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ASBESTOS PENETRATION TEST SYSTEM FOR CLOTHING MATERIALS

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ABSTRACT: For hazardous work such as asbestos abatement, there is a need to assess protective clothing fabrics and seam constructions to assure an adequate barrier against hazardous material.

The penetration of aerosols through fabrics usually is measured by challenging fabric samples with an aerosol stream at a constant specified airflow. To produce the specified airflow, pressure differentials across the samples often are higher than exist in a work environment. This higher airflow results in higher aerosol velocities through the fabric and, possibly, measured penetration values not representative of those actually experienced in the field. The objective of the reported work was to develop a test method that does not require these higher airflows.

We have designed and fabricated a new system that tests fabric samples under a low, constant, specified pressure differential across the samples. This differential is adjustable from tenths of a mm Water Gauge (hundredths of an inWG) to over 25-mmWG (1-inWG). The system operates at a pressure slightly lower than its surroundings. Although designed primarily for asbestos, the system is equally applicable to the testing of other aerosols by changing the aerosol generator and detector. Through simple modification of the sample holders, the test apparatus would be capable of evaluating seam and closure constructions.

KEYWORDS: Asbestos, clothing penetration, new test system, constant pressure differential

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Testing clothing materials for aerosol penetration is similar to determining filter efficiencies as the materials act, essentially, as filters. This testing can be accomplished under conditions either of a constant flow through the fabric or a constant pressure drop across the fabric. A simplified block diagram of a constant flow system is shown in Figure 1. The flow through the material sample is maintained at a constant, specified value and the concentration of the aerosol upstream and downstream of the sample determined. While on-line optical techniques have often been used to measure these concentrations, this has not been done previously with an asbestos challenge. Filters are used to collect the challenge asbestos samples upstream, and the penetrating fibers downstream, of the material samples. These filter samples are then counted either by optical or electron microscopy. The numerical value of the penetration is defined as the ratio of the downstream to upstream aerosol counts.

While this is a valid test method, there are two concerns. First, it is a very time-consuming and expensive process to count the fibers on the filters. A number of areas on a number of different filters need to be examined because of the small number of fibers that penetrate, particularly with an efficient material. Even if a sufficient number of areas are counted to provide statistically meaningful results, the actual counting procedure is very operator-sensitive. Different people observing the same area of the same sample often will count a different numbers of fibers. This can cause large errors when there are only a few fibers present.

The other and more fundamental problem is the use of a specified constant flow. Consider two materials, one with a high and the other a much lower air permeability, and a specified 1.7 L/min flow through a 37-mm diam. piece of material resulting in a face velocity of 158 cm/min. This is the flow that has been specified in at least one asbestos test system. [1]. Reported flows in a non-asbestos aerosol test system [2] gave a face velocity of 110 cm/min. These flows can be attained with a small pressure drop across materials of sufficiently high air permeability. However, much higher pressure drops are required to maintain these flows through much less permeable materials. This results in a test condition that is not representative, and airflows through the fabric sample that are much higher, than actually occur in the workplace. These higher velocities decrease the aerosol penetration by impaction and increase the penetration because of shorter times for diffusional losses. Whether the overall result for any material being tested is increased or decreased penetration, as compared to what would happen in the field, is unknown. Thus, our objective was to develop and test a method that specifies a constant pressure differential across the fabric sample rather than a specified constant flow through the fabric thus negating, in large part, the question of changed penetration dynamics.

There is no question that the constant flow method can produce accurate and useful data. The concern is whether or not these data apply to the conditions under which clothing materials will be used. We believe a more realistic test will result if a pressure differential, more similar to those that actually occur across garments when they are being worn, is the specified test parameter.

TEST SYSTEM

A block diagram of an automated system meeting the above requirements is shown in Figure 2. An aerosol generator, more specifically an asbestos fiber generator, is connected to the bottom of the challenge aerosol chamber. This chamber, 30-cm diam by 61-cm long, not including the flow cones at both ends, is constructed of stainless steel. Both the inlet and outlet ports are 1.6-cm diam. To enhance mixing, a baffle is mounted in the bottom of the chamber 2.5-cm above the inlet port cone and a 35-CFM muffin fan is mounted 2.5-cm above the top of the baffle plate. A pressure transducer, referenced to the ambient environment, monitors the pressure inside the challenge chamber. The output of this transducer is used to maintain a 6-mmWG differential with respect to ambient pressure by adjusting a flow control valve between the chamber outlet port and exhaust pump. This is a necessary safety feature as the system is designed to operate using asbestos as a challenge media.

Six sample heads are mounted around the midline of the challenge chamber. Each 3-in (75-mm) diam fabric sample is held between two aluminum washers that have o-rings mounted around their outside edges. Different size washer can be used to test different size fabric samples, which allows some control of the total airflow. These o-rings seal the washers to the walls of the sample head. A metal cone is fitted into the head and secured by an aluminum ring. This design has proven to maintain a gas tight sample head. A second pressure transducer senses the pressure across the fabric sample, the signal from which is fed to a controller. The controller, in turn, regulates the flow through a control valve in order to maintain a specified pressure drop across the fabric sample. We have used a 5-mmWG (0.2-inWG) differential in our testing.

The fiber concentrations in the air passing through the fabric are determined with a modified commercial aerosol monitor (MIE model FM-7400). Unfortunately, the monitor requires 2 LPM airflow for proper operation and sample airflows are usually much less than this. To overcome this problem, the 2 LPM of air that flows through the monitor is filtered and injected back into the system just downstream of the fabric sample where it mixes with the air penetrating the fabric. With this design the pressure transducer and its associated valve and vacuum pump only need to control the airflow that passes through the fabric. This flow is measured with an accurate flow meter and exits the system through the vacuum pump. A sequencer is used to sequentially select electric solenoid valves that connect the appropriate sample heads to the monitor. Two specially designed rotating valves are used to switch the monitor sample and return lines to the appropriate operating sample head.

There is also a problem when measuring the challenge concentration. The challenge flow through the chamber is much greater than the 2 LPM required by the monitor. Removing this 2 LPM flow will cause the chamber pressure to go unstable. This air is directed to the monitor and returned to the chamber by operating two-way, full flow valves that select either challenge or sample flows, and returns the air to the chamber.

The penetration of aerosols through a fabric is defined as:

$$P = C_D / C_C$$

where:

C_D = concentration downstream of fabric

C_C = challenge concentration.

Because of the dilution of the downstream aerosol flow:

$$C_D = \frac{C_M(V_T + 2000)}{V_T}$$

where:

C_M = measured concentration

V_T = volume flow through the fabric, so that

and

$$P = \frac{C_M(V_T + 2000)}{C_C V_T}$$

Because of this dilution, no air leaks can be tolerated in the system, especially with small flows through the fabric. For example, even though a 1 cm³/min leak is small compared to the total 2000 cm³/min going through the monitor, it can be very large compared with the flow through the fabric.

A second complication arises from the fact that only 10 cm³/min of the total of 2000 cm³/min passing through the asbestos aerosol monitor are actually analyzed. This means, therefore, that high challenge concentrations, 200 fibers/cm³ or higher, are needed to obtain statistically meaningful numbers of fibers, in a reasonable test time, downstream of low penetration fabric samples. However, the monitor has an upper measurement limit of 25 fibers/cm³ so that the challenge aerosol must first be diluted before it can be analyzed.

RESULTS

To verify that the system operated as designed, two separate sets of tests were performed using an oil aerosol and light scattering photometer detector. In the first tests, six sets of six samples each from three different rolls of a spunbonded polyolefin (SPB) fabric were tested (108 samples total). The second tests were with unidentified fabrics submitted by ASTM Subcommittee F23.10. While a total of eight different fabrics were

submitted, only three could be tested as the others were too permeable and the flows through them could not be maintained at the requisite 5-mmWG (0.2-inWG).

The results from the SPB samples are shown in Table 1. We have no independent information about aerosol penetration through any of these fabrics so the actual values reported here are of little consequence. The interest in these data is in the variability of the results within each set, the variability between sets for any one fabric, and in the fact that fabric SPB-1 is different from the other two SPB fabrics. While these data do not prove the accuracy of the measurements, they do show that materials with different penetrations can be differentiated. We believe the data also show variability between different samples from the same fabric.

Table 2 shows the results from three of the unidentified materials. Again, the relative penetrations of the various fabrics are obvious. An interesting result was obtained with fabric #1. While flow was seen when the fabric was mounted in one direction but not when it was reversed in the sample holder, no penetration was detected with either fabric orientation.

Few tests have been performed using an asbestos fiber challenge. This is because the program was stopped, due to lack of funds, before the challenge aerosol diluter was installed and tested. However, results from tests with SPB-1 that were run showed very low penetrations. In fact, essentially no penetration was detected in two of three tests. There was a possibility that the penetrating fibers were being lost in the system between the fabric and the asbestos monitor. Various temporary modifications were made to the system to determine whether this was happening and no evidence for it was found. Finally, the asbestos monitor was removed and sample filters placed just downstream from the fabric samples so that all the air that passed through the fabric was passed through the sample filter with no dilution. The asbestos fibers on these filters were counted by optical microscopy. The effective area of the sample filters was 180 mm² requiring approximately 23,000 fields to cover the whole effective area. In two tests, one lasting 11 hr. and the other 8 hr., no fibers were seen in 100 fields. One fiber per field would have been expected assuming a nominal penetration of 0.05, Table 1.

Because of the underlying variability in the material, these two asbestos data points do not prove that asbestos fiber penetration, under these low pressure differential test conditions, is much lower than for oil aerosols. However, the vastly different shapes of the two aerosol types would suggest some differences might be expected, particularly at the low flows involved. One might also infer that asbestos penetration might be considerably different under these conditions as compared to those from a constant flow test with considerably higher flows.

TABLE 1-- Results of Spunbonded Polyolefin Penetration Tests

SPB-1		SPB-2		SPB-3	
Sample Flow cc/min	Fractional Penetration	Sample Flow cc/min	Fractional Penetration	Sample Flow cc/min	Fractional Penetration
Set No. 1		Set No. 1		Set No. 1	
33	0.005	65	0.029	73	0.028
34	0.060	40	0.043	91	0.057
70	0.089	45	0.087	68	0.122
75	0.069	65	0.035	42	0.011
57	0.227	69	0.045	49	0.021
64	0.055	Ave.	0.048	106	0.008
Ave.	0.084	Std. Dev.	0.023	Ave.	0.041
Std. Dev.	0.075	RSD	0.479	Std. Dev.	0.043
RSD	0.893			RSD	1.049
Set No. 2		Set No. 2		Set No. 2	
50	0.238	63	0.03	103	0.074
44	0.265	38	0.046	81	0.085
24	0.072	48	0.081	76	0.131
13	0.080	80	0.029	59	0.021
54	0.024	70	0.045	75	0.105
Ave.	0.136	59	0.154	78	0.037
Std. Dev.	0.108	Ave.	0.108	Ave.	0.075
RSD	0.794	Std. Dev.	0.050	Std. Dev.	0.041
		RSD	0.956	RSD	0.547
Set No. 3		Set No. 3		Set No. 3	
38	0.059	24	0.036	74	0.092
31	0.049	32	0.07	55	0.064
40	0.179	31	0.025	70	0.098
36	0.096	37	0.077	87	0.122
54	0.160	30	0.034	26	0.028
54	0.133	Ave.	0.048	43	0.019
Ave.	0.113	Std. Dev.	0.023	Ave.	0.070
Std. Dev.	0.053	RSD	0.479	Std. Dev.	0.041
RSD	0.469			RSD	0.586

	Set No. 4		Set No. 4		Set No. 4
88	0.131	39	0.035	60	0.009
90	0.279	48	0.041	46	0.080
57	0.433	35	0.018	54	0.029
50	0.070	38	0.015	64	0.050
57	0.137	32	0.013	49	0.042
51	0.056	36	0.037	49	0.109
Ave.	0.184	Ave.	0.027	Ave.	0.053
Std. Dev.	0.145	Std. Dev.	0.012	Std. Dev.	0.033
RSD	0.788	RSD	0.444	RSD	0.623
	Set No. 5		Set No. 5		Set No. 5
68	0.091	25	0.035	45	0.036
99	0.636	41	0.006	58	0.071
54	0.068	18	0.04	38	0.046
53	0.077	22	0.008	28	0.009
67	0.086	18	0.026	19	0.007
84	0.298	Ave.	0.023	40	0.082
Ave.	0.210	Std. Dev.	0.015	Ave.	0.042
Std. Dev.	0.226	RSD	0.652	Std. Dev.	0.031
RSD	1.076			RSD	0.738
	Set No.6		Set No.6		Set No.6
38	0.045	33	0.016	53	0.062
32	0.064	41	0.105	38	0.059
54	0.084	21	0.023	54	0.076
76	0.150	62	0.113	39	0.052
88	0.107	25	0.122	38	0.054
40	0.112	17	0.02	64	0.168
Ave.	0.093	Ave.	0.067	Ave.	0.078
Std. Dev.	0.038	Std. Dev.	0.052	Std. Dev.	0.045
RSD	0.409	RSD	0.776	RSD	0.577
	OVERALL		OVERALL		OVERALL
Ave.	0.083	Ave.	0.047	Ave.	0.060
Std. Dev.	0.065	Std. Dev.	0.035	Std. Dev.	0.040
RSD	0.783	RSD	0.745	RSD	0.667

TABLE 2-- Results of ASTM Fabric Penetration Tests

Volume Flow cc/min	Fractional Penetration	Volume Flow cc/min	Fractional Penetration
Fabric #1		Fabric #1	
Dark side away from challenge		Dark side facing challenge	
159	0.000	4	0.000
99	0.000	2	0.000
131	0.000	3	0.000
70	0.000	3	0.000
38	0.000	3	0.000
117	0.000	3	0.000
Ave.	0.000	Ave.	0.000
Std. Dev.	0.000	Std. Dev.	0.000
RSD	0.000	RSD	0.000
Fabric #2		Fabric #2	
62	0.060	49	0.026
123	0.052	100	0.048
57	0.029	35	0.022
125	0.065	81	0.064
40	0.003	39	0.078
84	0.050	Ave.	0.048
Ave.	0.043	Std. Dev.	0.024
Std. Dev.	0.023	RSD	0.500
RSD	0.535		
Overall for Fabric #2			
	Ave.	0.045	
	Std. Dev.	0.023	
	RSD	0.511	
Fabric #3			
17	0.015		
15	0.010		
16	0.011		
13	0.003		
15	0.008		
13	0.003		
Ave.	0.008		
Std. Dev.	0.005		
RSD	0.625		

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