

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. Biological Safety Cabinet (BSC) - a specially constructed cabinet that is designed to protect workers and the environment from dangerous agents, especially bacteria and viruses. BSCs are more specifically defined in Reference 6-1.
 - c. Blast gate - a sliding valve used in ducts to create additional pressure loss in the duct and restrict flow.
 - d. 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.
 - e. Density Factor - the ratio of actual air density to standard air density ($= 0.075 \text{ lb/ft}^3$).
 - f. Entry loss - loss in pressure caused by air flowing into a duct or hood (in inches H_2O).
 - g. Fan - a mechanical device which physically moves air by creating a pressure differential.
 - h. Flange - a surface at and parallel to the hood face which provides a barrier to unwanted air flow from behind the hood.
 - i. Hood - a shaped inlet designed to capture contaminated air and conduct it into the exhaust duct system.
 - j. Hood Flow Coefficient - The ratio of 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.
 - k. 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.
 - l. Plenum - pressure equalizing chamber.
 - m. Replacement (make-up) air - the volume of outdoor air intentionally supplied to a building to replace air being exhausted.
 - n. 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 ("wg; in H₂O) and may be positive or negative.

- o. Total pressure - the algebraic sum of the velocity pressure and the static pressure. May be positive or negative (in H₂O).
- p. Velocity pressure - the kinetic energy 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 (in H₂O).

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. The digital manometers are an electronic devices that senses pressure changes. Its calibration is set within the electronics but their internal calibration must be verified periodically.
- (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 standard dry air with the density factor of 1 (defined as 70° F, Sea Level, 80° F dew point and static pressure (SP) > -20 "wg). For actual flow rate, derive and use the density factor in equation 6-2 in accordance with 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 standard duct volumetric flow rate using Equation 6-1. For actual duct flow rate, correct equation 6-1 by using the density factor in accordance with reference 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 7½ duct diameters downstream and 2½ 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) Hood Type: - (Slot, Booth, Canopy, Flanged and /or unflanged hood etc) 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.

NOTE: NMCPHC has posted guidance on entering ventilation measurements in DOEHS at <http://www.med.navy.mil/sites/nmcphc/Documents/industrial-hygiene/Navy-Guidance-and-Tips-for-using-DOEHS-IH-Ventilation.pdf>

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 Navy occupational safety and health (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).
- d. Biological Safety Cabinet (BSC) Ventilation Measurements. BUMED industrial hygienists are sometimes asked to measure BSC ventilation. Although IH personnel can make measurements that may be useful in identifying potentially malfunctioning BSCs (i.e., troubleshooting), they are usually neither trained nor equipped to "certify" a BSC.

(1) Field Certification of BSCs.

- (a) Frequency of Certification. The Centers for Disease Control have recognized expertise in the area of BSCs. CDC's guidance on BSC certification is stated in References 6-3 Appendix A as follows: "The operational integrity of a BSC must be validated before it is placed into service and after it has been repaired or relocated. Relocation may break the HEPA filter seals or otherwise damage the filters or the cabinet. Each BSC should be tested and certified at least annually to ensure continued, proper operation."
- (b) Industrial Hygiene Personnel Authorized to Certify a BSC. Industrial Hygiene personnel that certify BSCs shall be certified under the NSF International Field Certification of BSC Program. Details of that certification program can be obtained from NSF International via the internet at www.nsf.org.
- (c) Certification Procedures. Field testing of Class II Biological Safety Cabinets (BSCs), Types A1, A2, B1, and B2, must be conducted in compliance with the requirements of Reference 6-5, Annex F, using specialized equipment and procedures. Additional information is available in Reference 6-3, Appendix A.
- (d) Contracting versus In-House Certification of BSCs. Due to the cost of the training and required specialized test equipment (e.g., aerosol photometer for filter testing, aerosol generator, etc.) and the ready availability of certified personnel who contract to provide Field Certification of BSCs, it is unlikely to be cost effective for BUMED IH personnel to provide Field Certification of BSCs in CONUS. IH Program Offices that are considering developing the capability for Field Certification of BSCs should consult with their Regional Industrial Hygiene staff before making a commitment.

(2) BSCs Used for Handling Hazardous Drugs and other Pharmacy BSCs. Reference 6-6 establishes requirements for certification of BSCs used for handling Hazardous Drugs. Chapter 21 of Reference 6-7 establishes requirements for certification of pharmacy BSCs in general. Pharmacy BSCs shall be maintained in accordance with those two references and usually require recertification every six months.

(3) Requests for Evaluation of BSCs. Due to their expertise, IHS may be called upon to investigate airflow or filter issues associated with BSCs. If the IH responding to such a request is currently certified by the NSF to perform field certification of BSCs, he/she may act within the scope of that NSF certification. If the IH performing the work is NOT certified by the NSF to perform field certification of BSCs, he/she may comply with the request if the following actions are taken:

- (a) Do NOT place any labels or stickers of any type either on the BSC or in the area of the BSC that document the measurements made. This is to prevent such items from being misinterpreted as a "certification" label.
- (b) Ensure that the written report of such "troubleshooting" assistance makes it perfectly clear that the work performed was not a "certification" of the BSC.

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.** NAVOSH ventilation standards may cover three general categories: health, fire and explosion, and special conditions. References 6-7 through 6-21 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 6-14 through 6-18.
 - (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 6-19 through 6-21 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, National Fire Protection Association (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 6-20 and 6-21. 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.);

9. REFERENCES.

- 6-1 American Conference of Governmental Industrial Hygienists (ACGIH). *Industrial Ventilation - A Manual of Recommended Practice*. 28th Edition. Cincinnati: American Conference of Governmental Industrial Hygienists, 2013 (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 Centers for Disease Control and Prevention (CDC): The National Institutes of Health (NIH). *Biosafety in Microbiological and Biomedical Laboratories*, 5th Edition. Washington, DC: U. S. Government Printing Office, 2007 (or latest edition).
- 6-4 NSF/ANSI 49-2007. *Class II (laminar flow) biosafety cabinetry*. NSF International, Ann Arbor.
- 6-5 BUMEDINST 6570.3 Series
- 6-6 Manual of the Medical Department (MANMED), NAVMED -117
- 6-7 OPNAVINST 5100.19 Series
- 6-8 Occupational Safety and Health Administration (OSHA). *Occupational Safety and Health Administration Technical Manual*, Section III, Chapter 3, Ventilation Investigation. OSHA Instruction TED 01-00-015. Washington, D.C.: U.S. Department of Labor. Available at <https://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_3.html>
- 6-9 NAVSEA S6470-AA-SAF-010, *Gas Free Engineering Program*.
- 6-10 Code of Federal Regulations, Title 29, Part 1910.146, *Permit-required Confined Spaces*.
- 6-11 Code of Federal Regulations, Title 29, Part 1915, Subpart B, *Confined and Enclosed Spaces and Other Dangerous Atmospheres in Shipyard Employment*.
- 6-12 Naval Ships' Technical Manual, S9086-CH-STM-030, Chapter 074 (Volume 3), *Gas Free Engineering*.
- 6-13 Unified Facilities Criteria(UFC), Industrial Ventilation, 25 October 2004
- 6-14 Code of Federal Regulations, Title 29, Part 1910.94, *Ventilation*.
- 6-15 Code of Federal Regulations, Title 29, Part 1910, Subpart Q, *Welding, Cutting and Brazing*.
- 6-16 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*.
- 6-17 Code of Federal Regulations, Title 29, Part 1915, section 32, *Toxic Cleaning Solvents*; and section 51, *Ventilation and Protection in Welding, Cutting and Heating*.
- 6-18 Code of Federal Regulations, Title 29, Part 1918.94, *Ventilation and Atmospheric Conditions*.

6-19 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*.

6-20 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*.

6-21 Code of Federal Regulations, Title 29, Part 1926.803, *Compressed Air*.