Chapter 1

Use of Local Exhaust and Dilution Ventilation

Ventilation is an important method of reducing exposures to airborne contaminants. It also serves other purposes such as preventing the accumulation of flammable or explosive concentrations, facilitating material reuse, and ensuring community environmental protection. The proper design and the use of ventilation systems require an understanding of the principles governing their operation as well as insight into practical solutions to exposure problems.

Today, of course, any discussion of workplace exposures to airborne contaminants goes beyond industrial operations. Potential problems from employee exposures to indoor air pollutants in office and commercial buildings are recognized as an important issue in worker health and safety.

Dilution Versus Local Exhaust

There are two major types of industrial ventilation: *dilution* (or general) ventilation and *local exhaust.*

Dilution Ventilation

Dilution occurs when contaminants released into the workroom mix with air flowing through the room (Figure 1-1). Either natural or mechanically-induced air movement can be used to dilute contaminants. Dilution ventilation is used in situations meeting these criteria:

- Small quantities of contaminants are released into the workroom at fairly uniform rates.
- Sufficient distance from the worker (or source of ignition for fire/explosion hazards) to the contaminant source allows dilution to safe levels.
- Contaminants are of relatively low toxicity or fire hazard so that no major problems will result from unanticipated minor employee exposure or concentration exceedances.
- No air cleaning device is needed to collect contaminants before the exhaust air is discharged into the community environment.
- No corrosion or other problems arise from the diluted contaminants in the workroom air.

The major disadvantages of dilution ventilation are 1) large volumes of dilution air may be needed and 2) employee exposures are difficult to control near the contaminant source where dilution has not yet occurred.

Dilution ventilation is also called general ventilation. However, in many industrial plants, the overall heating and cooling air system is referred to as the general ventilation system. To avoid confusion, the term *dilution* will be used for contaminant control systems. The design of dilution ventilation systems is discussed later in this chapter.

Local Exhaust Ventilation

Local exhaust systems capture or contain contaminants at their source before they escape into the workroom environment. A typical system consists of one or more hoods, ducts, an air cleaner if needed, and a fan

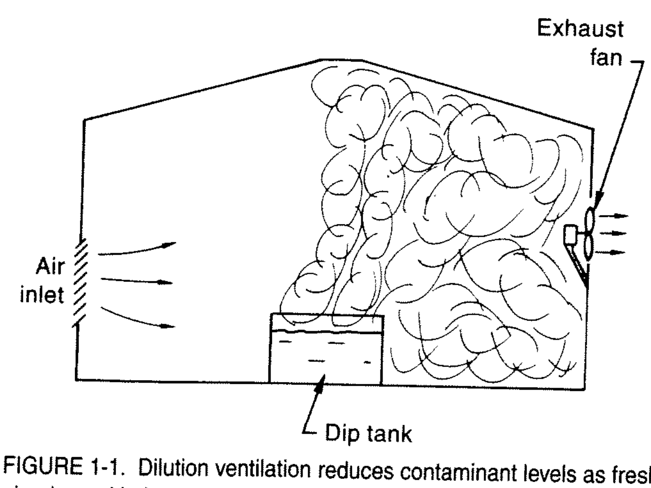

FIGURE 1-1. Dilution ventilation reduces contaminant levels as fresh air mixes with the contaminants in the workroom air.

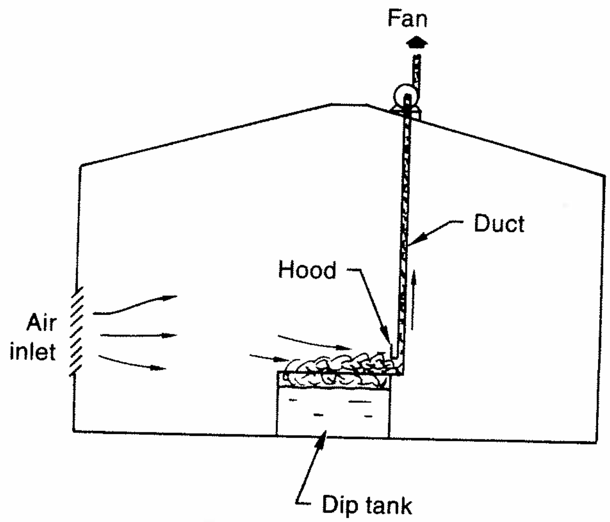

FIGURE 1-2. Local exhaust ventilation captures or contains contaminants at their source before they disperse in the work environment.

(Figure 1-2). The primary advantage of local exhaust systems is that they remove contaminants rather than just dilute them. Even with local exhaust, some airborne contaminants may still be in the workroom air due to uncontrolled sources or less than 100% collection efficiency at the hoods. A second major advantage of local exhaust is that these systems require less airflow than dilution ventilation systems in the same applications. The total airflow is especially important for plants that are heated or cooled because heating and air conditioning costs are an important operating expense. These cost factors are discussed in Chapter 11.

Local exhaust systems may be more difficult to design than dilution systems. The hoods or pickup points must be properly shaped and positioned to control contaminants, and the fan and ducts must be designed to draw the correct amount of air in through each hood.

Using Ventilation Effectively

The goal of this book is to help you use ventilation, especially local exhaust ventilation, effectively. If you understand how exhaust ventilation systems function and follow a few basic airflow principles during design, your system will provide the protection to employees that you intend. Understanding how the system functions will also help you to diagnose and correct problems in existing ventilation systems.

One concept repeated several times in this text is that the hoods are the most important part of the local exhaust system. There are three different types of hoods: 1) those that enclose the contaminant source; 2) those that are positioned to catch a stream of contaminants thrown out by a source or released in a given direction (such as a hot dip tank); and 3) those that reach outside the hood to capture contaminants. The welding hood shown in Figure 1-3 is a popular type of capturing hood. Chapter 6 describes the different hood types and their use, but a vital phase of any ventilation project is deciding which type of hood is best for each contaminant source and then choosing the airflow required for each hood to work properly. If the original hood selection is wrong, the system will probably never reduce airborne contaminants sufficiently even if the ducts and fan are properly designed. Hood selection is based on the characteristics of the contaminants, the way contaminants disperse when released, and the physical layout of the plant.

Other Uses of Ventilation

Control of contaminants in the workroom air for health protection or fire/explosion prevention is not the only use for ventilation. Other uses include comfort, material control and reuse, and environmental protection.

Comfort

Heat, odors, and tobacco smoke can be removed from working or living areas by exhaust ventilation. Air supply systems furnish heated or cooled air depending on the season. Heat can, of course, be a health hazard in extreme exposures, and then heat control is more than just a comfort consideration. Dilution (or general) ventilation is most often used for comfort ventilation to control temperature, humidity and radiant heat load and to provide fresh air circulation without drafts.

Material Control and Reuse

Local exhaust ventilation can be used to conserve reusable materials or those that cause housekeeping

FIGURE 1-3. Welding hoods have sufficient airflow to reach outside of the hood to capture welding fumes.

problems. It is advantageous to install ventilation if a reusable material that is released from a process can be collected by a ventilation system and then removed from the airstream (using an air cleaner) for recycling at a lower cost than replacing the material. Other waste materials cause a housekeeping problem rather than a health concern. These materials can also be collected in a ventilation system and removed for disposal with an air cleaner. Sawdust from woodworking shops is a good example. Although very fine sawdust can remain airborne and presents a fire or health hazard, most of the material collected in the local exhaust system is too large to remain airborne and so piles up on the floor around the equipment. It is often more efficient to collect this material in a local exhaust system than to sweep it up.

Community Environmental Protection

Environmental protection is linked to material reuse in that similar ventilation systems are used to control the contaminants produced by the industrial process, and air cleaners are used to remove the contaminants before the air is discharged to the community environment. For environmental protection systems, however, the aim is to remove materials so that the residual in the discharged air meets air pollution standards; the material collected in the air cleaner may have no reuse value.

Some environmental regulations set limits on the amounts of pollutants that can be discharged from specific industrial operations. For example, U.S. Environmental Protection Agency standards[1] govern the discharge of many pollutants to the atmosphere. To meet these standards, a local exhaust system with the proper air cleaning device may be needed.

Many of the ventilation system features for reducing employee exposures also apply to systems for material recycling or environmental protection.

Other Exposure Control Techniques

Ventilation is only one way to reduce employee exposures. An employee's exposure to an airborne substance is related to the amount of contaminants in the air and the time period during which the employee breathes the concentration. Any factors that interrupt the exposure pattern by reducing the amount of contaminant in the employee's breathing zone or the amount of time the employee spends in the area will reduce the overall exposure. To lower exposures, review the contaminant source, the path it travels to the worker, and the employee's work pattern and use of protective equipment.

Source Control

In addition to local exhaust ventilation, here are some ways to reduce the amount of contaminants released into the workroom air:

- Practice preventive maintenance to repair leaks or control other factors that increase emissions.
- Substitute less toxic materials for those currently in use. Carbon tetrachloride is an example of a solvent that was once widely used but has been replaced with less toxic solvents in almost every application. Another illustration is the substitution of artificial abrasives for sand in abrasive blasting cleaning operations to reduce exposure to free silica.
- A change in the process to reduce the amount of contaminant released. For example, the use of a water spray when cutting concrete pipe (Figure 1-4) prevents dispersion of dust without ventilation. The use of large bulk sacks (Figure 1-5) for dry powders in place of individual smaller sacks can reduce the dust emissions that accompany the dumping and disposal of the small sacks.

Exposure Pathway Modifications

The route by which a contaminant travels from a source to a worker's breathing zone is called the exposure pathway. Modifications to this pathway impact the exposure levels.

Dilution ventilation affects the exposure pathway because it disperses and removes contaminants before workers breathe the air. Other choices include:

- Lengthening the exposure pathway by increasing the distance between the source and the worker. The dilution rate is influenced by drafts and other air motion, but in almost all cases, the contaminant concentration decreases with increased distance from the source. However, some situations can act to "shorten" the exposure pathway, thus causing higher

FIGURE 1-4. Water spray controls contaminants as pipe is cut. This is one of several control methods in addition to ventilation.

FIGURE 1-5. Bulk sacks with a spout at the bottom to drain the contents can reduce dust emissions when transferring dry materials. *(Courtesy B.A.G. Corp.)*

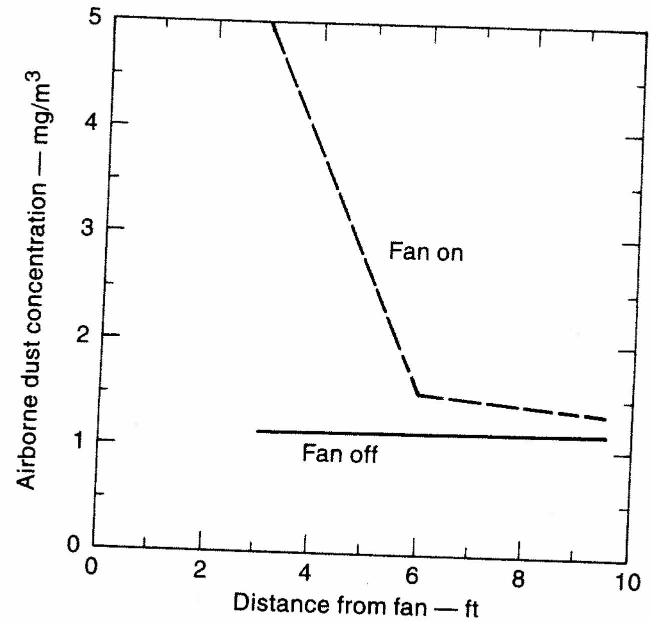

FIGURE 1-6. Effects on airborne dust concentrations from a grinding wheel of a window fan (located 2 feet away), blowing across the grinding wheel.

exposure than expected. For example, Figure 1-6 illustrates the effect of a window fan on airborne dust levels near a surface-grinding operation. When the fan was blowing across the grinder toward the worker, the airborne concentration in the worker's breathing zone was almost five times higher than the concentration when the fan was off.(2) If a window fan is needed in this work area, the air movement should be directed away from the grinder.

- Interrupting the exposure pathway with physical barriers such as doors, curtains, or baffles to impede the movement of contaminated air toward workers.
- Isolating the process or the worker. Usually this involves moving one or the other to a different room to minimize exposure levels and exposure time. This especially applies to workers who are not directly involved with the process releasing the contaminants. The degree of isolation required depends on the toxicity of the contaminant, the amount of contaminant released, and the work patterns around the process. Often moving a unit to another room is sufficient, while in other cases, a control room supplied with fresh air for the operators may be needed.

Sometimes airborne levels of contaminants can be monitored continuously with a sensor that alarms when concentrations exceed an established level. When an alarm sounds, the workers or supervisors take steps to reduce airborne levels. This approach is useful to detect abnormal operating conditions that cause excessive emissions.

Other Steps to Reduce Exposures

Steps that reduce airborne contaminant levels are usually preferred; however, other mechanisms can also be employed to reduce exposures. For example,

- Work procedures should allow workers to do the job with minimum exposure. Procedures should cover such topics such as venting equipment before opening it, flushing equipment with safe materials to remove chemicals, and where to stand during the job to minimize exposure levels.
- The use of personal protective equipment, such as respiratory protective devices, are another option. There are a variety of respirators suitable for different contaminants and levels of exposures. They are divided into two main classes: air purifying respirators (Figure 1-7) that remove contaminants from ambient air; and atmosphere supplying respirators that provide respirable air to the worker from an air compressor, large compressed air cylinder, or, in the

FIGURE 1-7. Air purifying respirators, such as this full-face cartridge respirator, remove contaminants from the ambient air. *(Courtesy Scott Health & Safety)*

case of a self-contained breathing unit (Figure 1-8), from an air cylinder carried by the worker.

Generally, respirators are used for routine tasks only when engineering controls or work procedures do not reduce exposures to acceptable levels. Respirators may be needed during emergencies or unusual conditions. Federal and state OSHA regulations contain specific requirements for respirator use.(3) Follow these standards when establishing a respirator program.

FIGURE 1-8. This self-contained breathing apparatus is an example of atmosphere-supplying respiratory protective equipment. Breathing air is provided from a safe source independent of the air around the worker. *(Courtesy Scott Health & Safety)*

- Training and education should be implemented to help employees reduce exposures. If contaminants do not have a noticeable odor or other sensory warning properties, employees may not understand how exposures occur. This information, as well as knowledge of the potential health effects, help to engage employees in devising methods to reduce their exposures.

When Are Controls Needed?

Controls are used to keep exposures at acceptably low levels. In most cases, ventilation or another exposure control technique is needed if sampling shows that employee exposures exceed allowable levels, if an oxygen deficiency could occur, if buildup of flammable or explosive materials exceeds safe limits, or if other evidence of harmful exposures exists. There are several sources of exposure recommendations or legal standards. The exposure regulations that apply to most employers in the United States are the Permissible Exposure Limits (PELs) promulgated by federal OSHA(3) or by corresponding state agencies. The PELs are a list of more than 400 different chemicals with allowable exposure levels for each substance. Exposure guidelines are also published by professional groups such as the annual list of Threshold Limit Values (TLVs®) from the American Conference of Governmental Industrial Hygienists (ACGIH®)(4), or by consensus groups such as the American National Standards Institute (ANSI); these are often more current than the OSHA PELs. Other countries or regions have their own standard-setting and consensus bodies.

In some cases, the need for ventilation for certain materials or tasks is explicitly stated in a regulation or recommended practice; e.g., for welding on cadmium, lead, or other toxic metals. For these specific situations, ventilation is required since experience shows that airborne levels in unventilated workplaces can be expected to exceed acceptable limits. U.S. OSHA standards relating to ventilation are covered in Chapter 3.

Minimizing Exposures

Exposure standards do not exist for all chemicals and other substances used in the occupational environment. Current standards are set using available toxicological information along with a safety factor, but they do not claim to protect all workers in all exposure situations. Whenever an exposure causes significant discomfort or apparent adverse health effects, it should be reduced even if no numerical health exposure standard is exceeded.

The long-term effects of many compounds on the human body are unknown. It is good industrial hygiene practice to minimize exposure to chemicals whenever possible. Chapter 4 contains guidelines for evaluating employee exposures to airborne materials.

Dilution Ventilation Systems

As mentioned previously, there are two types of exhaust ventilation: *dilution* ventilation (also called general ventilation), which dilutes the contaminants in the workroom air to acceptable levels; and *local exhaust* ventilation, which captures or contains contaminants at their source before they disperse into the workroom. Some advantages and disadvantages of these systems were discussed earlier in this chapter. The bulk of this book focuses on local exhaust ventilation; however, the remainder of this chapter will cover the application and design of dilution ventilation systems.

Dilution, Not Removal

It is easy to picture air moving through the work area in a straight path from the air inlet to the exhaust fan, almost as if traveling inside an invisible duct (Figure 1-9), to whisk contaminants out of the workroom. However, dilution does not occur in this manner. Instead, the incoming air diffuses throughout the room. Some of it passes through the zone of contaminant release and dilutes the contaminants to a lower concentration. The dilution continues as the material moves farther from the process until the contaminated air is removed by the exhaust fan. Depending on the location of the air inlet and exhaust fan, and the total airflow through the room, a considerable time period may elapse after the process stops before all contaminants are removed from the room. Dilution occurs from natural ventilation as well as from mechanical systems that use fans or other air moving devices.

Natural Ventilation

Natural ventilation is air movement within a work area due to wind, temperature differences between the exterior and interior of a building, or other factors where no mechanical air mover is used.

Even moderate winds can move large volumes of air through open doors or windows. For example, a 15 mile/hr wind blowing directly at a window with an open area of 36 ft^2 can move 25,000 ft^3/min or more through the window if the air can freely escape from the building through a doorway or other large opening. This may be enough dilution airflow if the wind is reliable, or if production can be scheduled to coincide with favorable winds and the building is not shielded from the wind by trees, hills, or other structures. In many regions, this large dilution air volume must be heated in winter, which is an important cost factor that can override the apparent savings of a system with no mechanical air mover.

Air movement due to temperature differences may be more useful than motion caused by wind. Hot processes heat the surrounding air and the rising column of warm air will carry contaminants upward. Roof ventilators allow escape of the warm air and contaminants (Figure 1-10). As long as a worker does not have to lean over the heated process and breathe the rising contaminated air, this type of natural ventilation may be adequate. A good supply of replacement air for the building is needed, especially during winter when doors and windows may be closed to minimize drafts.

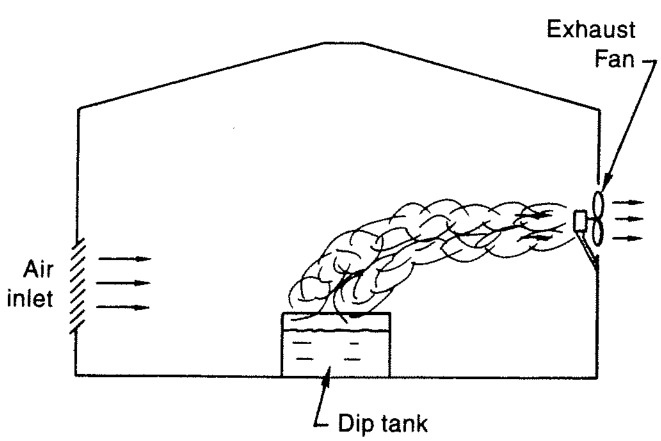

FIGURE 1-9. **Incorrect** visualization of dilution ventilation. The contaminants actually disperse throughout the right half of the room, as shown in Figure 1-1.

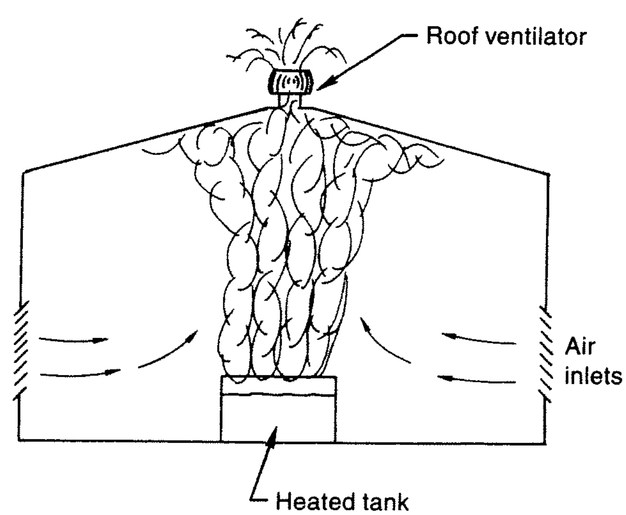

FIGURE 1-10. Natural ventilation as heated air rises around a hot process. This is not acceptable if a worker bends over the tank and breathes the contaminants.

Mechanical Ventilation

Mechanical systems range from simple wall-mounted propeller fans (Figure 1-1) to complex designs with engineered supply and exhaust systems. Propeller fans can provide a constant, reliable flow of air, but a major characteristic is that they are efficient air movers only as long as an adequate supply of replacement or makeup air can *readily* enter the area being exhausted (as described in Chapter 9). The more complex make-up air systems, with separate air supply fans and ducts, increase the dilution effectiveness but approach local exhaust systems in installation and operating costs.

Evaluating the Feasibility of Dilution Ventilation

Deciding whether dilution ventilation is a good choice depends on these factors:

- The air volume needed to dilute the contaminants to safe levels may be excessive if large quantities of contaminants are released.
- Sufficient dilution must occur before workers inhale contaminated air. If employees work close to the contaminant source, the dilution airflow may have to be significantly increased to reduce concentrations to safe levels before the contaminated air reaches the employees' breathing zones. This can be a real problem in work operations such as manual gluing or surface-coating where workers bend over the work and breathe solvent vapors. Additionally, dilution ventilation for fire protection must occur before the contaminants reach a source of ignition.
- The rate of contaminant release, or evolution, should be reasonably constant. This avoids the need for high airflow rates to provide adequate dilution during short periods of peak contaminant release.

Adjusting "Theoretical" Dilution Calculations for Workplace Conditions

The equations for calculating dilution airflow are covered in the remainder of this chapter. As background, however, it is important to understand two factors that must be considered whenever applying these equations:

- The mathematical equations for calculating the dilution airflow rate required for either health protection or fire/explosion prevention are based on the concept that the contaminant is released at a certain rate (ft^3/min), and so the ventilation system must move the correct airflow (ft^3/min) to dilute this generation rate of contaminant to an acceptable level. The "theoretical" equations assume that complete mixing occurs in the room. This means that all of the dilution air helps to dilute the contaminant to acceptable levels before anyone breathes the air (or, for fire/explosion prevention, before the vapors reach a source of ignition). Complete mixing rarely occurs in real world situations.

  The dilution equations discussed below and contained in the ACGIH *Industrial Ventilation Manual*[5] for systems designed to protect health (as contrasted with fire/explosion prevention) adjust for these considerations. The airflow equations contain a "K" factor which increases the theoretical quantity needed to dilute the contaminants to adjust for incomplete mixing. The equations for fire/explosion prevention do not have a separate factor to account for incomplete mixing. For fire/explosion systems the designer must add an additional safety factor if incomplete mixing is an issue.
- These equations will yield the airflow needed to keep airborne level precisely at the "target concentration" used in the dilution equations. If the OSHA *Permissible Exposure Limit* or ACGIH *Threshold Limit Value* (TLV) is selected as the target concentration, the "theoretical" equations will yield the required airflow to keep airborne levels exactly at that level. The "target concentration" should be selected so that concentrations are well below the acceptable exposure level. The equations for fire/explosion prevention use a "S_f" factor to keep the work area at or below a specified percent of the Lower Explosive Limit for the material.

In all cases it is the designer's responsibility to apply an overall margin of safety that adequately accounts for factors such as:

- The design and layout of the exhaust fan and any air supply system (in relation to the work operation) that impacts how much of the airflow actually works to dilute the contaminants before workers breathe the air or the contaminated air reaches a source of ignition.
- Any significant unknown information or parameters about a new process or operation that could impact the amount of contaminant released or whether the release is constant or irregular.
- Any additional "safety factor" needed to account for circumstances such as non-routine work patterns that could bring workers closer than expected to the contaminant source, or other conditions where an added safety factor is warranted.

Dilution Ventilation System Layout

Dilution systems work best when the air inlet and exhaust fan are located so that as much air as possible flows through the zone of contaminant release. Only the air that passes through the area where contaminants are released is available for immediate dilution of contaminants to safe levels. For the dilution air to be effective at all, it must dilute the contaminants before they reach an employee's breathing zone. As illustrated in Figure 1-11, system layout has a direct impact on the "K" factor used in the dilution equations.

The plant should be arranged so that air movement is from cleaner to dirtier areas. Locate the processes or locate the fan so that the units which release contaminants are as close as possible to the fan. Also eliminate or provide separate exhaust for areas where contaminants may accumulate and defeat the dilution effect of the airflow from the overall system.

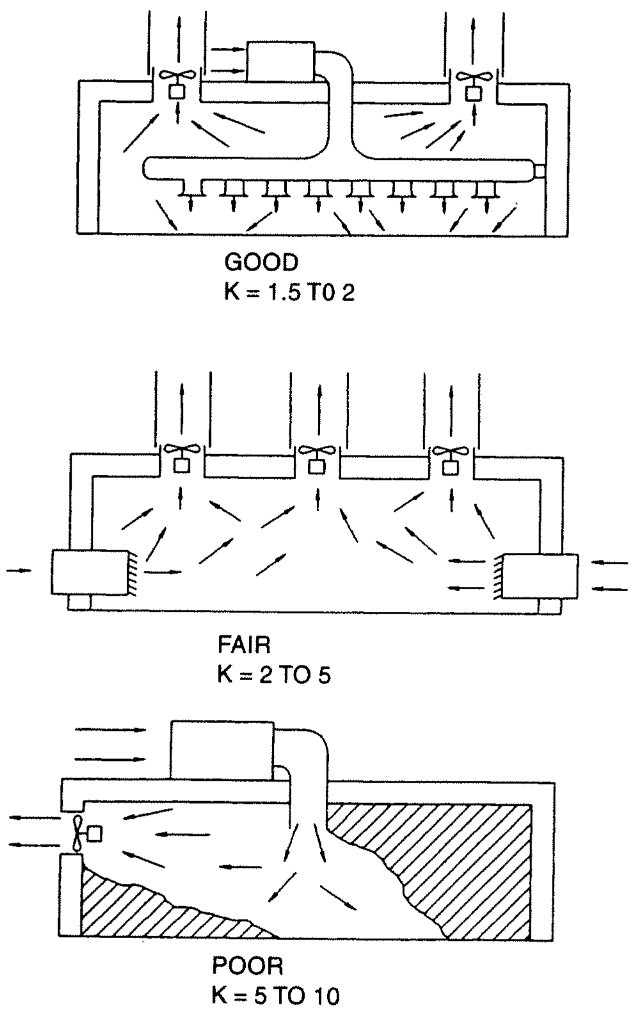

FIGURE 1-11. Examples of how inlet and exhaust locations can impact the value of "K" for a dilution ventilation system. The other factors described in the text must also be considered when selecting the appropriate value of "K" for the airflow calculation. *(Source: ACGIH[5].)*

TABLE 1-1. Toxicity Guidelines for Dilution Ventilation

Toxicity Class	TLV Range, ppm
Slightly Toxic	>500
Moderately Toxic	≥100–500
Highly Toxic	<100

Other Factors Affecting the "K" Value

For more toxic chemicals, a higher "K" value may be warranted to prevent harmful overexposure in case the expected dilution does not occur before workers breathe the contaminants. Although there is no firm toxicity classification system, the ACGIH *Industrial Ventilation Manual*[5] uses the guidelines in Table 1-1 based on the TLVs assigned to chemical substances as an indication of acceptable occupational exposure levels. TLVs are explained in Chapters 3 and 4.

In addition, the "K" value for any system is influenced by other circumstances such as any work patterns that could bring workers closer than anticipated to the contaminant source, the likelihood of greater than expected contaminant emissions, seasonal changes in the amount of natural ventilation, or other factors which impact the concentration of contaminants in the breathing zone of the workers.

Calculating Dilution Airflow for Health Protection

When a chemical is released at a constant rate into a ventilated workroom, the concentration profile follows the diagram in Figure 1-12. There is a gradual concentration buildup until a steady-state condition is reached. At this concentration, the emission rate and removal rate are in equilibrium so the concentration remains about constant. After chemical release stops, there is a gradual purging of the workplace air until the concentration reaches zero. The goal in calculating dilution airflow is to select an airflow rate (ft^3/min) that yields a steady-state concentration which is well below the exposure standard for the chemical.

From a practical standpoint, calculating the airflow for the steady-state control of the contaminant is very important. The buildup rate and the purging rate are usually less important calculations, except that the purging rate equation can estimate how long it will take the fan to remove the contaminated air from the work environment after the release or generation of contaminant ceases.

The amount of dilution airflow required depends on the physical properties of the contaminant (molecular weight and specific gravity [compared to water]), rate of contaminant release, the acceptable airborne concentration, and the relative efficiency of the total air volume flowing through the area in diluting the contaminants

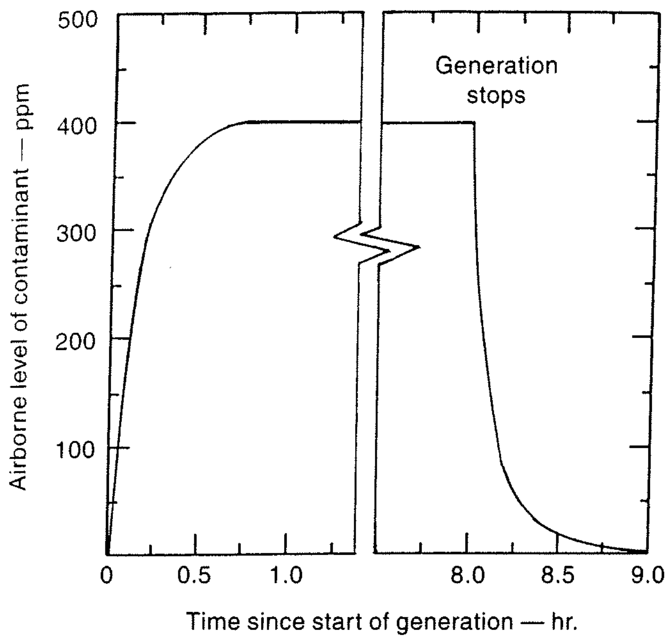

FIGURE 1-12. Concentration buildup and purging at the starting and stopping phases of contaminant generation.

(i.e., the "K" factor). The "buildup and purging" calculations also use the room volume as a parameter.

Dilution Ventilation for Health—Steady-state

The equation for calculating the steady-state dilution airflow rate for toxic or irritating contaminants is:

$$Q=\frac{F\times sp\,gr\times W\times K\times 1{,}000{,}000}{M\times L} \quad \textbf{(1.1)}$$

where: Q = dilution airflow, ft^3/min
F = conversion factor for units of W, from Table 1-2
sp gr = specific gravity of liquid (water = 1.0)
W = amount of liquid used per time interval (see Table 1-2)
M = molecular weight of contaminant
L = "target" airborne concentration of contaminant to be maintained in the work environment (usually based on OSHA PELs or TLVs® with an appropriate safety factor), ppm
K = dimensionless safety factor to increase the calculated airflow rate over the minimum, in order to take nonideal conditions into account. K normally ranges from 3 to 10 depending on the overall effectiveness of the ventilation system and uniformity of contaminant evolution. A higher K value is associated with poor airflow conditions and other unknown conditions or circumstances which could increase exposures to workers. (See Figure 1-11)

TABLE 1-2. Factors for Calculating Dilution Ventilation Airflow*

Amount of Liquid Used per Time Interval (*W*)	Conversion Factor (*F*)
pints/hr	6.7
pints/min	403.
gallons/hr	53.7
gallons/min	3222.
liters/hr	14.1
liters/min	846.

*For use in Equations 1.1, 1.3, and 1.6.

Example: A cleaning solvent containing 60% Isopropanol is used at the rate of 5 pints/hr in an open-bay work area. The general layout of the workroom prevents some of the dilution air from passing directly through the zone of contaminant evolution at the workbench; assume a value of 5 for "K." Calculate the dilution airflow requirement to maintain the concentration at 25% of the TLV.

Answer: The amount of solvent released is 60% of 5 pints/hr, or 3 pints/hr. The specific gravity of Isopropanol is 0.79 and its molecular weight is 60.[6] Based on the list in the *TLV/BEI* book, the current TLV for Isopropanol is 400 ppm; note that this value should be checked against the current edition. Thus, the "target" concentration is 100 ppm. From Table 1-2, an F factor of 6.7 is used in Equation 1.1 when solvent evaporation is expressed in units of pints/hr. Applying Equation 1.1:

$$Q=\frac{F\times sp\,gr\times W\times K\times 1{,}000{,}000}{M\times L}$$

$$Q=\frac{6.7\times 0.79\times 3\,\text{pints/hr}\times 5\times 1{,}000{,}000}{60\times 100}$$

$$Q=13{,}233\,ft^3/min$$

As this example illustrates, the magnitude of the safety factor "K" has a direct influence on the airflow calculation. Unfortunately, the appropriate value for "K" in many situations is ambiguous, and it is difficult to assign it a meaningful value. Thus, it is difficult to be confident that exposure measurements after the dilution system is installed will show that exposures have been reduced sufficiently. In addition, since one variable in Equation 1.1 is the target exposure limit for the chemical, any reduction in the exposure limit (as new health information becomes available) can require extensive upgrading of the dilution system. For example, if the exposure limit is halved, twice as much dilution airflow will be required to maintain the steady-state concentration at a new level that gives the same degree of protection.

Dilution Ventilation for Health—Concentration Buildup

These calculations estimate the concentration of contaminants from when emissions first begin until the level reaches steady-state conditions. Since these calculations are more complex than Equation 1.1, it is easier to define several new terms that can be used in the buildup equations:

$$Q' = \frac{Q}{K} \quad (1.2)$$

where: Q' = effective ventilation airflow, ft³/min
Q = actual ventilation airflow, ft³/min
K = dimensionless safety factor that accounts for any airflow that is not effective in diluting contaminants before they reach an employee's breathing zone (see complete definition under Equation 1.1)

$$G = \frac{F \times sp\,gr \times W}{M} \quad (1.3)$$

where: G = vapor generation rate, ft³/min
F = conversion factor for units of W, from Table 1-2
$sp\ gr$ = specific gravity of liquid (water = 1.0)
W = amount of liquid used per time interval (see Table 1-2)
M = molecular weight of contaminant

To calculate the concentration at any time (when the original contaminant concentration is zero), use this equation:

$$C_t = \frac{G[1 - e^{\left(\frac{-Q' \times t}{V_r}\right)}] \times 1{,}000{,}000}{Q'} \quad (1.4)$$

where: C_t = concentration at any elapsed time t, ppm
t = time since contaminant release began, minutes
V_r = room volume, ft³

Example: In the previous example, what is the concentration after 10 minutes assuming that the workroom measures 15 ft × 30 ft × 12 ft high (V_r = 5400 ft³)?

Answer: Apply Equations 1.2 and 1.3 using the information from the previous example:

$$Q' = \frac{Q}{K} = \frac{13{,}233\,\text{ft}^3/\text{min}}{5} = 2647\,\text{ft}^3/\text{min}$$

$$G = \frac{F \times sp\,gr \times W}{M}$$

$$G = \frac{6.7 \times 0.79 \times 3\,\text{pints/hr}}{60} = 0.26$$

Then use Equation 1.4 to calculate the airborne concentration after 10 minutes:

$$C_{10} = \frac{G[1 - e^{\left(\frac{-Q' \times t}{V_r}\right)}] \times 1{,}000{,}000}{Q'}$$

$$= \frac{0.26[1 - e^{\left(\frac{-2647 \times 10}{5400}\right)}] \times 1{,}000{,}000}{2647}$$

$$= 98.2[1 - e^{\left(\frac{-2647 \times 10}{5400}\right)}]$$

$$= 98.2[1 - e^{-4.9}] = 98.2[1 - 0.01]$$

$$C_{10} = 98.2[0.99] = 97.2\,\text{ppm}$$

Dilution Ventilation for Health—Purging

When further release or generation of contaminant has ceased, the concentration after any time period can be calculated from:

$$C_t = C_{original}\,[e^{\left(\frac{-Q' \times t}{V_r}\right)}] \quad (1.5)$$

where: C_t = concentration at any time t, ppm
$C_{original}$ = concentration when generation ceased, ppm
t = time since contaminant release ceased, minutes

Because of the mathematical relationship involved, C_t will never reach zero. However, the time to reach very low concentrations (approaching zero) can be estimated. Figure 1-12 illustrates concentration as a function of time during purging.

Example: Using information in the previous two examples, what will be the concentration 30 minutes after the solvent operation ends for the day, assuming that the fan continues to run? (Assume that a steady-state concentration of 100 ppm existed in the room when the work stopped.)

Answer: Applying Equation 1.5:

$$C_{30} = 100\ \text{ppm}\,[e^{\left(\frac{-2647 \times 30}{5400}\right)}]$$

$$C_{30} = 100\,[e^{-14.7}] = 100\,[0.0000004] \approx 0\ \text{ppm}$$

So the ventilation system will completely remove the Isopropanol vapors within 30 minutes after release ceases.

Dilution Airflow Design Data

As an option to using Equations 1.1 through 1.5, the ACGIH *Industrial Ventilation Manual* contains airflow recommendations for some applications such as general welding and use of lift trucks powered by internal combustion engines inside buildings.

For example, a dilution airflow of 5000 ft^3/min for each propane-fueled lift truck and 8000 ft^3/min for each gasoline-fueled lift truck is recommended under the following conditions:(5)

- A regular maintenance program incorporating final engine tuning through carbon monoxide analysis of exhaust gas must be provided, with CO concentrations no higher than 1% for propane-fueled trucks and 2% for gasoline-fueled trucks.
- Periods of lift truck operation do not exceed 50% of the working day.
- A reasonably good distribution of airflow must be provided.
- The volume of space must be at least 150,000 ft^3/lift truck.
- The truck must be powered by an engine of less than 60 hp.

This type of design information is especially helpful for new facilities where no ambient contaminant measurements can be conducted prior to system design.

Calculating Dilution Airflow for Fire and Explosion Prevention

Dilution ventilation is used to reduce concentrations of flammable or explosive gases, vapors, or dust to safe levels well below their lower explosive limit (LEL). The dilution must occur before the contaminated air reaches any source of ignition. The accumulation of flammable or explosive mixtures in basements, pits, and other locations also must be considered in addition to diluting vapors in the general work area. The equation for calculating dilution airflow for fire/explosion prevention is:

$$Q = \frac{F \times sp\,gr \times W \times S_f \times 100}{M \times LEL \times B} \qquad \textbf{(1.6)}$$

where:
- Q = dilution airflow, ft^3/min
- F = conversion factor for units of W, from Table 1-2
- sp gr = specific gravity of liquid (water = 1.0)
- W = amount of flammable liquid used or released per time interval (see Table 1-2)
- S_f = dimensionless safety factor that depends on the percentage of LEL acceptable for safe conditions. For some applications, the concentration should not exceed 25% of the LEL so $S_f = 4$ (i.e., $100 \div 25 = 4$); for other situations, S_f values of 10 or higher may be needed.
- M = molecular weight of contaminant
- LEL = lower explosive limit of contaminant, percent
- B = constant reflecting that the LEL decreases at elevated temperatures. B = 1 for temperatures up to 250°F, B = 0.7 for temperatures above 250°F.

Equation 1.6 is based on the assumption that 100% of the dilution air is effective in diluting the contaminant before the contaminated air reaches a source of ignition. If this is not the case, the calculated Q must be multiplied by an additional safety factor.

Some operations release peak amounts of contaminants over a short time period. For example, drying ovens evaporate solvents rapidly during the first few minutes after objects are placed in the oven. The value selected for W should reflect peak release rates.

When both employee exposure and fire/explosion prevention are considered for the same operation, the dilution flow rate calculated using Equation 1.1 usually governs because the acceptable airborne levels for breathing are significantly lower than the LELs for almost all, if not all, substances.

Air Density Adjustments Due to High Temperatures

Equations 1.1 through 1.6 assume that the dilution air has standard density of 0.075 lb/ft^3. This is the density of air at 70°F, 29.92 in. of mercury atmospheric pressure, and 50% relative humidity. Factors that affect density are temperature, altitude, and humidity. Density correction calculations are explained in Chapter 9. For dilution systems, the most common factor is high temperature within drying ovens or similar enclosures. Density adjustments for high temperatures can be calculated from:[5]

$$Q_{actual} = Q_{calculated}\left(\frac{460^{\circ}F+T}{530^{\circ}F}\right) \quad (1.7)$$

where: Q_{actual} = dilution airflow at actual temperature, ft^3/min
$Q_{calculated}$ = dilution airflow calculated from Equations 1.1 or 1.6, ft^3/min
T = actual dilution air temperature, °F

Example: One gallon of toluene evaporates per hour in an adhesive drying operation at 200°F. Observations show that most of the solvent evaporates within the first 10 minutes of the drying cycle. How much airflow is needed to keep the concentration at 20 percent of the LEL?

Answer: Since one gallon evaporates within about 10 minutes, the appropriate value of W to account for the peak evaporation rate is:

$$W = \frac{1 \text{ gallon}}{10 \text{ minutes}} = 0.1 \text{ gallon/min}$$

From Table 1-2 the appropriate value of "F" is 3222. The specific gravity of toluene is 0.87, the molecular weight is 92 and the LEL is 1.3%.[7] Since the temperature is less than 250°F, B = 1. To maintain the concentration at 20% of the LEL, $S_f = 5$ (i.e., 100 ÷ 20 = 5). Applying Equation 1.6:

$$Q = \frac{F \times spgr \times W \times S_f \times 100}{M \;\; LEL \;\; B}$$

$$Q = \frac{3222 \times 0.87 \times 0.1 \times 5 \times 100}{92 \times 1.3 \times 1}$$

$$Q = 1172 \, ft^3/min$$

Since this operation is at 200°F, adjust the calculated airflow using Equation 1.7:

$$Q_{actual} = Q_{calculated}\left(\frac{460^{\circ}F+T}{530^{\circ}F}\right)$$

$$= 1172 \, ft^3/min\left(\frac{460^{\circ}F+200^{\circ}F}{530^{\circ}F}\right)$$

$$Q_{actual} = 1172\,(1.25) = 1465 \, ft^3/min$$

Summary

Ventilation is an effective way to control toxic or flammable contaminants. There are two types of ventilation for contaminant control: *dilution* ventilation that reduces contaminant concentrations by diluting them with fresh air; and *local exhaust* ventilation systems that capture or contain contaminants at their source before they are dispersed in the workroom.

Although both types of ventilation are useful, local exhaust is usually preferred when it is feasible. Advantages include more positive control of employee exposures and lower overall airflow requirements. On the other hand, dilution ventilation systems may be less expensive to install and operate for small and moderate sized systems if heating costs during the winter are not excessive.

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