STUDY ON THE DISTRIBUTION OF CHEMICAL CONCENTRATION IN AN EXPERIMENTAL LABORATORY WITH LOW-VELOCITY DOWNFLOW VENTILATION

Expected graduation 2023.3, Environment Systems
47216648 WANG XUEYU 王 雪鈺
Supervisor: Prof. Yoshito Oshima

Keyword: Chemical Laboratory, Downflow ventilation, Chemical Risks

1. Introduction

About 40% of laboratory personnel's time is spent in the laboratories. And with the gradual advancement of experimental research in highly sophisticated domains such as medication, optics, and nuclear. Experimental study will investigate an increasing number of synthesis and development, and herein reveals new risks. Some of these risks are plainly visible, such as VOCs, particulate matters, radioactive materials, physical hazard that may cause explosive, flammable, combustible, oxidizer effects. However, the toxicological properties of some new materials are not currently well recognized. The evaluation of the risks associated with certain nanoparticles has not kept pace with the development of novel materials, much alone applicable legislation and standards.

Ventilation systems are the primary and efficient means of eliminating contaminants in indoor spaces. Designing a general ventilation for a laboratory is, however, complicated. The purpose of general laboratory ventilation is threefold: it must (i) help control the airborne chemical hazards below levels that may cause harm to occupants (acute or chronic effects, cancer etc.), property (corrosion, chemical residue), and environment (pollution, chemical accumulation), (ii) provide proper temperature and humidity for the occupants and the general experiment tasks conducted on the bench-top, and (iii) energy efficiency through commensuration with the level of risk to airborne contamination.

There are two prevalent types of airflow distribution organization in the chemical laboratories: the mixing ventilation system, and the displacement ventilation system. Given that a number of VOC-based contaminants are generally of higher density than air[1], it is important to pay attention to the concentration distribution of dense gaseous contaminants and their transport behavior under efficient ventilation schemes. This study was determined to investigate the ventilation performance of a novel downflow ventilation implemented in a chemical laboratory. The experiment began from two perspectives: ventilation rates and exhaust locations and utilized one typical dense chemical to determine how these two factors influenced the airflow pattern in the breathing zone. This study provided substantial ramifications for the development of innovative downflow ventilation and implications for energy efficiency.

2. Methods

(1) Geometry of model laboratory with downflow ventilation

This investigation was conducted in a full-scale laboratory mock-up with dimensions of 2.7 m × 5.3 m × 3.0 m, as is depicted in Fig. 1. (a - d). The supplied air was set at 25°C and the air flux was set as 600 m^3/h, 1100 m^3/h and 2200 m^3/h, according to the calculations, the corresponding face velocity of the textile duct is 0.02 m/s, 0.04 m/s and 0.06 m/s. The floor exhaust was an open cube with effective exhaust area of 1.0 m^2. The exhaust cube can be positioned anywhere on the detachable floor. Consequently, two places were selected for this experiment: the center and the corner, which are often utilized to set up laboratory bench-ups and experimental equipment. The targeted chemical was put on the square bench with the height of 1.1 m and the width of 0.3 m.

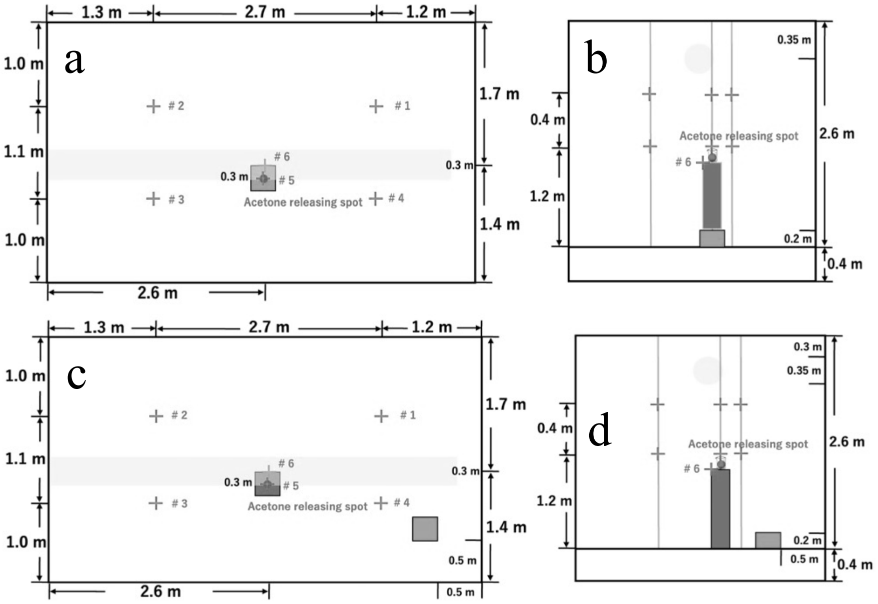

Fig. 1. Measurement locations: (a, b) horizontal and vertical locations under center scenario; (c, d) horizontal and vertical locations under corner scenario.

(2) Measurement method of the targeted chemical

Acetone was selected as the targeted individual VOCs because high use frequency and low toxicity. The acetone concentration was measured at five positions (detector #1 to #5) at different height (1.2 m and 1.6 m), and detector #6 was placed in the vicinity of 5 cm on the benchtop.

(3) Measurement method of airflow field

The Computational Fluid Dynamics (CFD) simulation method was employed by using FlowDesigner 2022. The geometry simulated was the room described in Fig. 1. Particle Image Velocimetry (PIV) analysis was employed to observe the local airflow pattern on the benchtop.

3. Results

This investigation evaluated the acetone distribution and airflow field to assess the ventilation performance of a novel downflow ventilation system. The experiment particularly focused on local feature of the contaminant distribution and airflow field within breathing zone and in the vicinity of the contamination source.

(1) Acetone distributions with different ventilation rates in the breathing zone

- Quick removal

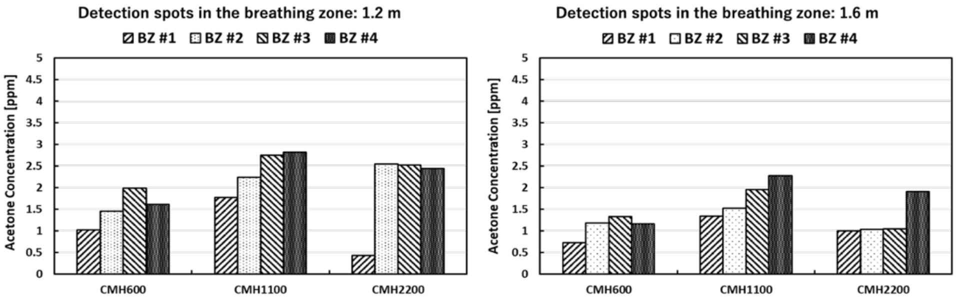

Fig. 2. Time-weighted average of the concentration of acetone in breathing zone at different ventilation rates: (a) in the height of 1.2 m; (b) in the height of 1.6 m.

(2) Acetone distributions with different ventilation rates near the contamination source

- Vertical stratification
- Marginal increase in ventilation performance caused by higher ventilation rate

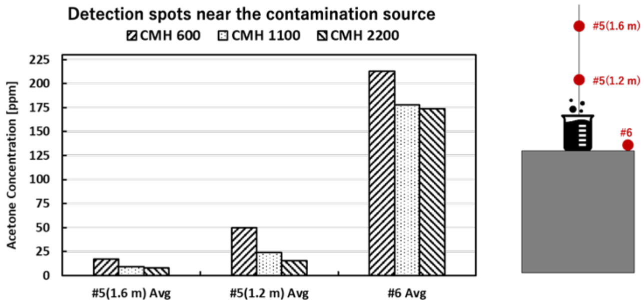

Fig. 3. Time-weighted average of the concentration of acetone in breathing zone at different ventilation rates

(3) Acetone distributions with different exhaust locations in the breathing zone & near the contamination source

- Shorter contaminant transport path in the center scenario

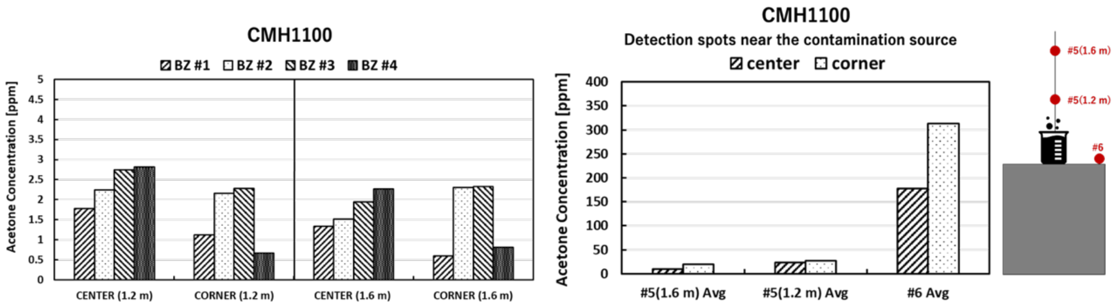

Fig. 4. Time-weighted average of the concentration of acetone in breathing zone (left) and near the contamination source (right) under the ventilation rate of CMH1100.

(4) Airflow field under different exhaust locations

- Different dense gas transport characteristics

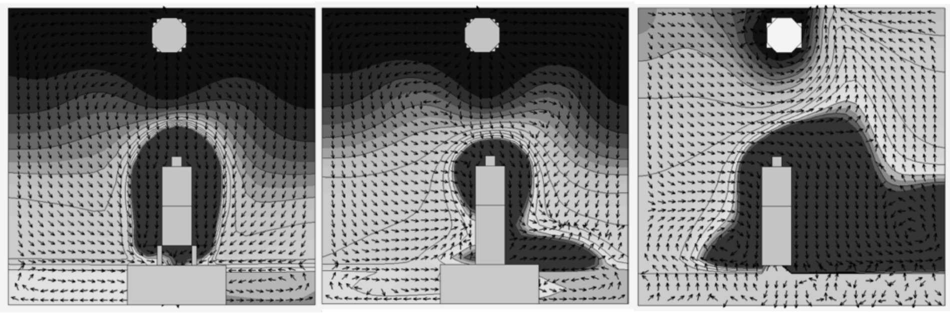

Fig. 5. Cloud map of acetone diffusion process (x = 2.46 m) under three exhaust locations with fixed ventilation rate of CMH600: left-center; middle-corner; right-ceiling

(5) Local airflow field on the benchtop

- Consistency in advective force and dense gravity effect

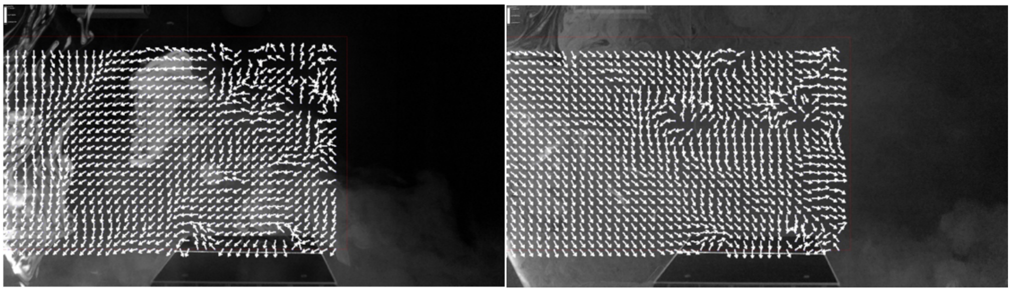

Fig. 6. PIV results of the airflow field on the benchtop with different exhaust locations (ventilation rate: CMH2200): in the center (left); in the corner (right).

4. Conclusion

This research focused on a downflow ventilation scheme using acetone as the targeted chemical under different ventilation rate and exhaust locations. It is found that

- ➢ For the dense gaseous pollution in low-velocity airflow field, the downflow ventilation is applicable for efficiently removing the hazardous chemicals in comparing to the traditional ceiling-mounted returns.
- ➢ For the breathing zone, increasing the ventilation rate will not necessarily bring about obvious ventilation effects. Also, the exhaust location on the floor will not have much effect on the contaminant concentration within the breathing zone.
- ➢ For the areas in the vicinity to the contamination source, the local airflow pattern plays a more important role. And general indoor ventilation system does not provide spontaneous protection from exposure to the hazardous chemicals. Ventilation requirements should combine with appropriate work practices to achieve acceptable concentrations of air contaminants.