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VENTILATION FOR CONTROL

The provision of a safe and healthful working environment entails three primary components: (1) awareness of potential hazards (*recognition*); (2) assessment of these hazards (*evaluation*); and (3) abatement of these hazards (*control*). Although a great deal of attention has been given to awareness and assessment, including toxicological research, epidemiological studies, standards setting, and environmental monitoring, the single most crucial element in the program—the reduction or elimination of the problem—has curiously been ignored. In a survey of industrial hygiene literature, 40% of the papers published in one journal over a $3\frac{1}{2}$-year period addressed monitoring, 24% addressed physical effects and epidemiology, 8% covered personal protection, and less than 8% were devoted to environmental control (Hammond, 1980). As Hammond (1980) states:

> One would hope in 10–20 yr time to be able to look back and find the monitoring and the environmental control rankings reversed, with the ongoing and necessary epidemiology holding its central position. This would place monitoring nearer its correct position as a back up to good environmental control.

A similar review of the industrial hygiene literature conducted more than a decade later (Burgess, 1993) demonstrated little improvement in the ranking of environmental control papers. To place the use of ventilation in perspective with other mechanisms for environmental control, an introduction to those mechanisms follows.

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1.1 CONTROL OPTIONS

The methods used to control worker exposure to harmful materials or conditions in the occupational environment have been categorized in a number of ways as shown in Table 1.1. In nearly all cases, the most effective approach is the combination of controls into an integrated package. The elimination of an offending agent from the workplace, accompanied, if necessary, by its replacement with a safer material, should be considered first in any effort to control the environment. The substitution of less hazardous materials has become quite common in industry, as knowledge of dangers from certain materials becomes available. For example, hydrocarbon-solvent-based paints are being replaced by water-based paints. Purchasers of some organic solvents are specifying that these solvents contain only trace amounts of benzene contamination. The principle of elimination and substitution applies to equipment and processes as well as materials. Newer machinery is often designed to minimize dust generation and release, for example. Processes can be modified to incorporate contaminant reduction techniques. The introduction of a raw material in pellet form in rubber compounding is less likely to generate dust than the same material presented as a powder.

If it is not feasible to eliminate the contaminant from the workplace, another approach is to isolate it from the workers who frequent the area. Distance and physical

Table 1.1 Classifications of Methods for Control of Air Contaminants

First (1983)

Material substitution
Processing change
Equipment change
Local exhaust ventilation
General (dilution) ventilation
Equipment enclosure
Employee enclosure

Gideon et al. (1979)

- Control at source
  - Material substitution
  - Process or equipment change
  - Isolation
  - Local exhaust ventilation
  - Work practice
- Control at workplace
  - General exhaust ventilation
  - Housekeeping
- Control at worker
  - Isolation/personal protective equipment

Burgess (1995)

- Toxic materials
  - Eliminate
  - Replace
  - Dust control
  - Reduce impurities
- Equipment and process
- Task modification
- Facility layout
  - Ventilation
  - General ventilation
  - Local exhaust ventilation

Sherwood and Alsbury (1983)

Automation, alternative methods
Substitute materials, methods
Plan layout, enclosures, remote
Local exhaust ventilation
Dilution ventilation
Personal protective equipment

barriers, preferably around the process, but possibly around the workers, can provide protection. In either case, this method of control is usually accompanied by a ventilation system. When the process is isolated, the emphasis is on exhausting the contaminated air from the process. In contrast, when the worker is isolated, the emphasis should be on supplying clean air to the worker's station.

Administrative controls such as worker rotation through hazardous areas can also be implemented. In the nuclear power industry, exposure to radiation is limited on a 3-month as well as an annual basis. Any worker achieving the maximum permissible exposure before the end of the pertinent period is transferred to a low-radiation work area for the balance of time. In hot environments, workers should be allowed to rest in a cool area on a frequent basis throughout the workshift to allow time for the body to recover from the thermal stress. Other administrative controls include biological monitoring, worker education, and equipment maintenance. In all cases, administrative controls should be combined with attempts to reduce the hazard through engineering controls.

The focus of this volume, the use of ventilation, is ubiquitous in the modern workplace. Virtually every industrial and commercial facility contains some form of ventilation system for environmental control. The intent may be comfort (temperature, humidity, odors), safety (flammable vapors), or health (toxic particles, gases and vapors, airborne contagions).

The last resort for preventing exposures to toxic chemicals is personal protection, in the form of respirators and protective garments. Respiratory protection is used when all other controls are inadequate or when the possible failure of those controls would produce a hazardous situation.

1.2 VENTILATION FOR CONTROL OF AIR CONTAMINANTS

A review of the literature reveals that there was a great deal of interest in the theoretical and engineering aspects of industrial ventilation in the late 1930s and the early 1940s. The pace of the activity increased with the onset of World War II, with many of the articles covering industrial processes with direct defense applications, such as shipyard welding, rubber life-raft manufacturing, and synthetic-rubber production. It was during this time that pioneering industrial hygienists and engineers such as Phillip Drinker, Theodore Hatch, Allen Brandt, Constantin Yaglou, Leslie Silverman, W. C. L. Hemeon, and J. M. DallaValle were all very active. Much of the information was eventually incorporated into the first edition of the *Industrial Ventilation Manual*, published by the American Conference of Governmental Industrial Hygienists (ACGIH) in 1951.

The New York State Department of Labor's Division of Industrial Hygiene and Safety Standards published a *Monthly Review* beginning in the 1920s. Articles appearing in the late 1940s and early 1950s presented several theoretical and practical guides for the use of ventilation for contaminant control. In the mid-1950s, the Division of Occupational Health of the Michigan Department of Health began publication of *Michigan's Occupational Health*, a newsletter by industrial hygienists and other occupational health professionals that contained numerous articles on practical applications of industrial ventilation. The Michigan Department of Health contributions by James Barrett, Bernie Bloomfield, and Marvin Schuman were joined by those of George Hama, Knowlton Caplan, and Ken Robinson and others to provide core material for the ACGIH's manual as it evolved in the 1950s.

Ventilation engineers categorize systems as being either general (dilution) or local exhaust ventilation systems. The most basic form of ventilation is *general or dilution ventilation*, consisting simply of an exhaust fan pulling air out of the workplace and exhausting it to the outdoors. A general ventilation system may include a replacement air system, replacement-air distribution ducting, and in rare situations, air-cleaning equipment on the exhaust stream. As shown in Table 1.2, general exhaust ventilation can be used if the contaminant(s) of interest is not highly toxic and if the rate of generation is predictable. It is not usually the system of first choice to the ventilation designer, but may be the most practical for a situation where there are many contaminant sources scattered throughout the workplace or where the sources are mobile (e.g., forklift trucks in a warehouse).

Local exhaust ventilation (LEV) implies an attempt to remove the contaminant at or near the point of release, thus minimizing the opportunity for the contaminant to enter the workplace air. The ability of a LEV system to accomplish this task is dependent on its proper design, construction, and operation. The nominal LEV system includes an exhaust hood, ducting, a fan, and an exhaust outlet. As with general exhaust ventilation, additional components, such as replacement air systems and air-cleaning devices, may (and should) be included. Local exhaust systems are used in a wide variety of settings, from research laboratory hoods to commercial kitchens to foundries. LEV systems can, and should, be used in the vast majority of situations in preference over general exhaust.

In addition to the nominal system described above, there are a number of special types of LEV systems, used for particular applications and types of equipment. A *low-volume/high-velocity system* involves the positioning of a small hood adjacent to, or surrounding, the point of contaminant generation. A relatively high capture velocity [10,000 fpm (50 m/s) to 15,000 fpm (76 m/s)] is attained at a low airflow [60 cfm (0.03 m^3/s) to 150 cfm (0.07 m^3/s)] by designing a small hood opening. These systems operate at much higher static pressures than traditional ventilation systems but have

Table 1.2 Ventilation Control Hierarchy

Type of Ventilation[a]	Hood Type	Example
LEV	Total enclosure	Glovebox
LEV	Partial enclosure	Laboratory hood
LEV	Low-volume–high-velocity, tool-integrated	Portable grinder
LEV	Exterior hood	Welding hood
GEV	Mechanical exhaust	Roof ventilators
GEV	Natural	Wind-induced

[a] LEV = local exhaust ventilation; GEV = general exhaust (dilution) ventilation.

Source: Adapted from BOHS (1987).

the distinct advantage of minimizing the total exhaust flow, thus reducing the need for expensive replacement air.

Push–pull hoods are used on wide, open-surface tanks where exhaust slots on either side would be inadequate to draw air from the center of the tank. Instead, one side of the tank is fitted with a source of supply air while the other remains as an exhaust. A jet of air from the supply side is blown across the tank surface and collected in the exhaust hood.

1.3 VENTILATION APPLICATIONS

The design goal of industrial ventilation is to protect the worker from airborne contamination in the workplace. To the newcomer this may suggest installing a system that will reduce exposure below the Permissible Exposure Guidelines or an appropriate action level. This is not the case. The professional will design the system to meet the goal of “as low as reasonably practical.” Within this control approach the effectiveness of the major ventilation techniques is shown in Table 1.2. There is no agreement on the position of low-volume–high-velocity systems since its effectiveness varies greatly depending on the degree of integration with the tool.

Soule (1991) reviews the application of the two major ventilation control approaches, dilution and local exhaust ventilation (Table 1.3). In most industries dilution is not the primary ventilation control approach for toxic materials. It is accepted that local exhaust ventilation will not provide total capture of contaminant and dilution ventilation is frequently applied to collect losses from such systems. In addition, it is used for multiple, dispersed, low-toxicity releases.

The specific design methods for both general exhaust ventilation and local exhaust ventilation are available, however an important predesign phase identified by Burton (1997) as problem characterization is frequently given little attention (Table 1.4). This is a topic that can be best addressed by an industrial hygienist who can provide data on emissions, air patterns, and worker movement and actions.

If the process is new, a videotape of a similar operation with the same unit operations may be available. The best of all worlds would be the availability of

Table 1.3 Application of Local Exhaust and General Exhaust Ventilation

Local Exhaust Ventilation	General Exhaust Ventilation
Contaminant is toxic	Contaminant has low order of toxicity
Workstation is close to contaminant release point	Contaminants are gases and vapors not particles
Contaminant generation varies over shift	Uniform contaminant release rate
Contaminant generation rate is high with few sources	Multiple generation sources, widely spaced
Contaminant source is fixed	Generation sites not close to breathing zone
	Plant located in moderate climate

Table 1.4 Information Needs for Problem Characterization

Emission Source Behavior
Location of all emission sources or potential emission sources
Which emission sources actually contribute to exposure
What is the relative contribution of each source to exposure
Characterization of each contributor:
Chemical composition, temperature, rate of emission, direction of emission, initial emission velocity, continuous or intermittent, time intervals of emission
Air Behavior
Air temperature
Air movement
Mixing potential
Supply and return flow conditions
Air changes per hour
Effects of wind speed and direction
Effects of weather and season
Worker Behavior
Worker interaction with emission source
Worker location
Work practice
Worker education, training, cooperation

Source: Burton (1997).

a video-concentration tape. If the facility is a duplicate of one in the company the industrial hygienist should visit the operation with the ventilation designer. Frequently the designer is an outside contractor. In this case it is important that the problem characterization approach be followed and an information package be provided the designer.

The precautions that should be reflected in the design have been discussed in detail elsewhere, but should include worker interface, access for maintenance, and routine testing. Computer-aided manufacturing/design (CAM/CAD) technology now permits precise placement of equipment and ductwork so that ad hoc placement by the installer should be a thing of the past. As discussed earlier, it may be worthwhile to "mock up" a specific design solution prior to final design and construction. This is especially true when a large number of identical workstations are to be installed.

General cautions are appropriate on the use of available design data for control of industrial operations. The ACGIH *Industrial Ventilation Manual* provides the most comprehensive selection of design plates for general industry ACGIH (2001). Each of these plates provides four specific design elements: hood geometry, airflow rate, minimum duct velocity, and entry loss. The missing element is the performance of the hood in terms of percent containment or capture efficiency.

Although ventilation control designs on standard operations in the mature industries have been published, performance has rarely been reported. It is important to evaluate performance by diagnostic air sampling both to ensure that the worker is protected and to prevent overdesign. The latter was shown to be the case in the design for control of a push–pull system for open-surface tanks (Sciola, 1993). A mock-up of one tank demonstrated that satisfactory control could be achieved at minimal airflow. Operating at the reduced airflow rate saved \$100,000 in installation costs and \$263,000 in annual operating costs.

1.4 CASE STUDIES

One of the more clear examples of the effectiveness of ventilation as a prime factor in the reduction of an industrial disease problem is the case of the Vermont granite workers exposed to silica in the first half of the twentieth century. Around the beginning of the century, pneumatic tools were introduced into the granite-cutting industry. These tools were capable of generating large amounts of airborne dust, much more than had been produced with the hand tools used previously. The net result of this new technology was a dramatic rise in the death rate attributable to tuberculosis* among granite cutters using these new tools, at a time when the national tuberculosis mortality rate was steadily declining (Fig. 1.1). The association of the mortality rate with dust level was quite dramatic (Fig. 1.2). The pneumatic tool users and cutters (group A) had the highest dust levels and the highest death rates. Lower concentrations and mortality rates were observed in group B (surface machine operators) and group C (those exposed to general plant dust). The lowest mortality rates were observed in group D, workers who were exposed to less-than-average dust concentrations, such as personnel associated with sandblasting, an operation that had always been done with local exhaust ventilation. These data led the state of Vermont to require workplace controls in the granite-cutting sheds to reduce the dust concentration to below 10 million particles per cubic foot (mppcf).[†] In the late 1930s, local exhaust ventilation was installed as the primary workplace control. The immediate effect on the dust concentrations was a 10 to 80% reduction between 1937 and 1940 (Fig. 1.3). For all four occupational groups, the concentrations were reduced below 10 mppcf. Further decreases were noted in 1955 and 1972 as more processes became dust controlled. By 1967 it was recognized that silicosis had been virtually eradicated in the Vermont granite sheds.

Similar data from underground iron-ore mines in the Lake Superior area indicate the tremendous impact that a good ventilation system can have for reducing dust levels (Urban, 1950). A combination of ventilation and wet drilling produced a

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*Silicosis, a fibrosis of the lung tissue caused by the inhalation of quartz dust, is often associated with tuberculosis because it favors the growth of the tubercle bacilli. Furthermore, advanced silicosis and the early stages of tuberculosis produce similar x-ray images, complicating the diagnosis. Silicosis, while disabling, is seldom fatal in itself. However, the accompanying tuberculous infection is.

[†] For typical granite dust, 10 mppcf, as defined with an impinger collection and light-microscopy analysis, is approximately equal to 0.1 mg of quartz per cubic meter of respirable dust.

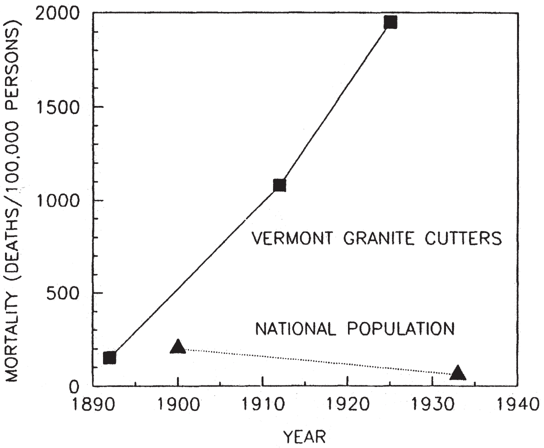

Figure 1.1 Annual data on mortality from tuberculosis for Vermont granite workers and the national population from 1890 to 1935, as power tools were being introduced to the industry. [Data from Albert E. Russell (1936), "Silicosis and Other Dust Diseases," The Harold S. Boquist Second Annual Memorial Lecture, University of Minnesota.]

reduction from 50 mppcf to 5 mppcf between 1920 and 1945, as shown in Fig. 1.4. In 1934, wet drilling and a "moderate ventilation control" program were initiated. In 1939, increased demand for ore raised production rates. Simultaneously, ventilation was improved, with larger air volumes being moved through the mines. In Fig. 1.4, the effect of the improved ventilation is quite noticeable.

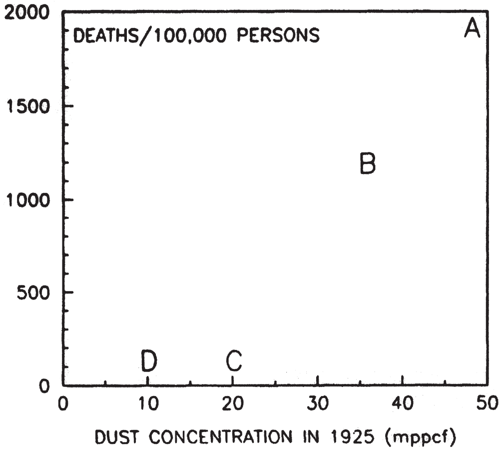

Figure 1.2 Tuberculosis mortality rates (1930) among Vermont granite workers shown in relation to dust concentration (1925) for each of four occupational groups. A, pneumatic tool users; B, surface machine operators; C, workers exposed to plant dust; D, workers at ventilated operations. [Data from Albert E. Russell (1936), "Silicosis and Other Dust Diseases," The Harold S. Boquist Second Annual Memorial Lecture, University of Minnesota.]

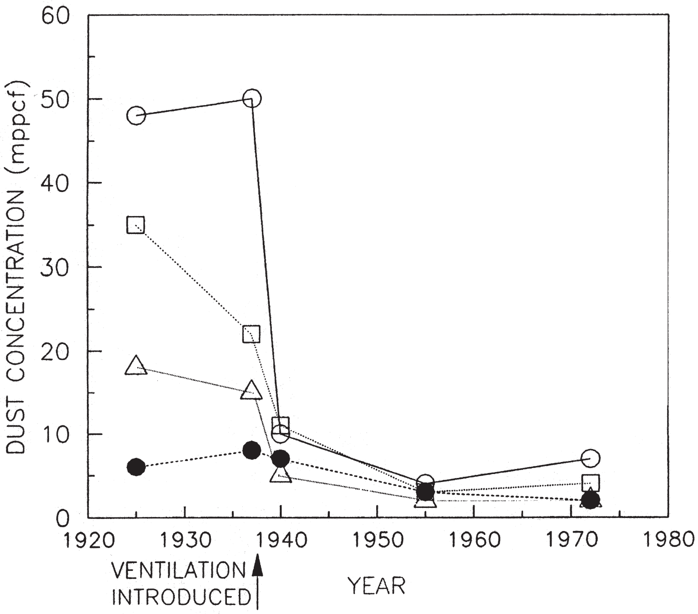

Figure 1.3 Dust concentrations for four occupational groups in Vermont granite mills. Open circles, group A; open squares, group B; open triangles group C; filled circles, group D. The introduction of exhaust ventilation in the late 1930s is accompanied by a dramatic decline in exposures for the heavily exposed groups. [Date are from G. P. Theriault, W. A. Burgess, L. J. DiBerardinis, and J. M. Peters (1974), "Dust Exposure in the Vermont Granite Sheds," *Arch. Environ. Health* **28**:12.]

In shipyards, welding in poorly ventilated areas presented a serious health problem, particularly when the metal being welded was galvanized steel. In one report, tests were performed to determine the reduction in zinc and lead fumes (Rosenfeld, 1944). Without mechanical ventilation, the air was found to contain 4.4 mg/m^3 of lead fume and over 100 mg/m^3 of zinc fume. The introduction of an exhaust duct to within 20 in. of the arc dropped the air concentrations to 0.16 mg/m^3 of lead fume and 1.8 mg/m^3 of zinc. Bringing the exhaust duct within 6 in. of the arc showed a further reduction, to 0.044 and 0.92 mg/m^3 of lead and zinc fume, respectively.

1.5 SUMMARY

There is no doubt that exhaust ventilation is one of the most effective tools available to the industrial hygienist for controlling the workplace environment. Its effectiveness can be enhanced by combining it with other control methods. However, it must be designed, installed, and operated intelligently if its full potential is to be realized. Errors made in the design phase can be quite costly. Any system must be checked after installation to assure that it conforms to the design specifications and that the

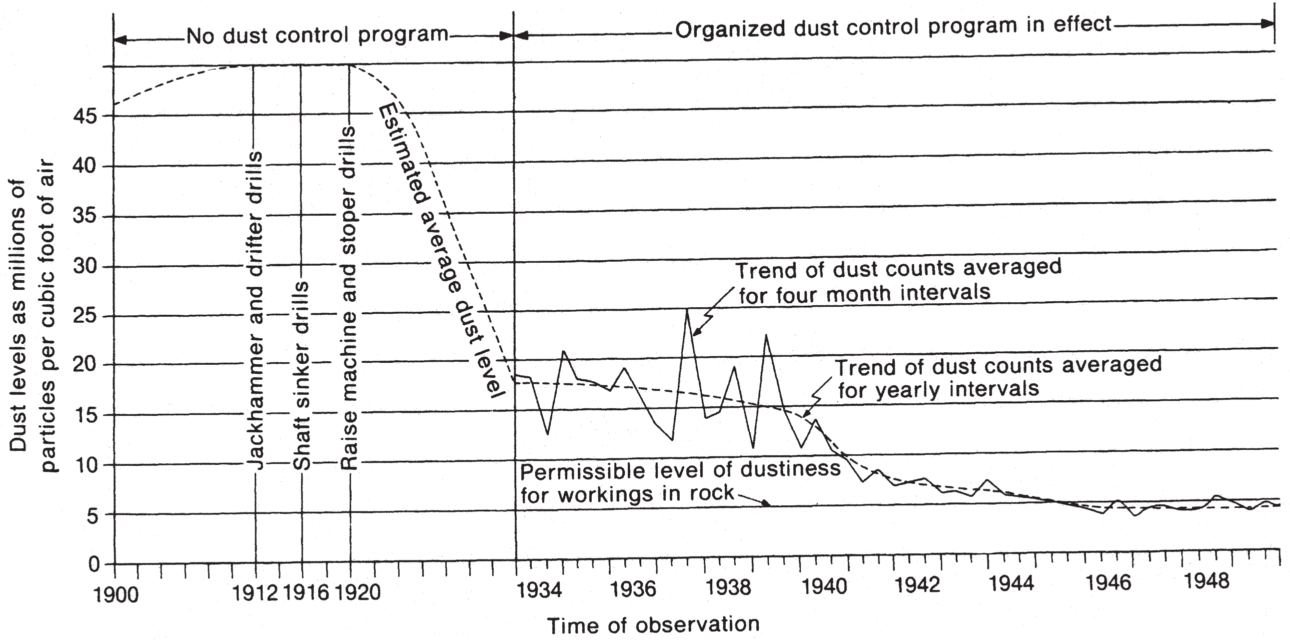

Figure 1.4 Results of a two-stage dust control program in the underground iron-ore mines of the Lake Superior region. The wet drilling and modest ventilation controls introduced in the early 1930s effected a noticeable improvement. The improved ventilation in the late 1930s spurred a more rapid decline in dust concentrations. [From E. C. J. Urban (1950), "The Control of Certain Health Hazards Encountered in Underground Metal Mines," *Am. Ind. Hyg. Assoc. Q.* **10**:201.]

concentration of the contaminant of interest is reduced to the specified level. Finally, lack of maintenance on any system will produce a degradation in performance over time.

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