CONF-880815--9

UCRL- 99423
PREPRINT

Development of a High-Efficiency, High-Performance Air Filter Medium

W. Bergman
S. R. Sawyer

SEP 0 1 1988

20th DOE/NRC Nuclear Air Cleaning Conference
Boston, Massachusetts
8/22-25/88

REPRODUCED FROM
BEST AVAILABLE COPY

August 16, 1988

Lawrence Livermore National Laboratory

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the *understanding that it will not be cited or reproduced without the permission of the* author.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DEVELOPMENT OF A HIGH-EFFICIENCY, HIGH-PERFORMANCE AIR FILTER MEDIUM*

W. Bergman and S. R. Sawyer
Lawrence Livermore National Laboratory
P.O. Box 5505, Livermore, California 94550

UCRL--99423

DE88 016280

Abstract

A unique high-efficiency particulate air (HEPA) filter medium has been developed for applications in high temperature and high pressure environments. This filter medium is a composite made from quartz and stainless-steel fibers that have been sintered together. The composite medium has the same efficiency and pressure drop as standard HEPA glass media, but has four times the tensile strength and can operate continuously at temperatures up to 500°C. In a conventional HEPA, the binder burns out above 250°C and the medium loses its strength; our composite filter medium has no comparable loss of strength even at 500°C.

I. Introduction

High-efficiency particulate air (HEPA) filters are universally used to protect workers and the environment from hazardous airborne material. These filters were designed for applications having relatively low particle loadings at essentially ambient temperature and pressure conditions. Although commercial HEPA filters have proven to be very satisfactory for such routine applications, they are prone to failure at high temperatures, high pressures, and high humidities.[1-4] In many cases, these extreme environments can destroy the filter element, thereby allowing contaminated air to escape. A number of credible accident scenarios have been proposed in nuclear reactors involving high temperatures, pressures, and humidities that may damage existing HEPA filters and subsequently allow contamination of workers and the environment.[1-4]

Several different solutions have been proposed to address the problems of HEPA failure under credible accident conditions. A HEPA filter made from polypropylene and polycarbonate fibers was developed to withstand structural failure under high pressure, high humidity, and high acid conditions; unfortunately, this filter's efficiency degrades above 90°C, and above 150°C the medium is completely destroyed.[5]

Another approach to the problem is to fabricate high-efficiency filters from a fibrous stainless-steel medium.[6,7] Although these stainless-steel filters are able to withstand the adverse environments of high temperature, pressure, and humidity, they do not have efficiencies comparable to HEPA filters (the stainless-steel filter has only a 60% efficiency at its minimum).

The development of a HEPA filter that can withstand high temperature, high pressure, and high humidity conditions requires a careful selection of filtering materials, optimum construction design, and submicrometer size of the fibers or other filtering elements. The primary reason for using glass microfibers in ordinary HEPA filters is that bulk fibers having diameters as small as 0.3 μm (which are responsible for the high efficiency of HEPA filters) are easily available. Unfortunately, these microfibers cannot be formed into a high-

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48.

strength filter medium using conventional adhesives. The prospects for finding a better adhesive are not very good because all organic adhesives and even silicon glues degrade at high temperatures.

It appears that a filter medium made from a single component cannot simultaneously meet the requirements of high strength, high temperature resistance, and high efficiency.

II. Composite Filter Medium of Sintered Quartz and Stainless Steel Fibers

Conventional HEPA filters cannot withstand temperatures above 250°C due to the burning of the adhesive that bonds the glass fibers together. We reasoned that if a substitute method for bonding glass microfibers could be found, then the resulting filter medium would have the desired resistance to high temperatures. Moreover, if this alternative bonding method could provide the tensile strength of a sintered stainless-steel medium, then the resulting filter would also have the desired strength.

Our reasoning led us to the development of a composite sintered filter medium made from a mixture of stainless-steel and quartz fibers. Quartz microfibers with an average diameter of 0.5 μm would provide the high efficiency, while stainless-steel fibers with an average diameter of 2 μm would provide the bonding mechanism for the quartz fibers and give the composite medium its high strength. Sintering the composite filter medium fuses the metal fibers together and mechanically holds the quartz fibers in a random three-dimensional cage structure. We used quartz fibers rather than glass fibers because glass would have melted during the initial high-temperature sintering operation.

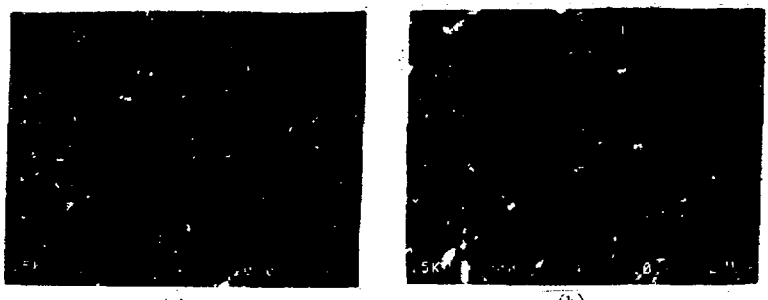
We prepared a series of composite filter media in which we varied the volumetric fractions of quartz in ten-percent increments from 0% quartz to 100% quartz. The filter media were prepared by first blending the steel and quartz fibers in a water suspension; the water suspension was then drained through a screen, thereby forming a filter mat. Finally, we sintered the composite filter mats in a hydrogen furnace at 1100°C for two hours.

Electron micrographs were taken of the composite filter samples to examine how well the glass and stainless steel fibers are dispersed. Figures 1 and 2 are electron micrographs of the medium containing 40% quartz by volume at a magnification of 200 x and 1000 x, respectively. We found this medium to have a filter efficiency and pressure drop comparable to standard HEPA media. The stainless-steel fibers have a uniform diameter of 2 μm, while the quartz fibers have a distribution of diameters around 0.5 μm.

This size difference allows the steel fibers to be distinguished from the quartz fibers in Fig. 1(a) at 200 x and 2(a) at 1000 x. To show a clearer distinction between the steel and quartz fibers, we have also taken electron micrographs using the backscattered electrons in Figs. 1(b) and 2(b). In the backscattered mode, the higher Z fibers (steel) appear white. The conventional electron micrographs [Figs. 1(a) and 2(a)] are obtained from the emission of secondary electrons, which are independent of Z number, and show both steel and quartz fibers as white images. Since each set of electron micrographs in Figs. 1 and 2 was taken of the same viewing area of the filter, by comparing the a figures (showing both stainless-steel and quartz fibers) and the b figures (showing only the stainless-steel fibers) we can readily see how well the quartz fibers are dispersed in the supporting cage network of steel fibers, as intended.

(a) (b)

Figure 1. Scanning electron micrographs of 40% quartz, 60% steel fibers at 200 x magnification. (a) Image using secondary emission electrons, showing both the quartz and stainless steel fibers. (b) Image using backscattered primary electrons, showing only the stainless-steel fibers.



(a) (b)

Figure 2. Scanning electron micrographs of 40% quartz, 60% steel fibers at 1000 x magnification. (a) Image using secondary emission electrons, showing both the quartz and stainless steel fibers. (b) Image using backscattered primary electrons, showing only the stainless-steel fibers.

III. Filter-Efficiency Tests of the New Medium

Sample sheets containing different percentages of quartz fiber were evaluated in our filter test laboratory to determine the fraction of quartz fibers required to yield a filter efficiency and pressure drop comparable to standard HEPA filters. Each of the filters was tested at a face velocity of 2 cm/s to simulate the flow through a standard HEPA filter. In these tests we used a heterodisperse dioctyl sebacate (DOS) aerosol generated with a Laskin nozzle. Particle concentration as a function of particle size was determined before and after the filter using a differential mobility analyzer coupled to a condensation nuclei counter and a LAS-X laser spectrometer. For the high-efficiency filters, we used a diluter operating at about 1200 to 1 dilution to dilute the upstream aerosols; the filter-penetration curves were corrected for the particle losses in the diluter. Details of our filter-efficiency tests are presented more thoroughly elsewhere.[8]

Figures 3-5 show penetration as a function of DOS particle diameter for composite filter media with increasing volume fractions of quartz fibers from 0% to 50% in ten-percent increments. For comparison with commercially available filters, we have also included the filter penetration as a function of particle size for standard HEPA filter media (Fig. 4) and for the Bekaert sintered-steel fiber filter in (Fig. 3). Several trends can be seen in these figures. The most apparent trend is the decrease in filter penetration (i.e., higher efficiency) with increasing quartz volume fraction. In addition, as the volume fraction of quartz increases, the width of the penetration curve decreases and the particle size of maximum penetration shifts to smaller sizes. This can be seen quantitatively in Table I. These observations are in agreement with filtration theory.

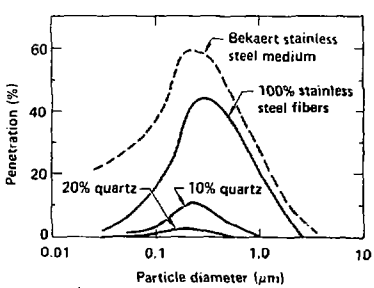


Figure 3. Filter penetration as a function of particle diameter for filters, including one containing 100% stainless-steel fibers, 10% and 20% quartz, and a Bakaert stainless-steel medium for comparison.

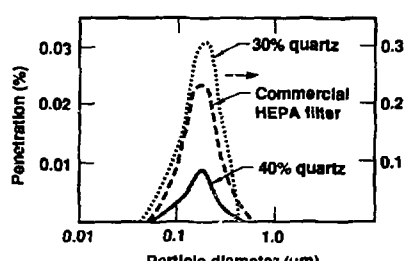


Figure 4. Filter penetration as a function of particle diameter for composite filters having 30% quartz, 40% quartz, and a commercial HEPA filter for comparison.

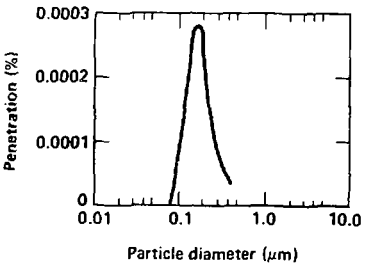


Figure 5. Filter penetration as a function of particle diameter for composite filter having 50% quartz and 50% stainless-steel fibers.

Table 1. Particle size of maximum penetration and width of penetration curve for the new composite filter media.

% Quartz	Width (μm)	Particle size (μm)
0	0.77	0.27
10	0.30	0.22
20	0.26	0.22
30	0.14	0.19
40	0.13	0.17
50	0.10	0.17

In Fig. 6, we have compiled the data from Figs. 3-5 into two curves showing the percent filter penetration as a function of percent quartz by volume. The dashed curve represents the maximum penetration while the solid curve represents the penetration at 0.3-μm diameter. (We have included the penetration curve for 0.3-μm diameter particles because that curve corresponds to the current certification test for standard HEPA filters.) According to Fig. 4, the HEPA filter has a penetration of 0.005% for 0.3-μm diameter particles (the standard certification test using 0.3-μm particles measured 0.006%, which shows our tests are in close agreement). Referring to Fig. 6, we see that this penetration would correspond to one of our composite filters having 36% quartz by volume.

The penetration data for the composite filters for 0.3-μm diameter particles has also been plotted in Fig. 7 as a function of the filter pressure drop. As expected, the filters having a lower penetration due to the greater fraction of quartz fibers also have a higher pressure drop. On this curve we have included the data point for HEPA filters. Note that the point falls on the same curve, which suggests that the average fiber diameter of the HEPA filter is also the same as our 36% quartz composite medium. From Figs. 6 and 7, it is clear that we can make composite sintered filters having the same efficiency and the same pressure drop as a standard HEPA filter.

IV. Filter-Strength Tests

One of the primary reasons for developing our composite sintered medium is to achieve a much stronger filter medium than a current HEPA filter. We conducted a series of tensile-strength tests on uniformly cut samples of the same media tested for aerosol penetration above. Each sample was attached to an Instron tensile-strength tester operated at a constant rate of elongation. Figure 8 shows the force at which each sample failed as a function of the percent quartz in the sample. In general, we see that the filter becomes easier to tear as the percentage of quartz increases; however, comparing the tear strength of the standard HEPA medium (170 g) to the comparable composite medium (36% quartz), we see that the composite medium requires four times the tearing force.

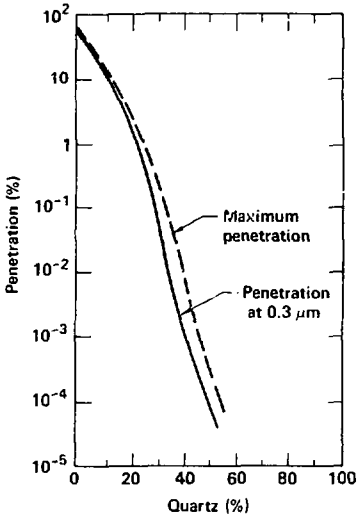


Figure 6. These curves show filter penetration as a function of quartz percentage in the composite medium. Note the quartz percentage that yields comparable results to a standard HEPA medium (from Fig. 4) is 36% quartz.

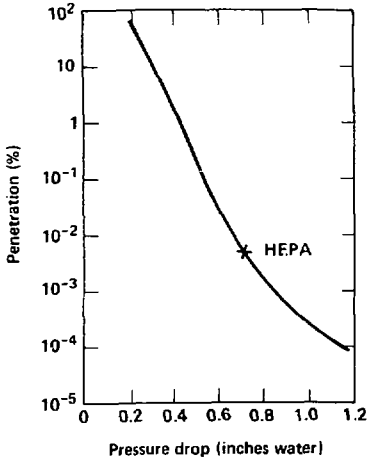


Figure 7. Filter penetration for 3-μm diameter particles as a function of pressure drop. A standard HEPA filter has been included, showing that our composite filters are comparable.

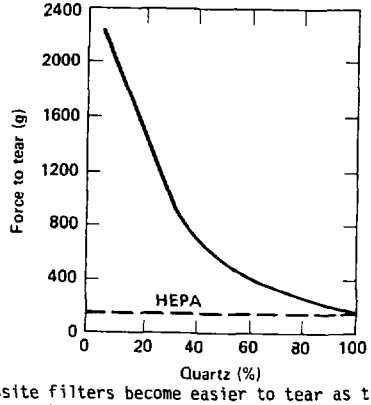


Figure 8. The composite filters become easier to tear as the percentage of quartz fiber increases. However, the tear strength of a comparable composite filter is about four times greater than a standard HEPA filter.

V. Conclusions

We have demonstrated the feasibility of constructing a metallic HEPA filter medium, that is resistant to high temperatures as a composite of sintered quartz and stainless-steel fibers. This medium has a comparable efficiency (99.995%) and pressure drop (0.7") to the standard HEPA glass medium but can be operated continuously at temperatures up to 500°C instead of 250°C and can withstand four times the tearing force.

VI. References

1. Burkett, M. W., Martin, R. A., Wolfe, S. D., Fenton, D. L., and Gunaji, M. W., "Fire simulation in nuclear facilities," Proceedings of 18th DOE Nuclear Airborne Waste Management and Air Cleaning Conference, National Technical Information Service, CONF-840806, pp. 597-628, Baltimore, MD, (1984).

2. Rudinger, V., Ricketts, C. J., and Wilhelm, J. C., "Limits of HEPA-filter application under high-humidity conditions," Proceedings of 18th DOE Nuclear Airborne Waste Management and Air Cleaning Conference, National Technical Information Service, CONF-840806, pp. 1058-1084, Baltimore, MD, (1984).

3. Hackney, S., "Fire testing of HEPA filters installed in filter housings," Proceedings of the 17th DOE Nuclear Air Cleaning Conference, National Technical Information Service, CONF-820833, pp. 1030-1050 (1982).

4. Gregory, W. S., Martin, R. A., Smith, P. R., and Fenton, D. E., "Response of HEPA filters to simulated accident conditions," Proceedings of the 17th DOE Nuclear Air Cleaning Conference, National Technical Information Service, CONF-820833, pp. 1051-1068 (1982).

5. Alken, W., Bella, H., Rudinger, V., and Wilhelm, J. G., "Development of a HEPA filter with high structural strength and high resistance to the effects of humidity and acid," Proceedings of 18th DOE Nuclear Airborne Waste Management and Air Cleaning Conference, National Technical Information Service, CONF-840806, pp. 1085-1096, Baltimore, MD, (1984).

6. Klein, M. and Goosens, W. R. A., "Aerosol filtration with metallic fibrous filters," Proceedings of 17th DOE Nuclear Air Cleaning Conference, National Technical Information Service, CONF-820833, pp. 504-522, (1982).

7. Dillmann H. G. and Pasler, H., "A filter concept to control airborne particulate releases due to severe reactor accidents and Implementation using stainless steel fiber filters, Proceedings of 18th DOE Nuclear Airborne Waste Management and Air Cleaning Conference, National information Service, CONF-840806, pp. 1417-1428 Baltimore, MD, (1984).

8. Bergman. W., Biermann, A., Kuhl, W., Lum, B., Bogdanoff, A., Hebard, H., Hall, M., Banks, D., Mazumder, M., and Johnson, J., "Electric Air Filtration: Theory, Laboratory Studies, Hardware Development and Field Evaluations," Lawrence Livermore National Laboratory, Livermore, CA, UCID-19952 (1983).