CHAPTER 30

INDUSTRIAL LOCAL EXHAUST SYSTEMS

INDUSTRIAL exhaust ventilation systems collect and remove airborne contaminants consisting of particulate matter (dust, fumes, smokes, fibers), vapors, and gases that can create an unsafe, unhealthy, or undesirable atmosphere. Exhaust systems can also salvage usable material, improve plant housekeeping, or capture and remove excessive heat or moisture.

Local Exhaust Versus General Ventilation

Local exhaust ventilation systems can be the most cost-effective method of controlling air pollutants and excessive heat. For many manual operations, capturing pollutants at or near their source is the only way to ensure compliance with threshold limit values (TLVs) in the worker's breathing zone. Especially where recirculation is not used, local exhaust ventilation optimizes ventilation airflow, thus optimizing system costs.

In some industrial ventilation designs, the main emphasis is on filtering air captured by local exhausts before evacuating it to the outdoors or returning it to the production space. As a result, these systems are evaluated by filter efficiency. However, if only a small percentage of emissions are captured, the degree of separation efficiency becomes almost irrelevant.

The pollutant-capturing efficiency of local ventilation systems depends on hood design, the hood's position relative to the source of contamination, and exhaust airflow. The selection and position of the hood significantly influence initial and operating costs of both local and general ventilation systems. In addition, poorly designed and maintained local ventilation systems can cause deterioration of building structures and equipment, negative health effects, and decreased worker productivity.

No local exhaust ventilation system is 100% effective in capturing pollutants and/or excess heat. In addition, installation of local exhaust ventilation system may not be possible in some circumstances, because of the size or mobility of the process. In such situations, general ventilation is needed to dilute pollutants and/or excess heat. Air supplied by the general ventilation system is usually heated and can be air conditioned. Supply air replaces air extracted by local and general exhaust systems and improves comfort conditions in the occupied zone.

Chapter 12, Air Contaminants, of the 2001 *ASHRAE Handbook—Fundamentals* covers definitions, particle sizes, allowable concentrations, and upper and lower explosive limits of various air contaminants. Chapter 29, Ventilation of the Industrial Environment, of this volume, Goodfellow and Tahti (2001), and Chapter 1 of *Industrial Ventilation: A Manual of Recommended Practice* (American Conference of Governmental Industrial Hygienists [ACGIH] 2001) detail steps to determine air volumes necessary to dilute contaminant concentration using general ventilation.

Sufficient makeup air must be provided to replace air removed by the exhaust system. If replacement air is insufficient, the building pressure is negative relative to local atmospheric pressure. Negative pressure allows air to infiltrate through open doors, window cracks, and combustion equipment vents. As little as 12 Pa negative pressure can cause drafts and might cause backdrafts in combustion vents, thereby creating a potential health hazard. Negative plant pressure can also cause excessive energy use. If workers near the plant perimeter complain about cold drafts, unit heaters are often installed. Heat from these units is usually drawn into the plant interior by the infiltration air velocity, overheating the interior. Too often, this overheating is addressed by exhausting more air from the interior, causing increased negative pressure and more infiltration. Negative plant pressure reduces the exhaust volumetric flow rate because of increased system resistance, which can also decrease local exhaust efficiencies. Wind effects on building balance are discussed in Chapter 16, Airflow Around Buildings, of the 2001 *ASHRAE Handbook—Fundamentals.*

Positive-pressure plants and balanced plants (those with equal exhaust and replacement air rates) use less energy. However, if there are clean and contaminated zones in the same building, surplus pressure in contaminated zones could cause contaminants to move into clean zones.

Exhaust system discharge may be regulated under various federal, state, and local air pollution control regulations or ordinances. These regulations may require exhaust air treatment before discharge to the atmosphere. Chapter 25 of the 2000 *ASHRAE Handbook—HVAC Systems and Equipment* provides guidance and recommendations for discharge air treatment.

LOCAL EXHAUST FUNDAMENTALS

System Components

Local exhaust ventilation systems typically consist of the following basic elements:

- Hood to capture pollutants and/or excessive heat
- Ducted system to transport polluted air to air cleaning device or building exhaust
- Air-cleaning device to remove captured pollutants from the airstream for recycling or disposal
- Air-moving device (e.g., fan or high-pressure air ejector), which provides motive power to overcome system resistance
- Exhaust stack, which discharges system air to the atmosphere

System Classification

Contaminant Source Type. Knowledge of the process or operation is essential before a local exhaust hood system can be designed.

Hood Type. Exhaust hoods are typically round, rectangular, or slotted to accommodate the geometry of the source. Hoods are either enclosing or nonenclosing (Figure 1). **Enclosing hoods** provide more effective and economical contaminant control because their exhaust rates and the effects of room air currents are minimal compared to those for nonenclosing hoods. Hood access openings for inspection and maintenance should be as small as possible and out of the natural path of the contaminant. Hood performance (i.e.,

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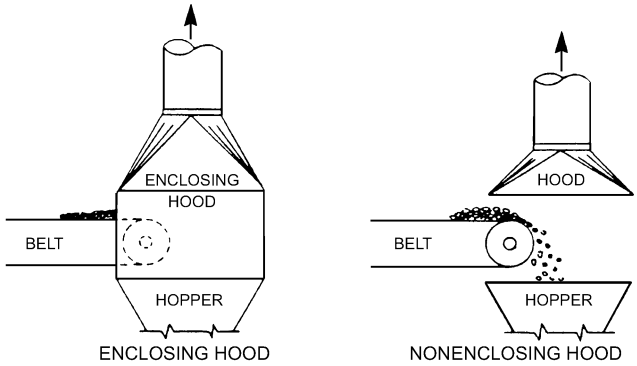

Fig. 1 Enclosing and Nonenclosing Hoods

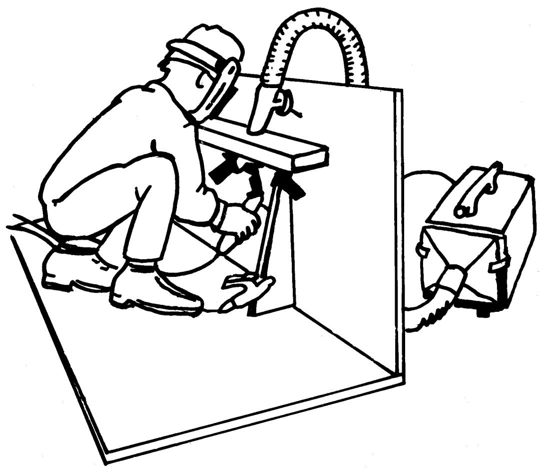

Fig. 2 Portable Fume Extractor with Built-in Fan and Filter

how well it captures the contaminant) must be verified by an industrial hygienist.

A **nonenclosing hood** can be used if access requirements make it necessary to leave all or part of the process open. Careful attention must be paid to airflow patterns around the process and hood and to the process characteristics to make nonenclosing hoods effective.

System Mobility. Local exhaust systems with nonenclosing hoods can be **stationary** (i.e., having a fixed hood position), **moveable, portable, or built-in** (into the process equipment). Moveable hoods are used when process equipment must be accessed for repair and loading and unloading of materials (e.g., in electric ovens for melting steel).

The portable exhaust system shown in Figure 2 is commonly used for temporary exhausting of fumes and solvents in confined spaces or during maintenance. It has a built-in fan and filter and a linear or round exhaust hood connected to a flexible hose. Built-in local exhausts are commonly used to evacuate welding fumes, such as hoods built into stationary or turnover welding tables. Lateral exhaust hoods, which exhaust air through slots on the periphery of open vessels, such as those used for galvanizing metals, are examples of built-in local exhausts.

Effectiveness of Local Exhaust

The most effective hood uses the minimum exhaust airflow rate to provide maximum contaminant control. The **capture effectiveness** should be high, but it would be difficult and costly to develop a hood that is 100% efficient. Makeup air supplied by general ventilation to

Table 1 Range of Capture (Control) Velocities

Condition of Contaminant Dispersion	Examples	Capture Velocity, m/s
Released with essentially no velocity into still air	Evaporation from tanks, degreasing, plating	0.25 to 0.5
Released at low velocity into moderately still air	Container filling, low-speed conveyor transfers, welding	0.5 to 1.0
Active generation into zone of rapid air motion	Barrel filling, chute loading of conveyors, crushing, cool shakeout	1.0 to 2.5
Released at high velocity into zone of very rapid air motion	Grinding, abrasive blasting, tumbling, hot shakeout	2.5 to 10

Note: In each category above, a range of capture velocities is shown. The proper choice of values depends on several factors (Alden and Kane 1982):

Lower End of Range	Upper End of Range
1. Room air currents favorable to capture	1. Distributing room air currents
2. Contaminants of low toxicity or of nuisance value only	2. Contaminants of high toxicity
3. Intermittent, low production	3. High production, heavy use
4. Large hood; large air mass in motion	4. Small hood; local control only

replace exhausted air can dilute contaminants that are not captured by the hood.

Capture Velocity. Capture velocity is the air velocity at the point of contaminant generation upstream of a hood. The contaminant enters the moving airstream at the point of generation and is carried along with the air into the hood. Designers use a capture velocity V_c to select a volumetric flow rate to draw air into the hood. Table 1 shows ranges of capture velocities for several industrial operations. These figures are based on successful experience under ideal conditions. Once capture velocity upstream of the hood and hood position relative to the source are known, then the hood flow rate can be determined for the particular hood design. Velocity distributions for specific hoods must be known or determined.

Hood Volumetric Flow Rate. For a given hood configuration and capture velocity, the exhaust volumetric flow rate (the airflow rate that allows contaminant capture) can be calculated as

$$Q_o = V_o A_o \tag{1}$$

where

Q_o = exhaust volumetric flow rate, m^3/s
V_o = average air velocity in hood opening that ensures capture velocity at point of contaminant release, m/s
A_o = hood opening area, m^2

Low face velocities require that supply (makeup) air be as uniformly distributed as possible to minimize the effects of room air currents. This is one reason replacement air systems must be designed with exhaust systems in mind. Air should enter the hood uniformly; interior baffles are sometimes necessary (Figure 3).

Airflow requirements for maintaining effective capture velocity at a contaminant source also vary with the distance between the source and hood. Chapter 3 of ACGIH (2001) provides methodology for estimating airflow requirements for specific hood configurations and locations relative to the contaminant source.

Airflow near the hood can be influenced by drafts from supply air jets (spot cooling jets) or by turbulence of the ambient air caused by jets, upward/downward convective flows, moving people, and drafts from doors and windows. Process equipment may be another source of air movement. For example, high-speed rotating machines such as pulverizers, high-speed belt material transfer systems, falling granular materials, and escaping compressed air from pneumatic tools all produce air currents. These factors can significantly reduce the capturing effectiveness of local exhausts and should be accounted for in exhaust system design.

Exhausted air may contain combustible pollutant/air mixtures. If it does, the amount by which the exhaust airflow rate should be increased to dilute combustible mixture must be verified to meet the requirements of National Fire Protection Association (NFPA) *Standard* 86.

Principles of Hood Design Optimization

Numerous studies of local exhaust and common practices have led to the following hood design principles:

- The hood should be located as close as possible to the source of contamination.
- The hood opening should be positioned so that it causes the contaminant to deviate the least from its natural path.
- The hood should be located so that the contaminant is drawn away from the operator's breathing zone.
- The hood must be the same size as or larger than the cross section of flow entering the hood. If the hood is smaller than the flow, a higher volumetric flow rate will be required.
- Worker position with relation to contaminant source, hood design, and airflow path should be evaluated on based on the principles given in Chapters 3 and 10 of ACGIH (2001).
- Canopy hoods (Figure 4) should not be used where the operator must bend over a tank or process (ACGIH 2001).

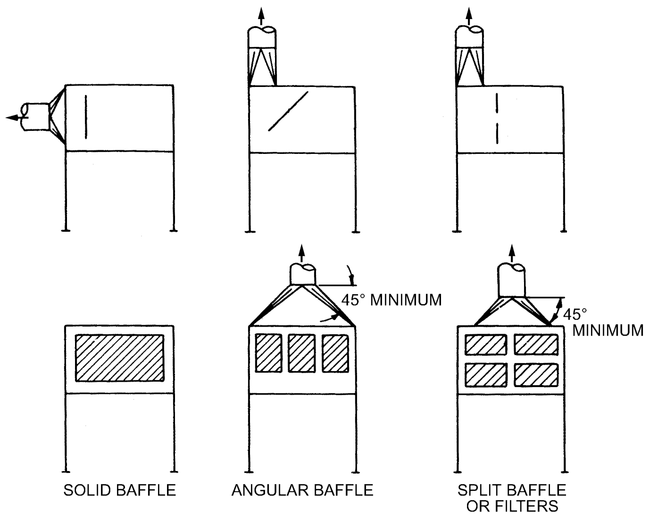

Fig. 3 Use of Interior Baffles to Ensure Good Air Distribution

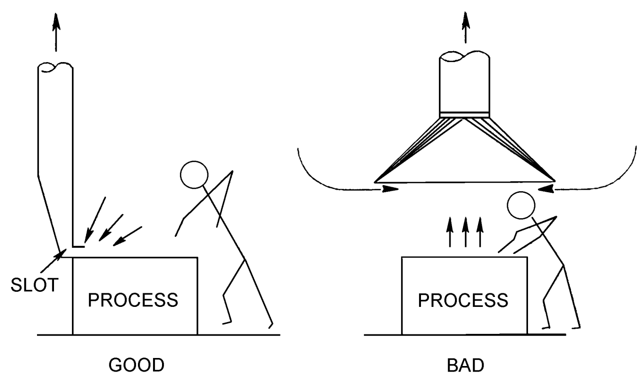

Fig. 4 Influence of Hood Location on Contamination of Air in the Operator's Breathing Zone

AIR MOVEMENT IN VICINITY OF LOCAL EXHAUST

Air velocities in front of the hood opening depend on the exhaust airflow rate, geometry of the hood, and surfaces surrounding the hood opening. Figure 5 shows velocity contours for an unflanged round duct hood. Studies have established the similarity of velocity contours (expressed as a percentage of the hood entrance velocity) for hoods with similar geometry (DallaValle 1952). Figure 6 shows velocity contours for a rectangular hood with an **aspect ratio** (width divided by length) of 0.333. The profiles are similar to those for the round hood but are more elongated. If the aspect ratio is lower than about 0.2 (0.15 for flanged openings), the flow pattern in front of the hood changes from approximately spherical to approximately cylindrical. Velocity decreases rapidly with distance from the hood.

Pressure Loss in Hoods and Ducts

A vena contracta forms in the entrance of the hood or duct and produces a pressure loss. The pressure loss can be described using pressure loss coefficient C_o or a static pressure entry loss (ACGIH 2001). When air enters a hood, the pressure loss, called **hood entry loss**, may have several components, depending on the hood's complexity. Simple hoods usually have a single pressure loss coefficient specified, defined as

$$C_L = \sqrt{\frac{P_v}{P_{s,h}}} \tag{2}$$

where

C_L = loss factor depending on hood type and geometry, dimensionless
P_v = $\rho V^2/2$ = dynamic pressure inside the duct (constant in the duct after vena contracta), Pa, ρ is air density in kg/m^3
$P_{s,h}$ = static pressure in hood duct because of velocity pressure increase and hood entry loss, Pa

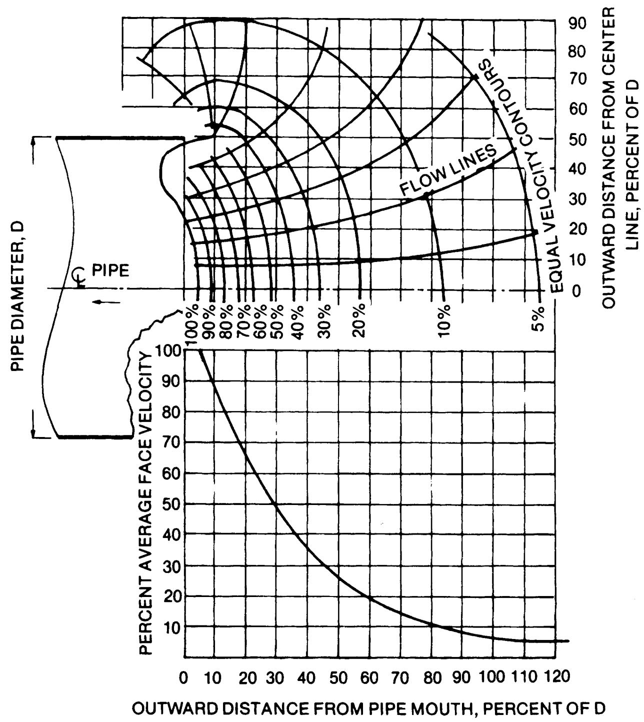

Fig. 5 Velocity Contours for Plain Round Opening
(Alden and Kane 1982, used by permission)

More information on loss factors and the design of exhaust ductwork is in Chapter 34, Duct Design, of the 2001 *ASHRAE Handbook—Fundamentals*, ACGIH (2001), and Brooks (2001).

The loss coefficient C_L is different from the hood entry loss coefficient. The entry loss coefficient C_o relates duct total pressure loss to duct velocity pressure. From Bernoulli's equation, hood total pressure is approximately zero at the entrance to the hood, and therefore the static pressure is equal to the negative of the velocity pressure:

$$P_s = -P_v \quad (3)$$

Static pressure in the hood/duct is the static pressure (velocity pressure) plus the head loss, which is expressed as a fraction of the velocity pressure, as

$$P_{s,h} = P_v + C_o P_v \quad (4)$$

Rearranged, the hood/duct static pressure $P_{s,h}$ (hood suction) for hoods is

$$P_{s,h} = (1 + C_o)P_v \quad (5)$$

and the change in total pressure is

$$\Delta P_t = P_{s,h} - P_v = C_o P_v \quad (6)$$

Loss coefficients C_o for various hood shapes are given in Figure 7. For tapered hoods, Figure 5 shows that the optimum hood entry angle to minimize entry loss is 45°, but this may be impractical in many situations because of the required transition length.

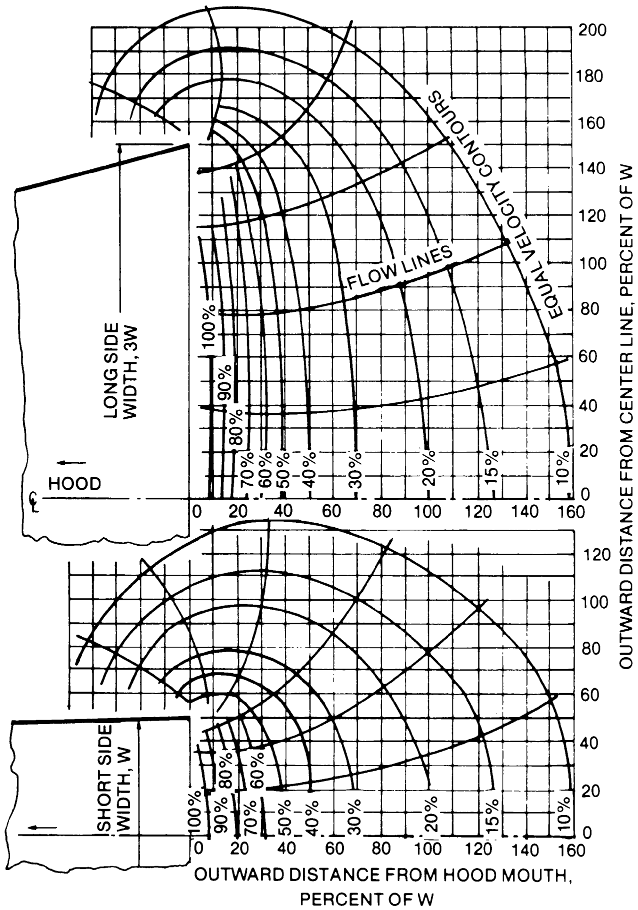

Fig. 6 Velocity Contours for Plain Rectangular Opening with Sides in a 1:3 Ratio with Sides in a 1:3 Ratio
(Alden and Kane 1982, used by permission)

A 90° angle, with a corresponding loss factor of 0.25 (for rectangular openings), is typical for many tapered hoods.

Example 1. A nonenclosing side-draft flanged hood (Figure 8) with face dimensions of 0.45 by 1.2 m rests on the bench. The required volumetric flow rate is 700 L/s. The duct diameter is 225 mm; this gives a duct velocity of 17.6 m/s. The hood is designed such that the largest angle of transition between the hood face and the duct is 90°. What is the suction pressure (static pressure) for this hood? Assume air density at 22°C.

Solution: The two transition angles cannot be equal. Whenever this is true, the larger angle is used to determine the loss factor from Figure 6. Because the transition piece originates from a rectangular opening, the curve marked "rectangular" must be used. This corresponds to a loss factor of 0.25. The duct velocity pressure is

$$P_v = \frac{\rho V^2}{2} = \frac{(1.19)(17.6)^2}{2} = 184 \text{ Pa}$$

From Equation (5),

$$P_{s,h} = (1 + 0.25)(184) = 230 \text{ Pa}$$

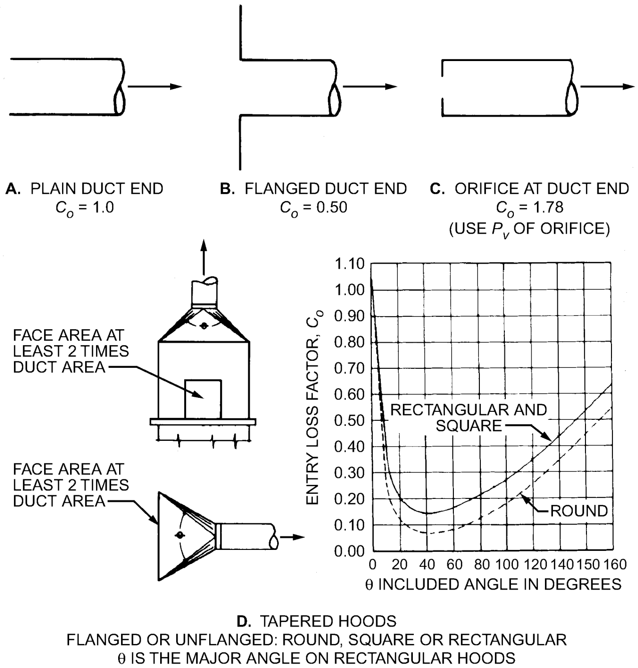

Fig. 7 Entry Losses for Typical Hoods

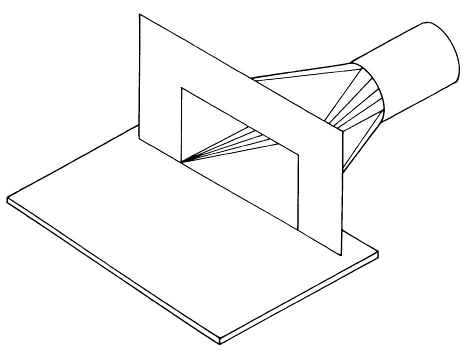

Fig. 8 Hood on Bench

Compound Hoods. Losses for multislot hoods (see Figure 9) or single-slot hoods with a plenum (compound hoods) must be analyzed somewhat differently. The slots distribute air over the hood face and do not influence capture efficiency. Slot velocity should be approximately 10 m/s to provide required distribution at minimum energy cost. Higher velocities dissipate more energy.

Losses occur when air passes through the slot and when air enters the duct. Because the velocities, and therefore the velocity pressures, can be different at the slot and at the duct entry locations, the hood suction must reflect both losses and is given by

$$P_{s,h} = P_v + (C_o P_v)_s + (C_o P_v)_d \tag{7}$$

where the first P_v is generally the higher of the two velocity pressures, s refers to the slot, and d refers to the duct entry location.

Example 2. A multi-slot hood has three slots, each 25 by 1000 mm. At the top of the plenum is a 90° transition into the 250 mm duct. The volumetric flow rate required for this hood is 0.78 m³/s. Determine the hood suction (static pressure). Assume air density at 22°C.

Solution: The slot velocity V_s is

$$V_s = \frac{Q}{A} = \frac{0.78}{(3)(0.025)(1)} = 10.4 \text{ m/s}$$

which is near the minimum slot velocity of 10 m/s. Substituting this velocity,

$$P_v = \frac{\rho V^2}{2} = \frac{(1.19)(10.4)^2}{2} = 64.4 \text{ Pa}$$

The duct area is 0.0491 m². Therefore, the duct velocity and velocity pressure are

$$V_d = \frac{0.78}{0.0491} = 15.9 \text{ m/s}$$

Substituting this velocity,

$$P_v = \frac{(1.19)(15.9)^2}{2} = 150.4 \text{ Pa}$$

For a 90° transition into the duct, the loss factor is 0.25. For the slots, the loss factor is 1.78 (Figure 6). The duct velocity pressure is added to the sum of the two losses because it is larger than the slot velocity pressure. Using Equation (5),

$$P_{s,h} = 150.4 + (1.78)(65) + (0.25)(150.4) = 303.7 \text{ Pa}$$

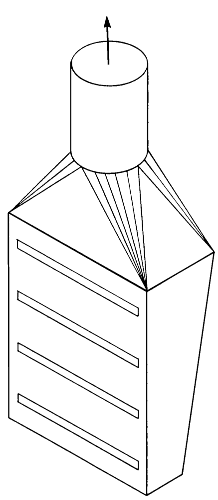

Fig. 9 Multislot Nonenclosing Hood

Exhaust volume requirements, minimum duct velocities, and entry loss factors for many specific operations are given in Chapter 10 of ACGIH (2001).

Overhead Hoods

If the process cannot be completely enclosed, the canopy hood should be placed above the process so that the contaminant moves toward the hood. Canopy hoods should be applied and designed with caution to avoid drawing contaminants across the operator's breathing zone (see Figure 6). The hood's height above the process should be minimize to reduce total exhaust airflow rate.

Sidedraft Hoods

Sidedraft hoods are typically used to draw contaminant away from the operator's breathing zone. With a buoyant source, a sidedraft hood requires a higher exhaust volumetric flow rate than a low canopy hood. If a low canopy hood restricts operation, a sidedraft hood may be more cost-effective than a high canopy hood. Examples of sidedraft hoods include multislotted "pickling" hoods near welding benches (Figure 3), flanged hoods, and slot hoods on tanks (Figure 10).

OTHER LOCAL EXHAUST SYSTEM COMPONENTS

Duct Design and Construction

Duct Considerations. The second component of a local exhaust ventilation system is the duct through which contaminated air is transported from the hood(s). Round ducts are preferred because they (1) offer more uniform velocity to resist settling of material and (2) can withstand the higher static pressures normally found in exhaust systems. When design limitations require rectangular or flat oval ducts, the aspect ratio (height-to-width ratio) should be as close to unity as possible.

Minimum transport velocity is the velocity required to transport particles without settling. Table 2 lists some generally accepted transport velocities as a function of the nature of the contaminants (ACGIH 2001). The values listed are typically higher than theoretical and experimental values to account for (1) damage to ducts, which would increase system resistance and reduce volumetric flow and duct velocity; (2) duct leakage, which tends to decrease velocity in the duct system upstream of the leak; (3) fan wheel corrosion or erosion and/or belt slippage, which could reduce fan volume; and (4) re-entrainment of settled particles caused by improper operation of the exhaust system. Design velocities can be higher than minimum transport velocities but should never be significantly lower.

When particle concentrations are low, the effect on fan power is negligible. Standard duct sizes and fittings should be used to cut cost and delivery time. Information on available sizes and the cost of nonstandard sizes can be obtained from the contractor(s).

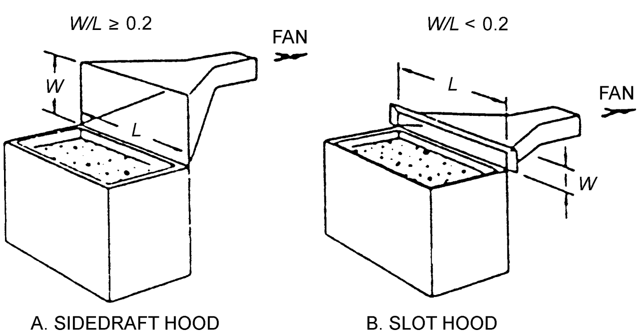

Fig. 10 Sidedraft Hood and Slot Hood on Tank

Table 2 Contaminant Transport Velocities

Nature of Contaminant	Examples	Minimum Transport Velocity, m/s
Vapor, gases, smoke	All vapors, gases, smoke	Usually 5 to 10
Fumes	Welding	10 to 13
Very fine light dust	Cotton lint, wood flour, litho powder	13 to 15
Dry dusts and powders	Fine rubber dust, molding powder dust, jute lint, cotton dust, shavings (light), soap dust, leather shavings	15 to 20
Average industrial dust	Grinding dust, buffing lint (dry), wool jute dust (shaker waste), coffee beans, shoe dust, granite dust, silica flour, general material handling, brick cutting, clay dust, foundry (general), limestone dust, asbestos dust in textile industries	18 to 20
Heavy dust	Sawdust (heavy and wet), metal turnings, foundry tumbling barrels and shakeout, sand-blast dust, wood blocks, hog waste, brass turnings, cast-iron boring dust, lead dust	20 to 23
Heavy and moist dust	Lead dust with small chips, moist cement dust, asbestos chunks from transite pipe cutting machines, buffing lint (sticky), quicklime dust	23 and up

Source: From American Conference of Governmental Industrial Hygienists (ACGIH®), *Industrial Ventilation: A Manual of Recommended Practice*, 24th ed. Copyright 2001. Reprinted with permission.

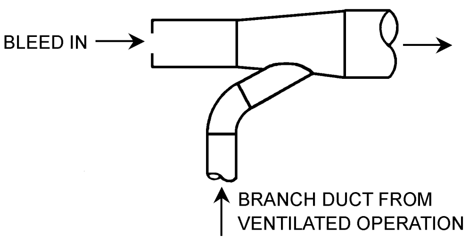

Fig. 11 Air Bleed-In

Duct Losses. Chapter 34 of the 2001 *ASHRAE Handbook—Fundamentals* covers the basics of duct design and design of metal-working exhaust systems. The design method presented there is based on total pressure loss, including fitting coefficients; ACGIH (2001) calculates static pressure loss. Loss coefficients are found in Chapter 34 of the 2001 *ASHRAE Handbook—Fundamentals* and in the ASHRAE *Duct Fitting Database* CD-ROM (ASHRAE 2002).

For systems conveying particles, elbows with a centerline radius-to-diameter ratio *(r/D)* greater than 1.5 are the most suitable. If $r/D \leq 1.5$, abrasion in dust-handling systems can reduce the life of elbows. Elbows, especially those with large diameters, are often made of seven or more gores. For converging flow fittings, a 30° entry angle is recommended to minimize energy losses and abrasion in dust-handling systems (Fitting ED5-1 in Chapter 34 of the 2001 *ASHRAE Handbook—Fundamentals*).

Where exhaust systems handling particles must allow for a substantial increase in future capacity, required transport velocities can be maintained by providing open-end stub branches in the main duct. Air is admitted through these stub branches at the proper pressure and volumetric flow rate until the future connection is installed. Figure 11 shows such an air bleed-in. Using outside air minimizes replacement air requirements. The size of the opening can be calculated by determining the pressure drop required across the orifice from the duct calculations. Then the orifice velocity pressure can be determined from one of the following equations:

$$P_{v,o} = \frac{\Delta P_{t,o}}{C_o} \tag{8}$$

or

$$P_{v,o} = \frac{\Delta P_{s,o}}{C_o + 1} \tag{9}$$

where

$P_{v,o}$ = orifice velocity pressure, Pa
ΔT_o = total pressure to be dissipated across orifice, Pa
$\Delta P_{s,o}$ = static pressure to be dissipated across orifice, Pa
C_o = orifice loss coefficient referenced to the velocity at the orifice cross-sectional area, dimensionless (Figure 6)

Equation (8) should be used if total pressure through the system is calculated; Equation (9) should be used if static pressure through the system is calculated. Once the velocity pressure is known, orifice velocity and size can be determined.

Occasionally, a counterweighted backdraft damper or spring-loaded air admittance valve, configured to allow airflow into the duct but not out, is used as an air bleed in lieu of an orifice in systems that operate under varying airflow conditions. This ensures the proper quantity of transport airflow inside the duct, helping to eliminate material fallout and subsequent duct blockage.

Integrating Duct Segments. Most systems have more than one hood. If the pressures are not designed to be the same for merging parallel airstreams, the system adjusts to equalize pressure at the common point; however, the flow rates of the two merging airstreams will not necessarily be the same as designed. As a result, the hoods can fail to control the contaminant adequately, exposing workers to potentially hazardous contaminant concentrations. Two design methods ensure that the two pressures will be equal. The preferred design self-balances without external aids. This procedure is described in the section on Industrial Exhaust System Duct Design in Chapter 34 of the 2001 *ASHRAE Handbook—Fundamentals.* The second design, which uses adjustable balance devices such as blast gates or balancing dampers, is not recommended, especially when abrasive material is conveyed.

Duct Construction. Elbows and converging flow fittings should be made of thicker material than the straight duct, especially if abrasives are conveyed. Elbows with $r/D > 2$ with replaceable wear plates (wear backs) in the heel are often used where particulate loading is extremely heavy or the particles are very abrasive When corrosive material is present, alternatives such as special coatings or different duct materials (fibrous glass or stainless steel) can be used. Cleanout openings should be located to allow access to the duct interior in the event of a blockage. Certain contaminants may require washdown systems and/or fire detection and suppression systems to comply with safety or fire prevention codes. These requirements should be verified with local code officials and insurance underwriters. NFPA *Standards* provide guidance on fire safety. Industrial duct construction is described in Chapter 16 of the 2000 *ASHRAE Handbook—HVAC Systems and Equipment.* Refer to the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA 1999) for industrial duct construction standards.

Air Cleaners

Air-cleaning equipment is usually selected to (1) conform to federal, state, or local emissions standards and regulations; (2) prevent re-entrainment of contaminants to work areas; (3) reclaim usable materials; (4) permit cleaned air to recirculate to work spaces and/or processes; (5) prevent physical damage to adjacent properties; and (6) protect neighbors from contaminants.

Factors to consider when selecting air-cleaning equipment include the type of contaminant (number of components, particulate versus gaseous, and concentration), required contaminant removal efficiency, disposal method, and air or gas stream characteristics. Auxiliary systems such as instrument-grade compressed air, electricity, or water may be required and should be considered in equipment selection. Specific hazards such as explosions, fire, or toxicity must be considered in equipment selection, design, and location. See Chapters 24 and 25 of the 2000 *ASHRAE Handbook—HVAC Systems and Equipment* for information on equipment for removing airborne contaminants. A qualified applications engineer should be consulted when selecting equipment.

The cleaner's pressure loss must be added to overall system pressure calculations. In some cleaners, specifically some fabric filters, loss increases as operation time increases. System design should incorporate the maximum pressure drop of the cleaner, or hood flow rates will be lower than designed during most of the duty cycle. Also, fabric collector losses are usually given only for a clean air plenum. A reacceleration to the duct velocity, with the associated entry losses, must be calculated during design. Most other cleaners are rated flange-to-flange with reacceleration included in the loss.

Air-Moving Devices

The type of air-moving device used depends on the type and concentration of contaminant, the pressure rise required, and allowable noise levels. Fans are usually selected. Chapter 18 of the 2000 *ASHRAE Handbook—HVAC Systems and Equipment* describes available fans; Air Movement and Control Association (AMCA) *Publication* 201, Fans and Systems, describes proper connection of the fan(s) to the system. The fan should be located downstream of the air cleaner whenever possible to (1) reduce possible abrasion of the fan wheel blades and (2) create negative pressure in the air cleaner so that air leaks into it and positive control of the contaminant is maintained.

Fans handling flammable or explosive dusts should be specified as spark-resistant. AMCA provides three different spark-resistant fan construction specifications. The fan manufacturer should be consulted when handling these materials. Multiple NFPA Standards give fire safety requirements for fans and systems handling explosive or flammable materials.

When possible, devices such as fans and pollution-control equipment should be located outside classified areas, and/or outside the building, to reduce the risk of fire or explosion.

In some instances, the fan is located upstream from the cleaner to help remove dust. This is especially true with cyclone collectors, for example, which are used in the woodworking industry. If explosive, corrosive, flammable, or sticky materials are handled, an injector can transport the material to the air-cleaning equipment. Injectors create a shear layer that induces airflow into the duct. Injectors should be the last choice because their efficiency seldom exceeds 10%.

Energy Recovery

Energy transfer from exhausted air to replacement air may be economically feasible, depending on the (1) location of the exhaust and replacement air ducts, (2) temperature of the exhausted gas, and (3) nature of the contaminants being exhausted. Heat transfer efficiency depends on the type of heat recovery system used.

If exhausted air contains particulate matter (e.g., dust, lint) or oil mist, the exhausted air should be filtered to prevent fouling the heat exchanger. If exhausted air contains gaseous and vaporous contaminants, such as hydrocarbons and water-soluble chemicals, their effect on the heat recovery device should be investigated. Chapter 44 of the 2000 *ASHRAE Handbook—HVAC Systems and Equipment* covers energy recovery.

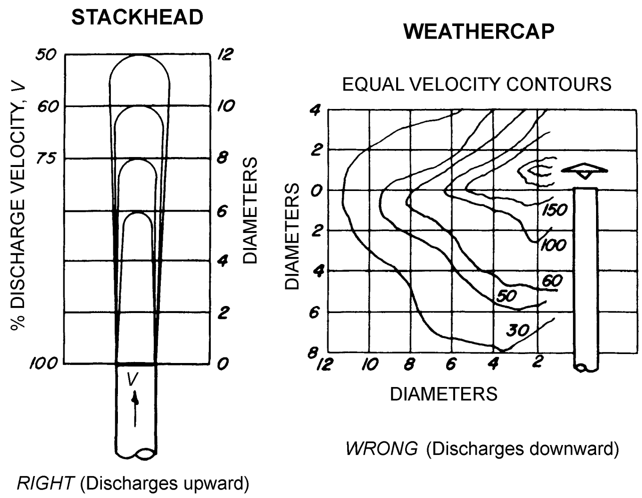

Fig. 12 Comparison of Flow Pattern for Stackheads and Weathercaps

Exhaust Stacks

The exhaust stack must be designed and located to prevent reentraining discharged air into supply system inlets. The building's shape and surroundings determine the atmospheric airflow over it. Chapter 15 of the 2001 *ASHRAE Handbook—Fundamentals* and Chapter 44 of this volume cover exhaust stack design.

If rain protection is important, stack head design is preferable to weather caps, which deflect air downward, increasing the chance that contaminants will recirculate into air inlets; have high friction losses; and provide less rain protection than a properly designed stack head.

Figure 12 contrasts flow patterns of weather caps and stack heads. Loss data for weather caps and stack heads are presented in the *Duct Fitting Database* CD-ROM (ASHRAE 2002). Losses in straight-duct stack heads are balanced by the pressure regain at the expansion to the larger-diameter stack head.

Instrumentation and Controls

Certain industrial exhaust systems may require positive verification of system airflow. Other instrumentation, such as dust collector level indication, rotary lock valve operation, or fire detection, may be required. Interfaces may be required with the process control system or with the balance of the plant ventilation system. Electrical devices in systems conveying flammable or explosive materials or in a hazardous location may need to meet certain electrical safety and code requirements. These requirements are determined by the owner, process equipment manufacturer, federal and state regulations, local codes, and/or insurance requirements.

OPERATION

System Testing

After installation, an exhaust system should be tested to ensure that it operates properly, with the required flow rates through each hood. If actual flow rates are different from design values, they should be corrected before the system is used. Testing is also necessary to obtain baseline data to determine (1) compliance with federal, state, and local codes; (2) by periodic inspections, whether maintenance on the system is needed to ensure design operation; (3) whether a system has sufficient capacity for additional airflow; and

(4) whether system leakage is acceptable. AMCA *Publication* 203 and Chapter 9 of ACGIH (2001) contain detailed information on preferred methods for testing systems.

Operation and Maintenance

Periodic inspection and maintenance are required for proper operation of exhaust systems. Systems are often changed or damaged after installation, resulting in low duct velocities and/or incorrect volumetric flow rates. Low duct velocities can cause contaminants to settle and plug the duct, reducing flow rates at affected hoods. Adding hoods to an existing system can change volumetric flow at the original hoods. In both cases, changed hood volumes can increase worker exposure and health risks. The maintenance program should include (1) inspecting ductwork for particulate accumulation and damage by erosion or physical abuse, (2) checking exhaust hoods for proper volumetric flow rates and physical condition, (3) checking fan drives, and (4) maintaining air cleaning equipment according to manufacturers' guidelines.

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