LA-UR- 97-241

CONF-9606239--2

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

TITLE: ASBESTOS PENETRATION TEST SYSTEM FOR CLOTHING MATERIALS

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SUBMITTED TO:

Sixth International Symposium on Protective Clothing, June 18-20, 1996
Oralndo, Florida





Los Alamos National Laboratory
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FORM NO. 836 R4
ST. NO. 2629 5/81

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# ASBESTOS PENETRATION TEST SYSTEM FOR CLOTHING MATERIALS

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**REFERENCE:** Bradley, O. D., Stampfer, J. F., Sandoval, A. N., Heath, C. A., and Cooper, M. H., **"Asbestos Penetration Test System for Asbestos"**, Performance of Protective Clothing, STP 1273, J. O. Stull and A. D. Schwope, Eds,., American Society for Testing and Materials, Philadelphia, 1997

**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 a 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 $cm^3$/min leak is small compared to the total 2000 $cm^3$/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 $cm^3$/min of the total of 2000 $cm^3$/min passing through the asbestos aerosol monitor are actually analyzed. This means, therefore, that high challenge concentrations, 200 fibers/ $cm^3$ 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/ $cm^3$ 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 $mm^2$ 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 Fabic #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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