BN-97-14-4

Potential Exposure to Airborne Contamination in Fan Penthouses

Gerhard W. Knutson, Ph.D., CIH
Member ASHRAE

ABSTRACT

Laboratory hoods are designed to capture contaminants generated in the laboratory and discharge them outside. In many laboratories this results in several fan systems. To provide a convenient location for maintenance to service the fans, the fans are often located in penthouses. Good design of laboratory ventilation requires that the duct be negative in occupied spaces. However, it is not possible to design a fan room or penthouse with the duct negative downstream of the fan. Consequently, when the system leaks after the fan, contaminated air can be released into the penthouse with potential exposure to maintenance and transient personnel.

To evaluate the potential hazard, the fan room of a chemistry building at a large university was evaluated. Tracer gas was released in several laboratory hoods, and the concentration of the tracer gas in the penthouse was monitored at locations that simulated typical operator positions.

The tracer gas testing in the chemistry building penthouse clearly demonstrated air leakage from the exhaust systems into the penthouse under normal operation. The measured tracer gas levels were low and show that typical exposure levels in the penthouse are below the current OSHA standards. However, because of the obvious odors and the uncertainty caused by low-level exposure to many different chemicals, modifications to the ventilation systems were recommended to reduce the amount of leakage in the penthouse. The recommendations included better sealing of the ventilation system and increased ventilation in the penthouse.

INTRODUCTION

A large midwestern university had recently remodeled its chemistry building. To reduce the potential of reentry, the design increased the stack height and placed reducer cones on the duct to produce a higher exit velocity. The design was complicated by two facts. First, the chemistry building had, in general, a single hood on each exhaust system. Second, the university architect desired to maintain the integrity of the roof of the building and allowed only a few roof penetrations. To reduce the number of roof penetrations, the several systems had extensive duct runs downstream from the fan.

After completion of the remodeling, maintenance personnel complained of organic odors in the penthouse. An inspection of the duct system demonstrated significant leakage. The long, and sometimes convoluted, duct system, with the added resistance due to the cone, had an unusually high static pressure. The high static pressure resulted in significant leakage from the duct.

A program to protect maintenance personnel was initiated. Access to the penthouse was restricted, personnel were provided with respiratory protection, and administrative controls were implemented at the hoods. In addition, the university sealed the positive pressure ducts with a silicone caulk.

The measures improved the situation. However, the integrity of the seal deteriorated with time. Since the odors still persisted in the penthouse, maintenance personnel remained concerned. Air samples were conducted for the most common solvents. Although the samples were generally low, the maintenance personnel remained concerned.

To assist the university in addressing the potential hazard, an investigation of the duct leakage in the penthouse was conducted.

Background

The chemistry building included both undergraduate and graduate classrooms and research laboratories. The building has over 100 individual exhaust systems. Each system provides exhaust for one or more laboratory hoods and other apparatus. Each exhaust fan is located in the penthouse on the top floor of the building. The discharge duct, from the fan to the roof penetration, is under positive pressure. The pressur-

Gerhard W. Knutson is senior consultant with Knutson Ventilation Consulting, Inc., Edina, Minn.

ized duct can cause leakage of exhaust air into the penthouse. Since the laboratory exhaust systems can be contaminated by chemicals used in the laboratories, there is concern about possible chemical exposure to maintenance personnel working in the penthouse.

The university established a procedure (Safe Operating Procedure for Assuring Fume Hoods Are Not Used While Being Serviced) to reduce the potential exposure to maintenance personnel while working on a specific system. However, there is no interruption of the work in other exhaust systems that are not being serviced. When there is leakage from these systems, there is a potential exposure of maintenance personnel. The purpose of this study was to determine the significance of leakage from the exhaust systems that are operating normally. To investigate the exhaust system leakage, several tracer gas tests were conducted over a two-day period.

Description of the Test Method

Tracer gas tests were conducted by releasing a tracer gas, sulfur hexafluoride, inside a laboratory hood and monitoring the concentration of tracer gas in the penthouse of the chemistry building. Sulfur hexafluoride was selected because it is nontoxic, odorless, colorless, noncorrosive, and easily detected by the instrumentation used. The tracer gas was released at a known release rate, 8 liters per minute (8 L/min), inside a laboratory hood. The hood sash was closed to ensure that all released tracer gas was exhausted through the exhaust system. Tracer gas was detected by an infrared spectrophotometer. The instrument was calibrated before the tests using the tracer gas from the cylinder that would be used in the tracer gas tests. The specifications for the release system and the detector system are included in ASHRAE Standard 110 (ASHRAE 1995).

Maintenance personnel selected four laboratory hoods that represented the "worst" systems for leakage, and they were tested.

The infrared spectrophotometer was placed on an access walk in the penthouse of the chemistry building. The detector probe was attached to a long hose to allow proper location of the probe without moving the instrument. The probe was placed at appropriate positions to represent a "breathing zone" exposure for maintenance personnel. The location of the detector probe was determined after conversations with maintenance personnel. Usually the probe was located above a motor at a fan close to the system that was receiving the tracer gas. A strip chart recorder was connected to the instrument to record the test results.

The tracer gas was released at 8 L/min for a specified period of time, usually five minutes. The concentration of tracer gas was recorded, starting when the tracer gas release began and continuing until the concentration fell to less than 10% of the peak concentration. When the probe was near the source, the length of sample was 10 minutes. When the probe was further away, the sample period was increased to 15 to 20 minutes.

TEST RESULTS

The results of the tests are tabulated in Table 1. Several different observations are necessary to evaluate the data.

Release Rate

The challenge to the hood was 8 L/min for a total of five minutes. Approximately 240 grams (0.53 pounds) of tracer gas were released for each test. The resulting concentration, which depends on the exhaust rate of the hood, was between 210 ppm and 400 ppm. Although these concentrations represent exaggerated release rates for most laboratory applications, the high rate was selected to ensure that the test program would produce measurable levels of tracer gas in the penthouse.

Exposure Levels

As shown in Table 1, the measured concentrations were relatively low. The highest reading measured was 2.1 ppm. The concentrations of tracer gas in the penthouse were generally low. However, when an organic material with a very low odor threshold is leaked into the penthouse, the odor could be very noticeable.

It is difficult to properly evaluate the potential health consequences of the leakage from an exhaust system. Assuming a more reasonable release rate within the hood, the exposure resulting from the exhaust system leakage can be estimated. The following examples illustrate typical projections.

- Benzene is a highly toxic material with a low OSHA standard. If benzene were used in a laboratory hood at a rate of 15 milliliters (about half an ounce) in a five-minute test and all the benzene were to evaporate, then the highest measured exposure would correspond to an exposure 20% of the OSHA standard.
- If toluene were used in the same experiment instead of benzene, the predicted exposure would be less than 1% of the OSHA standard.
- A reactive gas such as chlorine can pass through a reaction vessel, causing a chemical change in the solution in the vessel. A high rate would be 100 mL per minute. At the end of the reaction, the chlorine will pass through the vessel without reacting. Using the highest test results, the chlorine exposures would be about 5% of the OSHA standard.
- If hydrogen sulfide were used in the same experimental setup, the potential exposure would be less than 0.2% of the OSHA standard. However, the smell of rotten eggs would be very noticeable and objectionable.

These examples illustrate that the tracer gas tests show maintenance personnel exposure to be below the OSHA stan-

TABLE 1
Tracer Gas Levels, Chemistry Building Penthouse

Test	Release Location	Release Time	Detector Location	Maximum Concentration	Time of concentration Peak	Average Concentration	Test Duration	ppm-min.
1	23-T	5 min.	Above 23-S motor	0.92 ppm	5 minutes	0.56 ppm	10 min.	5.6 ppm-min.
2	23-T	5 min.	Above 23-R motor	0.97 ppm	5 minutes	0.55 ppm	10 min.	5.5 ppm-min.
3	23-T	5 min.	Above 23-U motor	1.09 ppm	5 minutes	0.63 ppm	10 min.	6.3 ppm-min.
4	23-T	5 min.	At 23-P disconnect	0.27 ppm	8 minutes	0.19 ppm	20 min.	3.8 ppm-min
5	23-R	5 min.	At 23-P disconnect	1.32 ppm	6 minutes	0.26 ppm	20 min.	5.2 ppm-min.
6	23-R	5 min.	Above 23-Q motor	2.10 ppm	5 minutes	0.93 ppm	15 min.	13.9 ppm-min.
7	23-R	5 min.	Above 23-R motor	0.97 ppm	3 minutes	0.59 ppm	10 min.	5.9 ppm-min.
8	23-R	6 min.	Above 23-S motor	0.80 ppm	4 minutes	0.40 ppm	10 min.	4.0 ppm-min
9	23-R	5 min.	Above 23-S motor	0.15 ppm	7 minutes	0.05 ppm	15 min	0.75 ppm-min
10	23-T	5 min.	At 23-P disconnect	0.25 ppm	4 minutes	0.10 ppm	10 min.	1.0 ppm-min.
11	23-T	5 min.	Above 23-I motor	1.93 ppm	4 minutes	1.2 ppm	10 min.	12 ppm-min.
12	23-T	5 min.	Above 23-H motor	1.26 ppm	4 minutes	0.71 ppm	10 min.	7.1 ppm-min.
13	23-T	5 min.	Above 23-G motor	1.22 ppm	4 minutes	0.66 ppm	10 min.	6.6 ppm-min.
14	23-I	5 min.	Above 23-E motor	0.34 ppm	7 minutes	0.18 ppm	10 min.	1.8 ppm-min.
15	22-C	5 min.	Above 22-B motor	1.2 ppm	1 minute	0.39 ppm	10 min.	3.9 ppm-min
16	22-C	5 min.	Above 21-Z motor	0.84 ppm	6 minutes	0.32 ppm	10 min.	3.2 ppm-min
17	22-C	5 min.	Above 22-F motor	< 0.05 ppm	N/A	< 0.05 ppm	10 min.	< 0.5 ppm-min
18	22-C	5 min.	Above 22-D motor	< 0.05 ppm	N/A	< 0.05 ppm	10 min.	< 0.5 ppm-min
19	22-C	5 min.	Above 22-C motor	0.60 ppm	3 minutes	0.22 ppm	10 min.	1.1 ppm-min

dard (OSHA 1996) or the ACGIH threshold limit value (ACGIH 1996-97) with reasonable, but high, rates of release within the hood. In addition, the calculations are based on peak concentrations, whereas the OSHA standard is based on eight-hour average exposures. On the other hand, the examples clearly show that there will be objectionable odors caused by the leakage from the exhaust systems. Since the university had a continuous program of sealing the duct, these examples may be considerably lower than would have been experienced if the duct had not been sealed.

Multiple Sources

The tracer gas was released in only one hood. However, when maintenance personnel are working in the penthouse, more than one source could influence their exposure. Since there are many exhaust systems in the penthouse, the exposure

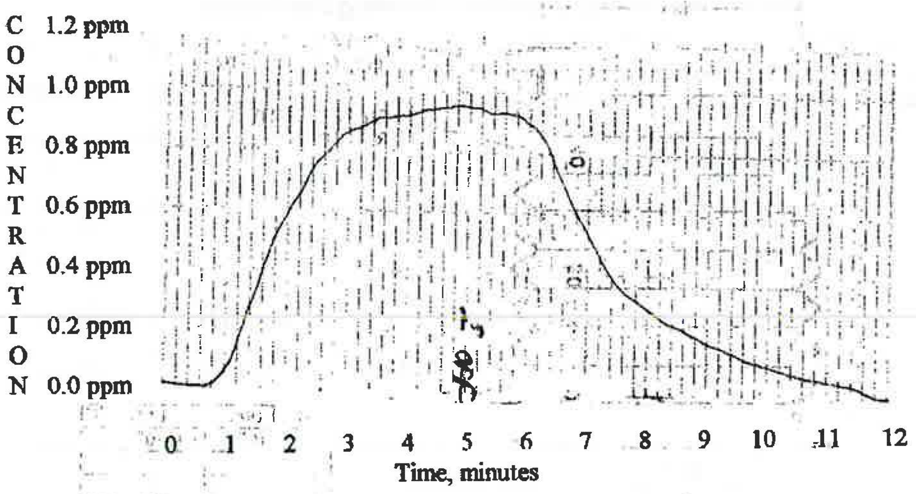

Figure 1 *Tracer gas test, release in system 23-T, detector probe above 23-R. Reference test 2 in Table 1. Tracer gas release 8 L/min, average concentration 0.55 of tracer gas, peak concentration 0.98 ppm at five minutes into the test.*

will be, to a degree, cumulative. At a point in the penthouse, the exposure due to leakage will be the sum of exposure due to all the adjacent systems. If the effects of the chemicals are additive, the exposures under a worst-case scenario should be below acceptable standards.

If the chemicals have a synergistic effect (have a greater toxicological effect together than either chemical has alone), the intermittent and independent release within the laboratory hoods can reduce the potential for significant exposure.

Duration of Exposure

During the tracer gas tests, the detector probe was placed at a fixed point, representative of a typical location occupied by maintenance personnel in the penthouse. As time proceeded, the measured concentrations would rise and nearly reach a state of equilibrium. After the tracer gas was turned off, the levels fell. The rise and fall were remarkably fast when the detector was close to the exhaust system that was being tested. The entire cycle took about ten minutes, with a five-minute release in the hood. Figure 1 shows a typical tracing from the infrared spectrophotometer. As the detector moved further away, the increase in concentration was delayed, was not as rapid, and did not reach the same peak concentration. In addition, the decrease in airborne concentration was slow. While standing about 20 feet from the fan with the tracer gas, the entire cycle took over 20 minutes. This dispersion was clearly due to the distance the tracer gas had to migrate.

DISCUSSION AND RECOMMENDATIONS

The tracer gas tests and an understanding of the operations within a laboratory hood demonstrate low-level, variable exposures due to leakage from the exhaust systems. In addition, the exposures could be to a variety of chemicals. Because of the obvious odors and the uncertainty caused by low-level exposures to many different chemicals, it is recommended that the ventilation system be modified to reduce the amount of leakage in the penthouse.

Control Measures

The measures recommended to reduce the potential exposure for maintenance personnel are associated with addressing the leakage for the system and improving general ventilation in the penthouse. Three steps recommended to reduce leakage include replacement of the exhaust duct with airtight duct, use of shaft seals at the penetration of the fan housing by the drive shaft, and replacement of the downstream flexible connection.

Duct Leakage

In all ventilation systems, the amount of duct leakage is always a concern. In the chemistry building exhaust systems, the leakage is a greater concern since the air could be contaminated. The tracer gas observed in the penthouse during the tests resulted from leakage from the exhaust duct.

To reduce the amount of leakage, maintenance personnel have sealed the joints and seams. With time, the seal is lost due to a variety of factors. Periodically, maintenance personnel repeat the process.

A better alternative is to replace the duct with a duct designed to reduce the leakage. Flanged and gasketed duct construction, with welded seams, can produce a system with almost no leakage.

Shaft Penetration

The fan impeller is driven by a shaft that penetrates the fan housing. When first looking at the fan, one would believe that the entire fan housing would be negative compared with the penthouse. However, a fan can, and often does, have a local positive pressure at the shaft penetration. This will cause air to

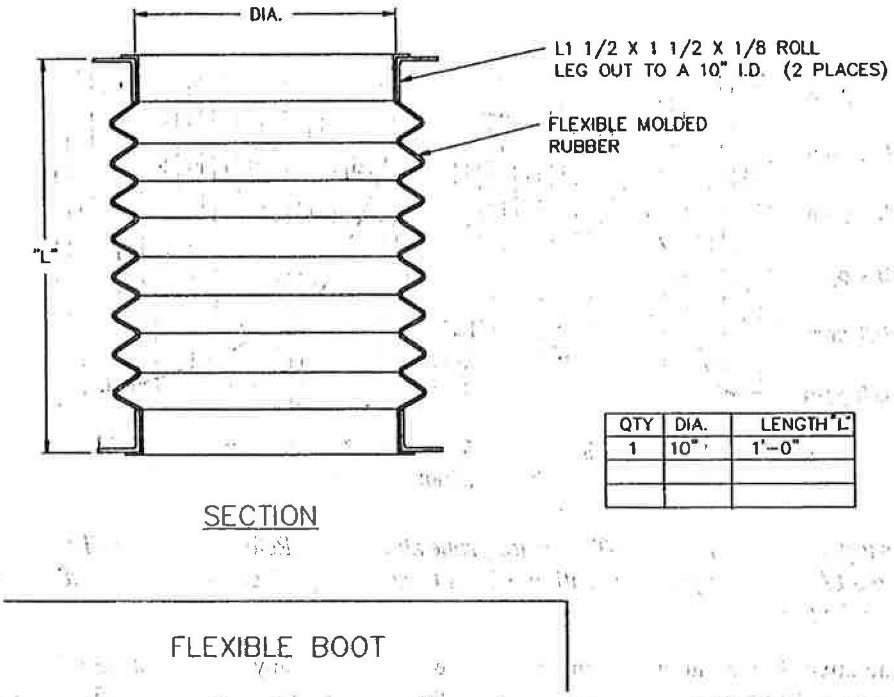

Figure 2 *Molded rubber boot.*

leak out of the fan. In the tests conducted for the chemistry building, leakage at the fan penetration was observed at all four fans that were tested, and the author believes that the single most significant contributor to the leakage is at the fan shaft penetration.

A shaft seal can be placed on the shaft to reduce leakage; however, no fan seal is completely effective. After time, all shaft seals will leak. With the application of shaft seals, a reduction in the leakage will occur. Nevertheless, it will be necessary to augment this measure with general exhaust ventilation in the penthouse.

Flexible Connection Leaks

The flexible connection on several of the fans had an obvious hole. To prevent this problem, a molded rubber boot (see Figure 2) should be applied to the outlet of the fan. The molded rubber boot provides a much better seal than the common flexible connection.

General Ventilation

After installation of the control measures to reduce leakage, some leakage will still occur. Adequate general ventilation is required to disperse the exhaust contaminants that leak into the penthouse area. However, there is no general rule of thumb to determine the amount of ventilation required. Two design approaches should be considered: air changes per hour and migration velocity.

Based on air changes, the ventilation rate should be 8 to 10 air changes per hour. This rate is typical for laboratory applications and can be applied to the penthouse. However, ventilation based on the number of air changes is more a measure of the size of the penthouse than it is a direct control measure.

A second method is to supply the air at one end of the penthouse and exhaust it at another. This would give the air a general direction of flow. The minimum velocity required to establish this flow would be 50 to 75 fpm.

Since the university was located in the northern part of the country, a heated supply system was required to maintain temperature above freezing.

CONCLUSIONS

1. The tracer gas testing in the chemistry building penthouse clearly demonstrated the potential for contaminated air to leak from the exhaust systems into the penthouse under normal operation.
2. The measured tracer gas levels from a single system were low and show that typical exposure levels in the penthouse are likely below the current OSHA standards. However, the university had sealed all of the positive pressure duct before the tests were conducted.
3. With several duct systems leaking at the same time, the potential exposure, based on the tracer gas tests would be below the OSHA standards.
4. Because of the obvious odors and the uncertainty caused by low-level exposures to many different chemicals, it is recommended that the ventilation systems be modified to reduce the amount of leakage in the penthouse.

5. The primary sources of tracer gas leakage were:
   - duct leakage from the positive pressure duct after the fan,
   - the shaft penetration to the fan housing, and
   - the flexible connection downstream from the fan.
6. To reduce potential leakage from the fan systems, three measures are required:
   - Replace the positive pressure exhaust duct to provide an "airtight" construction of the exhaust system.
   - Install shaft seals to reduce leakage.
   - Install molded rubber boots to reduce leakage from the flexible connections.
7. These measures will reduce the loss from the positive pressure duct in the penthouse. However, there will always be a potential for some leakage of contaminated air into the penthouse.
8. The penthouse should be provided with adequate exhaust ventilation to frequently exchange the air.

REFERENCES

ACGIH. 1996-97. *Threshold limit values for chemical substances and physical agents.* Cincinnati: American Conference of Governmental Industrial Hygienists

ASHRAE. 1995. *ANSI/ASHRAE 110-1995, Method of testing performance of laboratory fume hoods.* Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

OSHA. 1996. Occupational exposure to toxic substances in laboratories. *29 CFR Part 1910.* U.S. Occupational Safety and Health Administration.