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HEPA Filter Effectiveness during Tornado Conditions

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HEPA FILTER EFFECTIVENESS DURING TORNADO CONDITIONS

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W. S. Gregory

ABSTRACT

A preliminary investigation of the response of HEPA (high efficiency particulate air) filters to hypothetical tornado-generated pressure drops has been initiated. A small scale experimental apparatus suitable for testing 8-by-8-inch HEPA filters was constructed and operated for simulation of a pressure transient which achieves a 3-psi pressure magnitude during a three second rise time, maintains the 3-psi pressure for three seconds and then returns to ambient conditions in the next three seconds.

It was determined that 24-by-24-inch HEPA filters should be tested for the pressure transient and that it is possible to simulate the hypothetical tornado condition using the small scale apparatus. An experimental design for testing the 24-by-24-inch filters was made.

The data indicates that an air velocity of 90 fps will be generated through the test filter as a result of the 3-psi pressure drop. Visual inspection of the filters tested revealed no obvious structural failure and in addition no change was found in the efficiency of the filters after the tests. Flow-resistance data obtained indicates that the resistance of HEPA filters is independent of the depth of the filters at high flow rates. The velocity-resistance relationship shows a rate of increase in resistance at 60 fps.

I. INTRODUCTION

The question of the effectiveness of HEPA (high-efficiency particulate air) filter operation during a pressure transient caused by a hypothetical tornado has been posed. The primary objective of the work accomplished in this period of time was to obtain preliminary information for determining the need for testing HEPA filters for a tornado-induced pressure transient. If such testing was found necessary, an experiment was to be designed for testing 24-by-24-inch HEPA filters.

The specified tornado-generated pressure drop achieves a 3-psi magnitude during a three-second duration, maintains the 3-psi drop for three seconds and then returns to ambient conditions during the next three seconds. HEPA filters have been tested

for overpressures as large as 3 psi.^{1,2} These tests, however, were for shock pressure pulses on the order of a millisecond duration. The 3-psi pressure drop caused by the hypothetical tornado is attained during a three-second period, thereby introducing the possibility that a filter capable of surviving shock pressure pulses might still fail because of the high velocity of air moving through it. Velocities through HEPA filters become an important consideration in the design of plutonium plant ventilation systems. Effective filtration must be maintained throughout the tornado condition to avoid the release of radioactive contamination to the atmosphere.

Fibrous filters rely on relatively low pressure drops (.04 psi) and low flow (1000 cfm) through the filter in order to maintain effective filtration.

Because of this requirement, the literature review has revealed little information (technical or theoretical) on high-velocity flow through fibrous filters. Due to the limited amount of information available and the difficulties in predicting the response of HEPA filters to tornado-induced pressure transients, small-scale experimentation was initiated.

The small-scale experiment was designed for testing 8-by-8-inch HEPA filters. The main problem faced when simulating the hypothetical 3-psi, 3-second pressure transient is associated with obtaining and controlling the large quantity of air needed for the test. The use of 8-by-8-inch filters initially for test purposes, instead of 24-by-24-inch filters reduces by an order of magnitude the quantity of air required. This small scale test is therefore a relatively inexpensive way of identifying many of the problem areas to be encountered in designing an experiment for testing the large HEPA filters.

II. TEST EQUIPMENT

The small-scale test equipment is shown in Fig. 1. The experimental concept utilizes the fact a 3-psi pressure drop will cause a large volume of air to flow through the filter. This situation is simulated by storing a large quantity of air in a pressurized tank and then discharging it such that a 3-psi differential is attained across the filter. This discharge rate is such that a 3-psi magnitude is achieved at the end of a three-second period. A pneumatic ball valve along with the pneumatic regulator is shown in Fig. 2. Control apparatus for

FIGURE 2 Pneumatic Valve

opening and closing the valve is shown in Fig. 3. This mechanism consisted of two microswitches and a cam machined to actuate the microswitches for the three-second opening of the valve, three seconds full open, and the three-second time for closing.

Use of a large pressure regulator was planned to maintain the 3-psi differential across the filter. This regulator was not used, however. In its place, a small, inch-and-one-half gate valve was used to control the pressure across the filter.

An expansion tank was located downstream from the flow control valve. A schematic of the expansion tank is shown in Figure 4. The expansion tank was constructed to accommodate two 24-by-24-inch HEPA filters. These filters served to insure that air free of particulates is passed through the test filter, although the compressed air was passed through a pre-filter and a dryer. Velocity traverse measurements were made near the two 24-by-24-inch HEPA filters for assurance that an evenly

FIGURE 1 Experimental Apparatus

FIGURE 3 Valve Control Apparatus

DETAILS OF EXPANSION CHAMBER

FIGURE 4 Details of Expansion Chamber

distributed flow was being discharged through both filters. From the expansion tank, the air passed through a duct of sufficient length to achieve uniform flow before passing through the test filter.

The equipment used to monitor the tests is shown in Figures 5 and 6. Figure 5 shows the mercury-filled piezometer and continuous recorder utilized for measuring the magnitude-time relationship of the pressure transient. A water-filled differential from the pitot tube. Figure 6 shows a view of the pitot tube for determination of the air velocity and of the pressure transducer for measurement of the static pressure.

No attempt was made to control the relative humidity of the air used. The humidity of the air used in the tests was equal to that of the room air.

While the small-scale experiment was to be used to obtain data on the 8-by-8-inch HEPA filters, it

was also intended to be a test of the experimental concept itself. In general, the experimental concept proved to be sound. Data was obtained for designing a larger apparatus suitable for testing the

FIGURE 5 Pressure-Velocity Measuring Devices

Fig. 6 View of Pitot Tube and Pressure Transducer

24-by-24-inch HEPA filters. Use of the ball valve to control the flow proved to be troublesome. The rate of opening had to be varied to avoid a rapid build up of pressure across the filter. Part of the control problem was due to the pneumatic control system used. A more positive and dependable method of flow control for simulation of the initial three second period of the pressure transient was needed.

III. DATA

Two types of tests were performed using the experimental apparatus. The first test consisted of subjecting an unused 8-by-8-inch HEPA filter to a zero-to-3-psi pressure pulse over a three-second period and then maintaining 3 psi for three seconds before closing off the flow. Two HEPA filters of differing thickness (3 1/16 inch and 5 7/8 inch) were tested. The data obtained from this test is presented in Table I.

A continuous recording of the pressure transient in each case was also obtained using an automatic recorder. A tracing of this type of information is illustrated in Fig. 7. This recording was necessary to assure proper simulation of the shape of the pressure transient. The rate of travel for the recorder was .4 inches per second. As can be seen in Figure 7, the three-second closing of the valve was not achieved. A relatively constant pressure was maintained for three seconds, however. A great deal of effort was devoted toward achieving the 3-psi pressure drop over a full three-second period.

The second phase of testing done was to obtain flow-resistance data for both the 3 1/16-inch and 5 7/8-inch filters. The data was obtained by varying the pressure in the supply tank.

The data was taken at a barometric pressure of 26 inches of mercury and at an average relative humidity of 68 per cent.

IV. RESULTS

Using the data obtained during the 3-psi, 3-second pressure transient, the pressure and velocity through the filters was calculated. The pressure and velocity results are presented in Table IV.

No visual damage was observed for any of the filters tested. Structural failure did occur, however, in the test filters which were used to get the experimental apparatus operational. These filters failed after being subjected to several pressure transients. Failure always occurred at the downstream face of the filter where the fiber mat bends around a flow separator.

TABLE I
3-PSI, 3-SEC. PRESSURE TRANSIENT DATA

Filter Number	Filter Depth (in.)	Rated Flow (cfm)	Pressure Differential Across Filter (in. of Hg)	Pressure Differential Pitot Tube (in. of H ₂ O)	Pressure Supply Tank (psi)
185771	3 1/16	25	6.8	1.6	70
185778	3 1/16	25	6.4	1.6	70
20628075	5 7/8	50	6.6	1.5	70
20627053	5 7/8	50	6.2	1.7	70

Fig. 7 Continuous Pressure Transient Trace

Air flow and filter resistance values were obtained using the data from Tables II and III. The flow-resistance results for the 3 1/16-inch and the 5 7/8-inch filters are presented in Tables V and VI.

The results tabulated in Tables V and VI are also presented in Figure 8 along with the resistance values for both filters at their rated flow capacities. The resistance of the 5 7/8-inch fil-

ter is approximately twice as large as the resistance for the 3 1/16 inch filter. As shown in Fig. 8 this relationship does not hold at higher flow rates. At the higher flow rates, it seems that there is less opportunity for any transverse flow through the filter media. Fig. 9 illustrates the velocity resistance relationships for the filters. The relationships appear to be linear indicating laminar flow through the filter fiber. If pinholes had been present, it is likely that this would result in turbulent air flow through the pinhole and a resistance that is a function of the velocity squared.³ There was, however, a change in resistance of both filters at 60 fps or 1050 cfm. Fig. 9 shows an increase in the rate of resistance at this point.

TABLE II
FLOW-RESISTANCE DATA

Filter No. 20627069, Filter Depth: 5 7/8 inches

Test Run No.	Pressure Differential Across Filter (in. of Hg.)	Pressure Differential Pitot Tube (in. of H ₂ O)	Pressure Supply Tank (psi)
1	1.6	0.2	21
2	3.2	0.8	41
3	5.4	1.25	60
4	7.8	1.9	80

TABLE III
FLOW-RESISTANCE DATA

Filter No. 185790, Filter Depth: 3 1/16 inches

Test Run No.	Pressure Differential Across Filter (in. of Hg.)	Pressure Differential Pitot Tube (in. of H ₂ O)	Pressure Supply Tank (psi)
1	1.2	.1	12
2	1.8	.2	21
3	3.3	.7	41
4	5.2	1.3	60
5	7.4	2.0	80

Flow - Resistance Curve

Figure 8

TABLE IV
PRESSURE-VELOCITY RESULTS

Filter No.	Filter Depth (inches)	Pressure Across the Filter (psi)	Velocity Through the Filter (ft./sec.)
185771	3 1/16	3.34	91.4
185778	3 1/16	3.14	91.4
20628075	5 7/8	3.24	88.5
20627053	5 7/8	3.05	94.2

Efficiency tests were performed on the filters after they had been subjected to the pressure transient. The efficiencies obtained indicated that the filters were still capable of high-efficiency air filtration at their rated flow rates. This result

is not too surprising since the velocity-resistance curves in Fig. 9 do not indicate that a hole is present. Also most of the high velocity air probably passed through the filter where it bends around the flow separator leaving a large portion of the fiber mat undisturbed.

Velocity-Resistance Curve

Figure 9

TABLE V
FLOW-RESISTANCE RESULTS
Filter No. 20627069, Filter Depth: 5 7/8 inches

Test Run No.	Filter Resistance (psi) (in. of H ₂ O)		Air Velocity (ft./sec.)	Air Flow (cfm)
1	.8	22.8	32	568
2	1.6	44.4	65	1136
3	2.7	74.4	81	1421
4	3.8	105.6	100	1751

TABLE VI
FLOW-RESISTANCE RESULTS
Filter No. 185790, Filter Depth: 3 1/16 inches

Test Run No.	Filter Resistance (psi) (in. of H ₂ O)		Air Velocity (ft./sec.)	Air Flow (cfm)
1	0.6	16.8	23	401
2	0.9	25.2	32	568
3	1.6	44.4	60	1062
4	2.6	72.0	82	1449
5	3.6	99.6	102	1795

V. CONCLUSIONS AND RECOMMENDATIONS

The primary conclusion reached as a result of this preliminary study is that the 24-by-24-inch HEPA filters should be tested for the hypothetical pressure transient. There are a number of reasons for this conclusion. Little if any information on high velocity flow through HEPA filters can be found in the literature. Test observations using visual inspection indicate that the 8-by-8-inch filters are close to structural failure. Filters of the 24-by-24-inch size then, are likely to show structural failure in this pressure range due to loading across a longer span of material. Shock testing has shown that the 8-by-8-inch filters will survive a 3-psi loading but the 24-by-24-inch filters will not. The flow-resistance data obtained indicates that filter failure due to high air velocity is likely. The flow velocity through the filter media is usually less than 10 feet per minute at rated capacity. The flow-resistance data indicates that little transverse flow occurs, since the resistance of a 3 1/16-

inch filter is essentially the same as that for a 5 7/8-inch filter. Therefore, increasing the filter depth by providing more effective cross-sectional area and thereby reducing the velocity of air flow through the fibrous material is not effective at the high flow rates. The velocity of flow through the fiber, then, is on the order of 5000 feet per minute instead of the 10 feet per minute range. A change in the rate of increase of resistance occurs for the filters tested. This resistance change needs further investigation.

The second phase of this investigation was to design an experiment to test the 24-by-24-inch HEPA filters if such a test was needed. The small-scale experimental apparatus has shown that it is possible to simulate the hypothetical tornado conditions. Using the flow rate of 1800 cfm obtained in the small-scale experiment, the quantity of air required to test the 24-by-24-inch filters can be calculated along with the necessary sizing of the equipment needed. The primary problem with the test equipment

was in shaping the pressure pulse to attain a linear rate of increase in pressure to 3-psi. It is believed that the use of the large, eight-inch ball valve and its pneumatic regulator to control the flow was the reason for the difficulty encountered in shaping the pressure pulse. The experimental design described in the Appendix should alleviate this problem. The changes to be made would involve using the eight-inch ball valve as a rapid on-off method for initiating flow out of the high pressure tank. Downstream of the ball valve would be one or more orifices to reduce the pressure of the flow. Before the flow enters the expansion tank, a diamond-shaped throttle valve would be used to simulate the linear increase in pressure from normal flow to 3 psi.

The small-scale test apparatus could serve as a valuable aid if aerosol generation and measurement is required. The case where a filter is loaded with particulate matter also needs to be examined in any subsequent testing.

In summary, it is believed that this preliminary work has shown a need for testing the 24-by-24-inch HEPA filters during tornado conditions. The experimental apparatus used was capable of simulating the hypothetical tornado condition.

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APPENDIX

EXPERIMENTAL APPARATUS FOR TESTING

24-BY-24-INCH HEPA FILTERS UNDER TORNADO CONDITIONS

The same basic experimental concept used in the small-scale experimentation would be retained. A larger pressure tank at a higher pressure would be required. The expansion tank would have to be increased in size to accommodate the pre-filtering bank of filters. A bank of twenty filters would be required. This would require a 10-by-8-foot expansion tank. A stronger tank would have to be constructed, however, for the 24-by-24-inch test. A sketch of the experimental design is shown in Fig. A-1. Using the data obtained from the small scale experiment, a design flow rate of 20,000 cfm is expected to produce the proper pressure drop across the test filter.

Flow is initiated by use of a pneumatically regulated eight-inch valve. The pressure is reduced

by one or more orifices to approximately 50 psi. Flow control will be maintained by a diamond-shaped throttle valve. The square opening of this valve should allow accurate manipulation of the rate of increase or decrease of flow. A range of pressure drop versus opening time could be obtained. Control of this valve is maintained through the use of a lead screw driven by a variable-speed D.C. motor. Downstream of the throttle valve will be a flow diverter to distribute the flow uniformly over the bank of twenty 24-by-24-inch HEPA pre-filters. Following prefiltration in the expansion tank, the air will pass through a section of duct of sufficient length to achieve uniform flow. At the end of this length of duct will be the location of the test filter.

24-BY-24-INCH EXPERIMENTAL APPARATUS

Fig. A-1