American Industrial Hygiene Association Journal

ISSN: 0002-8894 (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/aiha20

CONTAMINANT REDUCTION BY VENTILATION IN A CONFINED SPACE MODEL—TOXIC CONCENTRATIONS VERSUS OXYGEN DEFICIENCY

Richard P. Garrison , Kiyoung Lee & Chulhong Park

To cite this article: Richard P. Garrison , Kiyoung Lee & Chulhong Park (1991) CONTAMINANT REDUCTION BY VENTILATION IN A CONFINED SPACE MODEL—TOXIC CONCENTRATIONS VERSUS OXYGEN DEFICIENCY, American Industrial Hygiene Association Journal, 52:12, 542-546, DOI: 10.1080/15298669191365171

To link to this article: https://doi.org/10.1080/15298669191365171

Published online: 04 Jun 2010.

AM. IND. HYG. ASSOC. J. 52(12):542–546 (1991)

Contaminant Reduction by Ventilation in a Confined Space Model—Toxic Concentrations versus Oxygen Deficiency*

Richard P. Garrison
Kiyoung Lee
Chulhong Park

School of Public Health, The University of Michigan, Ann Arbor, MI 48109

Airborne contaminants can create hazardous conditions in confined spaces (CS) across a broad range of concentrations, e.g., from relatively low, potentially toxic levels (ppm) to much higher levels (%) causing oxygen deficiency. This study investigated ventilation characteristics for isobutylene (IBE) at relatively low concentrations, simulating toxic levels. Experimental data were compared to results from previous studies of oxygen deficiency. Data were obtained at several locations in a cubical CS model, with several variable test parameters: ventilation mode (exhaust and supply), volume flow rate ("air changes" per hour), and ventilation inlet/outlet elevation (% of model height). Findings indicated similar ventilation characteristics, in general, for simulated toxic (IBE) levels compared to oxygen deficiency. Both IBE and O_2 deficiency data have shown that supply ventilation is typically more effective than exhaust and that CS locations aligned with supply outlets experience much more rapid contaminant reduction than do other locations. The data suggest that highly accurate predictions of ventilation characteristics cannot be expected for all cases with widely different contaminants and concentrations. Findings from this study indicate that ventilation guidelines for one range of contaminant concentration (e.g., causing oxygen deficiency) can be extended reasonably to encompass a broader range of concentration (e.g., to include toxic or flammable atmospheres).

Most fatal accidents in confined workplaces are caused by airborne contaminants.[1–3] Mechanical ventilation is an extremely important engineering control method for preventing the accumulation of hazardous contaminants in many workplaces, including confined spaces (CS). Ventilation can directly reduce contaminant concentrations but administrative controls (e.g., CS entry permits, entry attendants, atmospheric testing, or personal protective equipment) cannot.

Previous studies have investigated ventilation characteristics for the elimination of oxygen deficiency in confined space models.[4–6] These studies have produced an empirical database that describes ventilation performance as specific functions of several design/test parameters.

The objective of this study was to test and evaluate ventilation performance for air contaminants in a CS model at concentrations much lower than those that cause oxygen deficiency. If contaminants in relatively low, potentially toxic concentrations have ventilation characteristics that are similar to those for other contaminants in much higher concentrations (e.g., causing O_2 deficiency), then data obtained from either case (or situations in between, e.g., flammable concentrations) could be extended to additional applications—encompassing a broader range of potentially hazardous conditions. Many CS entry situations, such as waste water manholes, require consideration of both oxygen deficiency and toxic contaminants.[7]

The previous studies of oxygen deficiency investigated several design paramenters: ventilation mode (exhaust versus supply), ventilation volume flow rate (CS model "air changes" per hour, or ACH), ventilation inlet/outlet (I/O) elevation (%H, with H being CS model height), sampling location inside the CS model, and variations in CS model shape (cubical versus noncubical). The first two studies[4,5] were conducted by using nitrogen to cause oxygen deficiency. The third study[6] utilized several "heavier-than-air" (HTA) contaminants to cause oxygen deficiency.

Nitrogen is neutrally buoyant in air (specific gravity = 0.98). Findings from this study of simulated toxic concentrations are comparable to the previous results for nitrogen because the density of the "toxic" contaminated air is not significantly different from that of fresh air or from air in which oxygen has been displaced by nitrogen. Oxygen deficiency caused by HTA contaminants, which can include many toxic and flammable vapors, was found to have significantly different ventilation characteristics from those found with nitrogen.

The principal parameter used to describe ventilation performance for recovery from oxygen deficiency in the previous studies was the oxygen recovery time constant which describes the rate of change in oxygen concentration from an initial deficiency to an ambient concentration of 21% O_2. This parameter was obtained

*The authors gratefully acknowledge support for this study by the National Institute for Occupational Safety and Health, as part of a larger project to investigate ventilation for work in confined spaces.

from regression of the experimental data against an exponential model representing oxygen recovery as a function of time. The empirical regression data from these studies provided relatively high correlation to the experimental O_2 deficiency data.[4–6]

EXPERIMENTAL FACILITY AND METHOD

Figures 1 and 2 illustrate the experimental facility used in this study. The CS model, ventilation system, and sampling locations were the same as used for oxygen deficiency.[4] The CS model was cubical with each edge measuring 0.61 m (2.0 ft). Ventilation airflow was generated by a small, centrifugal blower with valves to control exhaust and supply airflow to the CS model. Ventilation volume flow rate was measured with an orifice-plate flowmeter and manometer. The ventilation pipe passed through a circular opening in the top of the CS model, located in the center of a corner quadrant. Air samples were drawn from four locations: (1) directly below the ventilation pipe at an elevation of 15% H; (2) and (3) at 50% H in the centers of adjacent vertical quadrants of the CS model; and (4) at 85% H in the quadrant opposite the ventilation pipe.

Toxic air contaminants can be hazardous in relatively low concentrations (i.e., 100s of ppm and often much lower). Ventilation (contaminant reduction) characteristics for substances present in potentially toxic levels can be simulated by many materials because dilution effects are not affected by toxicity. The primary mechanism for contaminant dilution in CS models and in actual confined spaces is the mixing of fresh and contaminated air caused by air movement. Mixing effects should not vary significantly for different substances in relatively dilute (e.g., ppm) concentrations.

In this study, isobutylene (IBE) was selected to simulate toxic concentrations because it was relatively safe to use and relatively easy to monitor. It was supplied through the bottom of the CS model from a cylinder containing a 1.0% mixture (10 000 ppm) of IBE in air. IBE concentrations were measured with a photoionization detector (PID). The PID was used with a Model 511A portable gas chromatograph (Thermo Electron Instruments, Franklin, Mass.), although a separation column was not used because no contaminant separation was needed. Analog signals from the PID were converted to digital data and recorded on a personal computer.

A multiple-point sampling system was used because there was only one PID. This system utilized four three-way solenoid valves, which were activated by

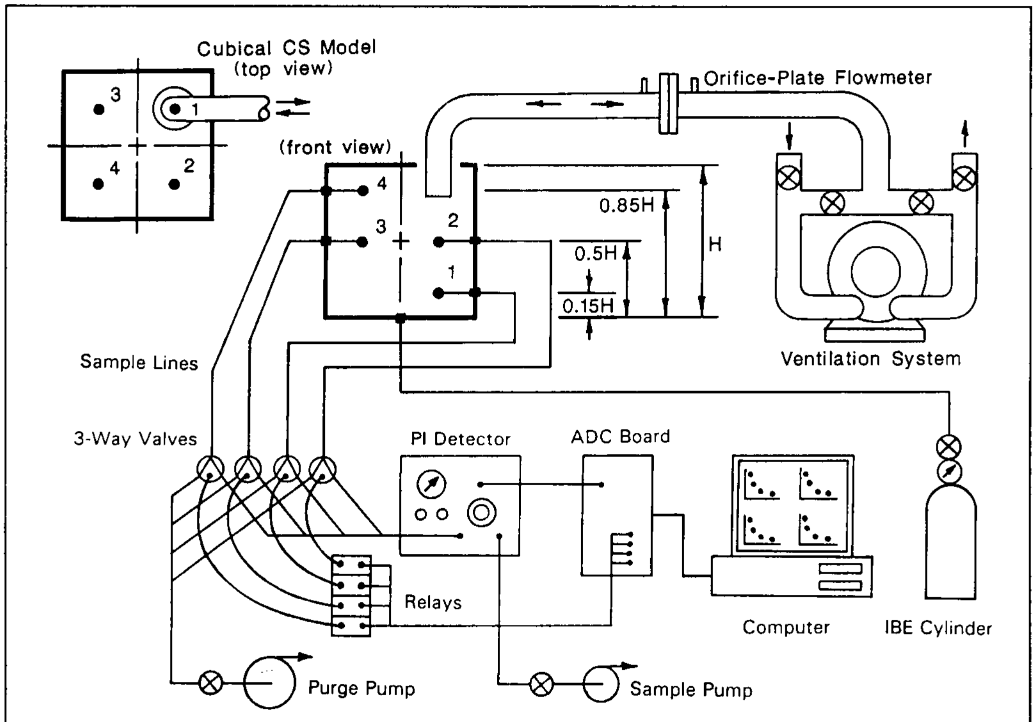

FIGURE 1. Diagram of experimental facility

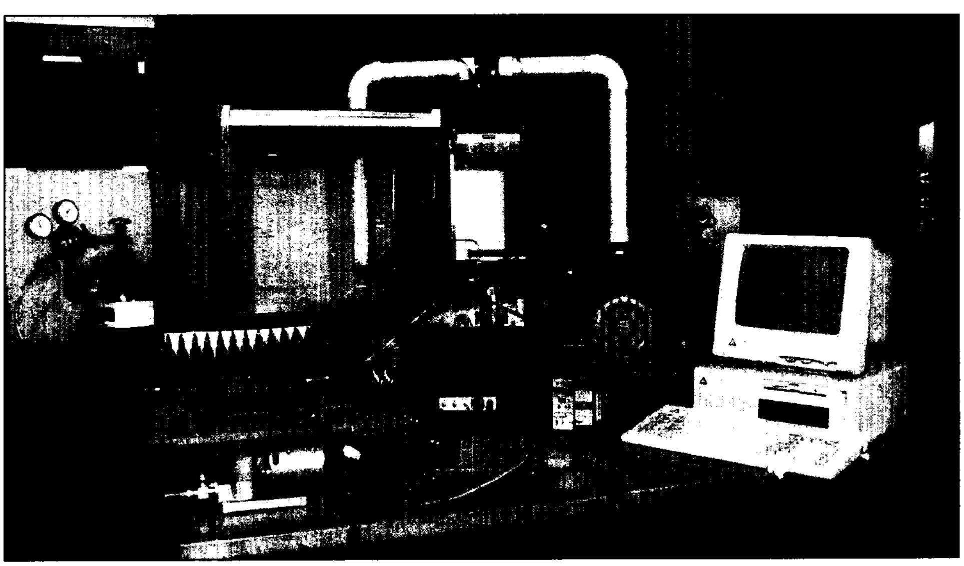

FIGURE 2. Experimental facility

relays operated by the computer. A purge pump was used to maintain fresh samples at each solenoid. Another pump was used to draw samples at a rate of 200 mL/min from the solenoids to the PID. The sampling system measured IBE concentration every 10 sec (i.e., every 40 sec at each of the four sampling locations). Measurements of oxygen concentration in the previous studies were made by using four electrochemical sensors with measurements at each location approximately every second.

The experimental testing included 24 (2 × 4 × 3) cases: two ventilation modes—exhaust and supply; four volume flow rates—10, 20, 40, and 60 ACH; and three ventilation inlet/outlet elevations—25%, 50%, and 75% H. Several different initial concentrations (C_0) of IBE were also tested (100, 350, 700, and 1400 ppm) encompassing a range representative of toxic contaminant hazards. A test run involved setting up the desired ventilation mode, volume flow rate (ACH), and I/O elevation (% H); establishing the initial IBE concentration in the CS model; starting the ventilation system; recording IBE concentration as a function of time; and terminating the test when the IBE concentration had fallen to about 1% of the initial value.

FINDINGS AND DISCUSSSION

Figure 3 presents experimental data from four typical test cases (volume flow rates of 10, 20, 40, and 60 ACH; supply ventilation; outlet elevation 25% H; Location 3, C_0 = 700 ppm). The concentration of IBE is expressed nondimensionally as a fraction (C/C_0) of the initial concentration. The change in C/C_0 is shown as a function of time (minutes) in the upper plot and as a function of the total CS model ventilation air volume (CSV) in the lower plot (CSV = ACH multiplied by ventilation time in hours).

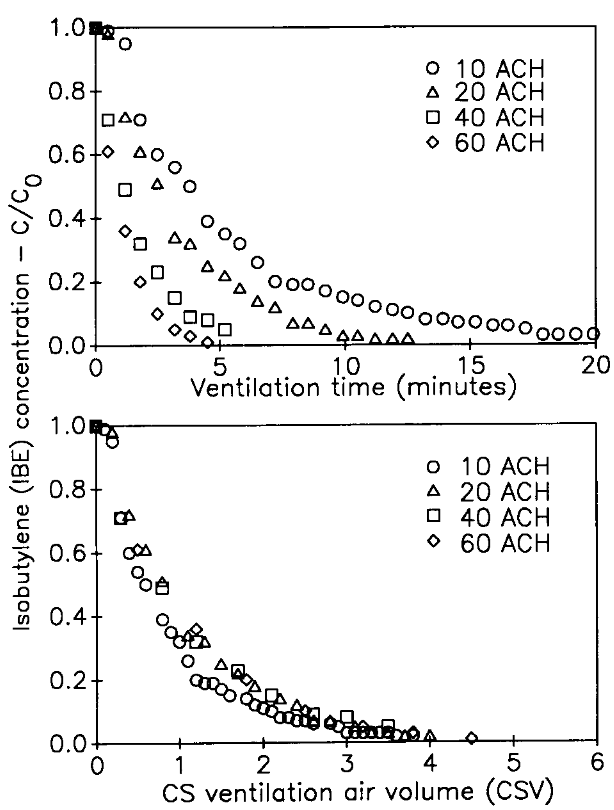

FIGURE 3. Typical contaminant (IBE) reduction as a function of time and CS ventilation air volume (CSV) at four volume flow rates (ACH)

Nondimensional parameters were selected for this and the subsequent figures because they have the potential for broader application in describing ventilation characteristics. The concept of total "air change" volume is sometimes applied for dilution ventilation, including confined spaces. The sizes of confined spaces vary greatly, from only slightly larger than the size of a man to many thousands (or even millions) of cubic feet. The capacities (flow rates) of ventilation equipment also vary greatly. Answers to questions on how long to ventilate a CS prior to entry are dependent upon CS size and ventilation flow rate and can be stated in terms of a total number of "air change" volumes.

It is important to understand that an air change is strictly a calculated parameter and that it is something of a misnomer. It does not mean complete, discrete displacement of contaminated air with fresh replacement air. Contaminant dilution by ventilation is a continuous process that involves the mixing of contaminated air and fresh air. It might be more appropriate to describe dilution ventilation in terms of total air volume expressed in units of CS volumes (CSV).

Regardless of how it may be designated, the total ventilation air volume is an overly simplified parameter. As shown (upper plot) in Figure 3, contaminant reduction is considerably more rapid at 60 ACH than at 10 ACH. However, it is also shown (lower plot) that the lowest flow rate (10 ACH) provided the most effective dilution as a function of the total CS ventilation air volume (CSV). The CSV concept is further complicated by the fact that contaminant concentrations may vary significantly with location inside the CS. Location characteristics can vary with the shape and size of a CS, the size and location of contaminant sources, and the ventilation design (number and size of CS openings, number and elevation of inlets/outlets, and exhaust/supply modes).

Figure 4 presents contaminant reduction curves, C/C_0 versus CSV, for a typical test case (exhaust 60 ACH, 25% H, Location 3). This figure shows that the relative reductions in IBE concen-

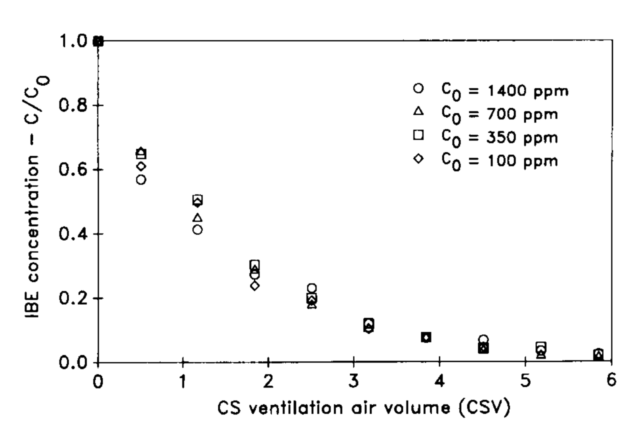

FIGURE 4. Typical contaminant (IBE) reduction for different initial concentrations (C_0)

tration were quite similar for different initial concentrations (i.e., C_0 = 100, 350, 700, and 1400 ppm). This supports use of the nondimensional parameter C/C_0.

Figure 5 shows IBE reduction and oxygen recovery (nitrogen reduction) data for three test cases (I: supply, 20 ACH, 25% H; II/III: supply/exhaust, 60 ACH, 50% H; all at Location 3). The curves for oxygen recovery were calculated by using the empirical time constants and the same ventilation times as for the experimental IBE data. Cases I and II indicate very similar ventilation characteristics. Case III, on the other hand, demonstrates that IBE reduction and oxygen recovery can also be significantly different.

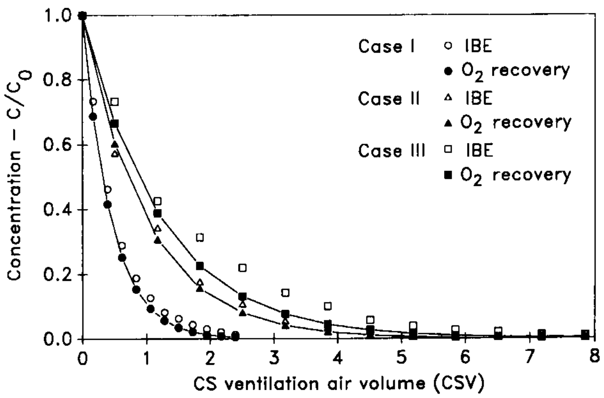

FIGURE 5. Comparisons of contaminant reduction for IBE and oxygen recovery for three test cases

Figure 6 is a plot of C/C_0 for eight test cases of IBE reduction and O_2 recovery (exhaust and supply, 20 and 60 ACH, 25% and 75% H). This figure includes all IBE data in the range from C/C_0 = 0.05 to 0.95. O_2 recovery data were obtained by interpolation between the two experimental O_2 data points nearest the time for each IBE data point.

The data in Figure 6 generally cluster around the line of agreement (i.e., a slope of 1.0). The points are more diffuse for higher contaminant concentrations (higher C/C_0). Regressional analyses of these data yielded an overall slope of 1.10 with a 95% confidence interval ranging from 0.99 to 1.22. Regressions for the specific locations (1, 2, 3, and 4), flow rates (20 and 60 ACH), and I/O elevations (25% and 75% H) provided similar results—slopes ranged between 0.96 and 1.29 with all 95% confidence intervals containing 1.0.

Figure 6 indicates that ventilation characteristics varied significantly but not greatly even for these greatly different contaminants and concentrations. The largest differences between simulated toxic contaminant (IBE) reduction and O_2 recovery were observed in the early stages of dilution. The tendency for regression slopes to be greater than 1.0 suggests that oxygen recovery was slightly faster than IBE reduction.

These findings indicate that general ventilation guidelines observed for specific contaminant conditions may apply across a relatively broad range of conditions. The results also suggest that highly specific characteristics and design data (e.g., the empirical database from the previous studies) may not always apply with great accuracy for significantly different contaminant conditions.

Figure 7 provides a comparison of exhaust and supply ventilation for two IBE test cases (40 ACH, 50% H). Supply ventilation was consistently more effective than was exhaust. Location 1 was very different from Locations 2, 3, and 4, showing much more rapid contaminant reduction for the supply mode because the location was in alignment with the supply outlet. These same general observations were made for oxygen recovery.[4]

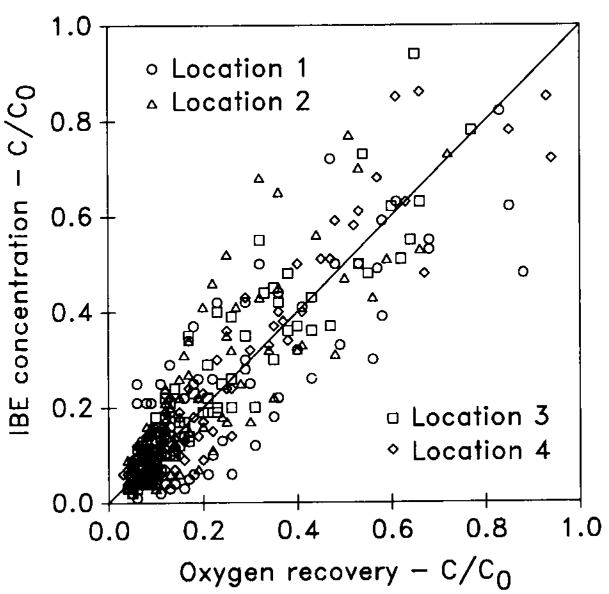

FIGURE 6. Comparison of contaminant concentration data for IBE reduction and oxygen recovery for eight test cases

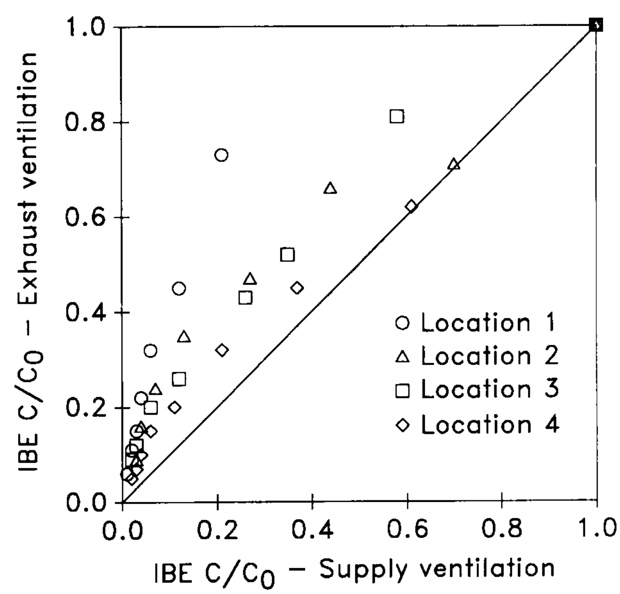

FIGURE 7. Example comparison of exhaust and supply ventilation for two IBE test cases

CONCLUSIONS

This study has shown that ventilation causes contaminant reduction in a generally similar manner across a broad range of concentrations, from potentially toxic (ppm) to oxygen-deficient (%) levels. Findings indicate that general guidelines learned under specific test conditions may be reasonably applied to other conditions. For example, supply ventilation is generally more effective than exhaust ventilation for reducing contaminant concentrations ranging from the simulated toxic (IBE) levels tested in this study to much higher levels associated with oxygen deficiency (previous studies). Results also suggest that specific empirical data (e.g., time constants for oxygen recovery) may have good accuracy for some CS ventilation situations and may have limited accuracy for other contaminant conditions. Empirical test data could be used in conjunction with safety factors to provide conservative estimates of ventilation time for contaminant reduction.

These observations may be intuitive. However, it can be reassuring to have data that confirm what is expected to happen. Experience with effective CS ventilation under one set of conditions can be applied to other conditions. Practical guidelines based on experience need to be studied and published to promote and facilitate CS ventilation.

Results from this study encourage the use of mechanical ventilation to reduce contaminant levels for a wide range of potentially hazardous concentrations. If mechanical ventilation were used more often for work in confined spaces, there would be fewer overexposures, accidents, injuries, and deaths during CS entries. However, ventilation alone is not sufficient to ensure safe entries in the presence of airborne contaminants. Atmospheric testing should be conducted to confirm safe levels, and other procedures should be followed to ensure safe CS entry.

REFERENCES

1. **Safety Sciences:** *Search of Fatality and Injury Records for Cases Related to Confined Spaces*. NIOSH Contract No. 10947. San Diego, Calif.: Safety Sciences, 1978.
2. **Yodaiken, R. and J. Larson:** Air Monitoring, Reporting Needed to Reduce Confined Space Hazards. *Occup. Health Saf. 56*:82–89 (1986).
3. **Garrison, R.P. and D.R. McFee:** Confined Spaces—A Case for Ventilation. *Am. Ind. Hyg. Assoc. J. 47(11)*:A-708–A-714 (1986).
4. **Garrison, R.P., R. Nabar, and M. Erig:** Ventilation to Eliminate Oxygen Deficiency in Confined Spaces—Part I: A Cubical Model. *Appl. Ind. Hyg. 4*:1–11 (1989).
5. **Garrison, R.P. and M. Erig:** Ventilation to Eliminate Oxygen Deficiency in Confined Spaces—Part II: Noncubical Models. *Appl. Ind. Hyg. 4*:260–268 (1989).
6. **Garrison, R.P. and M. Erig:** Ventilation to Eliminate Oxygen Deficiency in Confined Spaces—Part III: Heavier-than-Air Characteristics. *Appl. Occup. Environ. Hyg. 6*:131–140 (1991).
7. **Mignone, A.T., E.C. Beckhusen, K.O. Leary, and M. Gochfield:** Temporal Variation in Oxygen and Chemical Concentration in a Confined Workspace: The Wastewater Manhole. *Appl. Occup. Environ. Hyg. 5*:428–434 (1990).