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. Hazardous atmospheres are controlled by two primary methods; dilution ventilation, the supply of uncontaminated air to dilute the contaminated air to safe levels, and local exhaust ventilation, the removal of contaminated air at its source. Dilution ventilation is limited to when the contaminant is of low toxicity, generated at low levels and there is sufficient distance between the source of generation and the individual. By design, local exhaust ventilation precisely controls hazardous atmospheres allowing individuals to perform tasks in close proximity to the source of generation. This chapter focuses on the inspection and evaluation of local exhaust ventilation systems.

2. Definitions

a. Aerosols. Suspended liquid droplets formed by the condensation of water or other chemicals. Typically generated during machining and paint spraying operations. Aerosols in the range of 0.1 to 200 micrometers are frequently called fog or mist.

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

c. Biological Safety Cabinet (BSC). A specially constructed cabinet that is designed to protect workers and the environment from infectious agents and toxins (IAT).

d. Blast Gate. A sliding valve used in ducts to create additional pressure loss in the duct and restrict flow.

e. 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.

f. Density Factor (*df*). The ratio of actual air density to standard air density

$$\left(df = \frac{\rho_{actual}}{0.075\,\mathrm{lbm/ft^3}}\right)$$

g. Downstream. In industrial ventilation downstream refers to the direction in the system that is away from the source of generation (e.g., the fan is downstream of the hood).

h. Entry Loss. Loss in pressure caused by air flowing into a duct or hood (in inches H_2O).

i. Fan. A mechanical device which physically moves air by creating a pressure differential.

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

k. Fumes. Very small particles formed through vaporization of solid materials. Fumes are less than 1 micrometer in size.

l. Hood. A shaped inlet designed to capture contaminated air and conduct it into the exhaust duct system. There are two main categories of hoods:
   (1) Enclosing Hood. Partially or fully encloses the contaminant at its source of generation. (e.g., paint spray booth or laboratory hood).
   (2) Capturing Hood. Captures the contaminant in front of the face of its opening. Example: welding hood or slotted hood. When the contaminant is conveyed towards the hood by thermal buoyancy or momentum the capturing hood is referred to as a receiving hood (e.g., canopy hood on a furnace).

m. Hood Flow Coefficient. Also referred to as the Coefficient of Entry, this is 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.

n. Local Exhaust Ventilation (LEV). An engineered ventilation system that captures and removes contaminants at the source before they can be diluted into the ambient air of the work space.

o. Lower Explosive Limit (LEL). The lower limit of flammability or explosiveness 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˚ Fahrenheit (F). Above this temperature, it should be decreased by a factor of 0.7 since combustible or flammable liquids vaporize at a faster rate with higher temperatures.

p. Particulates. Particles that can remain suspended in air due to their size. Airborne particulates are typically below 500 micrometers in size.

q. Plenum. Pressure equalizing chamber.

r. Replacement (make-up) Air. The volume of outdoor air intentionally supplied to a building to replace air being exhausted.

s. Standard Air. Refers to the density of air = 0.075 lb/ft^3 at 70˚F, sea level and no moisture present.

t. Static Pressure (SP). 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) and may be positive or negative with respect to the atmospheric pressure.

u. Total Pressure (TP). The algebraic sum of the velocity pressure and the static pressure. Measurements should be taken upstream and perpendicular to the direction of flow so the airstream impacts the probe opening. It is usually expressed in "wg and may be positive or negative with respect to the atmospheric pressure.

v. Upstream. In an industrial ventilation upstream refers to the direction in the system that is towards the source of generation (e.g., the hood is upstream of the fan).

w. Vapors. Gases at room temperature usually formed form the evaporation of volatile liquids.

x. Velocity (V). In terms of ventilation this is the distance air has traveled per unit of time. Velocity is usually expressed in feet per minute (fpm).

y. Velocity Pressure (VP). The kinetic energy pressure in the direction of flow necessary to cause a fluid at rest to flow at a given velocity. Attained indirectly by subtracting SP from TP. Measurements should be taken upstream and perpendicular to the direction of flow so the airstream impacts the probe opening. It is usually expressed in "wg and is always positive.

z. Volumetric Flow Rate (Q). The measurement of the volume of fluid passing a specific location per unit of time. Flow rate is typically expressed as cubic feet per minute (cfm or ft^3/min).

3. Instrumentation

a. Manometer. 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 manometer is an electronic device that senses pressure changes. Its calibration is set within the electronics but their internal calibration must be verified periodically.

b. Pitot Tube. 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. When both tubes of the pitot tube are connected to a manometer, the VP is measured.

A standard pitot tube is used when the air stream is relatively free of dust or condensing vapors. When heavy dust or moisture is in the air stream an S-type pitot tube may be needed as its larger openings resist plugging. The S-type pitot tube must be calibrated against a standard pitot tube and VP must be corrected to actual VP.

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 as duct velocity becomes low the accuracy of the manometer and pitot tube combination decreases. Reference 6-1 recommends that the manometer and pitot tube combination be used when velocity is greater than 1500 fpm.

c. Static Pressure Probe. The SP probe resembles a small pitot tube but with a few differences. The SP probe is a single bent tube usually with a magnetic base on one end and a bullet shaped tip on the other end. There is no opening on its bullet shaped end rather a set of holes or ports (usually four) on the wall of the tube. The SP probe is not branched on one end, as is the pitot tube, therefore allowing attachment of only one tube. As the name implies it only allows measurement of static pressure.

d. Thermal (heated wire/element) Anemometer. 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. The probe can be used directly to measure air velocity in open spaces and at air exhaust and supply openings.

   Attachments are available to measure static pressure. 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. Battery charging and maintenance are extremely important and the battery voltage must be checked prior to instrument use. Reference 6-1 recommends that the thermal anemometer be used within the range of 30-400 fpm. Initial and periodic calibration are needed.

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

e. Swinging Vane Anemometer (vaneometer). Indicates air velocity as a function of the pressure exerted by the air stream on a swinging vane which is under tension and calibrated. Includes a variety of fittings which can be used to measure static pressure and a wide range of linear velocities.

   Dust, moisture or corrosive material in the atmosphere present a problem since air passes through the meter. The minimum velocity is 50 feet per minute unless adapted for a lower range. The instrument needs initial and periodic calibration.

   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.

f. Aneroid Gauge. Operates without liquid to measure pressure. The best known type is the magnehelic gauge. The magnehelic gauge transmits the change in air pressure from a diaphragm to an indicating pointer by way of magnetic linkage. Because there is no liquid involved there is no concern of evaporation, freezing or toxicity. Magnehelic gauges provide a wide range of measurement, they’re easy to read, portable and rugged. While they can be mounted in any position rezeroing is needed and periodic calibration checks should be performed as to the manufacturer’s suggestion.

4. Evaluation Methods

See reference 6-1 for a complete discussion on where to take measurements, the number of readings necessary, etc.

a. Accounting for Density Factor. The standard assumption is that there is an altitude of 0 ft., a temperature of 70˚F and an atmospheric pressure of 407 wg or 1 atm. If these environmental conditions do not exist at the site they may need to be accounted for as variances can significantly affect the calculation of volumetric flow rate. Since the 27th edition of the ACGIH Industrial Ventilation Manual, reference 6-1, it is recommended that density be considered for almost all systems.

(1) df_e = elevation density factor

$$df_e = [1-((6.73)(10^{-6})(z))]^{5.258}$$

Equation 6-1

Where:
z = Elevation in feet (ft)

NOTE: Elevation does not need to be considered in shipboard ventilation.

(2) df_t = temperature density factor

$$df_t = 530/(T + 460)$$

Equation 6-2

Where:
T = Temperature in Fahrenheit

(3) df_p = duct pressure density factor

$$df_p = (407 + SP)/407$$

Equation 6-3

Where:
SP = System static pressure, “wg

(4) df_m = moisture density factor

$$df_m = (1 + \omega)/(1 + 1.607\omega)$$

Equation 6-4

Where:
ω = Absolute moisture, lbm
water/pound dry air

NOTE: If air temperature is below 100˚F, correction for humidity is minimal and can be ignored for most industrial ventilation systems, per reference 6-1.

(5) Total density factor

$$df = (df_e)(df_t)(df_p)(df_m)$$

Equation 6-5

b. Pitot Tube Traverse Method for Round Ducts. Make two traverses across the diameter of the duct at right angles to each other. 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. 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). When these distances of straight duct are not available, use a schematic drawing to note the disturbance producing device, and distance between the pitot traverse and the device, per reference 6-2. Measure velocity pressure at the center of annular rings of equal area.

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.

Convert all velocity pressure measurements to velocity using Equation 6-6.

$$V = 4005\sqrt{\left(\frac{VP}{df}\right)}$$

Equation 6-6

Where:
V = Velocity (ft/min or fpm)
VP = Velocity pressure (”wg)
df = Density factor or ratio of actual density to standard density

NOTE: A density factor of 1 refers to standard dry air. For actual flow rate, derive and use the density factor in Equation 6-6 in accordance with reference 6-1.

c. Pitot Traverse Method for Square or Rectangular Ducts. Convert all velocity pressure measurements to velocity using Equation 6-6. Determine the average duct velocity and calculate the standard duct volumetric flow rate using Equation 6-7.

d. Volumetric Flow Rate. Volumetric flow rate is essential to evaluating the performance of an industrial ventilation system. Flow rate is not measured directly rather is determined by obtaining the product of velocity and area measurements. Calculate total volumetric flow rate using Equation 6-7.

$$\mathrm{Q} = \mathrm{VA}$$

Equation 6-7

Where:
Q = Volumetric flow rate (ft^3/min or cfm)
V = Average air velocity (ft/min or fpm)
A = Cross sectional area (ft^2)

e. Static Pressure Measurements. The preferred method of measuring static pressure is the use of a manometer and pitot tube or static pressure probe. SP measurements are obtained by connecting a tube between the perpendicular branch of the pitot tube and the negative side of the manometer. Static pressure may also be measured by connecting the manometer to an opening in the wall of the duct.

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. 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.

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(1) SP can be either a positive or negative value. As the value of SP goes up the value of VP goes down and vice versa. SP relates to VP and TP in the following equation:

$$\mathrm{TP} = \mathrm{SP} + \mathrm{VP}$$

Equation 6-8

(2) In exhaust ventilation SP should always be a negative value upstream of the fan and a positive value downstream of the fan. SP will increase across the fan and decrease across components, such as dampers, coils and air cleaners. VP should always be positive. Contradictions to these values indicate system problems, see Section 6, Trouble Shooting.

(3) Hood static pressure, SP_h, can be used to estimate volumetric flow rate through the hood by the following equation:

$$Q_{act} = 4005 \text{ x } C_e \text{ x } A \text{ x } (SP_h/df)^{0.5}$$

Equation 6-9

Where:
Q_{act} = Actual volumetric flow rate, cfm
C_e = Hood flow coefficient (refer to reference 6-1, Hood Entry Loss Factors)
A = Area of duct or opening at test location, ft^2
SP_h = Hood static pressure, “wg
df = Density factor

f. Face Velocity Traverse Method. Performing face velocity traverses at a hood is prone to a high degree of error due to the inaccuracies of instruments and variability between technicians as per reference 6-1. Whenever possible face velocity of a hood should be determined by performing pitot tube traverses on the duct connected to the hood and determining the cross-sectional area of the hood face. Reference 6-1, provides specific hood airflow equations according to the hood type in consideration. Face velocity traverses may be necessary when:
(1) Duct is inaccessible.
(2) Pitot tube traverses are not possible.
(3) Duct velocity is < 1500fpm, per reference 6-1.

Determine the area of the open face of the booth or hood. Measure air velocity at several points across the face of the booth or hood with a thermal, rotating vane or swinging vane anemometer, 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.

g. Capture Velocity Measurements. The proper capture velocity ensures that the designed flow rate is being achieved at a given distance to effectively prevent exposure. Capture velocity can be calculated by using hood design specific equations obtained from reference 6-1, Hood Airflow Equations. When the conditions within the space or work habits have been observed to influence the intent of the ventilation design, direct measurement should be conducted with an anemometer and compared to the calculated values.
(1) Measure air velocity at the point of contaminant generation. Document the distance from the hood. Factors affecting capture velocity which should be documented:
(a) Flanges - decrease the flow rate required 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.

(2) 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.

(3) 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 Surveillance

Ventilation surveillance is based on a process of deductive reasoning to establish a monitoring program suited to ensuring the performance of a system prevents inadvertent exposure to personnel. Refer to Section 5.i., for supplemental guidance on shipboard industrial ventilation surveys.

a. <u>Identification.</u> Ventilation systems must be first identified as needing monitoring. Those identified should be documented in the Defense Occupational Environmental and Health Readiness System Industrial Hygiene (DOEHRS-IH). Specific guidance on entering ventilation data into DOEHRS-IH can be found in Chapter 21 of the DOEHRS-IH Student Guide/User Manual. All changes to the ventilation system, such as, maintenance, process changes, inspection results, etc., should be documented in DOEHRS-IH.

To identify ventilation systems that need monitoring there should be a focus on applicable regulatory requirements, from both Title 29 of the Code of Federal Regulations (OSHA) and Title 40 of the Code of Federal Regulations (EPA), and on inherent risks to employees by contaminants in the areas of:

(1) Toxicity
(2) Flammability
(3) Physical hazard and a likelihood of rapid system degradation due to:
(4) Contaminant characteristics
(5) System capability
(6) System operability

b. <u>Historical Review.</u> Performing a historical review of a ventilation system is a necessary step to question if the design ever met the intent of the system to control the hazard during operation. Poor design and/or maintenance of a ventilation system may contribute to exposure if:

(1) A leak in the system causes a concentrated release of contaminant.
(2) The hood design moves contaminant towards the worker's breathing zone rather than away before being exhausted.
(3) Poor design and/or installation promotes misuse and incorrect maintenance.

c. Visual Inspection. Perform a thorough visual inspection of the ventilation system to reveal any alterations to the design, tampering with blast gates or dampers, poorly sealed cleanout doors, equipment or process changes, corrosion, physical flaws, etc.

d. Test Locations. Determine the necessary number of SP and VP test locations within the ventilation system for evaluation. Compliance testing may require the accuracy of two insertion points, perpendicular to one another for each VP test location. For routine surveillance one insertion point is sufficient, per reference 6-1, Appendix-C. If an insertion point has not been established for a determined location a hole should be drilled (not punched) in the duct or hood in reference to the diameter of the pitot tube. Holes should be closed with plugs after use. Refer to section 4. Evaluation Methods, parts c. and d. for using a pitot tube with round and rectangular duct.

e. Field Measurements. To properly calculate the performance of the ventilation system a series of measurements must be taken. These measurements include:
   (1) Barometric pressure. This can be measured directly by way of a barometer or indirectly through a local weather station. This measurement represents the ambient atmospheric condition.
   (2) Dry bulb temperature. Moisture content only needs to be measured if water is introduced into the system, per reference 6-1.
   (3) Duct and hood dimensions
   (4) Duct velocity pressure traverses
   (5) Static pressure
   (6) Capture velocity

   Using the determined density factors and the measured VP calculate velocity using Equation 6-6. Calculate volumetric flow rates for the test locations using Equations 6-7, 6-9 and hood airflow equations from reference 6-1.

f. Baseline Comparison. To determine the ongoing performance status of a ventilation system a comparison must be continually made to the baseline survey. A baseline survey should reflect measurements taken shortly after commissioning of the system to verify performance after installation is complete. Baseline comparisons should use +/- 10% of design airflow or face velocity, or +/- 20% of baseline static pressure as the corrective action range, per reference 6-1.

   NOTE: Do not solely use design criteria as the baseline. Design criteria are theoretical calculations used to determine how the industrial ventilation system should perform in the absence of actual ventilation measurements and air sampling.

   If a baseline survey is not available then one must be developed through professional judgement, recommended practices, mathematical modeling, permit applications and supporting air sampling data.

Establishing a baseline:

(1) Determine a theoretical performance criteria based on technical resources, drawings, manuals, modeling, etc.
(2) Gather static pressure measurements at all test points and airflow measurements at strategic test points on a weekly basis for 3 months to develop trending data. This is referred to as the "Startup Learning Period," per reference 6-1.
(3) Obtain exposure monitoring (air samples) data to show confidence in the ventilation control.
(4) Assign corrective actions during this time to bring the system within the determined baseline. Use +/- 10% of design airflow or face velocity, or +/- 20% of baseline static pressure as the corrective action range, per reference 6-1.
(5) Establish visual controls (e.g., Magnehelic gauges or other static pressure gauges), cleanout/inspection schedules and documentation of problem areas.
(6) After three months of biweekly measurements and appropriate corrective actions to maintain the baseline, reduce the frequency of measurements to monthly and continue to develop trending data.
(7) Following three months of monthly inspections that demonstrate minor deviation in system performance increase monitoring to a quarterly basis.
(8) Once a year of measurements has been obtained and the trending data indicates both performance consistency and an active maintenance program capable of ensuring performance this information may be used as the established baseline of the system.

g. <u>Survey Periodicity.</u> Measuring and assessing the need for and adequacy of ventilation systems is part of performing baseline and periodic industrial hygiene surveys. The frequency of system-wide monitoring should be conducted at least annually and whenever there has been an alteration or repair to the system, per reference 6-1. Annual ventilation measurement is a best practice but there are cases where the industrial hygienist may not be able to readily perform annual ventilation checks (e.g., afloat commands). Measurements should include static pressure and volumetric flow at each hood and branch end, as well as, static pressure at fan inlet and across air cleaning device. In addition, the survey should include inspecting all the ductwork and other equipment for external damage, abrasion and corrosion, per reference 6-3. A comparison between the current monitoring results and the baseline and/or previous surveys should be consistently made to develop trending data. A comprehensive checklist of the industrial ventilation system during specific intervals can be found in reference 6-4. The need for ventilation system monitoring is likely to be more frequent if any of the conditions below apply:

(1) OSHAs Substance Specific Standard Requirements. Some OSHA substance specific standards require periodic ventilation measurement and evaluation. The periodicity (annual, semi-annual, quarterly, etc.) is often linked to the measured exposures in relation to the standard's Action Level (AL) or Permissible Exposure Limit (PEL) of air concentrations for personal inhalation exposures.

(2) Changes in Production, Process, or Control. Some OSHA substance specific standards specify timeframes within which to measure and re-evaluate a ventilation system after such changes occur.
(3) System Problems or Maintenance Issues (e.g. - plugging or leaks), per reference 6-1.
(4) Frequent plugging or leaks indicate the need for corrective actions, which should be immediately followed by system measurements.
(5) Air sampling data is needed to understand the potential elevated contaminant levels outside of the system.
(6) Survey frequency should be conducted as frequent as needed to assess performance and predict plugging or leaks before they occur.
(7) The contaminant is highly toxic and has poor warning properties, per reference 6-1.
(8) The process must be shut down if the system fails, per reference 6-1.
(9) Exposure monitoring results indicate the concentration of emitted contaminants in the workroom air routinely exceed 10% of the occupational exposure limit, or odor threshold, per references 6-5 and 6-6.
(10) Manufacturer's specifications, per reference 6-4.
(11) An OPNAVINST or other naval guidance document dictates system or procedural requirements.
(12) Specific provisions as required by the National Fire Protection Association (NFPA) and/or building and fire codes imposed by local or state authorities, per reference 6-5.
(13) In the absence of a baseline survey.

h. Industrial Ventilation Survey Reports. The information gathered in the survey should be used to develop or continue to develop a trend of data that promotes predictive maintenance to optimize performance of the ventilation system. 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 ft^3/min, static pressure rating in "wg 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.

i. Shipboard Industrial Ventilation Surveys. The information gathered in the survey should be used to develop or continue to develop a trend of data that promotes predictive maintenance to optimize performance of the ventilation system. Specific ship class HVAC and industrial ventilation design criteria should be obtained for all ventilation surveys. The ventilation design criteria for all US Naval vessels, including Military Sea Lift Command ships can be obtained from the NMCPHC website under Industrial Hygiene, Specific Ship Ventilation Design Criteria. The ship's repair office should also be consulted during the course of the survey to determine if any repairs to the ventilation system or modifications to the space have occurred during availabilities.
(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 (IHO) 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).

j. BSC Ventilation Measurements. The BSCs referred to in this section are defined in reference 6-7 as being within DoD laboratories rated at biosafety level (BSL)-2, animal biosafety level (ABSL)-2, and higher where work with IAT is present (not including clinical laboratories).

NOTE: Industrial hygienists can make measurements that may be useful in identifying potentially malfunctioning BSCs (i.e., troubleshooting), but they are usually neither trained nor equipped to certify a BSC. Follow the guidance and requirements of references 6-7 through 6-11 which provide specific details.

(1) Field Certification of BSCs.

(a) Frequency of Certification. Per reference 6-7, "Certify BSCs after installation, before use, annually thereafter, and whenever there is maintenance, repair, filter change, movement of cabinets, and changes to the room that may affect the BSC performance." The Centers for Disease Control (CDC) have recognized expertise in the area of BSCs. CDC's guidance on BSC certification is stated in reference 6-8 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 need to be properly trained and equipped. Especially in CONUS, such personnel also need to be accredited under the NSF International Field Certification of BSC Program. Details of that program can be obtained from NSF International. Per reference 6-7, "Ensure certification and testing are performed by experienced, qualified personnel. It is strongly recommended that, whenever possible, accredited field certifiers be used to test and certify BSCs."

(2) Certification Procedures. Per reference 6-7, "Ensure Class II BSCs conform to and are certified to meet National Sanitation Foundation/American National Standards Institute (ANSI) Standard 49…for the applicable type of cabinet. " Field testing of Class II BSCs, Types A1, A2, B1 and B2, are to be conducted in compliance with the specifications of reference 6-9, Annex F, using specialized equipment and procedures. Additional information is available in reference 6-8, Appendix A.

(3) 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) and with the ready availability of certified personnel who contract to provide field certification of BSCs, it is unlikely to be cost effective for BUMED industrial hygiene personnel to provide field certification of BSCs in CONUS. Industrial hygiene 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.

(4) BSCs Used for Handling Hazardous Drugs and other Pharmacy BSCs. Reference 6-10 establishes requirements for certification of BSCs used for handling hazardous drugs. Chapter 21 of reference 6-11 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.

(5) Requests for Evaluation of BSCs. Due to their expertise, industrial hygienists may be called upon to investigate airflow or filter issues associated with BSCs. If the industrial hygienist responding to such a request is currently certified by NSF International to perform field certification of BSCs, the industrial hygienist may act within the scope of that certification. If the industrial hygienist performing the work

is NOT currently certified by NSF International to perform field certification of BSCs, the industrial hygienist 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. Troubleshooting

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:
   (5) 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.
   (6) Open clean-out doors and inspect inside of duct.
   (7) Check for closed or frozen dampers in ductwork.
   (8) Check for clogged collector or air cleaning devices.
   (9) Check for weather cap being placed too close to discharge stack. A ¾ duct diameter gap should be present between cap and stack. Current ventilation practice recommends NOT using weather caps.
   (10) Check for poorly designed duct work:
   (11) Short radius elbows (1½ to 2½ duct diameters radius of curvature recommended).
   (12) Branch entries into main duct at sharp angles. A 30□□angle of entry with main is recommended. Duct diameter expansions should be provided.
   (13) Duct is too small to carry air flow.
   (14) Duct velocities excessively higher than the needed transport velocity result in unnecessarily high static pressures.
   (15) Rectangular duct work is less efficient than round.
   (16) Check for high negative pressures as a result of lack of replacement air.
   (17) Propeller fan systems are sensitive to even slight negative pressures. This may reduce air flow.
   (18) 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 process air movement; cooling fans, air supply systems; and 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 6-12 through 6-26 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 6-12 through 6-23.
   (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 6-24 through 6-26 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 6-25 and 6-26. 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.

(b) 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.

(3) 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.

(4) 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 (e.g., displacement of air by the contaminant(s), depletion of oxygen caused by the operation).

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;

(1) Employee interviews
(2) Work practices
(3) 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, 6-18, 6-26 and specific NAVSEA HVAC Design Criteria.

9. References

6-1. American Conference of Governmental Industrial Hygienists (ACGIH). Industrial Ventilation - A Manual of Recommended Practice. (Note: two volumes - for Design and for Operation and Maintenance).Cincinnati: American Conference of Governmental Industrial Hygienists, (latest edition).

6-2. Unified Facilities Guide Specifications, Division 23 – Heating, Ventilating, and Air Conditioning (HVAC), Section 23 08 01.00 20, Testing Industrial Ventilation Systems, April 2006.

6-3. American National Standards Institute (ANSI) and American Industrial Hygiene Association (AIHA). ANSI/AIHA Z9.2-2012 – American National Standard – Fundamentals Governing the Design and Operation of Local Exhaust Ventilation Systems. Falls Church, VA: American Industrial Hygiene Association, 2012.

6-4. NAVOSH TM-2199-ENV, Industrial Ventilation Systems Operation and Maintenance Manual – Field Manual.

6-5. American National Standards Institute (ANSI) and American Industrial Hygiene Association (AIHA). ANSI/AIHA Z9.2-2012 – American National Standard – Fundamentals Governing the Design and Operation of Local Exhaust Ventilation Systems. Falls Church, VA: American Industrial Hygiene Association, 2012.

6-6. EPA/600/R-92/047, Reference Guide to Odor Thresholds for Hazardous Air Pollutants Listed in the Clean Air Act Amendments of 1990.

6-7. DODM 6055.18 Safety Standards for Microbiological and Biomedical Laboratories, latest edition.

6-8. 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, 2009 (or latest edition).

6-9. NSF/ANSI 49-2018 (or latest) Biosafety Cabinetry: Design, Construction, Performance, and Field Certification, Annex F

6-10. BUMEDINST 6570.3 Series

6-11. Manual of the Medical Department, NAVMED P117 Series

6-12. OPNAVINST 5100.19 Series

6-13. 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.

6-14. NAVSEA S6470-AA-SAF-010, Gas Free Engineering Program.

6-15. Code of Federal Regulations, Title 29, Part 1910.146, Permit-required Confined Spaces.

6-16. Code of Federal Regulations, Title 29, Part 1915, Subpart B, Confined and Enclosed Spaces and Other Dangerous Atmospheres in Shipyard Employment.

6-17. Naval Ships' Technical Manual, S9086-CH-STM-030, Chapter 074 (Volume 3), Gas Free Engineering.

6-18. Unified Facilities Criteria (UFC), Industrial Ventilation, 25 October 2004

6-19. Code of Federal Regulations, Title 29, Part 1910.94, Ventilation.

6-20. Code of Federal Regulations, Title 29, Part 1910, Subpart Q, Welding, Cutting and Brazing.

6-21. 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.

6-22. Code of Federal Regulations, Title 29, Part 1915, section 32, Toxic Cleaning Solvents; and section 51, Ventilation and Protection in Welding, Cutting and Heating.

6-23. Code of Federal Regulations, Title 29, Part 1918.94, Ventilation and Atmospheric Conditions.

6-24. 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.

6-25. 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.

6-26. NAVSEA 0938-LP-018-0010, Heating, Ventilation, and Air Conditioning Design Criteria for Surface Ships of the U.S. Navy.