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FIRE PROTECTION OF HEPA FILTERS BY USING WATER SPRAYS

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FIRE PROTECTION OF HEPA FILTERS BY USING WATER SPRAYS*

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Abstract

In experiments with a full-size section of an exhaust-ventilation system at the Lawrence Livermore Laboratory, fine water sprays used in conjunction with metal screen scrubbers and demisters successfully protected HEPA filters against hot fire gases. When a single HEPA filter was used, at an air-flow rate of 1000 cfm, temperature was reduced from 1500°F to ~300°F, with 4 gpm of water distributed through three nozzles. Variations in the heat and flow parameters, and in the spray and scrubber systems used, are described in this paper, and results are given.

I. Introduction

Where radioactive or toxic materials are handled, safe practice dictates that such materials be used in partial or total enclosures, e.g., hoods or glove boxes. Furthermore, the air pressure in such enclosures is maintained negative to that in the workroom, that in the workroom negative relative to that in the halls and offices, and that in the building negative with respect to the outside. The theory of these sequential pressure differentials is that all air leakages shall be inward from the cleanest to the most "contaminated" areas.

At LLL the workrooms are maintained at a negative air pressure by separate air-exhaust systems, equipped with HEPA (high-efficiency particulate air) filters, which serve to remove fine airborne particles that may escape from the enclosures. Each such workroom has individual exhaust systems leading to a common exhaust duct and blower. A prefilter followed by a HEPA filter is installed in the opening of the exhaust duct in the room. The general scheme is shown in Fig. 1.

Although elaborate precautions are taken to prevent and to suppress an unwanted fire, it is possible that one can occur in a radioactive-material enclosure or even in a workroom outside the enclosure. In either case, it must be assumed that containment of the radioactivity could be compromised; thus it is necessary to keep the fire and contamination from spreading to other areas, particularly to the outside environment.

The use of a fire damper - a metal plate that swings shut in the exhaust ductwork - will prevent hot gases from reaching the filters; but the resulting pressure buildup in the workroom will force heat, smoke, and contamination into other areas in the building. Hence, it is necessary to maintain exhaust ventilation to minimize this effect and to clear the room of heat and smoke as an aid to firefighting.

However, HEPA filters are subject to heat degradation as follows:⁽¹⁾

<u>Temperature</u>	<u>Service Time</u>
750°F	Less than 10 min
325°F	Up to 2 hrs
276°F	48 hrs

*Work performed under the auspices of the U.S. Atomic Energy Commission.

Fig. 1. Schematic diagram of one type of airflow system in a building where radioisotopes are used.

To protect our HEPA filters from heat damage, we carried out an experimental program at LLL, using combinations of water sprays, scrubbers and demisters. The results of this experimental program are the subject of this report. A current study aimed at preventing smoke from plugging the filters and thus pressurizing the fire room will be reported at a later date.

II. Experimental Criteria

The basis for the experimental setup was as follows:

1. The ductwork system was to be full-size, i.e., 26×26 in. in cross section.
2. It was to be operated at rated flow for a 24×24 -in. HEPA filter, i.e., 1000 cfm, although means were to be provided for varying the flow rate.
3. The experimental portion of the ductwork was to be modular; it should be capable of being rearranged easily, to vary the experimental conditions.
4. The system should be well-instrumented, to provide adequate data.
5. The "fire" temperature should be a "worst case," i.e., 1500°F ; this is about a 1/2-hr fire on the standard time-temperature curve.⁽²⁾

III. Experimental Setup

The experimental setup, shown schematically in Fig. 2 and pictorially in Figs. 3 through 8, consists of three sections, as follows:

1. A gas-fired heater section consisting of insulated and baffled ductwork. In this section outside air is heated and mixed uniformly to provide the desired "fire gas" inlet temperature.
2. An experimental section consisting of square, flanged pieces of ductwork 6, 12, and 24 in. long. The 12- and 24-in. sections contain viewports; all

Fig. 2. Schematic diagram of LLL experimental spray damper setup.

Fig. 3. View of spray damper experimental setup from fire end.

Fig. 4. View of spray damper experimental setup from exhaust end.

sections contain 1-in. pipe couplings, to permit the introduction of pressure taps, thermocouples, and water-spray piping, or to act as drains. Figures 9 through 12 show typical sections.

3. An exhaust section consisting of a square-to-round transition piece, 12-in.-diam flexible and rigid tubing, and an exhaust blower equipped with an adjustable gate damper.

Filters, scrubbers, and demisters used in this work were fastened to 1/4-in.-thick steel "picture frames" of the same external dimensions as the flanges of the duct sections. These frames holding the filter, scrubber, etc., were clamped in place between duct sections, according to the experiment. Figures 13 through 17 show these picture frames and the scrubbers, demisters, and filters used.

A variety of spray nozzles were tried external to the system and in preliminary fire and gas-cooling experiments. However, the more successful tests were conducted with the types shown in Fig. 18: pin-type hollow cone, modified hollow cone, and square-pattern solid spray. The sprays were operated at total water flows of 2 to 4 gpm. Excess water was drained from the duct through water seals and measured. By knowing the incoming and outgoing water flow rates and respective water temperatures, we could calculate sensible heats of absorption. "Lost" water was assumed to be evaporated; hence, we could compute latent heats of absorption.

Fig. 5. View of one arrangement of experimental section of LLL spray damper.

IV. Operating Procedure

For a given experimental setup, the system was checked under ambient flow conditions, and the gas fire was lit. When the inlet temperature (to the experimental section) reached 250°F, the sprays were turned on to a predetermined constant flowrate. Heating was continued to an inlet temperature of 500°F. This temperature was maintained at a steady state for 10 min, and typical readings of temperatures, pressure differences, and water flows were obtained. The inlet temperature was raised to 1000°F, and a 10-min set of steady-state readings was obtained. The temperature was then raised to 1500°F, and the process was repeated. The results (air temperature reduction, water usage, heat absorption, and pressure drops across scrubber, demister, and filter) were calculated from the data, and the next experiment was arranged in a manner intended to improve the situation. Successful experiments were repeated as a check. In later runs, the 500°F inlet-temperature portion of the test was omitted, and a test at 1250°F was substituted.

Fig. 6. View of one arrangement of experimental section of LLL spray damper.

Fig. 7. View of modified aft section of LLL spray damper setup.

Fig. 8. View of modified exhaust section of LLL experimental spray damper setup.

Fig. 9. Twenty-four-in. experimental duct section, showing means for introducing thermocouples.

Fig. 10. Six-in. duct sections.

Fig. 11. Twelve-in. duct section, showing one spray system.

Fig. 12. Elbow and transition piece.

Fig. 13. Mounting of HEPA filter in picture-frame holder.

Fig. 14. Perforated metal-sheet scrubber mounted in picture-frame holder.

Fig. 15. Graded metal mesh scrubbers.

Fig. 16. Demister herringbone crimped steel mesh, 2 in. thick.

Fig. 17. Demister: stainless steel wire and halogenated plastic filaments, 2 in. thick.

Fig. 18. Spray nozzles used in spray damper experiments.

V. Results

Some thirty tests were carried out, of which only the more interesting and successful are reported (Figs. 19-26). These are discussed briefly, below.

Test S-6.5 (Fig. 19)

A square-pattern, solid spray was aimed downstream at a stainless steel/Fluorocarbon demister 4 ft away. At a 1000°F feed temperature, the air temperature ahead of the HEPA filter was over 400°F . This was unsatisfactory.

Test S-6.7 (Fig. 20)

The same square-pattern solid spray was aimed downstream at a folded scrubber consisting of a double layer of perforated stainless steel sheet with offset holes.

Results

Water flow		gpm	
		2.0	2.5
Temperatures		°F	
Feed		500	1000
In spray		110	140
After scrubber		—	—
After demister		270	410
After HEPA		265	385
ΔP 's		in. H ₂ O	
Scrubber		—	—
Demister		1.0	0.70
HEPA		1.5	1.50
Total		2.5	2.2
Heat (absolute)		Btu/min	
Sensible		85	435
Latent		1740	5230
Total		1825	5665

Fig. 19. Data experiment S-6.5.

Although the air temperature ahead of the filter was less than 400°F for a feed temperature of 1000°F, the pressure drop across the scrubber was over 1.7 in. of water, yielding a total pressure drop of 3 in. of water for the system.

Results

Water flow		gpm	
		2.0	2.5
Temperatures		°F	
Feed		490	1005
In spray		100	130
After scrubber		235	>350
After demister		-	-
After HEPA		260	380
ΔP's		in. H ₂ O	
Scrubber		1.92	1.73
Demister		-	-
HEPA		1.26	1.28
Total		3.18	3.01
Heat (absolute)		Btu/min	
Sensible		90	395
Latent		1740	4650
Total		1830	5065

Fig. 20. Data experiment S-6.7.

Test S-6.9 (Fig. 21)

A square-pattern solid spray at 2.5 gpm aimed downstream a foot away from a 2-in.-thick graded steel-mesh scrubber followed by a 2-in.-thick demister produced a temperature ahead of the filter of 240°F with a feed temperature of ~1200°F. The

Results

Water flow		gpm		
		2.0	2.0	2.5
Temperatures		°F		
Feed		520	1005	1180
In spray		120	150	155
After scrubber		-	-	-
After demister		230	345	340
After HEPA		230	345	335
ΔP 's		in. H ₂ O		
Scrubber		0.10	0.10	0.10
Demister		0.05	0.07	0.07
HEPA		1.02	1.16	1.30
Total		1.17	1.33	1.47
Heat (absolute)		Btu/min		
Sensible		785	810	1155
Latent		2660	6750	8300
Total		3445	8560	9455

Fig. 21. Data experiment S-6.9.

pressure drop through the scrubber-demister combination was less than 1/4 in. of water.

Tests S-6.13/6.14 (Fig. 22)

Two pin-type hollow-cone sprays (one aimed upstream and one downstream, for a total flow of 2 gpm) with the same scrubber/demister combination as in S-6.9,

Results

Water flow		gpm		
		2.0	2.0	2.0
Temperatures		°F		
Feed		1000	1260	1495
In spray		260	310	340
After scrubber		-	-	-
After demister		335	410	445
After HEPA		300	355	400
ΔP 's		in. H_2O		
Scrubber		0.12	0.12	0.12
Demister		0.07	0.07	0.07
HEPA		1.35	1.47	1.95
Total		1.54	1.66	2.14
Heat (absolute)		Btu/min		
Sensible		875	810	765
Latent		7015	8520	9350
Total		7890	9330	10115

Fig. 22. Data experiment S-6.13, 6.14.

yielded a temperature of 450°F ahead of the filter, with a feed temperature of 1500°F and with the same low pressure drop.

Results

Water flow		gpm		
		3.0	3.0	3.0
Temperatures		°F		
Feed		1005	1250	1505
In spray		690*	885*	615*
After scrubber		-	-	-
After demister		265	300	360
After HEPA		270	300	350
ΔP's		in. H ₂ O		
Scrubber		0.13	0.13	0.13
Demister		0.04	0.04	0.04
HEPA		0.83	0.24	0.86
Total		1.00	1.01	1.03
Heat (absolute)		Btu./min		
Sensible		1740	1800	1815
Latent		6550	8200	9920
Total		8290	10000	11735

* Thermocouples not wet by sprays

Fig. 23. Data experiment S-6.19, 6.20.

Tests S-6.19/6.20 (Fig. 23)

With an arrangement similar to S-6.13, but with a larger pin-type nozzle aimed downstream, a temperature of 360°F ahead of the filter was achieved. In this case, the water flow was 3 gpm.

Results

Water flow		gpm			
		3.0	3.0	3.0	4.0
Temperatures		°F			
Feed		970	1250	1495	1495
In spray		600	745	770	840
After scrubber		-	-	-	-
After demister		275	340	375	315
After HEPA		245	285	330	285
ΔP 's		in. H ₂ O			
Scrubber		.15	.14	.14	.15
Demister		.06	.06	.06	.08
HEPA		.97	.99	1.00	.98
Total		1.18	1.19	1.20	1.21
Heat (absolute)		Btu /min			
Sensible		1785	1850	1850	2260
Latent		7050	7600	9720	14000
Total		8835	9450	11570	16260

Fig. 24. Data experiment H-1.0.

Test H-1.0 (Fig. 24)

With the same arrangement but a higher water flow (4 gpm), the temperature of the filter was further reduced to 315°F, again with a pressure drop of less than 1 in. of water.

Water flow		gpm	
		4.0	4.0
Temperatures		°F	
Feed		1010	1550
In spray		139	148
After scrubber		220	298
After demister		204	272
After HEPA		178	235
ΔP 's		in. H ₂ O	
Scrubber		.18	.18
Demister		.11	.11
HEPA		1.21	1.29
Total		1.50	1.58
Heat (absolute)		Btu./min	
Sensible		2030	2120
Latent		10400	14200
Total		12430	16320

Fig. 25. Data experiment H-3.1.

Test H-3.1 (Fig. 25)

With the same arrangement and water flow as in H-1.0, but with a 4-in.-thick scrubber, the temperature to the filter was just under 300°F, but the pressure drop through the heat exchange was increased slightly.

Results

Water flow		gpm		
		3.5	3.5	3.5
Temperatures		°F		
Feed		970	1230	1450
In spray		595	780	980
After scrubber		-	-	-
After demister		315	390	460
After HEPA		275	350	395
ΔP's		in. H ₂ O		
Scrubber		.44	.43	.41
Demister		.15	.14	.14
HEPA		1.98	2.16	2.24
Total		2.57	2.73	2.79
Heat (absolute)		Btu/min		
Sensible		1390	1460	1420
Latent		13600	14690	16400
Total		14990	16150	17820

Fig. 26. Data experiment V-1.0, at 2000 cfm.

Test V-1.0 (Fig. 26)

In this test the air flow rate was increased to 2000 cfm under ambient conditions. To compensate for the greater heat load, a third (pin-type hollow cone) spray was added, facing upstream between the scrubber and the demister. The water-flow rate was adjusted to 3.5 gpm, on the theory that three separate spray zones

might be more efficient than two. In this case, the temperature to the filter was 463°F for a feed temperature of 1450°F. Note that the pressure drop through the HEPA filter increased to 2.2 in. of water, and that through the heat exchanger system it increased to over 1/2 in. of water.

VI. Discussion

It will be noted that one difference between the S and H series of tests is the position of the HEPA filter. In the S series it was in the vertical run, and in the H series it was in the horizontal run, of the ductwork. The reason for these differences was the possible need for two different configurations at LLL. However, comparison of the results of Tests S-6,19/6.20 with those of the H series show no essential differences in the performance of the spray damper system.

The data indicate a progressive improvement in temperature reduction of the airstream ahead of the HEPA filter, coupled with a small pressure drop through the spray damper heat exchanger.

The arrangement shown for Test H-1.0 (Fig. 24) and operated at a water-flow rate of 4 gpm seems to be an optimum, based on our tests. We repeated this test for an hour at a feed temperature of 1500°F, with results essentially the same as shown in the original test.

As to the choice of spray nozzles, we believe that the pin-type hollow cone is more reliable than a solid cone, since, because of its construction, the pin-type hollow cone is less likely to become plugged with a small piece of rust or other debris.

The air temperature to the HEPA filter and the heat-absorption data for the tests made during the latter part of our work were plotted against the spray flow rate, by means of a least-squares fit (Fig. 27). It is clear that the air-temperature reduction is proportional to the water used, as is the heat absorbed.

At present we have added a subsystem for generating duplicable cool, warm, and hot smokes to the air stream, which in turn will be heated to various temperatures. We are also including the capability of adding various kinds of wetting agents to the spray system. By these means, we hope to be able to determine which of the smokes likely to be generated in a fire can cause the most trouble in plugging the HEPA filter, and what can be done about scrubbing them out. Thus, we hope to develop a system to protect the filters against the effects of a variety of fire conditions.

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Fig. 27. Cooling of heated air (1000 cfm) with hollow-cone water sprays and various scrubber/demister combinations. Dotted lines represent a feed temperature of 1500°F; solid lines represent 1000°F feed temperature.