Comments to 42CFR84

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June 24, 1994

MSA

We Applaud the Effort!

- *An incredible balancing act.*
- *More than 7 years in the making!*
- *Addressing more than 270 comments to the original proposal.*

The Modular Approach

- *Inch by inch!*

✓ *Improvements on a priority basis.*

✓ *Assures improvements to worker safety are implemented first.*

✓ *Facilitates adaptation.*

What NIOSH Wants from Module 1

1). "Produce significant improvements in the level of protection provided to wearers of respirators.

2). "Enable users to easily discern the level of protection that can be expected when using a respirator."

3). "Enable classification of the filters on their ability to inhibit penetration of particulates of the most penetrating size."

The additional benefit for health care workers

4). "Address an important public health need regarding the control of TB transmission... with six classes of respirators... expected to be markedly less expensive than respirators with HEPA filters."

Concerns & Comments

- *That significant improvements in worker protection won't be achieved.*
- *That users won't easily discern the level of protection.*
- *That filters aren't classified on their ability to inhibit particulates of the most penetrating size.*

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Why?

- *1). The "tiered" system can lead to misuse:*
  - *"solid only" particulates*
  - *"liquid and solid" particulates*

- *2). The test method that can overstate filter efficiency.*

- *3). As written, 42CFR84 permits certification of filters that show continued loss of filtering efficiency with exposure.*

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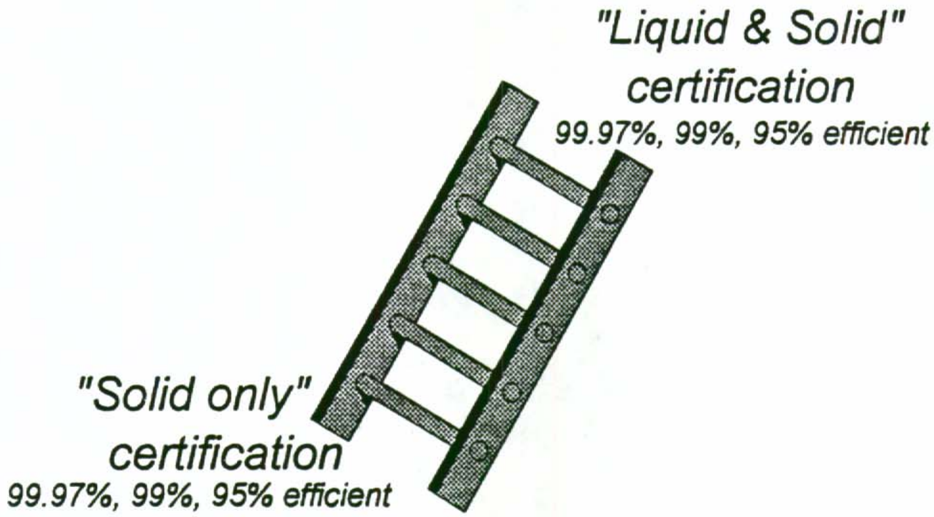
Today's Discussion... that 42CFR84 Should Require

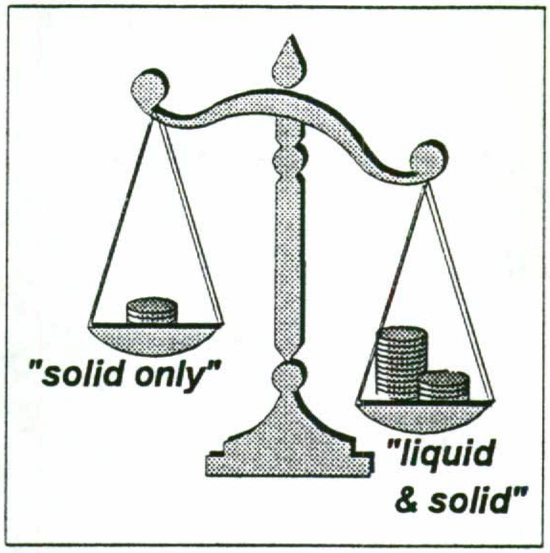
- ✓ *Just as in 1987, that only one certification class be established -- "liquid and solid".*
- ✓ *That thermally generated DOP be used as the challenge aerosol.*
- ✓ *Just as in 1987, the testing continue until filter penetration and filter efficiency have stabilized.*

A "tiered" system that can lead to misuse



Tiered system results

- "Solid only" will be a lot less expensive.
- Filter efficiency will become the driver.
- Misuse and misapplication will result.



The tiered system prevents NIOSH from achieving its goals.

1). "Produce significant improvements in protection provided to wearers of respirators.

2). "Enable users to easily discern the level of protection"

the solution...

in the 1987-released version, only one certification class was permitted -- liquid & solid.

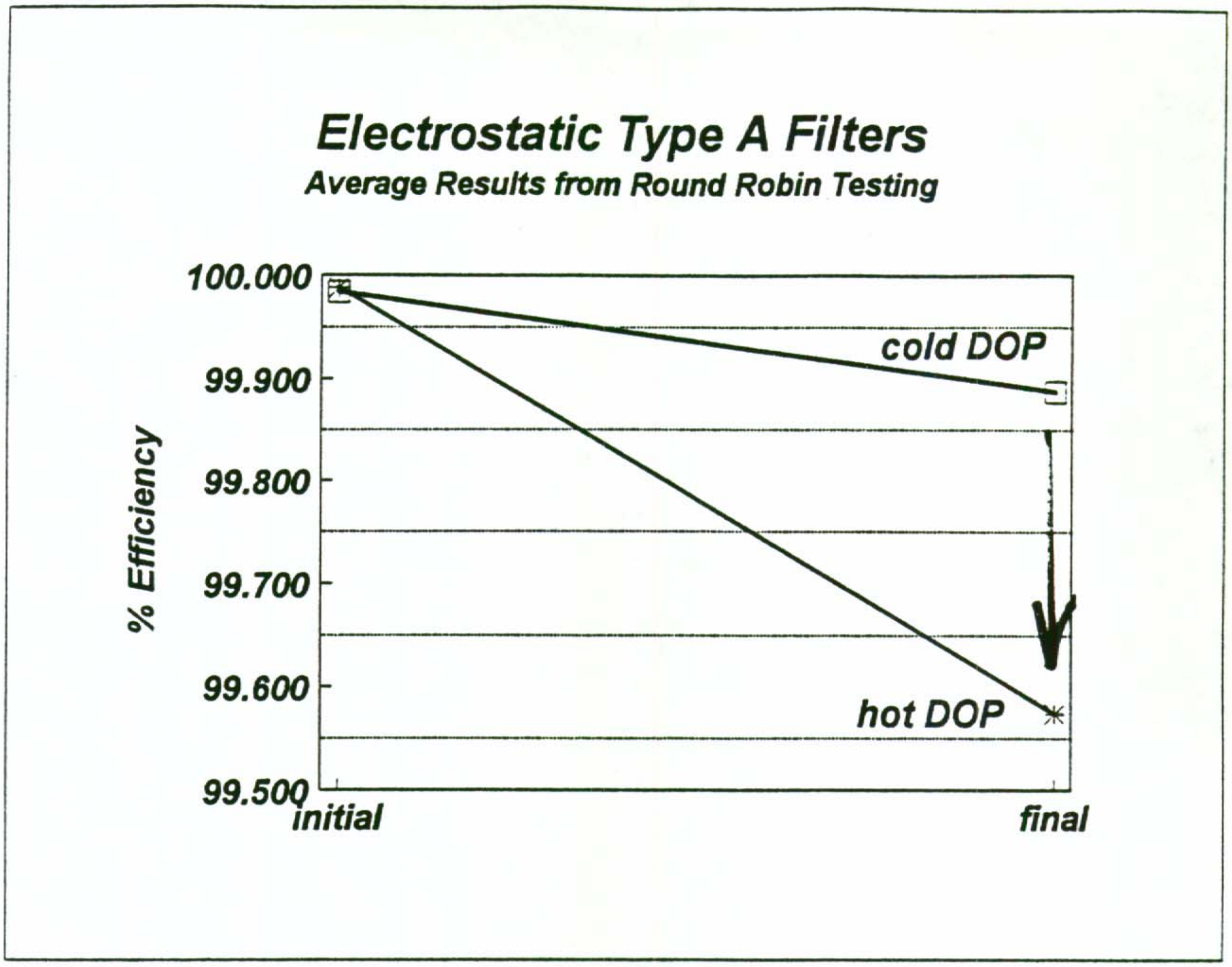
The test method can overstate filter efficiency

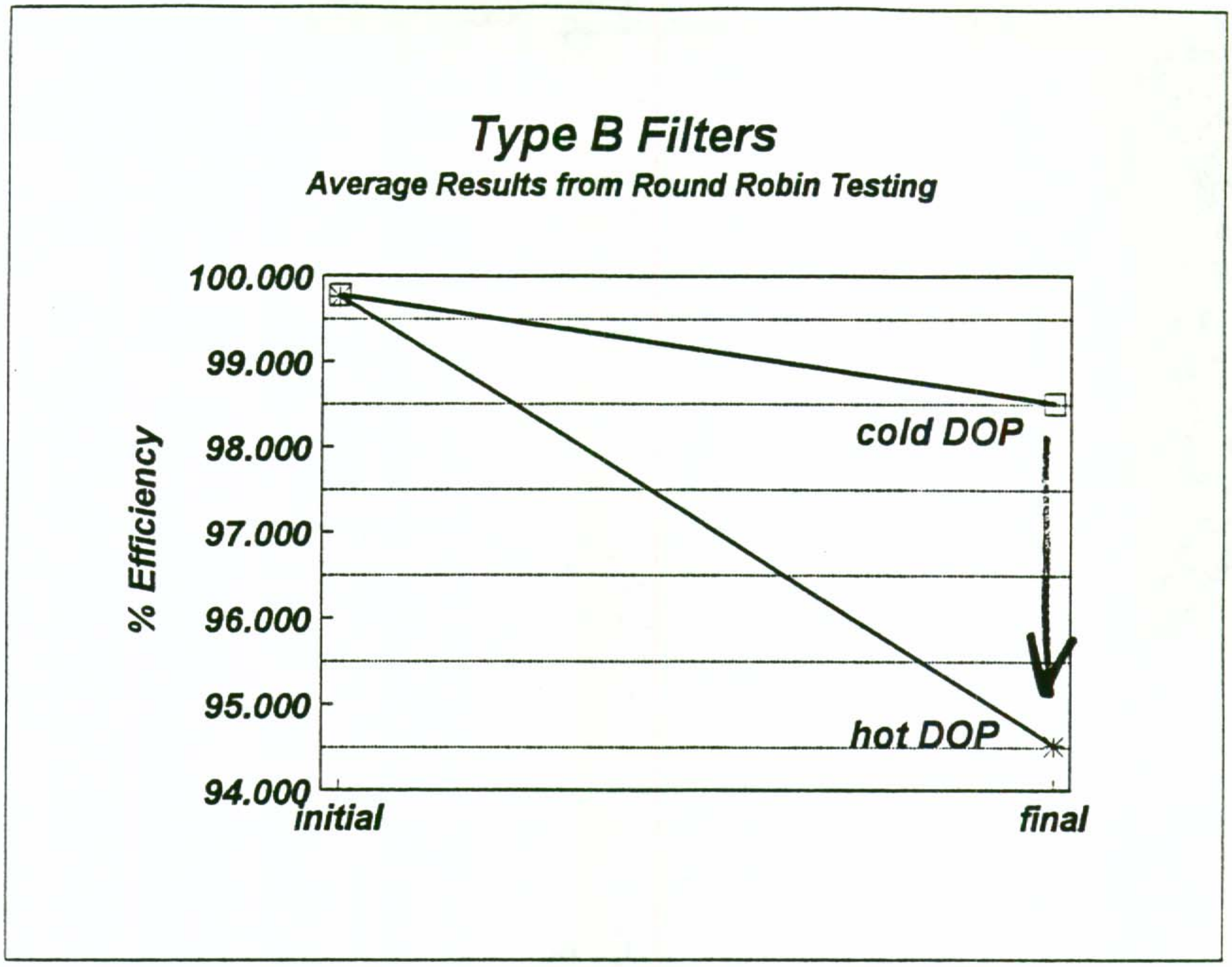
- *"enable classification of filters on their ability to inhibit penetration of particulates of the most penetrating size."*

- **DOP, the most penetrating aerosol.**

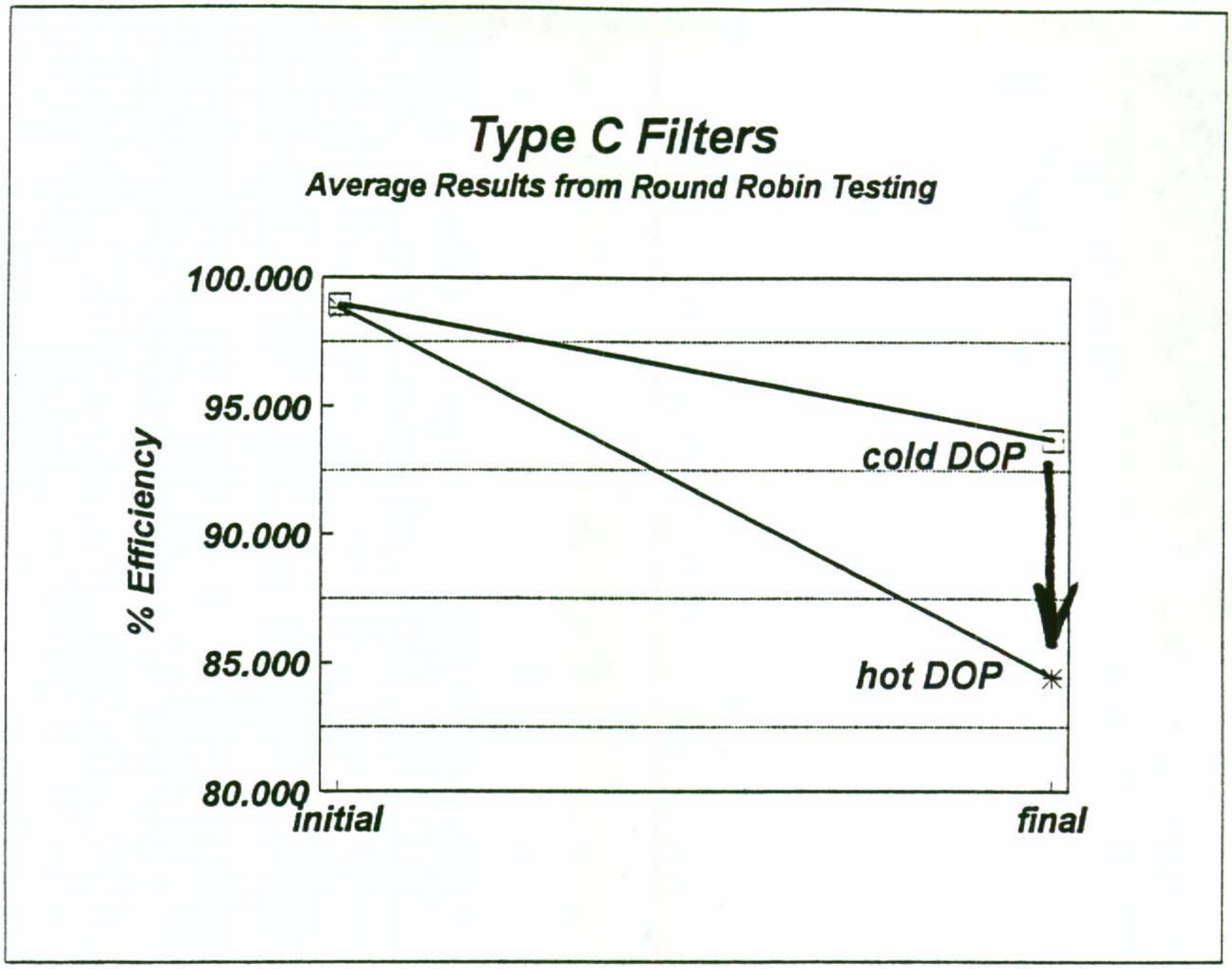
- **But how generated?**
  - **cold-nebulized? or**
  - **thermally generated?**

- **It'll give different results!**


Electrostatic Type A Filters
Average Results from Round Robin Testing
% Efficiency
100.000
99.900
99.800
99.700
99.600
99.500
cold DOP
hot DOP
initial
final



Type B Filters
Average Results from Round Robin Testing
100.000
99.000
98.000
97.000
96.000
95.000
94.000
% Efficiency
cold DOP
hot DOP
initial
final


Type C Filters
Average Results from Round Robin Testing
100.000
95.000
90.000
85.000
80.000
% Efficiency
cold DOP
hot DOP
initial
final

ISEA ROUND ROBIN TESTING RESULTS

Type A Filter Media

	Test Site 1					Test Site 2					Test Site 3					Test Site 4					Test Site 5 **					% pen. avg.	% efficiency
TSI (AFT)	A1	A2	A3	A4	A5	A1	A2	A3	A4	A5	A1	A2	A3	A4	A5	A1	A2	A3	A4	A5	A1	A2	A3	A4	A5		
initial pen.	0.015	0.016	0.014	0.011	0.013	0.015	0.012	0.013	0.009	0.012	0.026	0.027	0.019	0.036	0.037	0.009	0.012	0.008	0.008	0.010	*0.587*	*0.424*	*0.454*	*0.362*	*0.254*	0.016 initial pen.	
max penetr.	0.099	0.122	0.103	0.084	0.096	0.108	0.118	0.106	0.061	0.088	0.161	0.143	0.112	0.220	0.213	0.072	0.111	0.075	0.074	0.095	*1.270*	*1.000*	*1.050*	*0.904*	*0.714*	0.113 final	99.89%
	Test Site 1					Test Site 2					Test Site 3					Test Site 4					Test Site 5						
Q-127	A1	A2	A3	A4	A5	A1	A2	A3	A4	A5	A1	A2	A3	A4	A5	A1	A2	A3	A4	A5	A1	A2	A3	A4	A5		
initial pen.	0.002	0.003	0.001	0.002	0.001	0.024	0.023	0.017	0.017	0.021			0.016	0.017	0.020	0.027	0.025	0.019	0.008	0.021	0.001	0.001	0.001	0.001	0.002	0.012 initial pen.	
max penetr.	0.105	0.098	0.038	0.033	0.035	0.983	0.795	0.695	0.786	0.911			0.490	0.480	0.400	0.720	0.750	0.570	0.330	0.740	0.260	0.150	0.170	0.094	0.160	0.426 final	99.57%

cold
hot

Type B Filter Media

	Test Site 1					Test Site 2					Test Site 3					Test Site 4					Test Site 5 **					avg.	
TSI (AFT)	B1	B2	B3	B4	B5	B1	B2	B3	B4	B5	B1	B2	B3	B4	B5	B1	B2	B3	B4	B5	B1	B2	B3	B4	B5		
initial pen.	0.194	0.129	0.148	0.214	0.195	0.301	0.223	0.144	0.165	0.169	0.242	0.320	0.348	0.514	0.346	0.207	0.169	0.138	0.154	0.150	*1.460*	*1.330*	*1.350*	*1.550*	*2.000*	0.223 initial pen.	
max penetr.	1.270	0.966	1.170	1.670	1.810	2.060	1.820	0.943	1.070	1.270	1.380	1.680	1.780	1.840	1.830	1.920	1.290	1.080	1.320	1.670	*4.080*	*3.910*	*4.180*	*4.600*	*5.630*	1.492 final	98.51%
	Test Site 1					Test Site 2					Test Site 3					Test Site 4					Test Site 5						
Q-127	B1	B2	B3	B4	B5	B1	B2	B3	B4	B5	B1	B2	B3	B4	B5	B1	B2	B3	B4	B5	B1	B2	B3	B4	B5		
initial pen.	0.052	0.091	0.066	0.064	0.044	0.215	0.299	0.249	0.329	0.263	0.380	0.460	0.430	0.450	0.370	0.290	0.380	0.510	0.200	0.330	0.120	0.080	0.110	0.100	0.170	0.242 initial pen.	
max penetr.	1.950	2.950	2.350	2.300	1.500	6.310	7.260	7.730	9.340	8.080	5.900	6.900	7.300	6.600	6.800	6.100	7.900	7.900	4.900	6.400	3.600	3.200	4.700	3.800	5.300	5.483 final	94.52%

Type C Filter Media

	Test Site 1					Test Site 2					Test Site 3					Test Site 4					Test Site 5 **					avg.	
TSI (AFT)	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5		
initial pen.	0.78	0.99	0.85	0.95	1.00	0.82	0.98	0.70	1.00	0.97	1.41	1.63	1.71	1.17	1.10	0.95	1.26	0.80	1.05	0.90	*4.97*	*4.55*	*4.93*	*5.68*	*6.34*	1.051 initial pen.	
max penetr.	4.69	5.78	5.57	6.53	6.43	5.18	6.30	5.48	6.47	5.35	6.39	7.26	7.57	5.77	5.83	7.98	8.50	5.80	6.30	6.99	*14.30*	*12.50*	*13.10*	*13.80*	*15.70*	6.309 final	93.69%
	Test Site 1					Test Site 2					Test Site 3					Test Site 4					Test Site 5						
Q-127	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5		
initial pen.	0.53	0.65	0.45	0.53	0.48	1.37	1.48	1.42	1.45		2.40	2.20	1.60	1.40	1.90	1.50	1.50	0.80	1.10		0.83	0.80	0.74	1.10	1.10	1.19 initial pen.	
max penetr.	10.20	13.00	8.40	9.90	9.80	22.50	21.90	21.20	23.10		19.00	18.50	16.00	16.00	17.50	14.00	19.00	11.00	16.00		12.00	14.00	12.00	15.00	18.00	15.57 final	84.43%

** Test Site 5 reported that filter preconditioning was at relative humidities much higher than that called for in 42CFR84. It is believed that this increase caused dramatically higher initial penetrations and final penetrations. Therefore, those values in italics were not used in the "average % penetration" calculation.

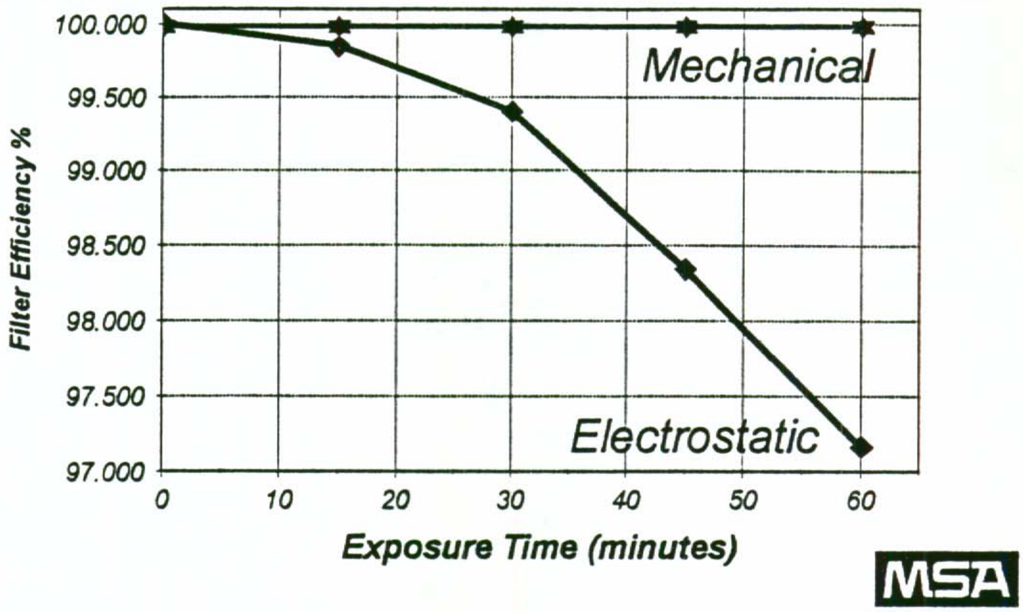
MECHANICAL FILTER TESTING

ISEA Round Robin Test Summary

ID	Type A Filter Media Test Site	AFT	Q-127	ID	Type B Filter Media Test Site	AFT	Q-127	ID	Type C Filter Media Test Site	AFT	Q-127
A1	1	0.012	0.009	B1	1	0.386	0.280	C1	1	2.270	2.300
A1	2	0.009	0.013	B1	2	0.353	0.382	C1	2	2.430	2.550
A1	3	0.018	0.016	B1	3	0.524	0.480	C1	3	2.870	3.200
A1	4	0.014	0.016	B1	4	0.486	0.480	C1	4	2.700	3.000
A1	5	0.013	0.008	B1	5	0.431	0.350	C1	5	2.500	2.000
A2	1	0.010	0.007	B2	1	0.405	0.290	C2	1	2.300	2.200
A2	2	0.010	0.016	B2	2	0.380	0.410	C2	2	2.450	2.430
A2	3	0.017	0.013	B2	3	0.539	0.550	C2	3	2.840	2.900
A2	4	0.014	0.017	B2	4	0.448	0.530	C2	4	2.590	2.700
A2	5	0.013	0.003	B2	5	0.408	0.320	C2	5	2.570	2.400
A3	1	0.012	0.006	B3	1	0.389	0.280	C3	1	2.350	2.100
A3	2	0.012	0.013	B3	2	0.441	0.411	C3	2	2.410	2.400
A3	3	0.018	0.017	B3	3	0.521	0.550	C3	3	2.850	3.000
A3	4	0.014	0.013	B3	4	0.454	0.530	C3	4	2.480	2.200
A3	5	0.014	0.007	B3	5	0.426	0.410	C3	5	2.330	2.200
A4	1	0.012	0.005	B4	1	0.370	0.280	C4	1	2.340	2.050
A4	2	0.010	0.017	B4	2	0.402	0.447	C4	2	2.340	2.430
A4	3	0.017	0.015	B4	3	0.520	0.530	C4	3	2.900	2.800
A4	4	0.012	0.015	B4	4	0.469	0.390	C4	4	2.580	2.500
A4	5	0.013	0.004	B4	5	0.427	0.310	C4	5	2.440	2.700
A5	1	0.011	0.007	B5	1	0.367	0.320	C5	1	2.340	1.950
A5	2	0.010	0.016	B5	2	0.381	0.422	C5	2	2.410	2.510
A5	3	0.016	0.016	B5	3	0.516	0.510	C5	3	2.890	2.800
A5	4	0.013	0.010	B5	4	0.470	0.350	C5	4	2.530	2.400
A5	5	0.013	0.004	B5	5	0.414	0.290	C5	5	2.460	2.100
	average	0.013	0.011		average	0.437	0.404		average	2.527	2.473
equiv. filter eff.		99.99%	99.99%			99.56%	99.60%			97.47%	97.53%

Electrostatic HEPA Filter Performance vs. Mechanical HEPA Performance

when tested against thermally generated monodispersed DOP using an ATI Q-127, model TDA-100 tester, over an extended period of time*



Conclusions

- ✓ *Cold DOP consistently overestimated filter efficiency.*

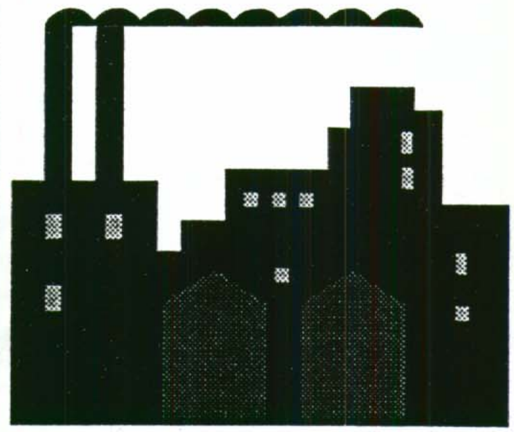
- ✓ *With each type of electrostatic filter, thermally generated DOP was more penetrating than cold DOP.*

- ✓ *With each type of electrostatic filter, performance was continuing to decline.*

It's not just DOP...

- ✓ Silkstone coal dust
- ✓ Foundry fettling fume
- ✓ Foundry burning fume
- ✓ Carbon brick dust
- ✓ Lead smelting fume
- ✓ Lead battery dust
- ✓ Ammonium chloride

ref: Blackford, Bostock, Brown, Loxley & Wake: "Alterations in the Performance of Electrostatic Filters Caused by Exposures to Aerosols." Proc. Fourth World Filtration Congress. 1986



And what about the user?

"enable users to easily discern the level of protection that can be expected when using a respirator"

- Where's the "indicator" that the electrostatic filter is losing efficiency?
- And the user can't detect, taste, or smell the "breakthrough" or loss in filtration efficiency.

→ *42CFR84 must address this concern.*

NIOSH Did!
7 Years Ago

- The 1987-released 42CFR84 addressed the issue.

- ***" if filter penetration is increasing when the 100mg challenge point is reached, the test shall be continued until there is no further increase in penetration."***

- Filtration efficiency is certified only <u>after</u> performance has levelled off.

What We All Want from Module 1

1). "Produce significant improvements in the level of protection provided to wearers of respirators.

2). "Enable users to easily discern the level of protection that can be expected when using a respirator."

3). "Enable classification of the filters on their ability to inhibit penetration of particulates of the most penetrating size."

What 42CFR84 Should Require

- ✓ *Just as in 1987, that only <u>one</u> certification class be established -- "liquid and solid".*
- ✓ *That thermally generated DOP be used as the challenge aerosol.*
- ✓ *Just as in 1987, that exposure continue until filter penetration and filter efficiency have stabilized.*

What about less expensive respirators for protection from TB?

- Unfortunately, cost impact analysis shows increased costs are likely.
  - Has a safe exposure limit been established?
  - Does an emergency substance specific standard from OSHA make more sense?

ALTERATION IN THE PERFORMANCE OF ELECTROSTATIC FILTERS CAUSED BY EXPOSURE TO AEROSOLS.

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ABSTRACT

Electrostatic filters are widely used in respirators because their electric field enhances filtration efficiency without causing any increase in airflow resistance; but exposure to aerosols reduces their performance. Results are given of the loss of filtration efficiency caused by the exposure of a variety of electrostatic filter materials to aerosols of various types. Industrial fumes vary considerably in the extent to which they cause deterioration in performance. The general characteristics of the degradation process are outlined, and a simple semi-empirical theory is developed to enable the degrading ability of aerosols for materials to be quantified and correlated with their physical characteristics.

INTRODUCTION

Electrically charged filter materials are widely used in respirators giving personal protection against respirable dust; and much has been written on the behaviour of electrically charged filter fibres and aerosol particles during filtration (see for example Davies, 1; Pich 2, 3). Electric forces augment the filtration efficiency without causing any increase in airflow resistance; and so an electrically charged filter has a fundamentally better quality than a filter that is similar in structure but uncharged.

Some of the materials used in respirators rely so heavily on their electric charge that, if the effect of that charge is lost, their filtration efficiency is reduced to a low level (Brown and Wake, 4). The charge on electrostatic filters can be reduced or rendered less effective by storage in adverse environmental conditions, by exposure to ionising radiation, or by exposure to aerosols. The last of these is by far the most important, because this process is inevitable if the filters are to be used at all; and it is important that this effect should be understood and quantified, so that the protection offered by a respirator after a reasonable degree of aerosol loading can be predicted, and its acceptability assessed.

Provision for measuring the aerosol penetration through filters after loading with coal dust exists in the British Standard Test for filtering facepieces (5); and some measurements of the degradation of filters after exposure to coke oven atmospheres have been published (Smith et al, 6), but quantitative data on this effect are few. This paper describes part of a continuing programme of work aimed at quantifying and understanding the process of degradation of electrostatic filter materials by both industrial aerosols and aerosols generated in the laboratory.

TYPES OF ELECTROSTATIC MATERIAL USED IN THE EXPERIMENTS

Four different types of electrostatic material were used in the investigations:-

Resin-wool material

This material has existed for several decades. It contains highly charged resin particles, attached to wool fibres with a charge of the opposite sign. The fibres are usually about 17μm in diameter, and can carry the highest surface charge density observed by the authors, though not in the most efficient configuration. The material is described in detail by Feltham (7).

Electret material

This material is now in widespread use, and has been described by van Turnhout et al (8). The fibres, which are comparable in size with wool fibres, are produced by shredding a sheet of polymer that has been charged by an electric corona, and they retain a high electric charge.

Electrostatically spun material

The two materials described above are produced in the form of fleeces or felts by carding

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the fibres. Electrically charged material can be made from fibres that are too fine to be carded, but which are extruded by electric fields, and made into fibrous material by air-laying. The fibres are typically about 4μm in diameter, and they carry charges of both signs, but at a lower level than the materials of carded fibres. Such material should be regarded as partly electrostatic and partly mechanical. Two types of material, which are chemically different and produced by different processes, are used in the tests. They are a polycarbonate material produced from a solution (Schmidt, 9) and a polypropylene material produced from a melt (Trouilhet, 10).

EXPERIMENTAL PROCEDURE

The filters were exposed to aerosols in batches of 36, using the apparatus shown in Figure 1. Dust laden air was drawn through the box at a rate such that each filter received air at a face velocity of 0.04 ms^{-1}. Equal distribution of flow was ensured by backing all of the test filters with identical high resistance filters, and the flow was controlled with a simple electronic feed-back device.

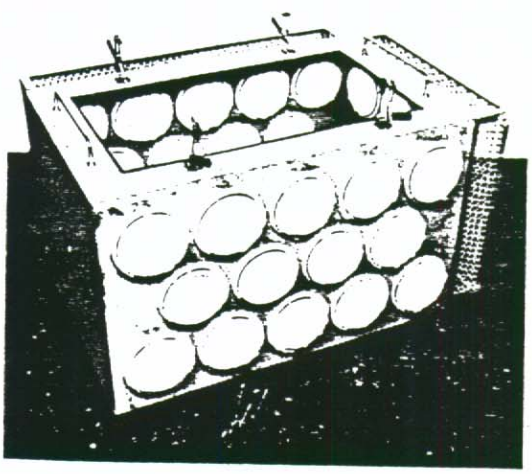

Fig.1 - Apparatus used for exposure of filters to industrial aerosols

Batches of filters were exposed, on site, to the following aerosols: aerosols produced at a foundry by the removal of superfluous material from steel castings using an abrasive wheel (fettling), or an oxygen-acetylene torch or electric arc (burning); refractory brick dust with a high carbon content; lead-containing aerosol produced by condensation at a lead smelter, and by dispersion, cold, at a lead battery assembly plant. In addition filters were exposed to coal dust in our own dust tunnel (Blackford and Heighington, 12) and to ammonium chloride aerosol produced by sublimation and condensation.

From time to time during the exposure the filters were removed, to be dried and weighed, and to have their pressure drop and BS 4400 standard sodium chloride aerosol (13) penetration measured, at a face velocity of 0.04 ms^{-1}.

SPECIMEN RESULTS

Many measurements have been made, and it is not possible to present all of the results here. However, a number of results can be usefully shown in detail, to illustrate the general trends observed. Figure 2 shows the penetration of the standard aerosol through electret filters as a function of the mass per unit area of deposited aerosols of various types, and it gives a general illustration of the difference in the extent to which equal masses of various aerosols cause reduction in filter performance.

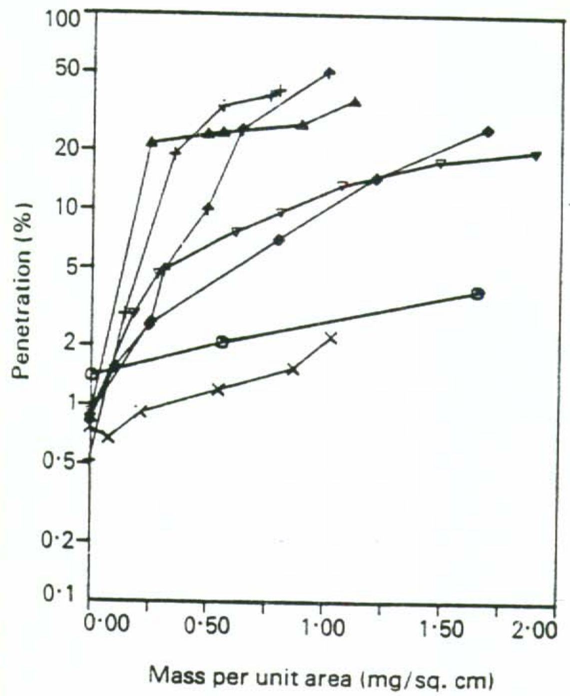

Fig.2 - Standard aerosol penetration through electret filters loaded with various aerosols
⊡ - Silkstone coal dust
△ - Foundry fettling fume
+ - Foundry burning fume
× - Carbon brick dust
◊ - Lead smelting fume
♠ - Lead battery dust
▽ - Ammonium chloride

The results for electret material are shown, because its mechanical stability and very low moisture regain enable repeatable measurements to be obtained. Other materials show similar trends, but experimental scatter is greater. All the aerosols listed in Figure 2 cause a practically monotonic increase of penetration with load, and there is no evidence that electret material clogs significantly in the form used, and under the conditions of these tests. Several filters were tested in each environment, but the figure shows only the filter that is closest to the average in its behaviour. The units on the x axis at Figure 2 are such that at this filtration velocity of 0.04 ms^{-1}, 1 $mg\ cm^{-2}$ of aerosol would be deposited in 7 hours if the ambient aerosol concentrations were 10 $mg\ m^{-3}$; or, in general terms, a concentration of K $mg\ m^{-3}$ and an exposure time of t hours would result in a deposition of $^{Kt}/_{70}$ $mg\ cm^{-2}$ of aerosol.

Figure 3 shows, for a larger number of electret filters, the effect of the two types of foundry aerosols. Figure 4 shows the fine polycarbonate material after exposure to the different lead-containing fumes. The fundamental difference apparent here is that this fine-fibred material clogs.

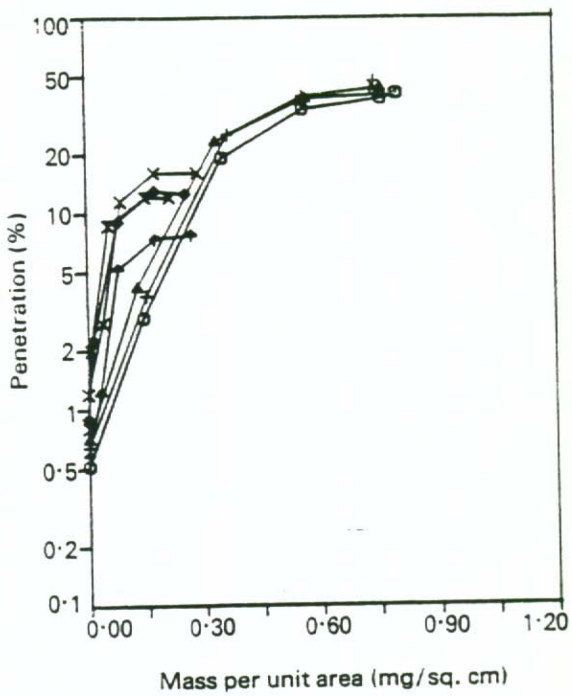

Fig.3 - Standard aerosol penetration through electret filters loaded with foundry aerosols
□△+- Burning fume
×◊♦×- Fettling fume

In Figures 2 to 4, the penetration is shown on a logarithmic scale, for convenience's sake. Moreover, the figures are computer graph plots, with successive data points joined by straight lines. This method of connecting points serves, principally, to illustrate which points correspond to readings made on the same filter. The graphs do not give reliable estimates of intermediate penetration values, but, in general, the characteristics obtained from the data do not require this, and the data points are not sufficiently precise to make the exercise of developing a better interpolation program worthwhile.

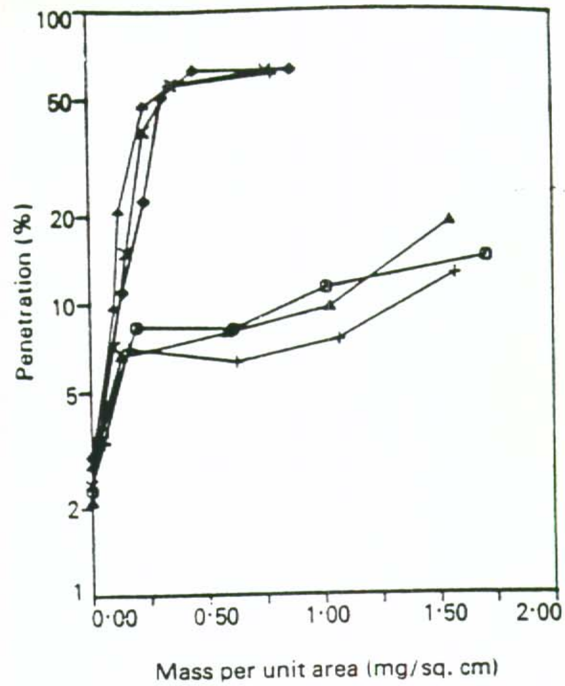

Fig.4 - Standard aerosol penetration through polycarbonate filters loaded with lead aerosols
□△+- Lead smelting fume
×◊♦- Lead battery dust

SEMI-EMPIRICAL THEORY OF FILTER DEGRADATION

The results shown so far illustrate that the process of degradation of electrostatic filters by aerosols is very complicated, and that the development of a quantitative theory to explain all that is observed will prove difficult. Deposition of aerosol within a filter is not uniform; the initial layers will be more heavily loaded. Their loss of filtration efficiency will cause a greater penetration of aerosol to the underlying layers, which will result in loss of efficiency here; and so the aerosol deposition profile will creep through the filter. A complete analysis will probably result in partial differential equations in a large number of interrelated variables.

It is important, though, even at this stage in the work, to obtain some link between theory and practice; and this is possible if attention is directed towards the early stages of each test, when the filters have light aerosol loads. Under such conditions it should be possible to develop a linear theory. Moreover, it frequently happens that a simple relationship holds well outside the range of parameters for which it can be rigorously justified. Let us start with the expression for the penetration, P, of an aerosol of identical particles through a filter (1).

$$P = \exp(-\alpha d) \qquad (1)$$

The parameter, α, can be called the layer efficiency, and it is a measure of the filter material quality. Although it will depend on the nature of the aerosol, the filtration velocity, and the packing fraction of the filter, it will not depend on the filter thickness, d, and has, therefore, a useful degree of generality. In practice, most aerosols consist of particles with a range of different penetrations, but equation 1 holds reasonably well if an average value is used for α, provided that the size distribution of the aerosol is not too wide. In practice it is usually possible to increase α by compressing the filter; but the penalty paid for this is an increase in pressure drop.

Equation 1 does not attempt to relate what is observed to fundamental aerosol properties, but it does enable the observed behaviour of an aerosol to be expressed by means of a single simple parameter. In the working that follows, a similar parameter, describing the effect of aerosol loading on filter performance, will be sought; and the theory will be developed for the general case in which the test aerosol is different from the loading aerosol.

Equation 1 can describe the penetration of a test aerosol through an unloaded filter, with an appropriate choice of α, α_T say. It can also describe the penetration of the loading aerosol, with its particular layer efficiency, α_L say; and it is straightforward to show that the mass of aerosol deposited, per unit volume of filter, $\mu(x)$, is given by

$$\mu_L\ (x) = \mu_o \exp\ (-\alpha_L x) \qquad (2)$$

μ_o is a constant, the meaning of which will become clear below. x is the coordinate in the direction of aerosol flow, and, within the filter, $0<x<d$. We now make the assumption that the layer efficiency for the test aerosol is reduced by an increment that is proportional to μ.

$$\alpha\ (\mu_L) = \alpha_T - B_{TL}\ \mu_L \qquad (3)$$

B_{TL} is a constant of proportionality, which is a measure of the effectiveness of the loading aerosol in reducing the layer efficiency for the test aerosol. This assumption of a linear relationship can be justified, in the low loading limit, for any of the existing theories of particle capture by electric forces (3, 4, 14). Moreover, it has the appeal of being the simplest assumption possible; but the best justification of linear theory will be the quality of agreement between prediction and observation. Equations 2 and 3 can be incorporated into the differential equation for test aerosol concentration, C, in a lightly loaded filter under test.

$$\frac{dC_T}{dx} = [- \alpha_T + B_{TL}\ \mu_o \exp\ (- \alpha_L x)]\ C_T \qquad (4)$$

The solution of equation 4 is

$$\ln \left| \frac{C_T\ (x = d)}{C_T\ (x = o)} \right| = - \alpha_T d + \frac{B_{TL}\ \mu_o}{\alpha_L} [1 - \exp\ (-\alpha_L d)] \qquad (5)$$

The mass of loading aerosol deposited, per unit area of the face of the entire filter, M, is

$$M_L = \int_o^d \mu_L(x)\ d = \frac{\mu_o}{\alpha_L}\ [1 - \exp(-\alpha_L d)] \qquad (6)$$

Combining equations 5 and 6, using the fact that the left hand side of equation 5 is, by definition, the logarithm of the penetration of test aerosol through a loaded filter, and the fact that the first term on the right hand side is the logarithm of the penetration of test aerosol through an unloaded filter, P_o, the result follows that

$$\ln \left| \frac{P_T}{P_o} \right| = B_{TL}\ M_L \qquad (7)$$

Equation 7 is precisely the sort of relationship that we require. B_{TL} is a parameter giving a simple quantitative estimate of the effectiveness of the loading aerosol in reducing the electrostatic filtration efficiency of the filter. B_{TL} does not depend on filter thickness, nor does it depend, explicitly, on α_L. All of the other unknowns in equation 7 can be easily measured.

This simple result means that scaled graphs can be used to obtain B_{TL}, which is simply the gradient of the logarithm of the penetration quotient as a function of loading, measured at the origin; though it must be reiterated that the simplicity of the prediction is the result of the simple assumptions made in deriving it.

ANALYSIS OF RESULTS

The validity of the approximations made in the preceding section will be revealed by the quality of fit of the experimental results to the corresponding predictions. The best illustration of this is given by the results obtained with electret filters subjected to foundry burning fume. These filters are chosen as before, because experimental scatter is small, and because both single and double thicknesses of material were used. Straightforward results for penetration against load are shown in Figure 5, where the graphs appear to differ considerably. In Figure 6, the logarithm of the penetration quotient is plotted, as in equation 7. Complete agreement with equation 7 would result in all of the graphs lying on the same straight line close to the origin. It is clear that the behaviour is roughly as the equation predicts; and the spread in the results may be due to slight compression of the thicker filters.

It is not possible to show all of the relevant graphs in this paper, but in most cases, a quality approaching that of Figure 6 is achieved. In certain cases anomalous results have been

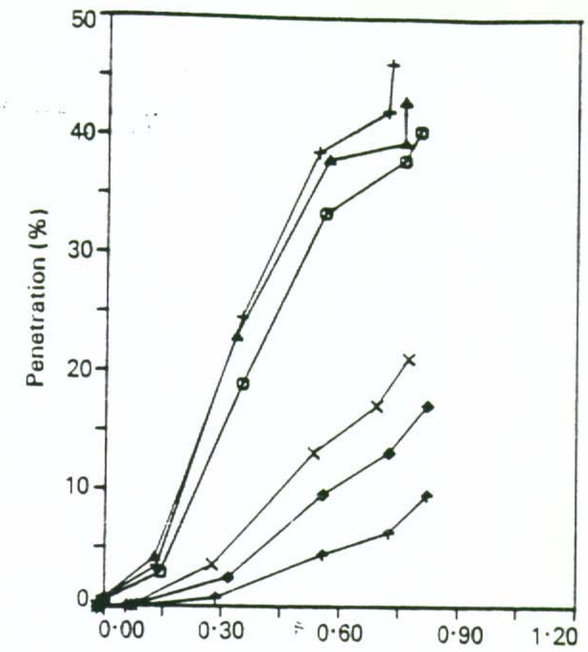

Fig.5 - Standard aerosol penetration through burning - fume laden electret filters

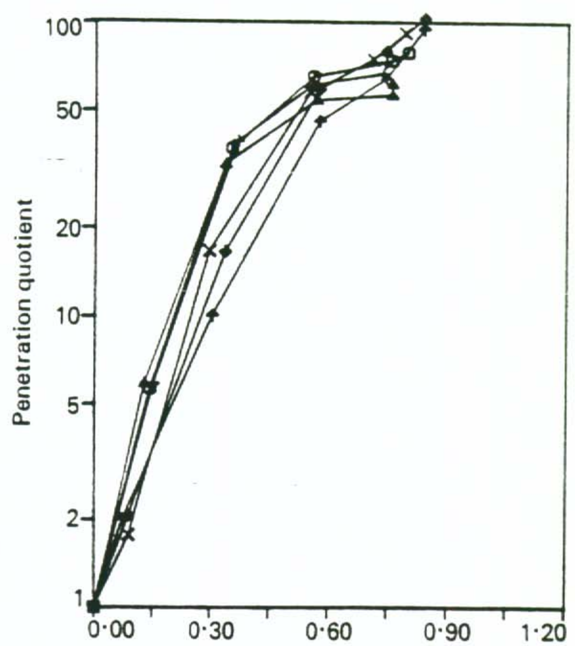

Fig.6 - Log (quotient) plot of standard aerosol penetration : same data as figure 5

rejected, because it is always possible that, when left in industrial conditions without supervision, a filter may be damaged or contaminated by the normal activities of industry carried out in a careless fashion.

The results are summarised in Table 1. Some data, particularly those on resin wool filters, and on filters with a hygroscopic scrim, were not analysed directly. Instead, penetrations were referred to exposure time, amd the weights obtained with other filters under the same conditions were used as presumed weight increases. Results to which this applies are bracketed. The tabulated values of B_{TL} are averages taken from a log (quotient)/linear plot of the experimental results for each batch of similar filters exposed to the same aerosol. Where the spread of individual results is very high, limits are quoted.

TABLE 1

Low Load Degradation Parameter, B_{TL} ($m^2\ g^{-1}$), for Various Filter Materials and Aerosols

FILTER MATERIAL

AEROSOL	Electret	Resin Wool	Poly-carbonate	Fine Poly-propylene
Silkstone Coal Dust	0.08	0.06	0.007-0.05	0.03-0.21
Carbon Brick Dust	0.11	(0.55)	0.16	-
Lead Smelting Fume	0.55	(0.79)	0.81	(3.00)
Lead Battery Dust	0.63	(0.92)	1.05	0.70
Foundry Burning Fume	1.31	(1.43)	1.02	-
Foundry Fettling Fume	3.41	(2.05)	1.57	(0.43)
Ammonium Chloride	0.96	-	0.75	0.42

The most striking feature of those results is the large range in values of B_{TL}. For instance, it varies by a factor of almost fifty for electret filters. It is also clear that, if the aerosols are ranked according to the amount of degradation that they cause, then with the exception of the ammonium chloride aerosol, they are in the same order for electret and resin wool filters, and in a basically similar order for the other filters. However, just as a complete study of a new filter requires both layer efficiency and pressure drop, a full analysis of a loaded filter needs both B_{TL} and the rate of increase of pressure drop.

CLOGGING AND PRESSURE DROP INCREASE

Clogging of the filters by an aerosol may well increase their filtration efficiency and, therefore, reduce the effect of charge loss. This would tend to reduce the value of β_{TL} measured, and might cause the anomalies in Table 1. This advantageous effect is associated with the drawback of increased airflow resistance, and a simple linear treatment of this effect will be worthwhile. Such an exercise follows exactly the same lines as that for the penetration, except that equation 1 is replaced by

$$\Delta p_O = \varepsilon d \qquad (8)$$

where ε describes the resistance of an incremental layer of filter material. α_L appears in exactly the same way as before, and it is assumed that ε increases linearly with aerosol load in the following way

$$\varepsilon\ (\mu_L) = \varepsilon_O + \alpha_L \Delta p_O \mu_L \qquad (9)$$

The plus sign expresses the expectation that pressure drop will increase with aerosol loading and Δp_O in equation 9 is simply a scaling factor to ensure that the constant of proportionality, γ_L, has the same dimensions as β_{TL}. The result of the analysis is

$$\frac{\Delta p\ (\text{loaded}) - \Delta p_O}{\Delta p_O} = \gamma_L M_L \qquad (10)$$

TABLE 2

Pressure drop increase parameter, γ_L ($m^2\ g^{-1}$), for various filter materials and aerosols

FILTER MATERIAL

AEROSOL	Electret	Resin Wool	Poly-carbonate	Fine Poly-propylene
Silkstone Coal Dust	0.00	0.00	0.27	0.08
Carbon Brick Dust	0.00	(-0.03)	0.00	-
Lead Smelting Fume	0.01	(0.02)	0.12	(0.00)
Lead Battery Dust	0.00	(-0.02)	0.02	0.24
Foundry Burning Fume	-0.02	(-0.03)	(0.06)	-
Foundry Fettling Fume	-0.04	(-0.11)	0.07	(0.52)
Ammonium Chloride	0.00	-	0.04	0.05

The parameter, γ_L, can be extracted from the pressure drop data, though these results show more scatter than those of the penetration.

The results are shown in Table 2, where it can be seen that the anomalous results are associated with rapidly clogging filters. As expected, the coarse filter materials hardly clog at all; in fact, in many cases the pressure drop actually falls. This reduction in pressure drop is due to alterations in structure caused by both aerosol loading and manipulation of the material during removal from and replacement on the test apparatus. Different batches of polycarbonate and of fine polypropylene filters were used in the tests on coal dust and lead battery dust, and this may account for the greater clogging of polycarbonate by coal dust and polypropylene by lead battery dust.

AEROSOL CHARACTERISTICS

The basic similarity of the value of β_{TL} for the same aerosol acting on different materials suggests that the properties of the aerosol are critical in this process. Fundamental aerosol characteristics likely to affect the rate of degradation are size distribution, charge distribution, and chemical nature.

The aerosol size distributions for the carbon brick dust and the two types of foundry dust were measured with an aerodynamic particle sizer; but it was not possible to carry out such measurements on the lead-containing aerosols, and so in these cases, and in the tests using coal dust, Coulter analysis of the dust deposited on the filters was carried out. The ammonium chloride aerosol was examined with an Electrical Mobility Analyser. The results are shown in Table 3. Some information on the chemical nature of the aerosols was obtained by analysis of the X-rays emitted by particles captured on membrane filters subjected to electron bombardment from a scanning electron microscope. This technique, applied to our apparatus, enables elements with an atomic number greater than 10 to be identified, but it gives no accurate information on the relative abundances of the elements, nor on their state of chemical combination. The elements observed by this technique, or otherwise known to be present, are listed in Table 3.

DISCUSSION

A number of measurements have been carried out on the loss of performance of electrically charged filter materials after exposure to aerosols. It has been shown that the effect of the aerosols, in the low exposure limit, can, to an approximation, be described by a simple linear theory, expressing the effect of the aerosol on the filter material in terms of a single parameter, β. This parameter is about as fundamental a property as the single fibre efficiency, in that it can be considered constant throughout a filter of homogeneous structure, but that it will vary with filter packing fraction and filtration velocity.

TABLE 3

Aerosol Size Distribution and Chemical Composition

Aerosol	Number Average Dia. (μm)	Mass Average Dia. (μm)	Size Analysis Method	Chemical Composition
Silkstone Coal Dust	5.7	10.7	Coulter	Carbon and Incombustible matter
Carbon Brick Dust	0.7	5.3	APS	Carbon and Kaolin
Lead Smelting Fume	3.6	16.0	Coulter	Compounds of Pb,Sn,Ca,Si
Lead Battery Dust	3.9	9.6	Coulter	Compounds of Pb,Si,Ca,Fe
Foundry Burning Fume	1.3	4.7	APS	Compounds of Fe,Na,Al,Si, S,Cl,K,Ca,Ti, Cr,Mn
Foundry Fettling Fume	0.9	5.3	APS	Compounds of Fe,Na,Al,Si, S,Cl,K,Ca,Ti, Cr,Mn
Ammonium Chloride	0.05	0.32	Mobility Analyser	NH_4Cl

N.B. The average sizes are means in the case of Coulter Counter and Mobility Analyser results, and Medians in the case of APS results.

β appears to be more sensitive to aerosol type than to filter type, though there may simply be less variation amongst the materials used than amongst the aerosols encountered.

A Spearman rank correlation test (Freund,15) carried out on the order of β_{TL} for electret and resin wool materials and the average size for the industrial aerosols gives a correlation coefficient of -0.43 for the mass average and -0.37 for the number average. Perfect correlation would give a value of -1, and no correlation would give zero. The values above probably underestimate the importance of size, because two different methods of size analysis have been used; and it is clear that a correlation exists. It is also clear that this parameter alone is not sufficient to explain what is observed. The data on chemical nature of the aerosols are too few for any conclusions to be drawn; and the effect of the electric charge on the aerosol is a subject for future study.

Finally, a word of warning must be added about the direct use of β_{TL} as an estimate of filter quality. The parameter is as good in this respect as single fibre efficiency or layer efficiency. That is to say it gives some information, but not complete information. The value may be altered simply by making a material more tightly packed, but the penalty paid will be an increase in the parameter γ_L; just as layer efficiency may be improved by compression, but only at the expense of a higher pressure drop.

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