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Project Summary

Evaluation of New In-Facepiece Sampling Procedures for Full and Half Facepieces

Warren R. Myers and Richard W. Hornung

The manufacture, handling, and use of new chemical substances often require a level of personal protection that includes respirators. Because of the need for these respiratory protection devices, processes to evaluate penetration of full and half facepiece, negative-pressure respirators were studied.

The precision and bias were determined for five methods of sampling for inboard penetration through different areas of the face seal. The sampling procedures evaluated were: continuous, low sampling rate, flush on the respirator, mid-nose-mouth probing (CLF); continuous, high sampling rate, deep front-of-mouth probing (CHD); pulsed, exhalation, deep front-of-mouth probing (PED); exhalation valve discharge (EVD); and pulsed, inhalation, deep front-of-mouth probing (PID). The CLF procedure represents current in-facepiece sampling practice in the United States.

Based on evaluation with nine full facepiece respirators, the mean sampling biases were CLF: -21%; CHD: -3%; PED: 0.7%; EVD: -14%; and PID: -12.3%. For five half facepiece respirators, the mean sampling biases were CLF: -26%; CHD: -13%; PED: -4%; EVD: -2%; and PID: -24%. To some extent, the location of the face seal penetration, and the design of the respirator affected the bias of each method.

This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

A variety of protective clothing and equipment is often necessary to protect workers during the manufacture, handling, and use of new chemical substances. In most cases where a need for respiratory protection exists, air-filtering, negative-pressure, full and half facepiece respirators are recommended. Because of the inherent danger of exposure to such chemicals, extra care often must be taken to ensure worker protection. Various fit test procedures are used or have been suggested for evaluating the quantitative fit and protection of full and half facepiece, negative-pressure respirators. Recently published data has, however, demonstrated that the procedure commonly used in the United States is subject to large sampling biases. Factors that appear to contribute significantly to this bias include: location and depth of the sampling probe; location of the face seal leak; whether the wearer is breathing through the nose or the mouth; the aerosol size selectivity of different leak sizes; and the inspired air flow patterns and air mixing produced by

different facepiece designs. Consequently, the presently used test provides less than the desired level of assurance that full protection is being achieved.

This research sought to evaluate the bias and precision of alternative in-facepiece sampling procedures and compare them with the CLF procedure currently in wide use in the United States for both full and half facepiece respirators. The goal of the evaluation was to identify and recommend, if possible, an in-facepiece sampling procedure with lower bias and greater precision.

Test System

The system used to test the various respirators consisted of an acetone vapor generation and dilution system and an air/acetone feed line to one of the leak sites on the face seal of the respirator test setup. Each respirator, equipped with organic vapor cartridges, was mounted on a headform manikin with an airtight face seal. The headform could simulate nose or mouth breathing at a relatively constant rate between 18 and 19 cycles/min, by the use of a breathing machine. Leaks simulated by a hypodermic syringe needle were positioned in the various areas of the full and half masks. The syringe needle was connected to the acetone system, and inboard flow of acetone resulted from the negative pressure created during each inhalation cycle.

For pulsed sampling during inhalation or exhalation, a pressure sensitive switch activates a three-way solenoid valve attached to the in-facepiece sampling line. A calibrated flame ionization detector measured real-time acetone concentration in the collected samples. The "true" acetone concentration was measured in the line between the headform and the breathing machine. The apparatus is shown schematically in Figure 1.

Experimental Design

The experimental design for the full facepiece respirators was a fixed effects factorial model that considered three leak sites, two leak sites. and five sampling methods on nine models. The nine selected models were those brands (without nose cups) currently certified by NIOSH: American Optical, Cesco, Glendale, MSA, North, Pulmosan, Scott, USD, and Willson.

Based on preliminary testing, the (B) could best be measured as the of the difference between the in-f piece acetone concentration ($\hat{C}$) and "true" concentration (C/):

$$B = (\hat{C} - C/)C/$$

The experimental design was then s as an analysis of variance with B a dependent variable measured at d nated levels of the four factors: leak leak size, sampling method, and mod

For half facepiece respirators, 5 c 16 NIOSH-certified respirators tested: American Optical, MSA, S USD, and Willson.

Sampling Methods and Procedures

CLF Sampling Procedure

This is a continuous, low samplin (1 L/min, during inhalation and exhal procedure with the sampling mounted flush on the body of the piece in the area between nose mouth. The manikin headform is set simulate nose breathing.

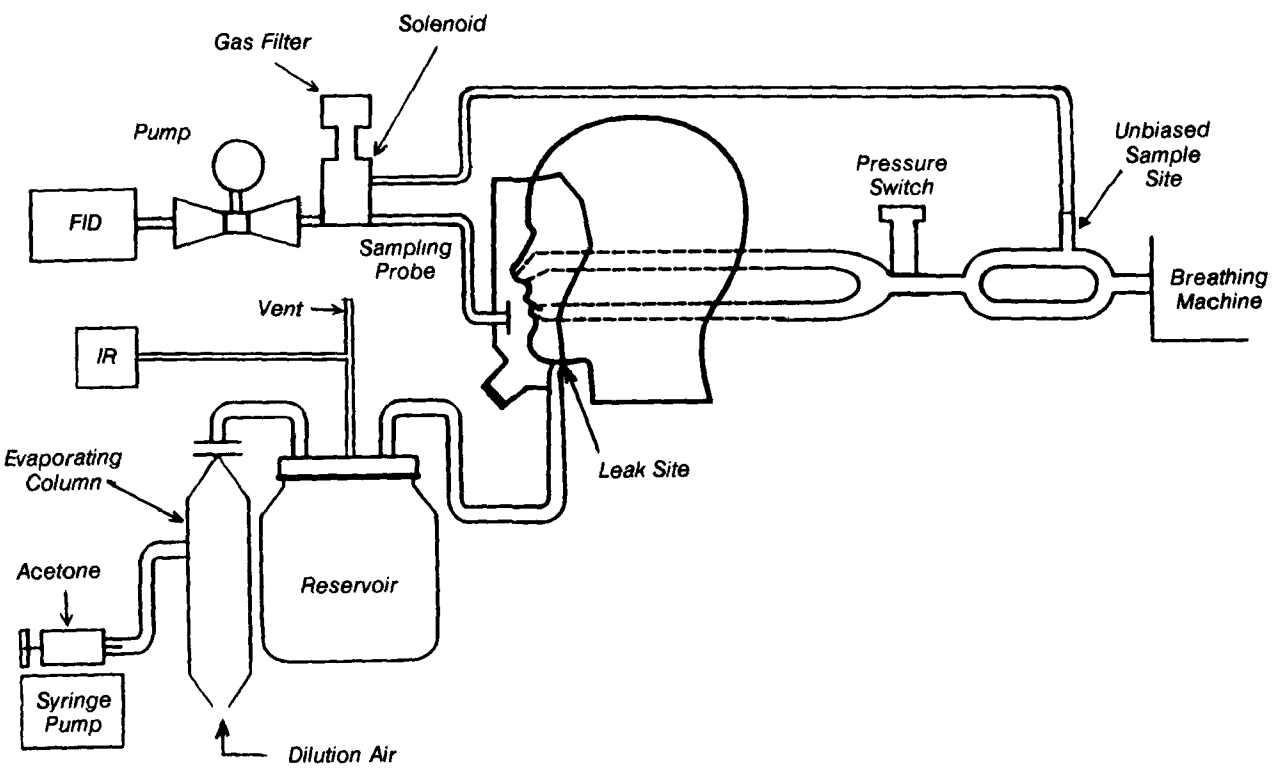

Figure 1. *Experimental test system used to evaluate the bias in different methods of sampling for inboard, face seal, penetration on h full facepieces.*

CHD Sampling Procedure

This is a continuous, high sampling rate (5 L/min during inhalation and exhalation) procedure with the sampling probe extended into the facepiece cavity and located in front of the mouth. The manikin simulates mouth breathing.

PED Sampling Procedure

In this method, pulses of air (contaminated with acetone) are collected from the facepiece only during exhalation using a deep probe location. The manikin simulates mouth breathing. It has been determined that sampling through the probe is not the same as sampling from the exhalation valve of the respirator.

EVD Sampling Procedure

This method employs high rate (5 L/min continuous sampling of the air discharged through the exhalation valve of the respirator whereas the manikin simulates mouth breathing.

PID Sampling Procedure

This procedure collects a pulse of air during inhalation, with the use of a deep probe location.

Results and Discussion

Because problems were encountered with the small leak size in the full facepiece respirators, data analysis was limited to the larger leak size. This reduced the number of variables to three. Note that the test system did not simulate any lung retention; this could increase average sampling bias values. Further, the test program was done with the use of a vapor challenge agent; very different results, with larger bias values, might be obtained with conventional oil mist or sodium chloride fit-tests or tests in workplace environments.

Because the five methods of testing varied considerably, statistical analyses were computed separately for each method. This study confirmed earlier results that the sampling bias is influenced by the leak location. It also indicated that the design of the facepiece influences the effect of leak location.

Of the five methods, the PED sampling procedure consistently gave the lowest sampling bias and the best precision in the full facepiece respirator tests. It also was less sensitive to the location of leak than was the CHD procedure. The EVD and PID procedures, although not as good as the PED and the CHD sampling procedures, still gave smaller (and approximately equivalent) sampling biases than did the conventional CLF procedure.

Based on a combined measure of precision and bias in which each factor is given equal weight (see Table 1), the ranking of the five methods would be:

PED > CHD > EVD > PID > CLF

With the half facepiece respirators, the strongest interaction existed between sampling method and manufacturer (design). Three-way interactions among manufacturer, leak size, and leak location were also significant in all but the EVD procedure. Although not as clear as with the full face pieces, the PED procedure again produced better mean sampling biases than did the conventional CLF procedure or the CHD procedure. Surprisingly, the EVD procedure produced much smaller biases with the half facepieces than it had with the full facepieces and was approximately equivalent to the PED procedure. Both the PID procedure and the conventional CLF procedure produced poorer results in the statistical analysis. Table 2 summarizes the precision and bias for the half facepieces. Based on the combined results, the methods would be ranked in the following order:

EVD > PED > CHD > CLF > PID

Based on the data with both half and full facepiece respirators, the PED sampling procedure appears to be significantly more precise and less biased than the conventional CLF sampling procedure now widely used in the United States. On that basis, it should be considered as a replacement for quantitative fit testing. Before a procedure change is made, however, it may be necessary to learn more about the PED procedure. For example, whereas the testing in this study was done at a 5 L/min sampling rate during exhalation, the effect of lower flowrates on bias needs to be evaluated, as will the effect of relative humidity on test validity and the effect of lung retention.

Conclusions and Recommendations

Several alternative sampling methods for in-facepiece respirator testing were evaluated and compared with a method widely used in the United States. Based on these tests, two of the alternative methods are clearly superior to the conventional CLF (continuous sampling, low flow, flush probe) method in sampling precision and bias. Of these, the PED method (pulsed sampling, exhalation, deep probe) appears to be superior for both full and half facepiece respirators. The PED procedure, however, will require further validation and equipment modifications before it can be substituted for the current test method. Until that is done, another of the alternatives, the CHD sampling procedure (continuous sampling, high flow, deep probe), should replace the conventional method with the use of CLF equipment.

Table 1. *Test Results for Five Procedures on Nine Full Facepieces*

Procedure	n	Precision SD	Mean Bias $\bar{B}$	Combined Measure* R
CLF	81	14.0	-21.3	25.5
CHD	81	11.8	-3.4	12.3
PED	81	5.0	0.7	5.0
EVD	80	11.9	-14.2	18.5
PID	81	21.0	-12.3	24.3

*$R = (SD^2 + \bar{B}^2)^{1/2}$

Table 2. *Test Results for Five Procedures on Five Half Facepieces*

Procedure	n	Precision SD	Mean Bias $\bar{B}$	Combined Measure* R
CLF	60	14.0	-25.9	29.4
CHD	60	11.7	-12.5	17.1
PED	60	5.0	-3.7	6.9
EVD	60	3.0	-2.3	3.8
PID	60	29.2	-24.1	37.9

*$R = (SD^2 + \bar{B}^2)^{1/2}$

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Warren R. Myers is now with West Virginia University, Morgantown, WV 26506; and Richard W. Hornung is with the National Institute for Occupational Safety and Health, Cincinnati, OH 45226.
***Raymond M. Frederick** is the EPA Project Officer (see below).*
The complete report, entitled "Evaluation of New In-Facepiece Sampling Procedures for Full and Half Facepieces," (Order No. PB 89-181 242/AS; Cost: $13.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
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Telephone: 703-487-4650
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