Applied Occupational and Environmental Hygiene

ISSN: 1047-322X (Print) 1521-0898 (Online) Journal homepage: https://www.tandfonline.com/loi/uaoh20

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Paul A. Baron

To cite this article: Paul A. Baron (2002) Using a Filter Bypass Leakage Test for Aerosol Sampling Cassettes, Applied Occupational and Environmental Hygiene, 17:9, 593-597, DOI: 10.1080/10473220290057871

To link to this article: https://doi.org/10.1080/10473220290057871

Published online: 30 Nov 2010.

Applied Occupational and Environmental Hygiene
Volume 17(9): 593–597, 2002
1047-322X/02 $12.00 + .00
DOI: 10.1080/1047322029005787 1

Case Studies

Using a Filter Bypass Leakage Test for Aerosol Sampling Cassettes

Dawn Tharr, Column Editor

Reported by Paul A. Baron

Background

The plastic two- and three-piece cassettes commonly used for collection of personal samples of airborne dust may be prone to bypass leakage if the cassettes are not properly assembled. The filter is clamped into place in the cassette by pressing together the base and the ring or cap of the cassette. If pressure is insufficient, or the base and mating piece are not aligned properly, air can flow through the inside of the cassette and around the filter (see Figure 1).[1] If too much pressure is used, the cassette can crack, also producing bypass leakage. This air flow can carry particles and contribute to loss of the particle mass that should have been collected on the filter, thus resulting in an underestimate of worker exposure.

Press-fitted cassettes continue to be widely used. Anecdotal indications of leakage have cropped up from time to time, but the issue has not been dealt with satisfactorily. Van den Heever and Tiernan[2] presented data on cassettes using a pressure drop measurement to indicate leakage. The average pressure drop for a specific cassette/filter combination was measured for a number of "good" cassettes; any decreased pressure drop observed for the assembled cassettes was attributed to bypass leakage. Establishment of this baseline pressure drop when assembling only a few cassettes has been cumbersome, and a more

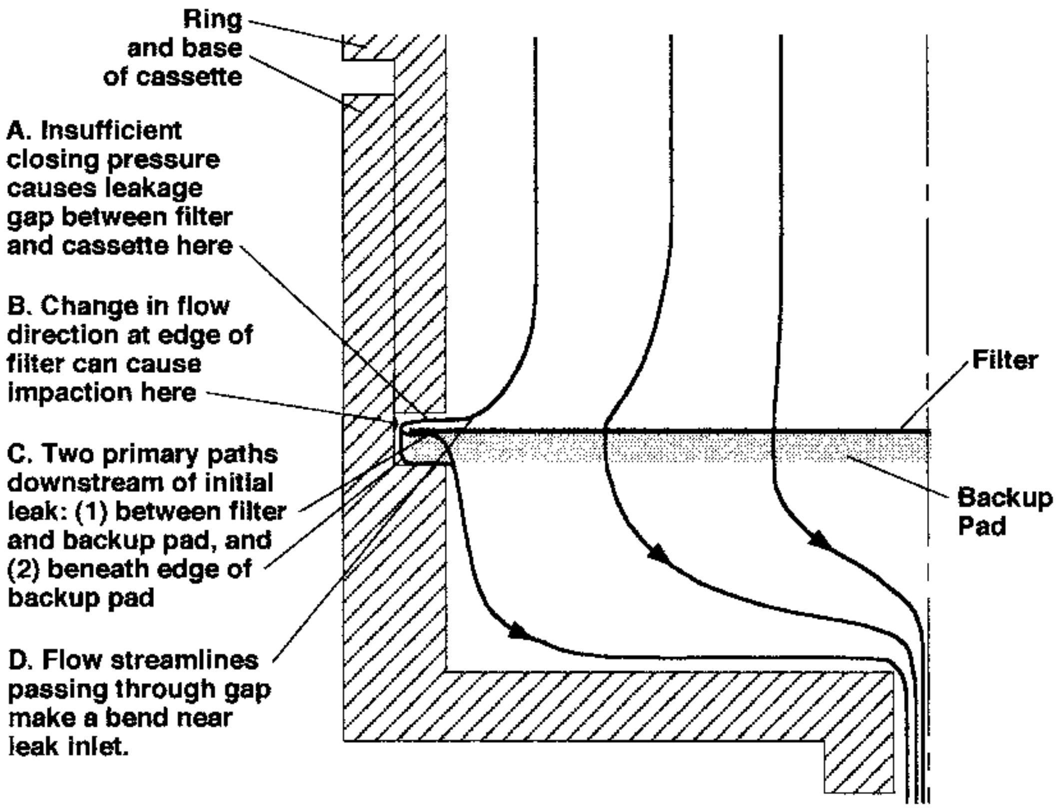

FIGURE 1
Schematic cross section of half of a filter cassette with several flow streamlines. An increasing gap height causes an increasing fraction of air to pass through the leak versus through the filter. Submicrometer particles are likely to follow the air flow through the leak and, when measured downstream, provide an indication of leakage.[3]

direct measure of leakage is deemed useful.

A New Leak Test

Recent studies used a particle counter to evaluate proper cassette assembly by measuring the penetration of ambient aerosol (primarily $< 1.5\ \mu$m) through the cassette.[1,3] Submicrometer particles were shown to penetrate small leaks and to be detected downstream of the cassette, while the filter was found to collect essentially 100 percent of the particles carried by air passing through the filter. These studies were initiated upon discovery of a poorly fitting batch of cassettes, and demonstrated that insufficient assembly pressure could result in high and variable bypass leakage.

The Baron et al. studies[1] indicated that the downstream submicrometer particle concentration in the leak test increased with increased bypass leakage, and could be related to mass loss from the filter, but not in a simple fashion. Some ambient particles were lost in the backup pad, downstream of the filter. In addition, mass lost from the filter was a function of the dust particle size, filter type, and particle "stickiness," e.g., oil droplets versus solid particles. The greatest mass loss occurred for solid compact particles larger than 2 μm in diameter (aluminum oxide). These impacted the filter surface and bounced, or were re-entrained into the leak. Carbon soot particles were also re-entrained into the leak and lost from the filter, but at a slightly lower rate than were solid particles. Oil droplets stuck to the filter for small leak rates, but were also lost at measured leak rates higher than about 15 percent. In addition, some of the aerosol entering the leak was collected on the edge of the filter. Thus, ambient aerosol penetration through bypass leaks can be used to indicate when cassettes have leaked, and the magnitude of the leak, but not to predict mass loss from the filter during sampling.

A particle counter capable of detecting submicrometer particles was used to measure the ambient aerosol concentration. The aerosol concentration downstream of the cassette was measured and compared to the ambient concentration. The percentage of aerosol downstream compared to ambient aerosol was then used as an index of leakage. A condensation particle counter (detects $> 0.02\ \mu$m; TSI, Inc., St. Paul, MN) and three optical particle counters—the Model 227 (detects $> 0.5\ \mu$m; MetOne Instruments, Grants Pass, OR), the Model 229A (detects $> 0.5\ \mu$m; Pacific Scientific Instruments, Grants Pass, OR), and Model 229B (detects $> 0.3\ \mu$m)—all give similar results when compared directly.[1]

Survey of Cassette Preparation Protocols

The particle count leak test was carried out in three separate laboratories on standard 25-mm and 37-mm cassettes prepared under routine conditions. Laboratories A and B used a pneumatic press to assemble the cassettes, while Laboratory C used hand assembly for these tests. Laboratories A and C used a Model 229A optical particle counter, while Laboratory B used a PortaCount. In the laboratory studies of bypass leakage, no significant difference was apparent among the types of particle counters used.[1]

A nominal value of one percent ambient aerosol leakage was used as an index of properly assembled cassettes. This value was chosen arbitrarily at the beginning of the study, and subsequent work indicated that, even at this level, about five percent of the dust mass could be lost from the filter under certain conditions, e.g., large solid particles. The results of the particle count leak tests are presented in Table I as a function of laboratory and filter type, and were analyzed relative to a one percent measured leak rate.

Laboratory A used a pneumatic press and was able to produce nearly 100 percent cassettes with less than one percent leak rate. Two exceptions were noted. Treated glass fiber filter cassettes exhibited apparently high leak rates. Subsequent careful reassembly of these cassettes resulted in acceptable leak rates (data indicated under "Assorted glass fiber filters—*subsequent retest*"). The issue of fiber filters is discussed below. Lab-assembled coal mine dust sampling cassettes (MSA, Inc., Pittsburgh, PA) exhibited the high leak rates because a nonstandard arrangement of filter/backup pads was used. Laboratory A also used hand assembly for certain types of cassettes, but eliminated this practice after initial evaluation with the leak test. Laboratory A used the leak test as part of a quality assurance program, and was eventually able to reduce the use of the test from 10 percent to about 2 percent of the samples after establishing appropriate cassette preparation techniques. Laboratory B achieved excellent leak test results for the 60 filter cassettes tested. Laboratory C achieved poor results using hand assembly, and 15 percent of the cassettes failed the 1 percent leak level for 94 cassettes. Unfortunately, the actual leak values for these tests were not recorded. The particle count leak test was shown to be an effective technique for evaluating cassettes and showed that hand assembly should generally not be used as a routine method for sampler preparation.

The distribution of leak rates for the data in Table I is presented in Figure 2. A major fraction (34%) of the cassettes exhibited $\leq$0.01 percent leakage by the particle count leak test. This suggests that very low bypass leakage levels can be achieved on a routine basis with properly manufactured cassettes assembled with proper pressure and good alignment. The broad peak, centered at 0.11 percent leakage, indicates that the test is helpful in finding cassettes that are not completely sealed, which allows for improvement in the assembly procedure. One reason that relatively few cassettes having high leak rates were reported here is that when significant leak rates were found, procedures or cassette/filter combinations were changed in subsequent cassette preparation.

Other filter holders and cassettes were evaluated in a NIOSH laboratory using the leak test. These included cassettes that used a threaded connection to form the filter seal, e.g., the Millipore asbestos

TABLE I
Particle count leak test results on filter cassettes prepared at three independent laboratories. Except for MSA cassettes (designed for the coal mine dust personal sampler), all cassettes were 37-mm plastic cassettes

Filter type	Number of cassettes	Pass test with <1% penetration (%)	Average penetration (%)
Laboratory A (press assembly)			
PVC 5.0 μm	417	98.8	0.13
PVC 0.8 μm	253	98.8	0.11
MCE 0.8 μm	209	100	0.07
PTFE 1.0 μm	89	97.8	0.28
MDA glass fiber	7	100	0.14
DNPH	6	100	0.062
F/HF	8	100	0.057
PTFE Cl/Br	5	100	0.14
Glass fiber	19	100	0.72
Reagent-treated glass fiber for MDI	64	9.4	8.2
Reagent-treated glass fiber for TDI	39	41	6.4
Assorted glass fiber filters—*subsequent test*	53	100	0.20
MSA lab-assembled 5.0 μm PVC	125	33	1.5
MSA factory-assembled 5.0 μm PVC*	100	100	0.2
Laboratory B (press assembly)			
PVC 5.0 μm	30	100	0.011
PTFE 2.0 μm	30	100	0.00034
Laboratory C (hand assembly)			
PVC 5.0 μm	94	85.1	0.028**
MSA lab-assembled heat-treated quartz fiber***	14	11.5	5.7
Heat-treated quartz fiber***	5	0	37

*These measurements were performed by the NIOSH Cincinnati laboratory and are presented here for comparison with Laboratory A–assembled cassettes using a nonstandard thickness of the combined filter/backup pad.
**Average penetration after failed cassettes were reassembled to pass test. The original leak penetration data were not recorded.
***Leak test performed after sampling was completed.

sampler. These readily gave excellent seals when finger-tightened, and had no observable bypass leakage.

A requirement for the particle count leak test to work is that no particles penetrate the filter. Filters produced in the early 1980s were found to exhibit penetration levels on the order of several percent.[4] Some filters that had been stored in the NIOSH labs from this period were tested and found to have significant penetration rates. Apparently, filter technology has improved over recent years, and the filters currently used for sample collection do not allow direct penetration of particles. Almost all currently available filter types tested at NIOSH support the requirement of no filter penetration. Capillary pore filters do allow direct penetration of particles smaller than the pore size, and the leak test will not work for this type of filter.

As noted in Table I and Figure 2, glass fiber filters tend to exhibit apparently high leak rates. These filters are formed from a mat of fibers, which are not strongly bound together, i.e., no binder is present. Some of these fibers can be released from the filter and detected downstream by a particle counter during a leak test. However, the only time that fiber release is a significant problem appears to be when bypass leakage is present. The air velocity in the leak is quite high (on the order of 5 m/s),[3] compared to the air velocity through the filter, and fibers can be entrained into the bypass leak flow. As a result, relatively small leaks in fibrous filters can produce higher particle concentrations downstream of the filter than upstream. However, this situation appears to be a temporary phenomenon, and after the leaking cassette is used for about 5 to 10 minutes, the downstream concentration drops by a factor of about 20 and stabilizes. Thus, the leak rate may be overestimated 20-fold. The test, therefore, still indicates the presence of a leak in these fibrous filters, but the absolute measured leak level is not useful.

Sampling at high flow rates produces a high pressure drop across the filter and can sometimes tear the filter or pull the filter away from the seal, resulting in bypass leakage. For example, asbestos samples are often taken at flow rates of up to 16 L/min by a 25-mm cassette. If a cassette is suspected of leaking during sampling, it is possible to apply the particle

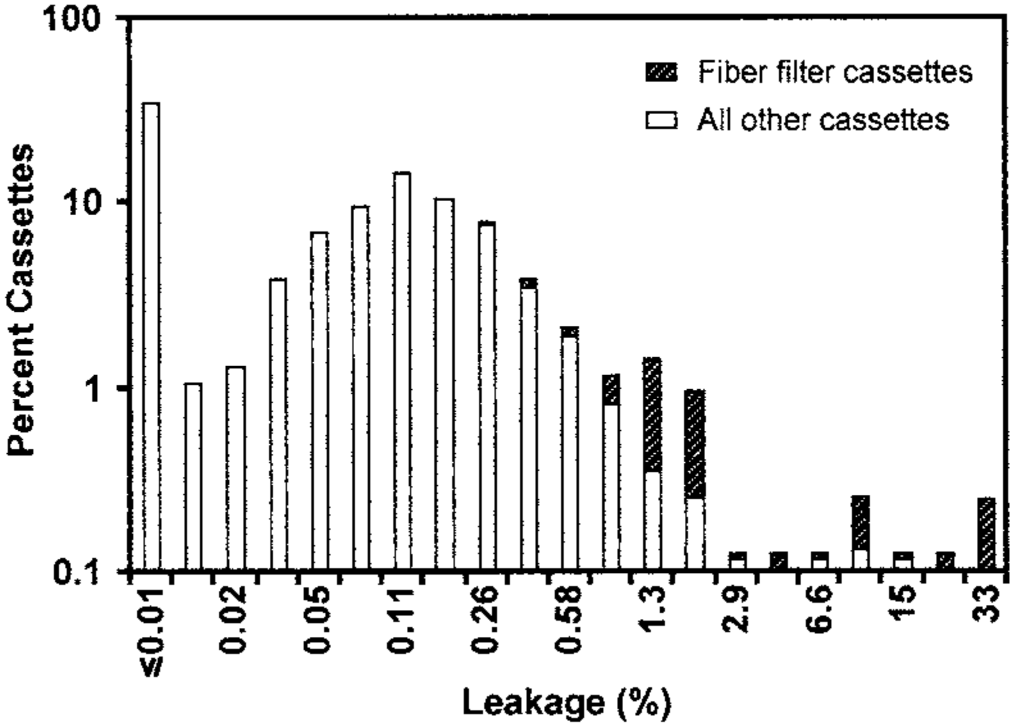

FIGURE 2

Percentage of cassettes in Table I with a given leak rate using the particle count leak test. A total of 853 cassettes were tested. Most of the cassettes with high leakage according to the leak test used fibrous filters without a binder. Bypass leakage was overestimated by the test for these cassettes.

count leak test after sampling; however, while postsampling leak tests agree with presampling leak tests when sampling dry dusts, they often do not indicate the presence of a leak when sampling carbon soot. It was observed in our evaluations that the soot clogged the pores of the backup pad in leaking cassettes and resulted in tests that indicated properly sealed cassettes. Thus, even though soot mass was lost from the filter, the postsampling leak test did not indicate leakage. Leak tests used after sampling may produce similarly incorrect results when other types of submicrometer particles, e.g., cigarette smoke, are sampled. It may be preferable to examine the edge of the filter—for incomplete compression or evidence of particle deposits in the seal region—to indicate an invalid sample.

Conclusions and Recommendations

The particle count leak test is simple and quick. It includes the following procedures:

1. Measure the ambient particle number concentration at the test location for a fixed time period (e.g., 1 min). The particle counter (optical particle counter or condensation particle counter) should be capable of detecting particles $\leq 0.5\ \mu$m.
2. Attach the cassette to be tested to the inlet of the particle counter. Keep connections as short as possible, and leak-free.
3. Measure the particle concentration downstream of the cassette for the same time period. It is usually obvious within the first 10–15 seconds of the measurement whether or not a cassette leaks. It is preferable to minimize the test time to reduce potential contamination of the filter.
4. Calculate the percent leakage by dividing the downstream concentration by the ambient concentration.

To ensure that mass loss is kept below one percent, the leak test should give a value less than 0.2 percent, which should be possible to achieve routinely with proper assembly technique. The only exception appears to be fibrous (e.g., glass, ceramic) filters without a binder; the leak test still works, but fibers released from the filter may cause overestimation of the leak rate.

Hand assembly of press-fitted cassettes appears to result in a substantial number of cassettes having bypass leakage. However, by checking each hand-assembled cassette using the leak test, one can reassemble leaking cassettes to correct the problem. It is recommended that either manufacturer-assembled cassettes or a press that is able to provide the appropriate pressure for good sealing be used. The appropriate pressure can be determined by using the leak test.

The leak test cannot be used to accurately predict mass losses from the filter during subsequent sampling. However, the test is still useful to ensure proper cassette assembly for more accurate sampling.

It is not recommended that the leak test be used after sampling, because fine particles may clog the passages in the leak downstream of the filter, which could result in a false indication of no bypass leakage.

The particle count leak test can be used on a routine basis for checking proper assembly, especially with new combinations of cassettes and filter media. The test can be used to train laboratory personnel in proper assembly technique. Each batch of unassembled cassettes from suppliers should also be leak-tested to ensure proper mating of cassette pieces. Cassettes preassembled by manufacturers were found to be leak-free, but it is recommended that cassettes from other sources be tested.

Acknowledgments

We thank Thomas Jefferson of the NIOSH Division of Respiratory Disease Studies, DataChem Laboratories, and the Wisconsin Occupational Health Laboratory for providing data on cassette leakage and comments on the leak test.

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EDITORIAL NOTE: Paul Baron is with the Division of Applied Research and Technology, NIOSH. For additional information, contact Paul Baron at NIOSH, 4676 Columbia Parkway, Cincinnati, OH 45226; telephone: 513-841-4278.

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