 6-1.

(5) Determine the average duct velocity and calculate the duct volumetric flow rate using Equation 6-1.

c. Pitot traverse method for square or rectangular ducts.

(1) Divide the cross-section into a number of equal area rectangles.

(2) Measure the velocity pressure at the center of each rectangle. Make enough readings so that the greatest distance between the centers is approximately 6 inches. In all cases, at least 16 measurements should be made.

(3) Convert all velocity pressure measurements to velocity using Equation 6-2.

(4) Determine the average duct velocity and calculate the duct volumetric flow rate using Equation 6-1.

d. Static pressure measurements.

(1) The preferred method of measuring static pressure is the use of a manometer and Pitot tube. Static pressure may also be measured by connecting the manometer to an opening in the wall of the duct.

(2) If static pressure is measured at the duct wall, it should be done $7\frac{1}{2}$ duct diameters downstream and $2\frac{1}{2}$ duct diameters upstream of any fittings. If this is not possible, drill (do not punch) four or more holes equally spaced around the duct in the same plane and average the readings.

(3) Measurements of hood static pressure for tapered hoods should be made a distance of one duct diameter from the

duct entry. For flanged or plain hoods, measure hood static pressure at 3 duct diameters from the hood.

e. Capture velocity measurements.

(1) Measure air flow at the point of contaminant generation.

(2) Factors affecting capture velocity which should be documented:

(a) Flanges - decrease the required flow rate to achieve a given capture velocity by providing a barrier to unwanted air flow from behind the hood. In most instances, the flange width should equal the square root of the hood area.

(b) Baffles - provide a similar effect by providing a barrier to unwanted air from the front or sides of the hood.

(c) Room currents - may be favorable or unfavorable to capture.

(d) Size of hood - large hoods create a large air mass in motion while small hoods create localized control only.

f. Smoke tubes. Observing generated smoke makes it possible to determine direction of air flow, turbulence and location of dead spots.

CAUTION: Ventilation smoke tubes may contain stannic oxychloride or titanium tetrachloride which produce hydrogen chloride gas, a strong mucous membrane irritant. Do not direct smoke toward an employee's eyes or breathing zone.

g. Visual inspection. A visual inspection of a ventilation system can detect such things as broken or corroded fan blades, broken or clogged duct work, dirty filters, etc.

5. VENTILATION SURVEYS.

a. The scope of the ventilation survey will primarily depend on whether measurements and/or calculations are intended for screening or baseline information.

(1) Screening. Screening measurements are usually obtained by the industrial hygienist during the periodic walkthrough portion of an industrial hygiene survey. Capture and

face velocities are usually all that are measured. These measurements are used to document airflow.

(2) Baseline evaluations. Evaluate ventilation systems in conjunction with the baseline industrial hygiene survey, unless otherwise specified in NAVOSH standards. Documentation should include a comparison of the design specifications to the performance data. If a design specification for a particular ventilation system does not exist, a baseline ventilation survey will serve as the benchmark. When the ventilation system does not control the hazard to within acceptable levels, notify the cognizant activity personnel and conduct another survey after repairs or modifications are completed.

b. Industrial ventilation survey reports. During ventilation surveys, include as much of the following information as possible in the survey report:

(1) Sketches and/or photographs of ventilation systems.

(2) Brief description of ventilation systems, e.g., natural, forced air, dilution, local exhaust or combinations.

(3) Locations and types of ventilation systems, hood face velocities, capture velocities, the appropriateness of the ventilation for the job and range of activities relative to hazard generation.

(4) Adequacy of make-up air. Explain how make-up air is obtained, exhausted or recirculated and whether it is contaminated.

(5) Records of periodic inspections and summaries of previous surveys/inspections. Use previous survey information as much as possible.

(6) Variables that affect ventilation, e.g., doors, windows, openings in building and processes affecting temperature, heating and cooling of the building and/or operation, local cooling fans, and seasonal characteristics.

(7) General comments on the effectiveness of the system and personnel work practices.

(8) Personnel exposure levels when the ventilation systems are operating.

(9) Fan manufacturer, model number, serial number, capacity in ft³/min, static pressure rating in inches of water gauge, and fan pulley diameter in inches.

(10) Fan motor manufacturer, model number, serial number, revolutions per minute, motor pulley diameter in inches and horsepower.

(11) Type, size and capabilities of the dust collector, and the status of filters, cyclones, etc. (e.g., operational, clogged, torn).

(12) Manufacturer, model number, serial number, and calibration date for air velocity meter used.

(13) References and standards upon which any recommendations are based.

(14) Survey date and signature of person performing survey.

c. Shipboard Industrial Ventilation Surveys. Shipboard HVAC and industrial ventilation design criteria is provided in Reference 6-2. Naval Ships Technical Manuals should be consulted first for ventilation requirements. Where Navy standards do not exist, Reference 6-2 authorizes use of Reference 6-1 for industrial ventilation requirements.

(1) For a number of reasons, most shipboard ventilation surveys are best accomplished while the ship is not underway. Major ventilation systems required for propulsion can be secured or operated at various speeds, ship's personnel are more available to assist, and there is easier access to hard-to-reach ducts and openings.

(2) Ventilation systems should be thoroughly traced and sources of replacement air for recirculation systems identified.

(3) On ships which are equipped with a Chemical Protective System (CPS), ventilation surveys should document the status of the CPS during the survey.

(4) Unauthorized ship alterations, such as cardboard vent covers, holes in ducts and cheesecloth dust-catchers, should be noted in the report as discrepancies.

(5) Interim and feasible alternatives to ship alteration corrections must be investigated for ventilation discrepancies.

(6) The industrial hygiene officer should assist the command in preparing 2K and 2L forms for corrective actions. These maintenance forms will be added to the Current Ship's Maintenance Project (CSMP).

6. **TROUBLE SHOOTING AN INDUSTRIAL EXHAUST SYSTEM - SOME HELPFUL HINTS.** Most of the following checks can be made by visual observation without the need for extensive measurements.

a. If the air flow is low in hoods:

(1) Check fan rotation. Reversed polarity in a three-phase electrical system will cause the fan to run backwards. A centrifugal fan running backwards may deliver only 30-50 percent of rated flow.

(2) Check fan revolutions per minute (rpm). Note unusual noises. For example, fan "squealing" may indicate belt slippage or loosening.

(3) Check for clogged or corroded fan wheel and casing.

(4) Check for clogged duct work:

(a) A high hood static pressure and low air flow may indicate an obstruction in the ductwork upstream of the hood static pressure measurement point. A low hood static pressure and low air flow may indicate a downstream duct obstruction.

(b) Open clean-out doors and inspect inside of duct.

(5) Check for closed or frozen dampers in ductwork.

(6) Check for clogged collector or air cleaning devices.

(7) Check for weather cap being placed too close to discharge stack. A $\frac{3}{4}$ duct diameter gap should be present between cap and stack. Current ventilation practice recommends NOT using weather caps.

(8) Check for poorly designed duct work:

(a) Short radius elbows ($1\frac{1}{2}$ to $2\frac{1}{2}$ duct diameters radius of curvature recommended).

(b) Branch entries into main duct at sharp angles. A 30° angle of entry with main is recommended. Duct diameter expansions should be provided.

(c) Duct is too small to carry air flow.

(d) Duct velocities excessively higher than the required transport velocity result in unnecessarily high static pressures.

(e) Rectangular duct work is less efficient than round.

(9) Check for high negative pressures as a result of lack of replacement air.

(a) Propeller fan systems are sensitive to even slight negative pressures. This may reduce air flow.

(b) High velocity drafts at door openings and windows usually result from lack of replacement air.

b. If hood air flow is satisfactory, but there is poor contaminant control:

(1) Check for cross drafts from

(a) Process air movement;

(b) Cooling fans, air supply systems; and

(c) Open doors and windows.

(2) Check for poor work practices.

(3) Check for an operation too far from the hood opening to maintain effective capture velocity.

(4) Check for poor hood enclosure (e.g., doors, baffles, or sides of hoods may have been removed).

(5) Check for misapplication of system to contaminant type (i.e., use of canopy hoods for control of toxic contaminants).

7. **CATEGORIES OF VENTILATION STANDARDS.** Navy Occupational Safety and Health (NAVOSH) ventilation standards may cover three general categories: health, fire and explosion, and special conditions. References 6-3 through 6-17 provide specific details.

a. Health-related standards. The standards in this category are intended to control exposures to below Navy OELs for air contaminants. Details are in References 6-10 through 6-14.

(1) Compliance should be achieved with the air flow specifications listed in health related standards.

(2) Ventilation is considered to be sufficient if personnel are not exposed to levels of air contaminants in excess of NAVOSH standards.

(3) In the event that air flow specifications are not achieved, but exposures are adequately controlled, a lower abatement priority or risk assessment code may be assigned to the ventilation system.

b. Fire and explosion related standards. The standards in this category, references 6-15 through 6-17, are intended to prevent fires and explosions. When working with ventilation systems of this type, the industrial hygienist must notify the cognizant gas-free engineer prior to conducting any tests or directing any adjustments.

(1) In the application of fire- and explosion-related ventilation standards, an operation has adequate ventilation when both of the following criteria are met:

(a) The requirement of a specific standard has been met (e.g., NAVOSH, NFPA).

(b) The concentration of flammable vapors is 25 percent or less of the lower explosive limit (LEL). Standards which are exceptions to the 25 percent of the LEL rule may be found in References 6-16 and 6-17. These allow no more than 10 percent of the LEL.

(2) To determine the concentration of flammable material, the industrial hygienist must do the following:

(a) Take and evaluate measurements from direct reading instruments (i.e., combustible gas indicators, detector tubes, etc.);

CAUTION: If explosive atmospheres are possible, equipment used must be rated as intrinsically safe for hazardous locations.

(i) If the reading on the combustible gas meter is greater than 25 percent of the LEL, immediate corrective action is necessary and the cognizant gas-free engineer must be immediately notified and consulted concerning such action.

(ii) Direct-reading instruments must also be used to determine if the ventilation system provides enough air to

reduce a flammable concentration to 25 percent or less of the LEL to all floor areas, pits or dead-air spots where flammable vapors may collect.

(b) Calculate the air volume required considering evaporation rates, etc., and the amount supplied to ensure that the flammable concentration does not exceed 25 percent of the LEL.

c. Special conditions standards. The standards in this category involve confined space operations and/or high hazard contaminants specifically designated in the standards. Professional judgment must be exercised in the evaluation of actual or potential hazards due to the high exposure levels which may be encountered in many of the referenced operations. Depending on the circumstances, specific training in "gas-free engineering" may be required to properly address confined space problems. . When working with ventilation systems of this type, the industrial hygienist must notify the cognizant gas-free engineer prior to conducting any tests or directing any adjustments. Factors which may be of assistance in determining whether an actual or potential hazard is present in a confined space operation include:

(1) The use of an oxygen meter and/or air sampling equipment;

(2) The size of the enclosure;

(3) The restriction of airflow;

(4) The potential for oxygen deficiency (i.e., displacement of air by the contaminant(s), depletion of oxygen caused by the operation, etc.);

(5) The toxicity of the substances to which the employee may be exposed. For example, the permissible exposure limit for propylene oxide is 20 ppm, the LEL is 2.3% or 23,000 ppm. The immediately dangerous to life and health (IDLH) concentration for propylene oxide is 400 ppm, less than 10% of the LEL;

(6) Employee interviews;

(7) Work practices; and

(8) Tendency of the environment to change (e.g., methane accumulation in sewer manhole).

8. DESIGN REVIEWS. Occupational health aspects must be considered, designed, and engineered into all facilities which

are acquired or constructed for use by Navy personnel. The cognizant industrial hygienist must participate in the review of plans and specifications for ventilation system construction, renovation and/or repair projects. Consult References 6-1, 6-2 and 6-9 for design criteria.

9. **REFERENCES.**

6-1 ACGIH. *Industrial Ventilation - A Manual of Recommended Practice*. 23rd Edition. Cincinnati: American Conference of Governmental Industrial Hygienists, 1998 (or latest edition).

6-2 NAVSEA 0938-LP-018-0010, *Heating, Ventilation, and Air Conditioning Design Criteria for Surface Ships of the U.S. Navy*.

6-3 OPNAVINST 5100.19 Series

6-4 OSHA. *Occupational Safety and Health Administration Technical Manual, Section II, Chapter 3, Ventilation Investigation*. OSHA Instruction TED 1.15. Washington, D.C.: U.S. Department of Labor. 1995.

6-5 NAVSEA S6470-AA-SAF-010, *Gas Free Engineering Program*

6-6 Code of Federal Regulations, Title 29, Part 1910.146, *Permit-required Confined Spaces*.

6-7 Code of Federal Regulations, Title 29, Part 1915, Subpart B, *Confined and Enclosed Spaces and Other Dangerous Atmospheres in Shipyard Employment*.

6-8 Naval Ships' Technical Manual, S9086-CH-STM-030, Chapter 074 (Volume 3), *Gas Free Engineering*.

6-9 MIL-HDBK-1003/17 Series, *Military Handbook, Industrial Ventilation Systems*

6-10 Code of Federal Regulations, Title 29, Part 1910.94, *Ventilation*.

6-11 Code of Federal Regulations, Title 29, Part 1910, Subpart Q, *Welding, Cutting and Brazing*.

6-12 Code of Federal Regulations, Title 29, Part 1926, section 57, *Ventilation*; section 154, *Temporary Heating Devices*; and section 353, *Ventilation and Protection in Welding, Cutting and Heating*.

6-13 Code of Federal Regulations, Title 29, Part 1915, section 32, *Toxic Cleaning Solvents*; and section 51, *Ventilation and Protection in Welding, Cutting and Heating*.

6-14 Code of Federal Regulations, Title 29, Part 1918.93, *Ventilation and Atmospheric Conditions*.

6-15 Code of Federal Regulations, Title 29, Part 1910, section 103, *Hydrogen*; section 104, *Oxygen*; section 106, *Flammable and Combustible Liquids*; section 107, *Spray Finishing Using Flammable and Combustible Materials*; section 108, *Dip Tanks Containing Flammable or Combustible Liquids*; and section 307, *Hazardous (classified) Locations*.

6-16 Code of Federal Regulations, Title 29, Part 1915, section 12, *Precautions and the Order of Testing Before Entering Confined and Enclosed Spaces and Other Dangerous Atmospheres*; section 13, *Cleaning and Other Cold Work*; section 35, *Painting*; and section 36, *Flammable Liquids*.

6-17 Code of Federal Regulations, Title 29, Part 1926.803, *Compressed Air*.