

The Effect of Inhalation Resistance on Facepiece Leakage

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Air purifying respirators use filters to remove particulate air contaminants. Resistance to airflow generally increases as the filter loads and a "filter cake" is formed. It has been recommended by ANSI and the Occupational Safety and Health Administration that filters should be replaced when the wearer notices they are hard to breathe through. Repeated face seal leak rate measurements were made during respirator wear over a range of simulated breathing resistances from 5.6 to 19.6 mm (0.22 to 0.77 inches) of water. The measured face seal leak rates increased as the breathing resistance increased and varied depending on the initial leak rate at the 5.6 mm pressure. The increase in face seal leak rate from 5.6 to 19.6 mm breathing resistance was as high as a factor of 4. Theoretically, a person with an initial respirator penetration of 2.5% could have that value increase to 10% as filter loading increased breathing resistance by 14 mm. Some research has shown that breathing resistances between 60 and 140 mm of water would be "noticeable but well tolerated." It is not known if workers would be able to detect an increase in breathing resistance that would lead to a significant increase in face seal leakage. These data suggest a need to establish a replacement schedule for all filters used in the workplace. How often a filter should be replaced is difficult to determine. Breathing resistance would vary depending on the individual filter and aerosol loading characteristics, the concentration of the aerosol in the workplace, and breathing rates.

Keywords: breathing resistance, filter replacement, respirators

Air purifying respirators use cartridges or filters to remove contaminants from the airstream. People who wear air purifying respirators are trained to replace the air purifying element when it is no longer serviceable.

Unlike gas/vapor cartridges, particulate filters generally tend to become more efficient with use. A filter cake is formed that increases filter efficiency and pressure drop. For this reason, it has long been recommended that workers replace filters when they become hard to breathe through or are damaged.⁽¹⁾ Filter replacement recommendations were made by the National Institute for Occupational Safety and Health (NIOSH) for filters meeting the 42 CFR part 84 requirements.⁽²⁾ NIOSH recommends that an R-series filter used in an oil atmosphere be replaced at the end of the shift. Manufacturers recommend replacement schedules for P-series filters used in atmospheres containing oil.⁽³⁾ No specific replacement schedule is recommended for N-series filters. The guidance on breathing resistance typically is used.

Campbell presented a model to describe respirator performance in terms of filter penetration and resistance.⁽⁴⁾ He proposed that as pressure drop across the facepiece increases, leak rate into the facepiece should also increase. More recently, several authors studied the effect of varying airflow rates on face seal leakage using fixed leaks.^(5,6) Pressure drop and face seal leakage increased with airflow.

Campbell⁽⁴⁾ and Myers⁽⁵⁾ noted that using needles to create "fixed" leaks prevents the dimensions of the leak from changing during the experiment. It is not known how increases in pressure drop affect face seal leakage while the respirator is worn and whether the leak dimensions change.

If increased breathing resistance increases face seal leakage, it could result in poorer respirator performance and an increase in exposure. The increase in breathing resistance that indicates the filter is "hard to breathe through" and its effect on face seal leakage is not known.

With the introduction of the controlled negative pressure fit-test instrument, leak rates can

be measured while a person wears a respirator. Thus, it provides a tool to look at face seal leak rate without having to simulate a leak with a needle.

In this study repeated measurements of face seal leak rate were made over a range of simulated breathing resistances while people were wearing respirators. The effect of increased breathing resistance on leakage into the respirator was then determined.

To determine the effect of filter loading on breathing resistance in a workplace, employees working in a battery manufacturing plant were given respirators equipped with high efficiency particulate air (HEPA) filters. At the end of the shift, the filters were collected and the airflow resistance determined. Personal air samples were collected to determine the degree of lead exposure.

METHODS

A controlled negative pressure (CNP) fit-tester (FitTester 3000, ADNI Nevada, Carson City, Nev.) is normally used to estimate fit factors. Fit factors are estimated for the controlled negative pressure fit-tester by dividing a modeled breathing rate by the measured leak rate. Assuming a breathing rate of 53.3 L/min (the default setting), a face seal leak rate of 500 cc/min would equate to penetration of ~1% (fit factor of 100).

The CNP fit-tester applies a negative pressure to a sealed respirator and measures the airflow required to maintain the pressure at the desired point. The pressure can be adjusted and simulates breathing resistance. To make this measurement, adapters replace the air purifying elements normally used on the respirator. One adapter has ports that allow the person to breathe; the ports are sealed during a measurement. The second adapter has two sample lines that connect to the CNP fit-tester. One is used to monitor pressure; the other is hooked to a vacuum source and is used to maintain the pressure inside the respirator facepiece at the desired setting.

To perform a test, the person wearing the modified respirator takes a deep breath and holds it. The breathing ports are sealed by temporarily closing a diaphragm on the breathing port inlet. The instrument is then started. Air is drawn out of the sealed respirator facepiece until the predetermined "challenge pressure" is reached. The "challenge pressures" can be set to various fixed values. The negative pressure causes air to leak into the facepiece from around the face-sealing area. The pump speed is then controlled to maintain the "challenge pressure." The amount of air that is pumped out of the facepiece during the test to maintain the negative pressure equals the air that leaks into the facepiece. Since the "breathing resistance" can be changed, the effect on leak rate can be determined.

Five people were randomly chosen to participate. All subjects were experienced respirator users. Each person received an explanation of the study and instructions on how the CNP fit-tester works. They were tested on one or more of six different respirators. No attempt was made to select a "good" or "poor" fitting respirator. This resulted in varying degrees of respirator fit.

The respirators were prepared for a leak measurement by placing the special sample adapters on the respirator and removing the inhalation valve from the sample side in accordance with the instrument's operating instructions.

The CNP fit-tester was first set for a negative pressure of 5.6 mm (0.22 inches) of water. Six repeated measures of the leak rate were made with the person looking forward while wearing the respirator. Then without changing position or disturbing the respirator, six measurements each were then made at negative 8.1,

TABLE I. Leak Rate (cc/min) at Various Breathing Resistances

Trial	Subject	5.6 mm	8.1 mm	10.9 mm	19.6 mm
1	1	20.9	22.3	23.6	32.9
2	1	21.0	15.7	15.8	28.2
3	2	24.6	18.9	26.9	28.9
4	2	32.8	22.9	37.0	27.4
5	3	56.6	74.0	94.2	156.0
6	2	88.4	121.0	159.0	262.0
7	4	173.0	248.0	310.0	480.0
8	1	244.0	335.0	426.0	678.0
9	5	419.0	570.0	747.0	1265.0
10	2	510.0	788.0	1243.0	2025.0
11	4	667.5	914.0	1174.0	1836.0

10.9, and 19.6 mm (0.32, 0.43, and 0.77 inches) of water. A final set was repeated at 5.6 mm of water to determine if the fit of the respirator had changed during the series of measurements. This constitutes one trial; duplicate trials were not made. A student's t-test was used to determine whether the initial and final measurements differed. If the difference was significant, the fit of the respirator was judged as having changed during the test and the data set was rejected.

To evaluate the effect of filter loading on airflow resistance, used HEPA filters (3M model 7255, 3M St. Paul, Minn.) were collected from a battery manufacturing plant. Each filter was used for one shift. A total of 38 filters were used over a 5-day period. After use, the airflow resistance was determined using the same test required for certification.⁽⁷⁾ The initial airflow resistance data from 35 quality control samples for the lot used was compared with the postuse airflow resistance for the 38 filters used in the study. The air concentration of lead was determined by collecting personal air samples.

RESULTS

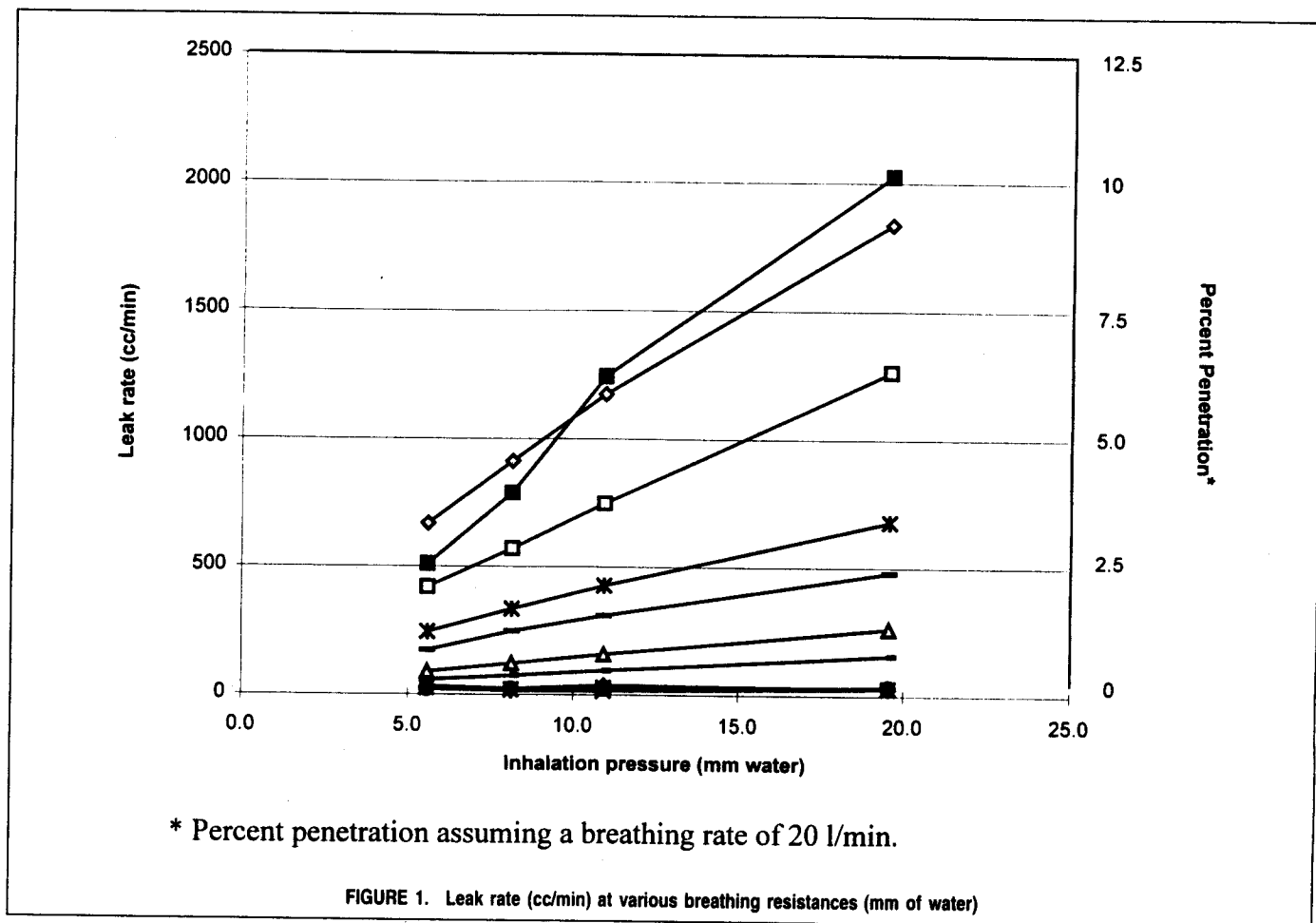
Table I shows each individual's average face seal leak rate found at the various breathing resistances used for each trial. This is shown graphically in Figure 1 (note: the first four sets of data overlap). The first and final set of measurements at 5.6 mm of water were combined and averaged.

The Fit Tester 3000 cannot measure face seal leak rates above 2000 cc/min. Higher initial face seal leak rates than those listed resulted in face seal leak rates greater than 2000 cc/min at the higher simulated breathing resistances. This limited the range of data that could be examined.

As shown in the graph and table, increasing breathing resistance increases the face seal leak rate. The rate of increase varies depending on the initial leak rate at 5.6 mm of water.

For the filters used in the lead battery manufacturing plant, using the NIOSH test criterion, the mean initial airflow resistance measurement from the quality control test was 22.6 mm of water.⁽⁷⁾ After use for a single shift, the mean pressure drop was 25.3 mm of water. The average increase in pressure drop was of 2.7 mm of water. A student's t-test showed the mean pressure drops were significantly different ($p < 0.001$).

Two different tasks were performed in the plant, a pasting job and battery assembly. The geometric mean concentration of lead determined from personal samples was 93 $\mu\text{g}/\text{m}^3$ for pasting and 200 $\mu\text{g}/\text{m}^3$ for the battery assembly job. The mass of aerosol deposited on the filter would have been greater than this amount



since it included lead oxide dust, lead fume, and any other solid aerosol present in the plant air.

DISCUSSION

The increase in faceseal leakage could be significant assuming the increase in faceseal leakage applies to higher initial leak rates and to respirator performance in the workplace. Consider the case in which a person has an initial penetration of 2.5% equivalent to a workplace protection factor of 40 for a half-mask respirator. The amount of penetration could increase to 10% equivalent to a workplace protection factor of 10 with a 14-mm of water increase in breathing resistance.

Filters used in a lead environment for a single shift at less than five times the permissible exposure limit of lead showed an increase in breathing resistance of nearly 3 mm of water.

Love concluded that breathing resistance's between 60 and 140 mm of water would be "noticeable but well tolerated" during the hardest work likely to be experienced by workers.⁽⁸⁾ However, for a person using a respirator, the question is what increase in breathing resistance from the initial resistance would be noticeable and objectionable. As a filter is used, there will be a gradual increase in resistance. Will a person note the increase in resistance before increased faceseal leakage reduces overall performance to unacceptable levels? Gradual changes in resistance in the well-tolerated range may not be noticed until the "not tolerated" range is reached.

If respirator users cannot detect a change in breathing resistance prior to an increase in faceseal leakage, that may affect safe use of the respirator, and then a replacement schedule must be set for all filters. How often a filter should be replaced would be difficult to determine. A replacement schedule would need to be based on when an increase in breathing resistance would be noticed; individual filter characteristics, including the rate of increase in breathing resistance as the filter is used; and the reduction in overall respirator performance due to the increase in breathing resistance.

Filter and aerosol loading characteristics, aerosol concentration, and work rate are some of the factors that will affect the rate of increase for breathing resistance. A single day's exposures to lead dust and fume in a battery manufacturing plant led to an increase in filter pressure drop. To set a replacement schedule based on a predetermined unacceptable increase in breathing resistance will require that loading characteristics be determined for each use of a filter.

For any individual, the performance of the respirator is not known. To establish a filter change-out schedule before performance deteriorates to unacceptable levels, a judgment on what decrease in performance is acceptable is required.

CONCLUSION

An increase in breathing resistance can cause an increase in faceseal leakage. The rate of increase appears to vary depending

on the initial leak rate. The increase in face seal leakage could lower respirator performance to unacceptable levels before breathing resistance is noted by the wearer. The effect may not be uniform among wearers, since the initial rate of face seal leakage appears to relate to the rate of increase in leakage versus the increase in breathing resistance.

This limited data is insufficient to determine when filters should be changed to avoid a decrease in respirator performance. Research is needed to identify the increase in breathing resistance that is noticed by workers. If breathing resistance increases significantly before being noticed, further studies will be needed to characterize filter loading of used filters and to establish criteria for filter replacement.

Until more is known, employee training should be modified to have employees replace filters when an increase in breathing resistance is first noticed instead of when breathing resistance becomes uncomfortable. As an alternative, NIOSH has suggested that filters certified under 30 CFR part 11 should be replaced daily.⁽⁹⁾ Although the approach of studying the potential effect of breathing resistance on face seal leakage described in this article has advantages over those using needles, it is a laboratory study. The authors are not aware of data indicating that the current practice for changing filters is wrong, but until more is known about how inhalation resistance changes in the workplace, it may be prudent to consider replacing all particulate filters daily.

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