A new quantitative method for testing performance of in-use laboratory chemical fume hoods

The American Society of Heating and Air-Conditioning Engineers (ASHRAE) 110-1995 tracer gas test method is a well-established measure of laboratory chemical hood performance, but it requires expensive equipment and trained personnel. This study proposes a new quantitative method for testing laboratory chemical fume hood performance using materials commonly found in laboratories. The method uses dry ice and warm water to generate visible fog and carbon dioxide (CO_2) gas, and then measures chemical fume hood leakage with a CO_2 detector. The fog can also be used as a visual aid to train workers in proper hood use. To compare the new method with the ASHRAE 110-1995 tracer gas method, both were used to test a conventional by-pass laboratory chemical fume hood under eight typical use conditions (comprised of different sash opening heights, thermal loads, and hood clutter). Average hood face velocity was maintained at 0.5 m/s (100 ft/min) ± 1% throughout all tests. The test results of the new method were comparable to those of the ASHRAE 110-1995 method. A significant regression equation was found in this study ($F(1,6) = 36.15$, $p = 0.001$), with R^2 of 0.858: SF_6 breathing concentration (in ppb) is equal to $-118.184 + 0.912 \times CO_2$ leakage values (in ppm). Using this regression equation, CO_2 leakage can be used to estimate SF_6 breathing zone concentrations. Ultimately, the new method is cheaper and easier to use than the ASHRAE 110-1995 method for routine hood performance evaluation.

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INTRODUCTION

A variety of hazardous substances are used in research laboratories. Because these contaminants can become airborne during research activities, laboratory chemical fume hoods are widely used to control and minimize worker exposure. The performance of a chemical fume hood represents its ability to contain and remove materials generated inside it. The hood is supposed to contain and remove toxic volatile materials, toxic gases, toxic aerosols, flammable chemicals, odorous materials, etc.

American Society of Heating and Air-Conditioning Engineers (ASHRAE) 110-1995 test

The Method of Testing Performance of Laboratory Fume Hoods, ASHRAE Standard 110-1995[1] is a reliable and precise method to measure hood performance. The ASHRAE 110-1995 test consists of flow visualization, face velocity measurement (the velocity of the air at the hood face), and a tracer gas containment test. For the tracer gas containment test, a mannequin is placed in front of a hood with a sampling probe in its breathing zone. An ejector is placed inside the hood and supplied with a tracer gas, usually sulfur hexafluoride (SF_6); ejector configurations and tracer gas flow rates are specified in the standard. Tracer gas breathing zone concentrations are then measured using a detector. Industry consensus guidelines suggest that a well-designed, properly balanced hood should emit a concentration less than 0.1 ppm for As Installed (AI) at the mannequin breathing zone when the supply air distribution is good outside the hood.[2,3]

The tracer gas containment test has its disadvantages. It is time-consuming, needs expensive equipment and materials including a gas analyzer, tracer gas ejector, SF_6 gas etc., and requires a well trained staff. Some organizations check the hood face velocity for routine evaluations, since it is a simple measurement. Unfortunately,

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there is no uniform agreement on a safe minimum face velocity, because there are so many other factors affecting hood performance.[4–6] To make matters worse, SF_6 has a very high Global Warming Potential (GWP), and the ASHRAE Standards committee is seeking alternative tracer gases or procedures to minimize the test's carbon footprint.[7] It is estimated that the GWP of SF_6 is 20,000 times that of CO_2 on a mass basis.[7]

Flow visualization

Flow visualization is usually done with tubes blowing smoke inside the hood, making the airflow into and inside the hood visible. This can also be used to train hood users in creating good containment, because it helps them to visualize, on site, how the airflow into and inside the hood is affected by their activities.

For flow visualization, a plentiful supply of non-toxic and non-irritating aerosols and low operating costs are desireable.[8] The dry ice fog visualization method that was developed by Adams[9] meets all those requirements. When dry ice is placed in a bowl of warm water, a white fog of condensed water vapor is generated, mixed with invisible CO_2. The fog is heavy and gets carried by the CO_2. The dry ice fog method has been adopted as one of the large-volume visualization challenge methods in the ASHRAE test method, which states that any release of smoke past the hood face is not acceptable.[1]

The dry ice fog method is a practical test method, as dry ice is used by researchers to keep their samples cold, and thus there are companies that supply it. It is less complicated than the ASHRAE 110-1995 test. There are some limitations to the dry ice fog visualization method: the fog cannot be seen when the CO_2 concentration generated from the dry ice is low (or the fog is not dense enough), and the test requires human judgment that may be subjective.[10]

Objectives

The objective of this study was to develop a more quantitative dry ice method that is inexpensive, portable, easy to use, and reliable. The specific aims were to (1) develop a protocol, hereinafter referred to as the CO_2 method, for quantitative testing of laboratory chemical fume hood performance using dry ice, warm water, and a carbon dioxide detector, and (2) compare the test results of the CO_2 method to those of the qualitative dry ice fog method, and to those of the ASHRAE 110-1995 tracer gas test method.

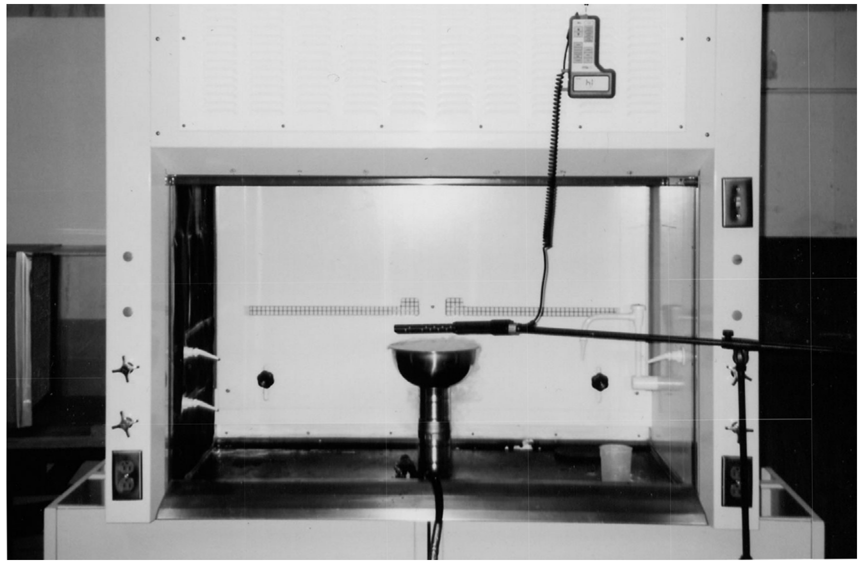

Figure 1. Setup of the new quantitative method for testing performance of laboratory chemical fume hoods.

METHODS

CO_2 method setup

Dry ice and warm water were used to generate visible fog as described in the large-volume visualization challenge section in the ASHRAE 110-1995 test method.[1] 200 g of dry ice pieces were deposited into 1L (1.1 qt.) of water with a temperature of $43 \pm 0.6\,^{\circ}C$ ($110 \pm 1\,^{\circ}F$), in a 2.8L (3 qt.) stainless mixing bowl of 23.8 cm (9⅜ in.) outer diameter and 10.2 cm (4 in.) height. Dry ice is extremely cold ($-78.5\,^{\circ}C$ or $-109.3\,^{\circ}F$); proper gloves and goggles were used when handling dry ice. About 85 L/min (3 ft^3/min) of carbon dioxide vapor were generated during the first minute.[9] The bowl was placed in the center of the hood on a cylinder base of 8.3 cm (3¼ in.) diameter and 22.9 cm (9 in.) height, as shown in Figure 1. The front edge of the bowl was aligned at 15.2 cm (6 in.) inside the hood face. Carbon dioxide (CO_2) concentrations were measured and logged using a Q-Trak IAQ Monitor (TSI, Inc., St. Paul, MN). The CO_2 probe was placed at the center of the hood, 40.1 cm (16 in.) above the hood benchtop and 3.8 cm (1½ in.) outside the hood face. Consequently, the CO_2 probe was located 7.6 cm (3 in.) higher than the top of the bowl. Figures 2 and 3 compare the setups of the CO_2 method and the ASHRAE 110-1995 tracer gas test method in plan view and side view, respectively. The differences in the setups are as follows:

- The top of the bowl (CO_2 source) was 33 cm (13 in.) above the hood floor, while the top of the SF_6 ejector was 38 cm (15 in.) from the hood floor.
- The CO_2 meter probe was 40.1 cm (16 in.) above the hood floor, while the SF_6 sampling point was 66 cm (26 in.) above the hood floor.
- The front edges of both the CO_2 bowl and the SF_6 ejector (bottom stem) were aligned at 15.2 cm (6 in.) inside the hood face, which put the center of the CO_2 bowl farther inside the hood than the center of SF_6 ejector.
- The CO_2 meter probe was placed 3.8 cm (1½ in.) outside the hood