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A Test Method for Quantifying Unfiltered Air Leakage into Enclosed Cabs

Objective

To develop a simple, practical, quantitative, and reliable field test method for measuring air leakage into enclosed cab filtration systems with the goal of making enclosed cabs a healthy and safe work environment.

Background

Enclosed cabs are an engineering control that can provide a safe, comfortable, and healthy work environment for equipment operators. Most modern day enclosed cabs have heating, ventilation, and air-conditioning (HVAC) systems for maintaining a comfortable temperature and a breathable quantity of air for its occupants. Various levels of filtration can be incorporated into the HVAC system to improve the ventilation quality of the air inside the cab by removing outside airborne pollutants such as dusts, aerosols, and vapors. However, outside air leakage around the intake filter into the HVAC system can notably diminish the effectiveness of the cab's filtration system. A poorly sealed cab HVAC/filtration system can be difficult to recognize because of its concealed system components and the invisible nature of some airborne pollutants that can penetrate the cab.

Researchers have previously measured airborne particulates in either ambient air or generated particulates inside a chamber surrounding the vehicle to quantify the particulate penetration into the enclosed cab. Several cab penetration studies have indicated that inconsistent and low particulate concentrations can yield unreliable cab performance results among replicated cab tests. Internal cab particulate generation such as dirty floors, interior surfaces, and abraded blower motor brushes can also interfere with measuring external particle penetration into the cab.

Approach

A desirable air leakage test method would use a relatively constant airborne tracer gas level around a vehicle's cab which would pose minimal health and safety risks to the user. Atmospheric gases have these desirable attributes and were considered for the air leakage tracer gas. The technique involves replacing the HVAC intake particulate filter with a tracer gas filter, measuring tracer gas concentrations inside and outside the cab filtration system, and then applying a mathematical formula to calculate leakage. NIOSH partnered with the Clean Air Filter (CAF) Company of Defiance, Iowa under a Cooperative Research and Development Agreement (CRADA) to develop this air leakage test method for evaluating the environmental integrity of enclosed cabs. This research focused on developing a timely stationary vehicle cab leak test inside an unoccupied cab. Cab leakage testing research was ultimately conducted using the carbon dioxide (CO_2) in ambient air as the tracer gas given that CO_2 instrumentation and gas-absorbent media were readily available for filtration and methodology development.

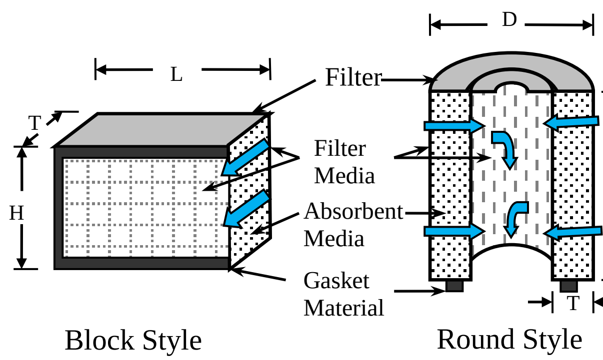

Figure 1. Carbon dioxide filter configurations (blue arrows depict airflow movement through carbon dioxide filter).

Figure 1 shows the typical CO_2 filter configurations constructed by CAF for leak testing enclosed cab filtration systems. Initial laboratory testing indicated that the CO_2 absorbent media bed thickness (T) needed to be greater than 2 inches (5.1 cm) inside the filter for efficient CO_2 removal. Three different types of CO_2 instruments were also examined in the laboratory for their suitability for the proposed leak test. It was apparent that all the instrument types examined can drift and would need daily CO_2 gas calibrations to ensure their accuracy for a multiple-instrument cab test method.

Because maintaining instrument accuracy during field testing can be challenging, a single-instrument cab testing methodology was developed to eliminate instrument bias errors and field calibration. This method measures relative CO_2

concentration differences inside and outside the cab filtration system using the same instrument at or near steady-state cab conditions. The equation shown below was developed to quantify air leakage around the CO_2 intake test filter by measuring CO_2 concentrations inside the cab, immediately after the intake filter, and outside the cab by using the same instrument. Air leakage is defined as the percentage of cab intake air that bypasses the filter media and is unfiltered.

$$Air\ Leakage,\% = \frac{Cab\ Conc. - Filter\ Conc.}{Outside\ Conc. - Filter\ Conc.} \times 100$$

Laboratory tests were conducted with controlled air leakages of 0%, 5.5%, and 11.5% into an unoccupied enclosed cab test stand. The leakage opening was downstream of two stacked block-style intake filters, which were 98% effective for removing CO_2. A mass airflow meter was used to measure the quantity of air leakage into the filtration system, and a hot wire anemometer was used to measure the intake airflow into the cab. The CO_2 instruments were located outside the unoccupied cab enclosure and sequentially sampled the air inside the cab, immediately after the intake filter, and outside the cab through sampling hoses routed to these locations. A Sable CA-10a CO_2 instrument (Sable Systems International, Las Vegas, NV) used during the laboratory testing was an active sampling instrument with an internal air pump and was suitable for this type of cab sampling procedure. Several Vaisala GM70 CO_2 instruments (Helsinki, Finland) used during the laboratory testing were passive handheld sampling instruments and had to be air aspirated by separate air sampling pumps to move the air from the various cab locations to the instrument's sensing chamber via calibration hood.

The best cab leak test procedure devised in the laboratory was the measurement of the inside cab concentrations for 3 minutes after they stabilize from the filtration system startup. Then, after 2 minutes of stabilization time between the sampling location changes, the CO_2 concentrations were measured for 3 minutes at the other two sampling locations. This sampling procedure was sequentially repeated three times at all the sampling locations for each leakage condition. This procedure was replicated twice on two different days in the laboratory.

Finally, this CO_2 leak test method was performed on a John Deere 7820 series tractor cab to demonstrate its application on an end-use vehicle cab. A round-style cartridge filter, as shown in Figure 1, was used for the test.

Results

Laboratory test results showed that the CO_2 leak test method similarly quantified the cab leakage as compared to the directly measured airflow leakage into the filtration system. Figure 2 shows the measured CO_2 leakages as compared to the airflow leakage measurements into the cab enclosure. The unity line on the figure illustrates good correlation of the CO_2 leakage test method with the airflow measurements using the Sable and Vaisala instruments.

Table 1 shows the data collected on the John Deere tractor cab for both the Sable and the Vaisala 1 instruments. The round-style CO_2 intake test filter provided better than 96% removal efficiency. This table illustrates the consistent measurement biases between the two instruments at the various sampling locations. However, each instrument measured comparable air leakages because relative CO_2 concentration differences in the cab filtration system were used to calculate leakage. This test method provides cab manufacturers, cab service personnel, and industrial hygienists with a measurement tool to ensure environmental cab integrity and minimize worker exposure to outside airborne substances.

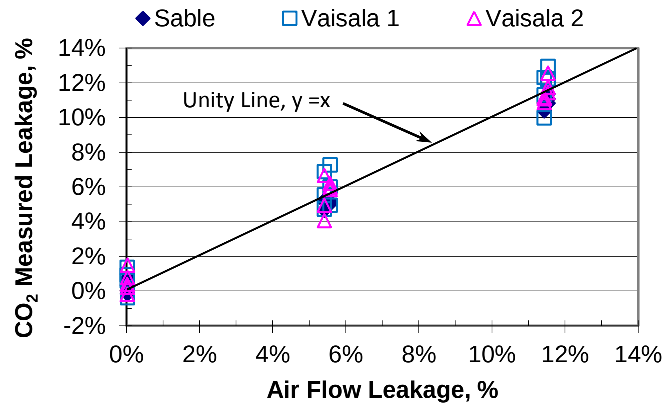

Figure 2. Air leakage test measurements made on the Clean Air Filter (CAF) Company's test stand.

Table 1. CO_2 measurements on the John Deere tractor cab

Instrument	Cab Conc. (ppm)	Filter Conc. (ppm)	Outside Conc. (ppm)	Cab Leakage (%)
Sable	19	14	420	1.2
	18	13	405	1.2
	17	13	429	1.0
Vaisala 1	47	43	441	0.8
	50	46	432	1.1
	52	42	438	2.5

ppm – parts per million

For More Information

For more information on this patented cab leakage method, contact John Organiscak, NIOSH (412-386-6675, jorganiscak@cdc.gov), Michael Schmitz, Clean Air Filter (800-488-4828, www.cleanairfilter.com) or the Health Communications Coordinator (OMSHR@cdc.gov), NIOSH Office of Mine Safety and Health Research, P.O. Box 18070, Pittsburgh, PA 15236-0070.

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