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**TITLE:** IN SITU TESTING OF TANDEM HEPA FILTER INSTALLATIONS WITH A LASER SINGLE PARTICLE SPECTROMETER SYSTEM

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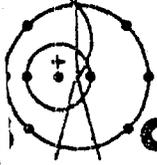
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IN SITU TESTING OF TANDEM HEPA FILTER INSTALLATIONS  
WITH A LASER SINGLE PARTICLE SPECTROMETER SYSTEM\*

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Abstract

System components and methodology for in place testing of tandem HEPA filters are described. The system consists of a very high volume thermal DOP generator for producing sufficient challenge aerosol, a single particle intra-cavity laser particle spectrometer for high sensitivity detection, a forward light scattering photometer to measure challenge aerosol concentration, and a diluter to interface the spectrometer and photometer measurements. Results of the measurements on 11 tandem HEPA installations are presented along with problem areas and recommendations for future work.

I. Introduction

In order to implement the testing of tandem HEPA filter installations, a series of feasibility studies was initially performed on a small laboratory scale system. Using the concepts of measurement and digital counting obtained by implementing an intra-cavity single particle laser spectrometer rather than the conventional instantaneous analogue read-out of a forward light scattering photometer, tandem filter protection factors (PF) of  $10^9$  were readily measured. Challenge aerosols composed of solids (NaCl) and liquid (DOP) were employed. The size distributions of these two aerosols were essentially identical, as were the individual filter PF's, as a function of particle size. These measurements displayed a minimum PF at  $0.19 \mu\text{m}$  with increasing protection on either side of this minimum. The fundamental difference in the use of liquid versus solid aerosols was in the rapid increase of pressure drop, i.e., filter plugging, that occurred with solid particulates, hence resulting in a semi-destructive test. The similarity of other results, however, suggests that DOP testing is a valid technique for exploring the critical behavior of filters.<sup>(1)</sup> The data also implies that since the size characteristics of a challenge aerosol are changed during the filter interaction, that the light scattering photometer PF's are really only a ratio of light scattering signals rather than a ratio of particle counts, masses, or areas. This follows from the very complex dependence on radius, wavelength, index of refraction, and concentration of the light scattering processes occurring within the photometer. In addition, the product of the PF's measured individually on a tandem system is likely to over estimate the system PF. This is a consequence of the first filter removing the most easily collected particles, hence effectively providing a

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challenge to the second filter of mostly difficult to collect particles. Only if the challenge aerosol were absolutely monodisperse would there be no measurement differences between the two detectors in the above situation, providing that the particle concentrations were kept low enough to avoid multiple scattering in the photometer and excessive coincidence errors in the spectrometer.

One additional advantage in the use of the spectrometer is its ability to integrate, i.e., store the particle count per size channel, over any required time period. This, coupled with the complete lack of instrument noise (a common feature of digital devices) enhances the detectivity for low particle concentration. In other words, it is not just an instantaneous rate, but the rate integrated over time that is measured. For extremely low concentrations, the measurement is facilitated by increasing the counting time.

In order to implement this technique for field test use, several new pieces of equipment had to be designed and built. Chief among these was a high volume thermal DOP generator<sup>(2)</sup> for producing the very large challenge aerosol concentrations required for tandem HEPA filter installation testing. This generator output is equivalent to 10 of the smaller commercially available units. A diluter for diluting the very high upstream challenge aerosol concentrations so that they are amenable to single particle measurement was also constructed.

The need for tandem HEPA filter testing was dictated by the desire to more accurately characterize system performance. Current test methods are limited to testing separate stages and may overestimate system performance. In addition to decreasing system downtime and worker exposure during testing, considerable dollar and space savings may be effected by designing tandem filter ventilation systems so they need not undergo stage-by-stage testing.

## II. Test Apparatus

For tandem HEPA testing, protection factors of  $10^7$  to  $10^8$  are encountered, as opposed to  $10^3$  to  $10^4$  for single filter testing. It is obvious that much greater concentrations of challenge aerosol are required for the tandem test. Even though the detectivity of the laser spectrometer is considerably enhanced over that of the photometer, excessive integration times are undesirable. Additionally, the presence of downstream background aerosol, due usually to ductwork leaks, can mask the presence of very small concentrations of test aerosol. Typically, a challenge aerosol of 10 to 100 times the concentration normally used for single filter testing is required. The laboratory system of a six stem Laskin generator and associated compressed air supply, when considered in the multiplicity required for an industrial application, is far too cumbersome. In several tests, commercially manufactured thermal DOP generators were used, but their individually variable outputs and operating periods made multiple units awkward to work with. The DOP reservoirs in these devices were enlarged, which increased the operation time, but the combined output from the several generators did not behave in a temporally constant fashion and the tending of two to four separate generators proved unacceptable.

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So that these difficulties could be overcome, an effort was directed at constructing a thermal DOP generator which would have an output several times that of the individual commercial generators and using the same basic principles of operation. The successful completion and splendid performance of this system provided confidence in the further scaling to a system providing ten times the output, i.e., 100 gms of DOP and 34 liters of CO<sub>2</sub>, per minute, when operated at 30 psi.

The primary aerosol detector is a LAS-X single particle intracavity laser spectrometer specifically designed for this measurement. The instrument measures particles in a size range of 0.1  $\mu\text{m}$  to 3.1  $\mu\text{m}$  in 0.1  $\mu\text{m}$  increments. The counts per size channel are stored and automatically printed out along with appropriate house keeping data such as time, date, and sample time. Graphical displays can be obtained with the use of an auxiliary oscilloscope or x-y recorder. Sample flow rate is 15 cm<sup>3</sup>/s, considerably greater than previous designs of this instrument.

The advantages of such an instrument are manifold. The ability to measure a size spectrum obviates the problems associated with trying to generate a monodisperse aerosol and, in fact, characterizes a filter system's efficiency as a function of size. The digital technology associated with single particle counting insures against instrumental background. The counting feature enables a measurement to continue until a statistically significant sample of N counts has been registered, the percentage error then being proportional to  $N^{-1/2}$ . This is all in contradistinction to the instantaneous photometer type of readout which derives from a gross scattering of light from a population of particles, and is insensitive to single particles.

In the measurement of very high concentrations of upstream challenge aerosol, precautions must be taken to insure that any optical measuring system is not operated in a range for which it was not designed. In the case of the particle spectrometer, this limit is set by a maximum count rate, or electronically, by the frequency bandwidth of the instrument. For a photometer, the limitation is imposed by the onset of multiple scattering. This typically occurs when the optical depth reaches a value of 0.1 or greater. For the range of aerosol sizes normally encountered in filter test measurements, this corresponds to a concentration of order 10<sup>7</sup>/cm<sup>3</sup>, which is reasonably below the concentrations used for the tandem testing procedure described in this paper. However, the upstream concentration will saturate the single particle detector.

In order to make use of the high saturation level of the photometer upstream and the great sensitivity of the single particle detector downstream, a diluter section is used in the measurement. This consists basically of a small wind tunnel into which HEPA filtered room air is drawn. A probe iso-kinetically samples the upstream challenge aerosol, introducing it into the diluter, where it is mixed with the much larger volume of clean air. Flow rate and pressure drop are controlled by varying blower power and throttling the air flow. Appropriate instrumentation is included to measure

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flow rate and pressure differentials. The dilution ratio, which is typically in the  $10^{-3}$  range, can be computed and/or measured. Since the size distribution of the diluted sample should be unchanged from the original population, the photometer is used to determine this value. Measurement of the diluted sample with the spectrometer will then provide the upstream count rate, which is proportional to the challenge concentration.

The diluter also serves a second, very important purpose in that it is responsible for bridging three of the seven or eight orders of magnitude associated with the measurement of the protection factor. Although the spectrometer dynamic range is essentially unlimited, decreasing the challenge concentration to a point where it is directly measurable would result in enormously long downstream measurement times.

The photometer used for these measurements may be any one of the conventional forward scattering types now used for conventional HEPA filter testing. It should be of the linear read-out variety and be gain switchable over at least three noise-free orders of magnitude.

The two major systems of DOP generator and diluter are mounted on two-wheel hand carts. The two detection instruments are hand portable. The complete system is shown in Figure 1.

### III. Procedure

The methodology associated with a tandem HEPA filter system test is not, with the exception of the dilution procedure, much different from conventional filter tests, but because of high protection factors usually involved, systems with flow rates greater than 20,000 CFM should usually not be attempted. The DOP generator is first emplaced as far upstream as is practicable. Appropriate iso-kinetic probes are installed and, if possible, centered immediately upstream and downstream of the tandem plenum. The upstream probe will usually consist of a probe pair so that the flows for both the diluter and photometer may be matched. The diluter has internal probes matched to the photometer and spectrometer flows. The generation of DOP is then initiated and monitored with the upstream sampling photometer until a steady state of generation obtains, at which time the photometer is switched to the diluter and a measurement made. Simultaneously, a diluter measurement is made with the spectrometer. Because of the still high concentration in the diluter, a spectrometer measurement for one minute will be quite sufficient. Over 10,000 counts will be registered in this interval, assuring an accuracy of better than 1%. The upstream concentration is now proportional to the product of the upstream photometer reading and the diluter spectrometer count rate divided by the diluter photometer reading. The downstream reading is made directly with the spectrometer. Ten minutes are typically required to obtain a count of 100, which will provide 10% accuracy.

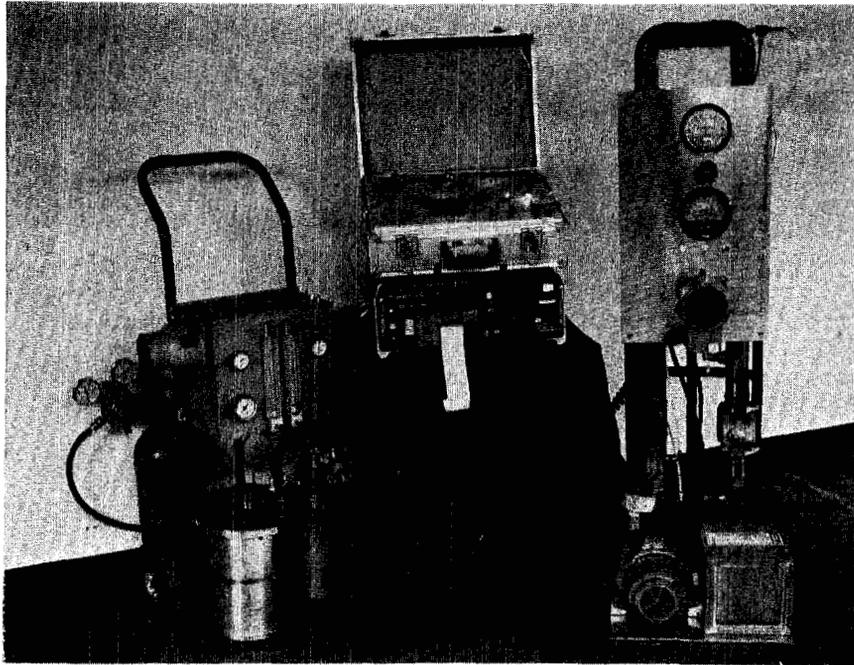


FIG. 1  
FILTER TEST APPARATUS - GENERATOR, DILUTER, DETECTORS

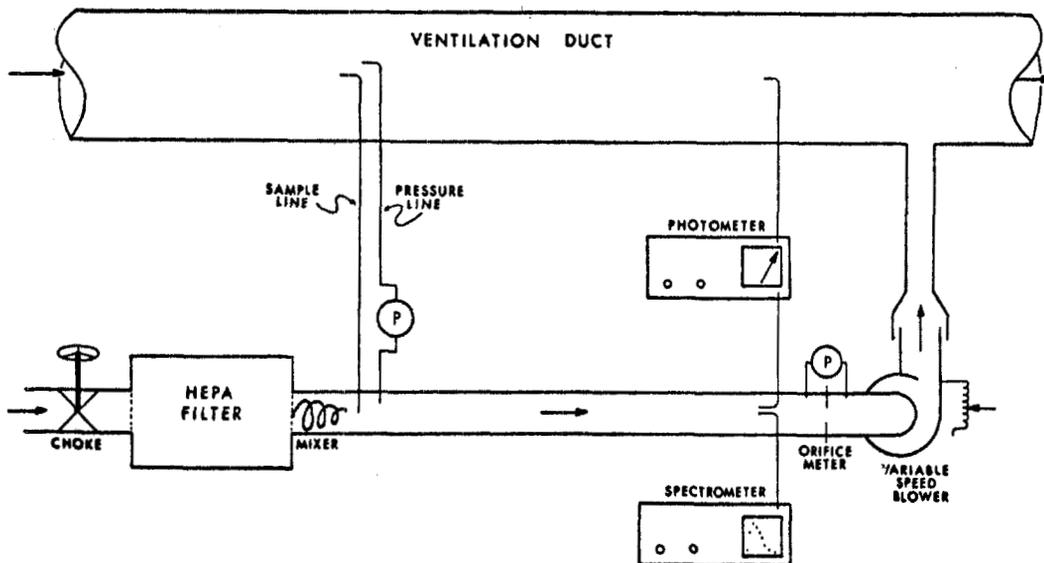


FIG. 2  
TEST PROCEDURE SCHEMATIC

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In a great many instances, a downstream background count will be present, due usually from in-leakage of ambient air into the downstream ducting, which is at a negative pressure with respect to the ambient air. In this case, background measurements should be made (with the aerosol generator turned off) before and after the system is challenged, so that they may be subtracted from the actual test measurement. Upstream background usually poses no problem because it is overwhelmed by the enormous challenge concentration. In some instances, the downstream background may be so high that it masks the test measurement. In this case, a lower limit on the system performance can still be obtained using the noncorrected downstream count. A schematic of the measurement procedure is shown in Figure 2.

### IV. Results

Table I tabulates the results of nine systems measured during the acceptance testing phase at the new LASL Plutonium facility. These measurements were accomplished with an earlier model low flow rate spectrometer designed primarily for laboratory use. Conventional photometer data, for the acceptance tests, were acquired for individual banks. As anticipated, the tandem protection factors derived from these latter measurements usually overestimated the system performance by about a factor of two.

The data shown in Table II were acquired with the LAS-X spectrometer. Because of operational constraints associated with the test schedule for LASL filter systems, only these installations were able to be tested up to this point, but they are of particular interest. System 1 shows a typical downstream background count rate which is small enough so that it can be successfully subtracted from the test count rate to produce a reasonably accurate test. System 2 displays a very different sort of behavior in that the background count rate increases after the system has been challenged and in fact is greater than the count rate taken during the challenge. It appears that there is an interaction between the DOP and the material collected on the filter which creates the change. Simultaneously, there is an increase of pressure drop of 25 mm across the filter. This particular system has been measured several times with similar results. Laboratory tests on clean filters do exhibit an increase in P.F. immediately after and during the challenge, but no background due to DOP was ever observed. The P.F. for this system was computed by using the maximum downstream value observed, 1.13, and calling this the lower limit or minimum P.F. for the system.

### V. Conclusions and Recommendations

The system that has been described can, of course, also be used for measuring single filter bank installations. One such system of 160,000 CFM flow rate was, in fact, successfully measured; a task virtually impossible with conventional test methods. The system has performed reliably and is readily portable. One problem area that has already been discussed is that of excessive downstream background. This situation is now under study using the

TABLE I  
TA-55 FILTER TESTS

<u>System</u>	<u>Tandem Test Protection Factor</u>
C	$7.2 \pm 1.3$ $10^7$
F	$2.7 \pm 0.3$ $10^7$
A	$1.3 \pm 0.2$ $10^8$
G	$1.8 \pm 0.4$ $10^7$
B	$9.8 \pm 2.8$ $10^7$
D	$5.6 \pm 1.6$ $10^7$
E	$5.5 \pm 1.3$ $10^7$
I	$4.2 \pm 0.4$ $10^5$
H	$6.2 \pm 0.7$ $10^6$

TABLE II  
CMR FILTER TESTS

	<u>System</u>	
	<u>CMR 1</u>	<u>CMR 2</u>
Flow Rate	17500 CFM	16400 CFM
Upstream Count Rate	$8.450 \times 10^7$	$6.184 \times 10^7$
Downstream Count Rate		
Before Test	$.30 \pm .10$	$.29 \pm .10$
After Test	$.30 \pm .12$	$1.13 \pm .20$
During Test	$2.20 \pm .27$	$.30 \pm .10$
Downstream Net	$1.90 \pm .29$	$1.13 \pm .20$
P.F.	$(4.4 \pm .7) \times 10^7$	$(5.5 \pm 1.0) \times 10^7$

concept of a self-identifying challenge aerosol that can be distinguished from background particulates. The phenomenon of changed efficiency due to the interaction of the challenge aerosol medium and the filter is one which should be thoroughly studied in order to avoid falacious high efficiency measurements on older, partially loaded filters.

#### VI. Acknowledgements

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