# Testing Air-Filtering Systems

## I. Procedure for Testing High-Efficiency Air Filters on Exhaust Systems

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ABSTRACT

SONGER, JOSEPH R. (National Animal Disease Laboratory, Ames, Iowa), JAMES F. SULLIVAN, and JAMES W. HURD. Testing air-filtering systems. I. Procedure for testing high-efficiency air filters on exhaust systems. Appl. Microbiol. **11**:394–397. 1963.—A procedure was developed for evaluating high-efficiency filters mounted in exhaust ducts at the National Animal Disease Laboratory. An aerosol of the test organism, *Escherichia coli* B $T_3$ bacteriophage, was generated in a chamber attached to a ceiling exhaust register in concentrations of at least 1000 viable organisms per $ft^3$ of air. Samples were collected from both the pre- and postfilter areas, and the number of organisms per $ft^3$ of air was determined. The efficiency of the filter was calculated from these figures. A total of 269 high-efficiency filters were tested. Of these, 249 had efficiencies of 98% or greater. The remaining 20, with efficiencies of less than 98%, were repaired and retested. No filter was accepted with an efficiency of less than 98%.

The principles of filter testing are essentially the same, regardless of the test material used. An aerosol of the test material is released upstream from the filter, air samples are collected in the pre- and postfilter areas, and the efficiency of a filter is calculated from the number of particles found in these samples.

Nonbacterial tests for evaluating filters have been used extensively. The National Bureau of Standards test (Dill, 1938), the American Society of Heating and Ventilating Engineers (1933) test, and the American Air Filter Institute (1956) test are useful in determining penetration of nonviable material and the minimal-size particles a filter is capable of arresting. These tests utilize a standard dust or smoke, and measure their volumes in influent and effluent air either by weight or a photoelectric instrument. These nonbacterial tests are of considerable value in rating filters for their retention of particulate material; however, the tests cannot be applied when rating filters for their retention of microorganisms. Particles from liquid or mineral solids have different adhesive properties than do bacterial particles, and forces that cause deposition of particles may also vary with the type of material used. Decker et al. (1962) stated that the bacterial test provides the most sensitive method of evaluating filters because it quantitates the viable organism that penetrates the filter.

Several methods which utilize a variety of organisms have been described for testing high-efficiency filters for their ability to arrest microorganisms. Decker et al. (1962, 1951, 1952, 1954) described tests using *Serratia indica*, *S. marcescens*, *Escherichia coli* B $T_3$ bacteriophage ($T_3$ coliphage), and *Bacillus subtilis* var. *niger* spores as test agents. Thorne and Burrows (1960) used foot-and-mouth disease virus, Sadoff and Almlof (1956) used $T_3$ coliphage tagged with radioactive phosphorus, and Maxon and Gaden (1956) used *B. subtilis* spores as test agents.

This report describes a procedure for evaluating high-efficiency filters mounted in exhaust ducts. The procedure, which was developed to meet the special design of the ventilation systems at the National Animal Disease Laboratory, consists of a system for the release, recovery, and quantitation of the test organism.

### MATERIALS AND METHODS

*High-efficiency filters.* The high-efficiency filters installed in the exhaust ducts of laboratory and animal-holding areas were composed of multiple units of five or six wedge-shaped frames. Each frame was covered with two 0.5-in. thick layers of glass-wool medium. This medium was composed of fibers 2 to 10 $\mu$ in diameter with a density of 0.6 $lb/ft^3$. Its clean filter resistance was 0.46-in. water gauge at 800 $ft^3$/min and 0.83-in. water gauge at 1200 $ft^3$/min for a unit (20 by 20 in.) consisting of five wedges of media. A unit (20 by 20 in.) had a total filter surface area of 37.5 $ft^2$. This medium had a filtering efficiency of 99.95% on fractions (0 to 5 $\mu$) of standardized free air cleaner test dust and was rated, by the manufacturer, at 80% efficient on 0.3-$\mu$ smoke by the Atomic Energy Commission dioctylphthalate test method.

These filters were mounted in the exhaust ducts above the ceiling in the laboratory and animal-holding areas, and were accessible only through access panels in the prefilter chambers. Figure 1 schematically illustrates the arrange-

ment of the filters in the exhaust ducts. Due to the variation in size of individual laboratories and animal-holding areas, the volume of air exhausted was not constant for all exhaust systems. The total surface area of the biological filter was varied to accommodate the exhaust air from a particular laboratory or holding area. Some biological filters were composed of two units of five or six wedges each, and others were made up of three units. Probes for collecting the aerosol samples were centered 6 in. from the front and rear of each filter unit. The number of air samples collected in each test depended upon the number of filter units in the system. In all cases, at least two samples were collected prefilter and two samples postfilter.

*Aerosol generator.* Aerosols were produced with a De Vilbiss 841 nebulizer (Fig. 2), which released 1.5 ml per min with a droplet size of 0.3 to 2 $\mu$. This nebulizer was selected because of its droplet size, high level of release, and large capacity.

*Aerosol sample collector.* Millipore standard filter holders equipped with limiting orifices (10 liters per min) were used for collecting air samples (Fig. 1, no. 9). Type AA (aerosol assay) membrane filters were used. These filters had a pore size of 0.80 $\mu$ ($\pm$0.05 $\mu$) and a flow rate of 33,000 cc/cm$^2$ per min at 25 C and 14.7 psi. Type AA filters, according to the manufacturer, will retain particles as small as 0.005 $\mu$ in diameter.

*Microorganism test system. E. coli* B cultures were maintained for the production and titration of $T_3$ coliphage. Daily passages were made in Tryptose Phosphate Broth. $T_3$ coliphage, the test organism utilized in the production of aerosols, was produced in Tryptose Phosphate Broth cultures of *E. coli* B. Three 3-liter flasks each containing 1 liter of Tryptose Phosphate Broth were inoculated with 5 ml of a 3-hr broth culture of *E. coli* B and incubated at 37 C. As soon as a definite turbidity developed in the flasks (about 2 hr), 5 ml of a suspension of $T_3$ coliphage contain-

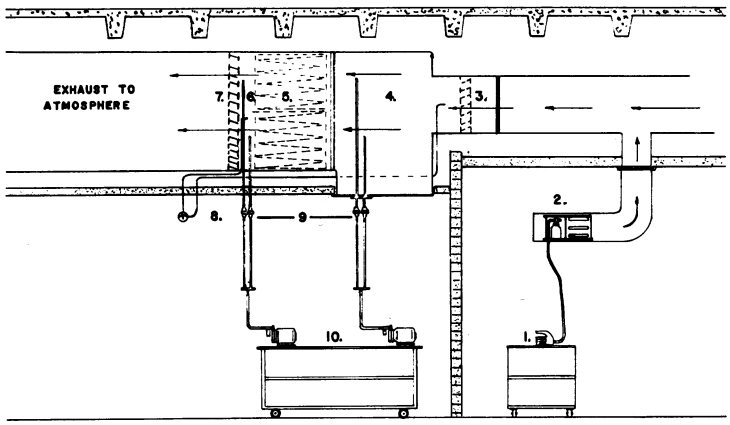


FIG. 1. *Schematic drawing of exhaust filters and equipment for testing. 1, compressor; 2, nebulizer; 3, prefilter damper; 4, prefilter chamber with sampling probes; 5, bacterial filters; 6, postfilter chamber with sampling probes; 7, postfilter damper; 8, Dwyer Magnehelic pressure gage; 9, Millipore aerosol samplers; 10, vacuum pump.*

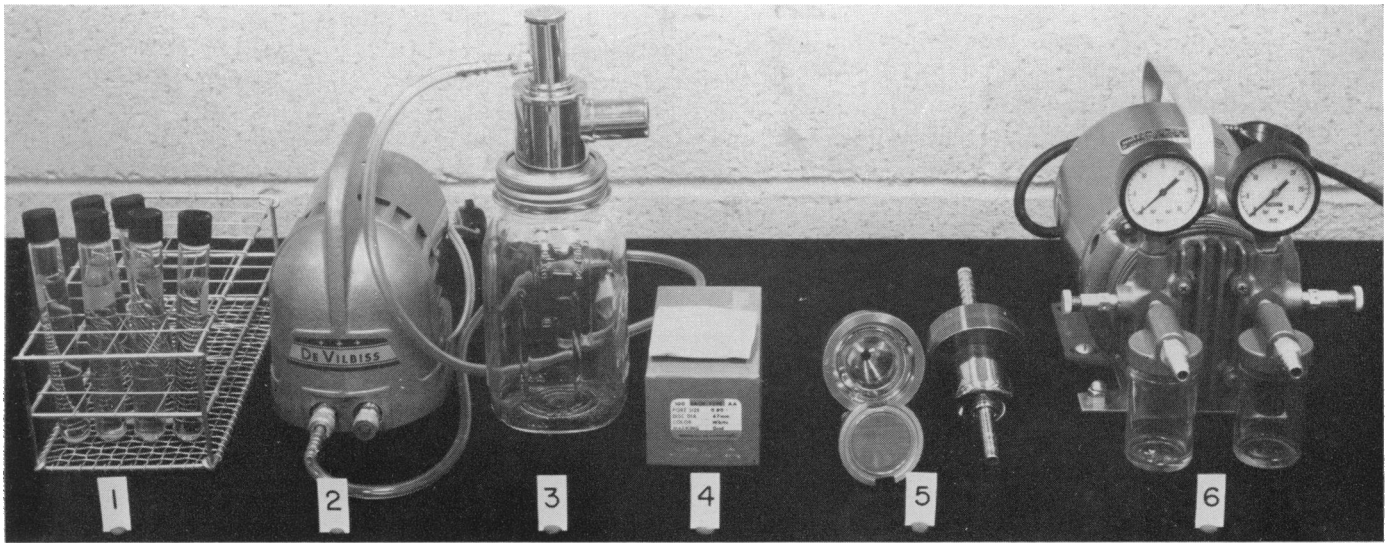


FIG. 2. *Materials necessary for testing filters. 1, $T_3$ coliphage; 2, nebulizer compressor; 3, nebulizer; 4, membrane filter discs; 5, Millipore membrane samplers; 6, vacuum pump.*

ing approximately $10^7$ particles per ml were added to the cultures. After complete lysis had occurred (about 2.5 hr), the lysate was filtered through a Seitz 0.1-$\mu$ filter, titrated, dispensed in screw-capped tubes, and stored in a refrigerator. Both *E. coli* B and $T_3$ coliphage were received from R. A. Packer, Department of Veterinary Hygiene, Iowa State University, Ames.

*Procedure for titrating $T_3$ coliphage.* The procedure for titrating $T_3$ coliphage is a modification of the agar layer method described by Adams (1950). Tenfold dilutions of the samples containing $T_3$ coliphage were prepared in 1% peptone. A 0.2-ml amount of each dilution of the $T_3$ coliphage was added to a tube of melted soft agar that had previously been inoculated with one drop of a 4-hr Tryptose Broth culture of *E. coli* B. This tube was then agitated vigorously, and its contents were poured onto the surface of a prepoured Tryptose Agar plate. After the agar had solidified, the plates were inverted and incubated at 37 C for 10 to 24 hr, at which time the plaques were counted and the results recorded. Since each plate was inoculated with 0.2 ml, the number of plaques per ml was found by multiplying the number of plaques per plate by 5.

*Procedure for testing biological filters.* Approximately 90 ml of $T_3$ coliphage, with a titer of $10^8$ particles per ml, were nebulized over a 23-min period into a chamber attached to a ceiling exhaust register, upstream from the biological filters (Fig. 1). A 5-min interval was allowed after the initiation of the aerosol release for the dispersion of the aerosol before sampling was started. Samples were collected for a period of 18 min by drawing air through the probes in the pre- and postfilter chambers into the aerosol sample collectors (Fig. 1). The sample volumes were regulated by the limiting orifices mounted in the sample collectors.

At least two samples were collected in the pre- and postfilter areas of each filter, and the evaluation of the filter was made on the basis of these samples. A total of 6.3 $ft^3$ of air was sampled in the 18-min collection period with each sampler. Sampler membranes were then removed and washed by vigorous pipetting in 31.5 ml of 1% peptone so that each ml of peptone contained the organisms from 0.2 $ft^3$ of air. Titrations were made as previously described, and plaques were counted between the 10th and 24th hr of incubation.

The significant dilution was that dilution with the highest number of countable plaques per plate. The number of plaques per ml of the sample was multiplied by 5 to arrive at the number of particles per $ft^3$ of air.

To calculate the efficiency of a filter, the following formula (Decker et al., 1962) was used:

$$\text{efficiency} = \frac{(\text{no. of organisms in}) - (\text{no. of organisms out})}{\text{no. of organisms in}} \times 100$$

## RESULTS

A total of 269 high-efficiency filters were tested, of which 249 had efficiencies of 98% or greater. Of these filters, 227 had efficiencies of 99% or greater, and the remaining 22 were between 98 and 99%. The 20 filters with an efficiency of less than 98% were repaired and retested. No filter was accepted with an efficiency of less than 98%. The number of tests conducted in the various buildings at the National Animal Disease Laboratory, with the challenge concentration of test organisms and the average precentage efficiency of the filter, are shown in Table 1.

In most cases of low filtering efficiency, the problem area in the filter was indicated by the results of the test. Usually, if there was a leak about the housing or a tear in the medium, the sample collected in the area of the leak would be quite high, although air samples from other areas were in an acceptable range. This was exemplified by most of the nonacceptable tests shown in Table 1. For example, in test 1 in module A-13, 11,250 viable organisms were collected in the prefilter area in front of the top unit and 16,500 viable organisms were collected in front of the bottom unit. In the postfilter area, 765 organisms were collected behind the top unit and 20 organisms behind the bottom unit. The filtering efficiency was 97.15%.

Upon examination, a piece of torn medium was found in the top unit. After the torn medium was replaced, test 2 was conducted. In the prefilter area in front of the top unit, 7750 viable organisms were collected per $ft^3$ of air and 7250 viable organisms were collected per $ft^3$ of air in front of the bottom unit. In the postfilter area, no viable organisms were behind the top unit and 5 viable organisms were collected per $ft^3$ of air behind the bottom unit. This resulted in an efficiency of 99.97%.

## DISCUSSION

This test was not designed as a critical test of the filter medium, although it would indicate low efficiencies if they existed, but was designed to test the filters as complete, installed units. Filters may function perfectly under isolated test conditions, but they may be improperly installed or serviced, and fail to accomplish the task for which they were designed.

Because of the design of the air system at the National

TABLE 1. *Results of filter tests conducted on high-efficiency filters using $T_3$ coliphage as test organism*

| Filter location | No. of filter tests | | No. of organisms per $ft^3$ before filtering | | | Filtering efficiency | |
|---|---|---|---|---|---|---|---|
| | Acceptable | Nonacceptable | Maximum | Minimum | Avg | Range (%) | Avg per cent |
| Bldg. 2, wing A | 64 | | 67,000 | 1125 | 37,569 | 98.1–100 | 99.63 |
| | | 9 | 160,000 | 2785 | 29,309 | 95.38–97.96 | 96.89 |
| Bldg. 2, wing B | 69 | | 192,000 | 1075 | 26,364 | 98.39–100 | 99.72 |
| | | 6 | 26,250 | 2265 | 14,919 | 77.0–97.78 | 92.67 |
| Bldg. 3 | 52 | | 4,600,000 | 1745 | 381,401 | 98.02–100 | 99.48 |
| | | 4 | 175,000 | 8750 | 64,312 | 88.0–97.60 | 95.31 |
| Bldg. 4 | 50 | | 67,500 | 1025 | 22,201 | 98.54–100 | 99.75 |
| | | 1 | 6250 | 6250 | 6250 | 96.64 | 96.64 |
| Bldg. 155 | 14 | | 33,500 | 1070 | 10,053 | 98.54–100 | 99.77 |
| | | 0 | | | | | |

Animal Disease Laboratory, it was necessary to release aerosols of the test agent in the laboratory and animal-holding rooms. *B. subtilis* and *S. marcescens* were considered as test agents, but were rejected because of the contamination problem they presented in these areas. $T_3$ coliphage, which is highly host-specific, was selected as the test agent because it presented no contamination problem. This organism was not as stable in an aerosol as other test agents considered, but no problem was encountered in generating aerosols of at least 1000 viable particles per $ft^3$ in air flows up to 4000 $ft^3$ per min. Filter tests in which the aerosol challenge concentration was less than 1000 particles per $ft^3$ were disregarded, and the filters were rechallenged with an increased aerosol concentration.

Due to the design of the high-efficiency filters, extreme care had to be exercised in installing the filter medium. As the medium-covered wedges were inserted into the filter housing, the medium had a tendency to roll and tear. This was alleviated by the installation of fiberglass screening, six strands per in., over the filter medium. This screening also facilitated the removal of the medium after decontamination with steam and formaldehyde.

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