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Klaus Willeke PhD, CIH & Usha Krishnan

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Focus On . . .

Present Procedures in Quantitative Respirator Fit Testing: Problems and Potential Solutions

Klaus Willeke, PhD, CIH
Usha Krishnan, Doctoral Candidate

Aerosol Research and Respiratory Protection Laboratory
Department of Environmental Health
University of Cincinnati
Cincinnati, OH 45267-0056

Occupational diseases caused by breathing contaminated air must be avoided primarily by engineering control measures that prevent atmospheric contamination.[1] When effective engineering controls are not feasible or while they are being instituted, appropriate respirators must be used. Several kinds of respirators are available in different shapes and sizes. The American National Standards Institute provides guidance on the proper selection of the respirator type based on the respiratory hazard.[2] The selected respirator should give at least a certain minimum fit to the face of the wearer. This minimum fit is specified in the federal regulations for each type of respirator. The fit of a respirator can be determined by qualitative or quantitative methods. When quantitative methods are used, the respirator fit is expressed as the ratio of the concentration of the test agent outside the respirator to the concentration of the test agent inside the respirator. This ratio is defined as the "fit factor" of the respirator for a particular wearer.

Present Procedures

Quantitative respirator fit testing allows one to select a respirator that gives a fit factor which equals or exceeds the specified minimum fit factor. When the test is performed with an aerosol as the test agent, the air-purifying cartridges of half-mask and full-facepiece respirators are replaced by high-efficiency particulate air filters so that aerosol leakage into the respirator cavity can be assumed to be caused only by imperfections in the faceseal, not by filter penetration. The subject puts on the respirator according to the manufacturer's instructions and then follows a set of exercises, making head and facial movements which simulate movements during normal work. An aerosol detector extracts a small amount of air from the respirator cavity during inhalation and exhalation and measures the concentration of aerosol in the extracted air. The detector also measures the aerosol concentration outside the respirator. The ratio of the two concentrations is the fit factor. Fit factors are determined for each exercise, and an overall fit factor for all exercises is calculated. This overall fit factor is compared with the minimum fit factor required by the standards, and a decision is made as to whether the respirator has an acceptable fit.

Sampling Bias

Figures 1 and 2 illustrate some of the problems associated with the currently used fit test procedures. Suppose the respirator wearer inhales 16 liters during one minute of inhalation and exhalation. This corresponds to an instantaneous inhalation flow rate of 32 L/min. Typically, the probe flow is 2 L/min so the total inflow is 34 L/min. If we assume a leakage flow of 1 L/min, a flow of 33 L/min has to be drawn through the cartridges. When high-efficiency particulate aerosol (HEPA) cartridges are used, as is usually the case, the penetration of the aerosol through the cartridges may be neglected. If none of the aerosol particles in the leak flow were lost during inhalation, and if all the aerosol in the leak flow were perfectly mixed inside the respirator, the fit factor, which is the ratio of contaminant concentration outside the respirator to inside the respirator, will equal the ratio of the total inflow to leak flow; in this case, it is 34. It has been noted that the faceseal leak flow proceeds to the nose along streamlines.[3–5] If the aerosol in the leak flow is not perfectly mixed with the air in the respirator cavity, the sampled concentration will not equal the concentration of contaminants inhaled. Since the probe flow rate is typically 2 L/min, it can only sample 2/34 = 1/17th of the respirator volume, and the recorded fit factor will be different from the true fit factor. Inadequate

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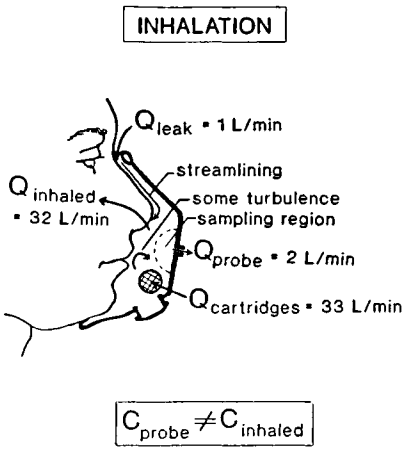

FIGURE 1. Example of flow distribution during inhalation.

mixing has been verified by noting a high dependence of sample concentration on the probe location and site of a leak.[3,6–8]

During exhalation, the same volume of air, 32 L/min, is exhaled by the respirator wearer. If the flow exiting through the leak site has the same rate of 1 L/min and the probe flow remains at 2 L/min, then the flow through the exhalation valve is 29 L/min. Some aerosol may be deposited in the lungs, whereby the concentration of aerosol during exhalation (Figure 2) may be lower than the concentration during inhalation even if the respirator cavity were perfectly mixed.

As a solution to this problem, we propose to fit test during a few seconds of breath holding at a sample flow rate comparable to the instantaneous inhalation flow rate. This modification is expected to reduce the sampling bias due to improper mixing and avoid decreases in sampled aerosol concentration due to lung deposition which is highly subject dependent. The test contaminant entering the respirator through the leak sites mixes with the clean air entering through the cartridges. Unlike the previous case where the probe flow rate was only 2 L/min, the probe flow rate now equals the inhalation flow rate. Thus, all the test contaminant entering the respirator during breath holding is sampled.

Work Simulation

In the currently accepted fit test procedure, potential changes in leak size and location that may occur during movements of the head or deformation of the face are simulated by side-to-side and up-and-down head movements and by mouth deformations through recitation of the "Rainbow Passage." While the wearer moves the head (Figure 3), the face may deform and a new leak may occur or the existing leak may increase or decrease. Work done in our laboratory has shown that the contribution of contaminants entering through this leak to the total contaminant concentration measured by the detector depends on the angle θ to which the head is moved and the time spent in that position.

Unfortunately, current fit test procedures do not regulate the angle of movement nor the time spent at certain angles. Thus, the measured fit factors are movement dependent. Repetition of head movements for a certain period of time attempts to average out the different leakages occurring during each unregulated head movement. However, each result depends on the degree of movements solicited by the tester and the movements actually performed by the subject.

We propose that sampling bias due to differences in leakage measured during each unregulated head movement can be minimized by performing fit tests in specific head positions. Fit

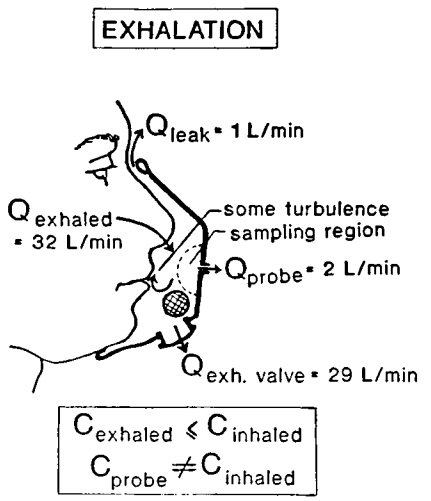

FIGURE 2. Example of flow distribution during exhalation.

factors or flow ratios in each of the different head positions can be determined, and these can be weighted depending on the work activity and the individual's work habits. The weighting factors can be selected based on the percent of time spent by the subject in different head positions during the course of a normal 8-hour workday.

We realize that our proposals are counter-intuitive. One prefers to breathe normally and move the head as one is accustomed to. However, if accurate and repeatable fit tests are to be performed, these suggestions eliminate several of the serious limitations

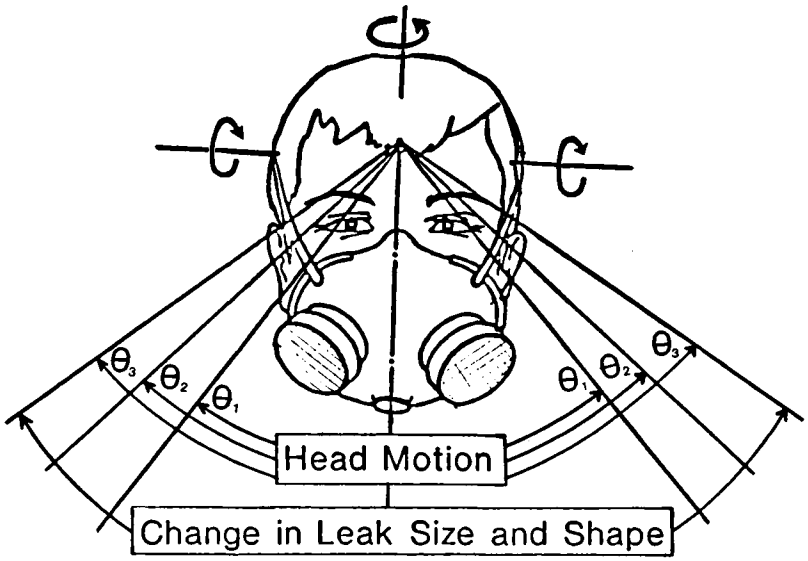

FIGURE 3. Fit testing in specific head positions.

of the current procedures.

Measurement of Faceseal Leak

The traditional method of quantitative respirator fit testing in the United States utilizes a photometer as the aerosol detector. The subject dons the respirator and enters a tent or booth where he or she is exposed to a test aerosol. The concentration of aerosol outside and inside the respirator is compared by measuring the light scattered by the aerosol. The tent and the aerosol generator required for this photometric test take up a lot of space.

More recently, use of the tent and aerosol generator has become redundant through application of a particle count test, performed with a continuous-flow condensation nuclei counter.[9] This method, commercially developed by TSI Incorporated as the "PortaCount," can be applied in rooms where the aerosol concentration is sufficiently high and invariable with time. The aerosol leakage recorded by the particle-count test is expected to be somewhat lower than the one recorded by the photometric test because the smaller aerosols detected by the particle count test may have higher diffusion losses in the leak sites than the approximately half-micrometer-sized particles seen by the photometer.

Examination of Figure 4 shows that the property that relates to the faceseal fit is the leak flow rate, Q_{leak}. The leak flow depends on the size and shape of the leak site and the pressure drop across the respirator which is given by the respiration rate and the type of air-purifying cartridges used.[10] The concentration of contaminant reaching the nose or mouth of the wearer depends on the concentration of the contaminant outside the respirator, the leak flow rate, the amount of contaminant removed in the leak channel, and the degree of dilution by the cartridge flow. As mentioned earlier, if none of the contaminant in the leak flow is lost during inhalation and if the penetration through the cartridges may be neglected, the flow ratio will equal the fit factor.

Current fit testing does not measure the degree of protection from contaminants; it evaluates only the degree of fit of a surrogate respirator of a certain brand to a specific face. Use of aerosols coupled with an aerosol detector of any kind, utilizing currently accepted procedures, does not measure faceseal fit accurately, as shown above. If the procedures are changed, as outlined above, tests with an aerosol or any other test agent would, in our opinion, become considerably more accurate.

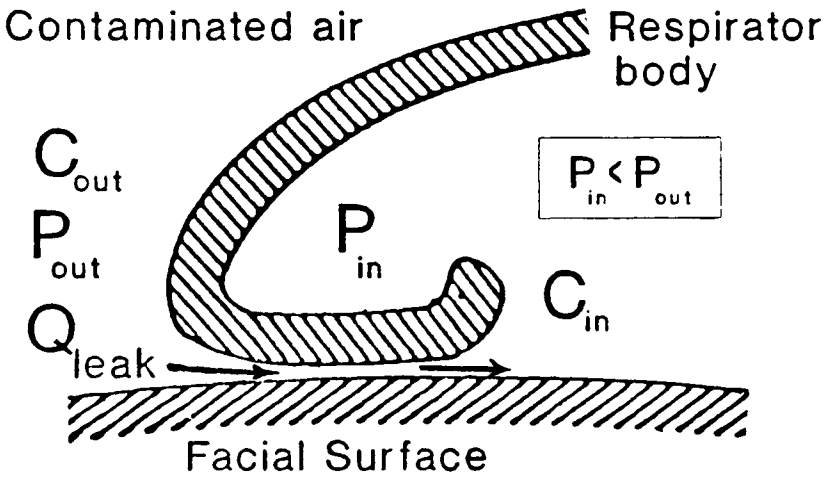

FIGURE 4. Faceseal leakage.

When only the faceseal fit is to be determined, as currently regulated, measurement of the leak flow is sufficient. If breathholding and testing in specific head positions are adopted for fit testing, flow tests, as well as tests with aerosols, gases, and vapors, are expected to give more accurate measures of fit. Flow tests, however, are considerably less expensive to perform. Also, flow tests can be used to fit test the actual field-used respirator since they do not require the respirator to be probed. The development of leak flow measurement techniques has been reported by different investigators.[11–13] Further developments are under way in our laboratory and in other places.

Future Needs

The ultimate goal of respirator wear is to protect the worker. It would, therefore, be of benefit to the occupational health community to be able to perform a simple test that measures or predicts the protection provided by the respirator actually worn. If the test is simple and quick, work could be interrupted for such measurements to check the effect of dust buildup and of sweating. Sweating may reduce or eliminate the leak sites by filling them with liquids, or it may increase leakage by causing slippage of the respirator on the face.

Furthermore, it appears that dust buildup on the exhalation valve and material deterioration may cause valve leakage during inhalation. A quick and easy respirator integrity test, performed before use, would enable one to eliminate respirators with malfunctioning exhalation valves and would therefore ensure that any leakage occurring is only due to faceseal leakage.

Acknowledgments

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ACGIH CHEMICAL SUBSTANCES TLV COMMITTEE TO CONSIDER COMMENTS ON BENZENE, HYDRAZINE, 4,4'-METHYLENE BIS (2-CHLOROANILINE), SILICA FUME (AMORPHOUS), AND TRIETHANOLAMINE

The Chemical Substances TLV Committee will be meeting tentatively on March 25-27, 1991, in Cincinnati. Agenda items will include the Notice of Intended Changes values and documentations for Benzene, Hydrazine, 4,4'-Methylene bis (2-chloroaniline), Silica fume (amorphous), and Triethanolamine. Interested parties who wish to present data on these substances at this meeting must have their written materials to William D. Kelley, Executive Secretary of ACGIH, prior to January 15, 1991. The meeting will be open, but only contributors of data as outlined above will be able to participate in any discussions. A time limit of two hours will be allotted for each substance.

Contact William D. Kelley at 513-661-7881 by December 15, 1990, for a space at the meeting.