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Electrostatic Effects in Fabric Filtration:

Volume II. Triboelectric Measurements and Bag Performance (Annotated Data)

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EPA REVIEW NOTICE

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Electrostatic Effects in Fabric Filtration: Volume II. Triboelectric Measurements and Bag Performance (Annotated Data)

by

E.R. Frederick

Carnegie-Mellon University
Schenley Park
Pittsburgh, Pennsylvania 15213

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EPA Project Officer: James H. Turner

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

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ABSTRACT

The construction and application details of a bench scale, single bag, experimental filter unit are described. Also considered at length are a variety of supporting and complementary evaluation procedures, together with the data that they provide. Of special significance among the latter are the methods for, and results of, the electrical determinations that are not normally applied to filter media and particulates. The effect of these electrical parameters on the collection process is considered and used to explain performance variations.

The results of a number of separate filtration studies, carried out on a variety of industrially generated particulates, including those from a power plant and from metallurgical and chemical processes, are reviewed in detail and explained, as permitted, on the basis of electrostatic properties. The collection of a flyash, for example, was favored by the use of mid-triboelectric position media and not by the highly electropositive or electronegative fabrics that are employed for their high temperature properties. Three different electric furnace dusts also tended to respond best filtrationwise with mid-triboelectric position fabrics, using appropriate constructions for different cleaning practices. Steel grinding and burning dusts were shown to offer very critical filtration characteristics that demanded control of aerosol flow and particulate loading, as well as special care in the selection of the filter media. A ferromolybdenum by-product dust was collected best by very electropositive fabrics, but three different, high resistivity polymeric dusts performed best with mid-triboelectric position fabrics of suitable construction. Silica was found to be collected most efficiently by high cover electropositive fabrics with variations in construction dependent upon the adopted method of cleaning.

PREFACE

It is generally conceded that electrostatics may play a role in the capture and retention of many kinds of dust particles during the filtration process. While this feature of particle-to-filter medium interaction is relatively easy to accept, the influence of electrostatics on collection efficiency, fabric cleanability and especially on particulate agglomeration is not always readily acknowledged nor easily justified. Opposition to the concept of significant overall electrostatic involvement in the filtration process persists despite the fact that electrical forces have already been shown to be much stronger than gravitational, thermal, adhesion, and often inertial forces for particles in the 0.1 to 1 μm range.[1]

If the collected particles and the collection medium are both subject to charging, and these processes are not disputed, and if these charges are of high magnitude and particularly of opposite polarity, it seems apparent that a high level of attraction can occur between the two materials. What tends to be more difficult to comprehend, though, is the influence of these electrostatic characteristics on the agglomerating tendencies of the particles being collected.

In this report, the obvious practical effects of electrostatics are recognized but the real key to superior performance is relegated to the agglomeration phenomon. As small particles are brought into close proximity by and/or on suitably charged fibers , a kind of aggregation is considered to occur that results in a porous deposit. A cake formation such as this then is indicated to be less resistant to gas flow than that of a compact cust layer occurring without such electrostatic interaction.

Recent activities devoted to studies of electrostatic augmentation in the mechanical separation, wet scrubbing or filtration of fine particles have reaffirmed the usefulness of this extra input for providing superior performance, in terms of both better operating parameters and collection efficiency. Despite this effort, however, little attention seems to have been directed, and

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[1]Whitby, K. T. and B. Y. H. Liu, The Electrical Behavior of Aerosols, In Aerosol Science, Davies, CN.(Ed.), New York, NY, Academic Press, 1966.

no direct evidence has been obtained to identify the fundamental principles that lead to such improvements. The work of Gaylord W. Penney reported in Volume I of this two-part series on Electrostatic Effects In Fabric Filtration, however, considered the basic principles and provides evidence to indicate that electrostatics truly does contribute to the formation of a porous deposit. If electrostatics by augmentation is a factor in this kind of change, then surely the same features accomplished by natural charging processes (contact/impact, etc.) should also be effective. Accordingly, in this report (Volume II of the series), the importance of, in fact, the critical need for, suitable electrostatic charge balancing (between medium and particulate) and obtainable naturally without augmentation, is stressed as the mechanism by which optimal filtration performance may be achieved. Ideal collectability is considered possible under normal baghouse conditions when, but only when, the appropriate electrostatic characteristics are established even without the need for - or restrictions imposed by - augmentation. Selection of the most favorable fabric then is made on the basis of its triboelectric properties commensurate with those of the particulate, while at the same time, giving appropriate consideration to the constraints of fabric construction.

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ACKNOWLEDGMENTS

The co-investigators are particularly grateful to Dr. James H. Turner, the EPA Project Officer, for his thoughtful considerations and technical support during the course of the investigative program. Others, too numerous to mention here, have contributed significantly to the success of the study through their cooperation in providing commercial and experimental filter media and in supplying problem dusts. The extraordinary assistance given by Messrs. John W. Brooks and Robert W. MacWilliams is acknowledged with sincere appreciation.

The project could not have functioned effectively without the dedication and independent contributions of the graduate student Robert Lembach and the technicians Ron Feigel, Kirk Ludington, David Richey, John Wieczorkowski and Brent van Zandt.

LIST OF DEFINITIONS AND ABBREVIATIONS

DEFINITIONS

aerosol	-- particulate dispersion in gas
agglomerate	-- consolidation of particles
antistat	-- charge bleed-off agent
augmentation	-- increase (of charge) artificially
cake	-- collected solids, removable by cleaning method
charge	-- electrical quality
...polarity	-- electropositive or electronegative property
...intensity	-- magnitude
...dissipation rate	-- loss rate
cleaning	-- particulate removal process
Dacron	-- a polyester fiber
Darlan	-- a dinitrile based fiber, discontinued
Dralon T	-- a polyacrylic fiber
dust	-- particles or particulates
efficiency	-- control effectiveness
electrostatic	-- electricity at rest
fabric	-- cloth structure
fiber	-- basic element of filter
fiberglass	-- fine glass fiber
filter	-- gas-particulate separator
Kevlar	-- aramid fiber
Kodel	-- polyester fiber
Microtain	-- proprietary acrylic name
Nomex	-- aramid fiber
nylon	-- polyamide fiber
particle	-- particulates or dusts
permeability	-- air flow-through rate
plug	-- particles held in or on fabric and not removed by cleaning
PVA	-- polyvinylacetate
resistance	-- electrical resistance
triboelectrification	-- rub-induced electrification
weave	-- fabric construction
yarn	-- construction element of woven fabric
yarn count	-- warp and filling yarns/unit length

ABBREVIATIONS

AATCC	American Assn. of Textile Chemists & Colorists
AF	Albany International or Globe Albany Corp.
AFI	Air Filters, Inc.
as	antistatic
cal	calendered
Carb	The Carborundum Co.
cond	conductive
cs	cotton system
DFTw	double faced twill
EId	E.I. du Pont de Nemours and Co., Inc.
F	filling yarn
°F	degrees Fahrenheit
fil	filament
fin	finish
g	gram
Gore	W.L. Gore & Assoc., Inc.
h	hour
H-as	Hyamine-antistatic agent
Hb	T.J. Heimbach Gmbh & Co. (Duren, Germany)
h cover	high cover
Hom	Homestead Mills
JPS	J.P. Stevens & Co., Inc.
knit	weaving variation by looping threads
lam	laminate
MSA	Mine Safety Appliance Co.
nap	high concentration of fiber ends
nat	natural
nd	not determined
os	one side
ΔP	pressure drop (in. w.c.) across filter
ΔPp	pressure drop (in. w.c.) across plugged filter
pe	polyester
pl	plain
pp	polypropylene
P & S	P & S Textiles Inc.
ptfe	polytetrafluoroethylene (Teflon)
Resp	respirator felt
Si, Sil	silicone
sp	spun
ss, s steel	stainless steel
st	staple
Tas	Taslan (bulked filament)
Tef	Teflon
tex	texturized (bulked yarn)
Troy	Troy Mills, Inc.
unt	untreated
USF	United States Filter Corporation
V	volts
W	warp
W-Ac	Western Acadia, Inc.
ws	woolen system
ZnR	Zinc resinate
C-T, CM-L, PG-C, R-C, RH-P, U-D, U-H, U-J, WPP-S	code letters identifying dust origin

VOLUME II

EXPERIMENTAL FILTRATION PROGRAM

CONCLUSIONS

A single bag, bench scale experimental fabric filter unit has been designed, built, modified, and used effectively to demonstrate how different fabrics produce very different filtration characteristics. These results, together with data from additional facilities for determining the electrical as well as other parameters of fabrics and particulates, indicate that filtration properties:

- differ with changes in only the fiber make-up of similarly constructed fabrics,
- differ with changes in only the construction of fabrics made from the same kind of fibers,
- differ with changes in the surface properties of the same fabric,
- differ with changes in the surface properties of the same particulate,
- seem to be influenced critically by the electrical properties of both particulate and filter fabric, and
- tend to be enhanced most significantly by the electrostatic conditions of the fabric filter that produce an agglomerated, porous-type filter cake.

RECOMMENDATIONS

The hit or miss tactics used so commonly in prescribing filter media, the questionable quality and the inconsistencies among media once specified all need to be eliminated if baghouses are to achieve their full potential for optimal overall performance. One of the first steps considered necessary to utilize fully the electrostatic properties is that of establishing the fabric's ability to develop an electrostatic charge. Secondly, the electrostatic properties of all industrial filter media as well as those of the particulates should be known. Thirdly, the preferred fabric filter media-collected particulate charge relationship for optimum collectability, efficiency and energy conservation should be established for filtration processes of concern.

In order to achieve these goals, the following specific recommendations are offered:

... include electrical resistivity among the specifications for fabric filter media;

... include the electrostatic properties of charge intensity, charge decay rate and triboelectric position in the list of properties of filter media;

... develop a procedure for determining the electrostatic properties of particulates;

... determine the influence of industrial environmental conditions on the charging properties of media and particulates; and

... establish an acceptable procedure for - and carry out, regularly, experimental evaluations of - the collectability of particulates for the purpose of providing accurate prescriptions for media and to relate the electrical as well as the other physical properties of media with filtration parameters.

EXPERIMENTAL FILTRATION FACILITIES

The bench scale fabric filtration system shown in Figure 1 was devised and fashioned to simulate the performance of one bag in a commercial baghouse and to supply information on every characteristic of its operation. This testing equipment allows for considerable versatility in evaluation procedures with the necessary instrumentation for reliable and complete delineation of electrical and other physical properties as well as filtration parameters. Most varieties of particulates may be processed by either the shaking, reverse air or pulse collector method. The more important characteristics of the test facility are described as follows:
(Please note that the letters referred to in the text identify the parts so noted in Figure 1.)

The particulate feeder (A), a critically important part of the filter unit, was changed in the course of the investigations, from the original vibrating-auger system to a vibrating and rotating gear type of dust dispenser. The latter was developed and used with agitation also applied to the dust in the hopper to introduce even the sticky and difficult-to-feed particulates into the air injector (B) continuously at a uniform rate. The quantity of dust occluded in the space between two teeth of the gear can be made to be quite consistent through the aid of the gentle settling afforded by vibration and the constant movement imparted by gentle stirring in the hopper. The separate parcels of dust are delivered at a rate determined by the gear's speed of rotation. These parcels, essentially of constant size for the gear now in use, are dispensed into the injector by a controlled (C) air stream where the dust is dispersed by moderately high (100 psi) air pressure. The resulting aerosol passes through the flow measuring venturi (D) and the heating section (E). Further on in the system, the aerosol reaches the sampling station (F) and the popper (G) vent (H) before the reheater (I) and header (J) under the test bag (K). Dust fallout from the aerosol before it reaches the bag as well as dust shaken from the test filter bag is collected in the jar (L). Incidentally, a determination of the ratio of the dust fallout into the header to that collected on the bag during repeated runs, serves to indicate the condition of the dust (i.e., the amount of aggregation and the relative concentration of coarse particles).

In operation, the test bag (K), suitably fitted between the two outside stitch lines with a fine, 30 gauge wire in order to

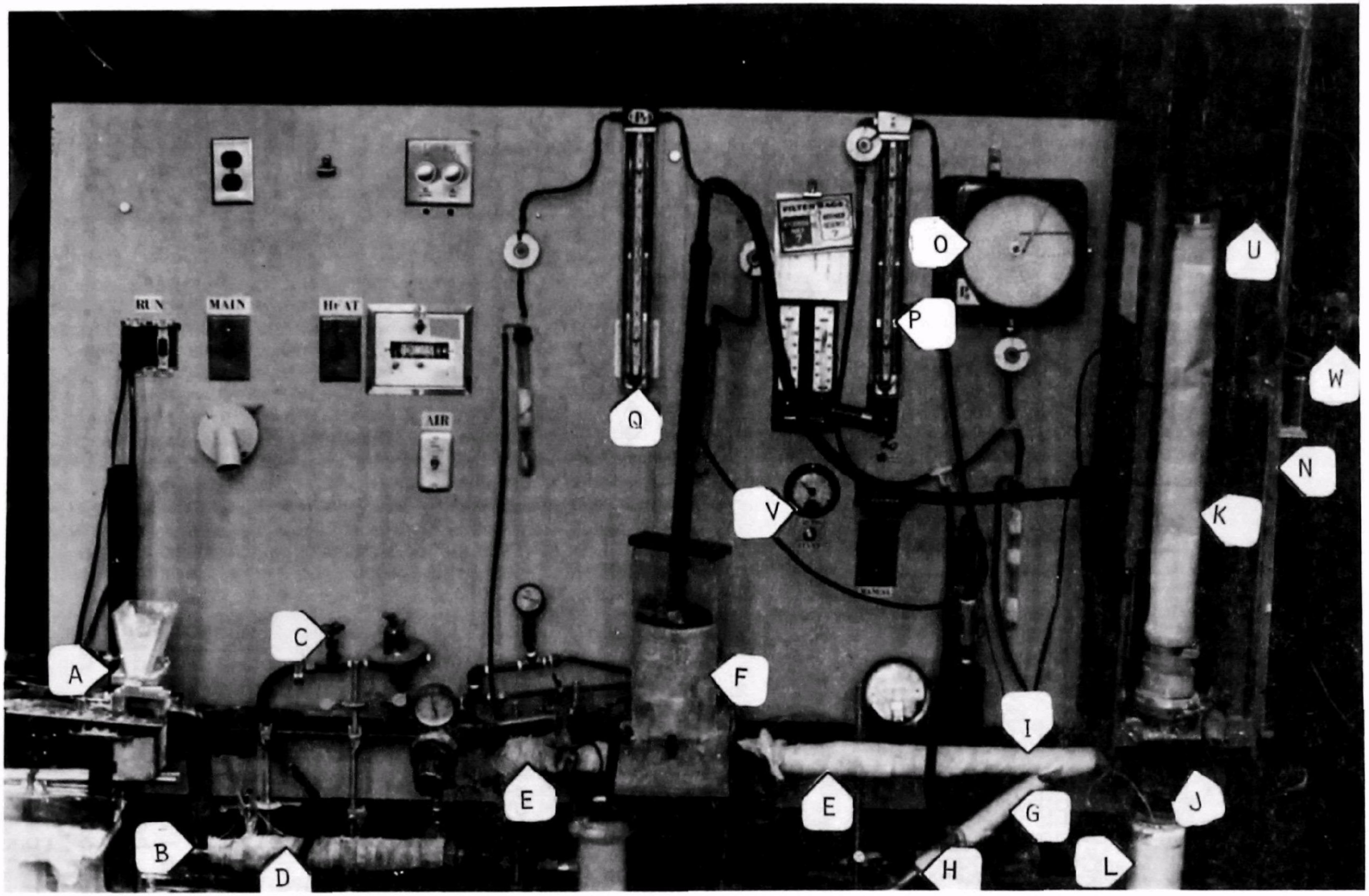


Figure 1 Experimental Filtration Equipment

allow electrical measurements during the filtration process, is enclosed in the cabinet (N). The cabinet is kept under a slightly negative pressure in order to exhaust any leaked dust to a large filter bag behind the panel. Appropriate taps are included, one in the header for pressure drop recording continuously on the chart (O) and for direct reading on the manometer (P). The flow rate of the aerosol stream is determined by means of a calibrated venturi (D) at the manometer (Q). In order to restrict the humidity of the aerosol and as needed to conform with commercial conditions, heat is applied to the air-dust stream at the regions (D) and (I) and controlled by the thermostat in the header (J).

Cleaning of the bag may be accomplished by the horizontal shake action imparted by the spring return-solenoid activated unit (U) or by means of the "popper" (G) system that applies a vacuum type, pull-back action.

EXPERIMENTAL FILTRATION PROCEDURE

The performance, filtrationwise, of different media in collecting various particulates is determined as a function of the weight of collected solids, the weight and air flow resistance of the plugged solids held within the fabric and the effectiveness of the fabric in retaining the particulates. The data needed for making appropriate filtration comparisons is obtained under uniform and reproducible conditions of essentially equivalent dust loadings, aerosol flow rate and, in these studies, to an arbitrarily, preselected and fixed pressure drop limit. Physical changes in the particulate from its condition in the initial dispersion to that found in the collected form from the collecting bag are also determined and the changes in appearance are recorded photographically. Following preliminary determinations of the filter bag weight, clean bag pressure drop, and resistivity, filtration is commenced and the changes in pressure drop across the filter fabric as a function of deposited cake are recorded on the chart (O) and read on the manometer (P). Periodically, in the course of the evaluation, when the pressure drop across the filter flow is halted to stop aerosol flow, the terminal pressure is recorded, the bag is removed from the header and weighed to determine collected solids (cake and plug). After reinstallation, the bag is cleaned by the selected method (shake, reverse air, or simulated pulse jet) and the plugged bag pressure drop is recorded. The cleaned bag is now removed from the header and weighed to determine the amount of accumulated plug. Simulation of the commercial reverse air cleaning process on woven fabric bags or simulation of the pulse air jet practice applied to felted fabrics is accomplished by means of the "popper." Its activation is accomplished by means of the switch and timer (V) to impart a controlled number of air pulses with fixed intermittent dormant periods, usually of one second.

The number of filtration cycles needed to reach equilibrium depends upon a number of material and operating conditions. Usually, at least ten separate filtration and cleaning operations, with at least five cake and plug weight determinations during the final cycles are required to establish these parameters.

SUPPORTING INSTRUMENTATION

A number of instruments, gauges and other supporting analytical facilities are required to determine dust loading, aerosol flow rate, pressure drop, clean, caked and plug bag weights, pressure drop, and permeability as well as the electrical properties of the filter fabric of the caked and plugged bags and of the dusts being filtered.

A balance (W) mounted for convenience at side of the bag enclosure serves to obtain clean, caked and plugged bag weights. Suitable balances are also available for determinations of dust loadings, particulate accumulations in the collector jar and leaked dust. Such other instruments or equipment as manometers, ammeters, voltmeters, timers, variable drives, vibrators, stirrers are also evident in Figure 1. In addition, back-up facilities are available such as a fabric permeometer (Figure 2), a fabric electrostatic generator-evaluator (Figure 3), dust resistivity measurement equipment (Figure 4) and such others as fabric sewing, washing and drying machines together with photographic facilities.

DETERMINATIONS OF ELECTRICAL PROPERTIES

Electrical Resistivity

The electrical resistivity of dusts and fabrics influences chargeability mostly by increasing the rate of charge dissipation. Antistatic finishes do not eliminate static, but they are effective in bleeding-off charges rapidly. Because these agents invariably reduce electrical resistance and they are used so extensively in the processing and/or production of fibers and fabrics, fabric resistivity data can serve to indicate the cleanliness of materials offered for filter use.

The electrical resistivity of a substance may be defined in two ways; through it and referred to as volume resistivity or over its surface and, of course, referred to as surface resistivity.

Volume Resistivity--

Volume resistivity refers to the electrical resistance measured through the bulk of the substance under noted conditions of temperature and humidity and is an especially important parameter of both particulates to be collected and filter fabrics. The guarded electrode method (ASTM D 257-61) is useful for determining either volume or surface resistivity, but other proceedures were adopted for making these measurements.

Test Procedure--

Consider, for example, a cube of material to be evaluated.

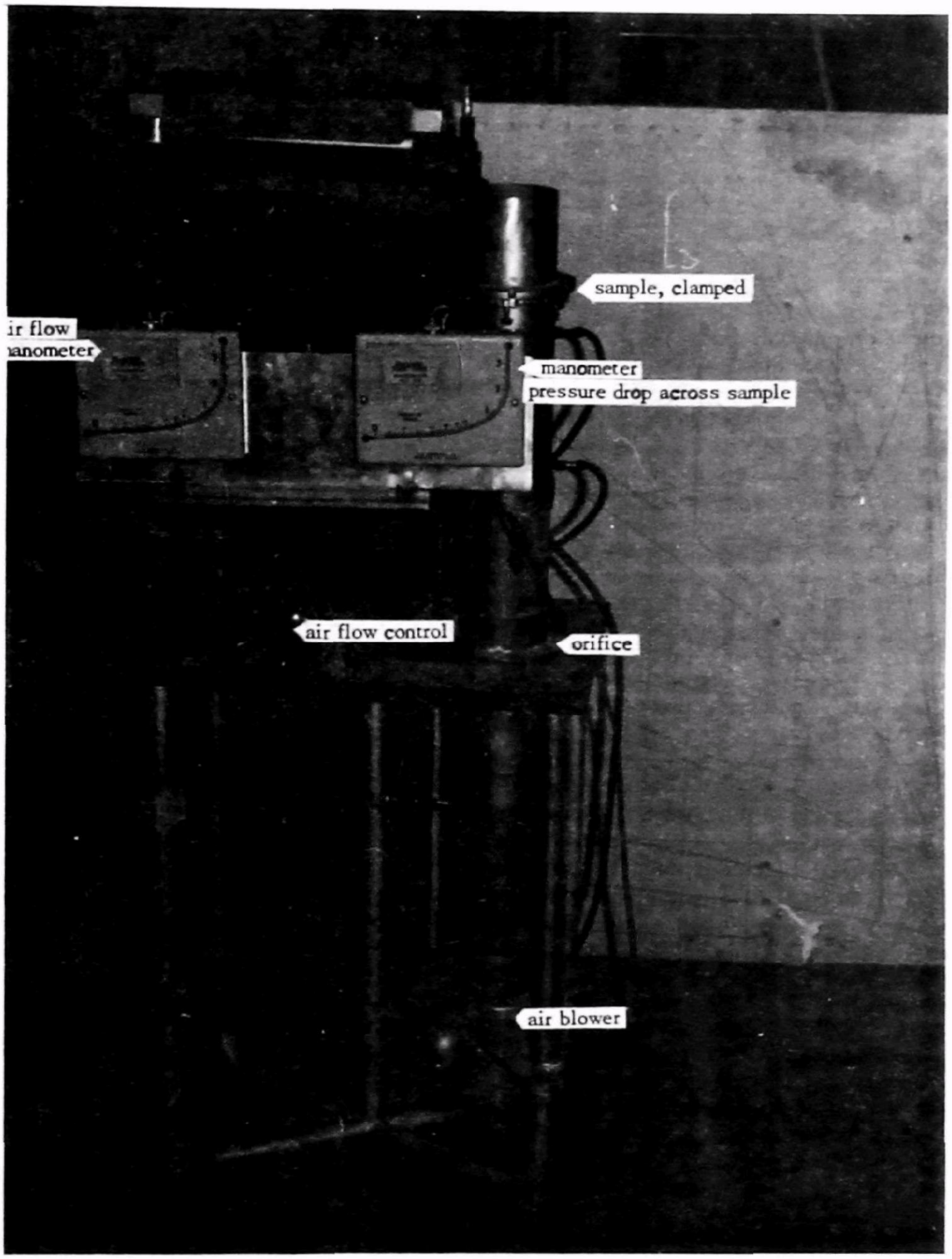
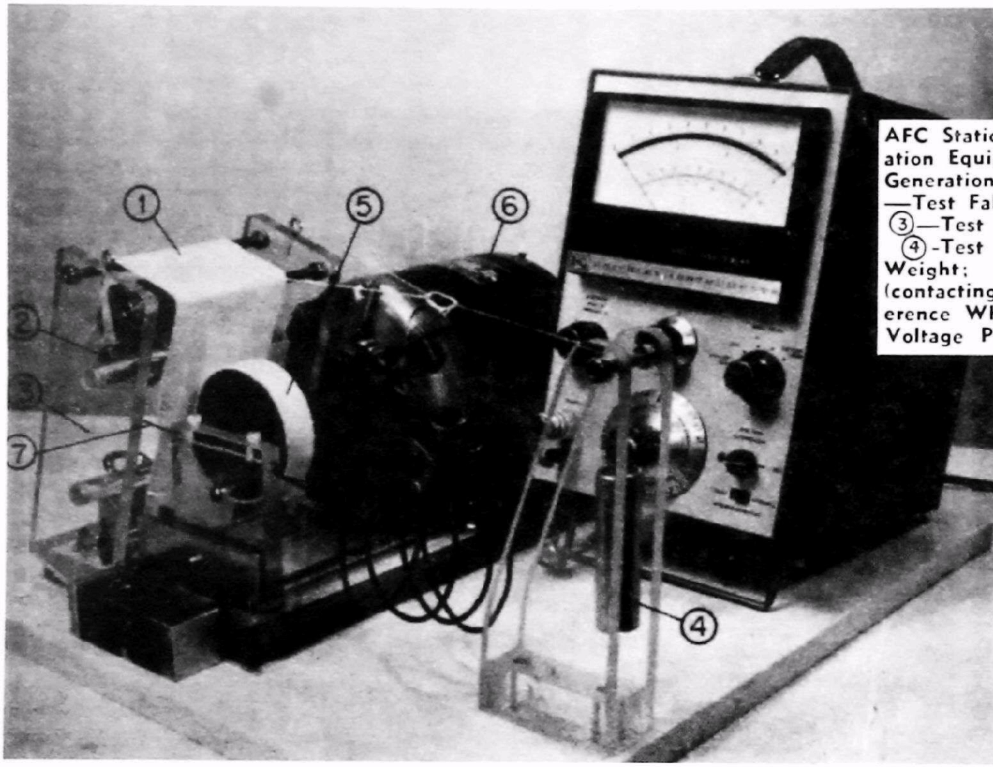
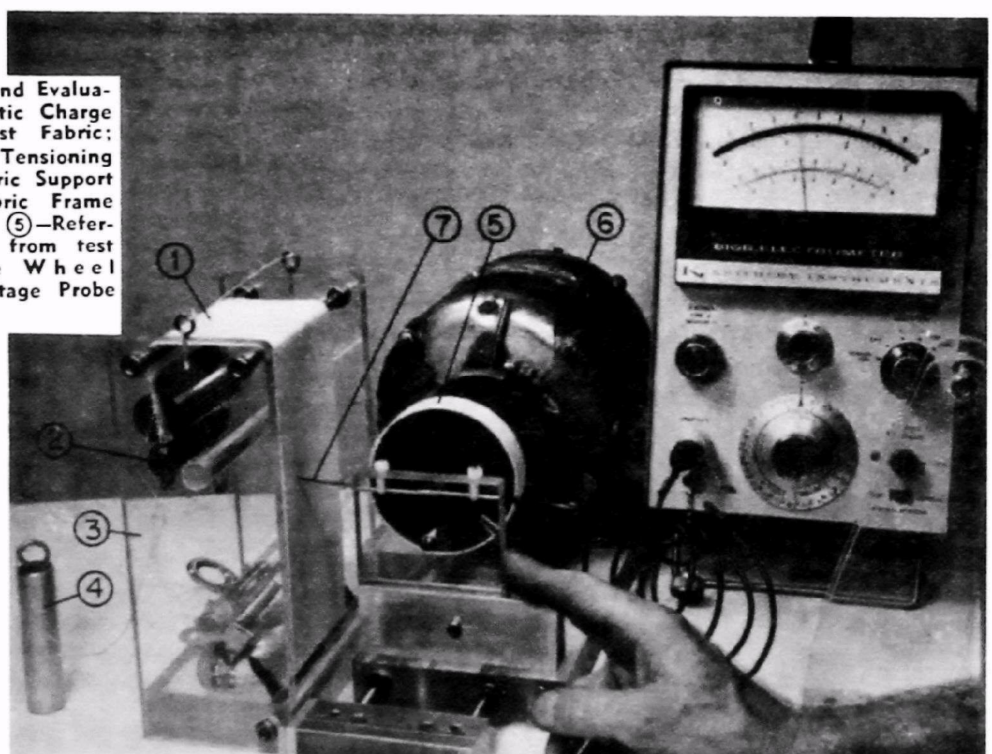


Figure 2 The Permeometer



3A

AFC Static Generation and Evaluation Equipment*— Static Charge Generation. (1)—Test Fabric; (2)—Test Fabric Tensioning Weight; (3)—Test Fabric Support Frame; (4)-Test Fabric Frame Tensioning Weight; (5)—Reference Fabric (contacting test fabric); (6)—Reference Wheel Drive Motor; (7)—Voltage Probe (retracted).



3B

AFC Static Generation and Evaluation Equipment*— Static Charge Measurement. (1)—Test Fabric; (2)—Test Fabric Tensioning Weight; (3)-Test Fabric Support Frame; (4)—Test Fabric Frame Tensioning Weight; (5)—Reference Fabric (removed from test fabric); (6)—Reference Wheel Drive Motor; (7)—Voltage Probe in Measuring Position.

FIGURE 3. FABRIC TRIBOELECTRIFICATION AND CHARGE MEASUREMENT

*U.S. Patent 3487296

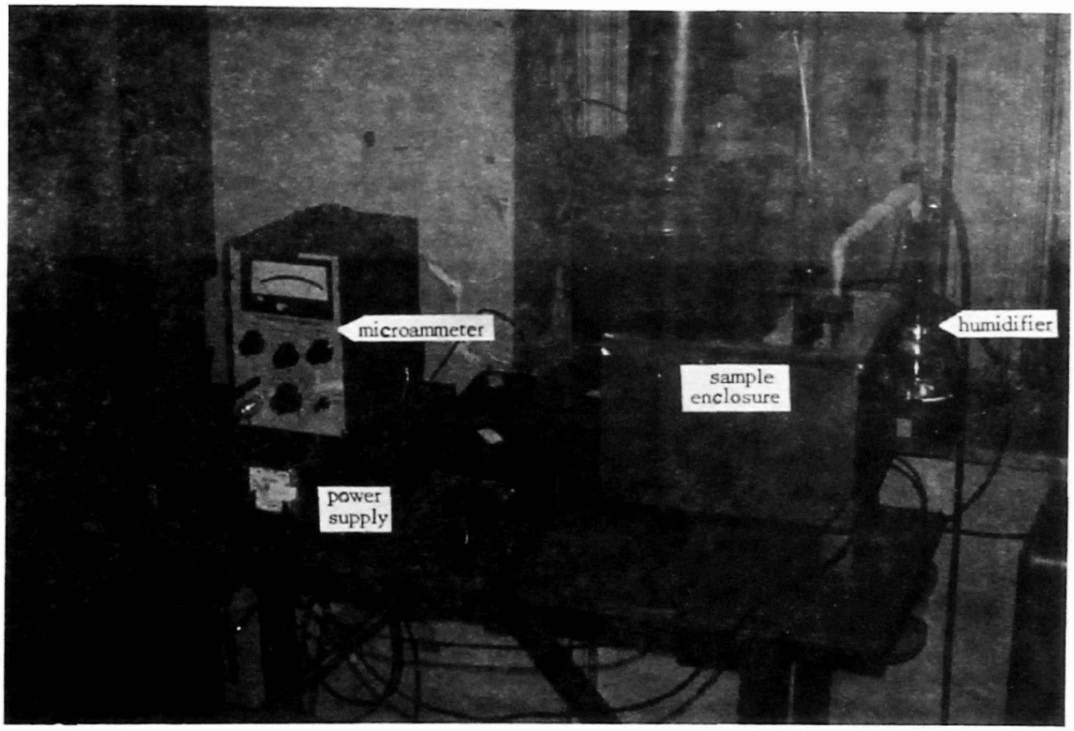


Figure 4 Dust Resistivity Equipment

With a conductive plate or a naturally conductive surface on opposite faces of the cube, a DC voltage is impressed in stages from low potential (∿ 200 V) to high values (∿ 2000 V) until a reproducible measure of current is obtained. From Ohm's Law, then, the value of resistance, R is calculated. Using the equation $R=\rho L/A$, volume resistivity (ρ) in Ω-cm is determined from the distance L(cm) between the faces and the area A(cm^2) of the smallest opposing face.

The procedure adopted in this laboratory to determine the resistivity of particulates is considered on page 28 with the apparatus shown in Figure 4.

Surface Resistivity of Fabrics--

The surface resistivity of filter fabrics as produced or as caked or just plugged may be determined by any of several procedures including the ASTM guarded electrode method[1] referred to above, the AATCC Test Method 76-1972[1] (approved as the ANSI L14.112-1973 method), or by the square method[1] described below and shown in Figure 5. Surface resistivity by this practice is defined as the resistance in ohms per square (Ω/□) of the test specimen.

It will be apparent that this is a relatively easy to carry out test employing no special weighted and shaped electrodes but only the 3 in. wide clamps to hold the specimen at a separation of 3 in. In operation, the equilibrated test specimen of suitable size (3"+ x 3"+), is clamped securely and the DC voltage is applied in stages beginning at a moderately low value of 200 V and gradually increased as required, usually up to 2000 V or until a reproducible value is provided for the measured current. Ordinarily, values of current below 10^{-11} or above 10^{-5} need only to be noted, not measured, as will become evident from the following discussion.

The current obtained by impressing a known voltage on the specimen and measured by means of the electrometer is used in the Ohm's Law relationship to calculate resistivity as follows:

$$\text{At voltage } E(V), \text{ resistivity } R\ (\Omega/\square) = \frac{E \text{ (applied voltage) V}}{I \text{ (measured current) amps}}$$

Where E is usually 500 V but may be increased to at least 2000 V as required;

I is the current in amperes; and

R is the calculated resistance in ohms per square, Ω/□.

[It will be apparent that because the path of the impressed voltage covers both the top and bottom surface of a fabric, the value of the resistance determined under these conditions will actually be one half of the real value, and the true surface resistivity will be twice that measured. Ideally, then, especially since filter

[1]Data obtained by these methods are essentially equivalent and well within the limits needed to determine whether or not a fabric carries an antistatic finish.

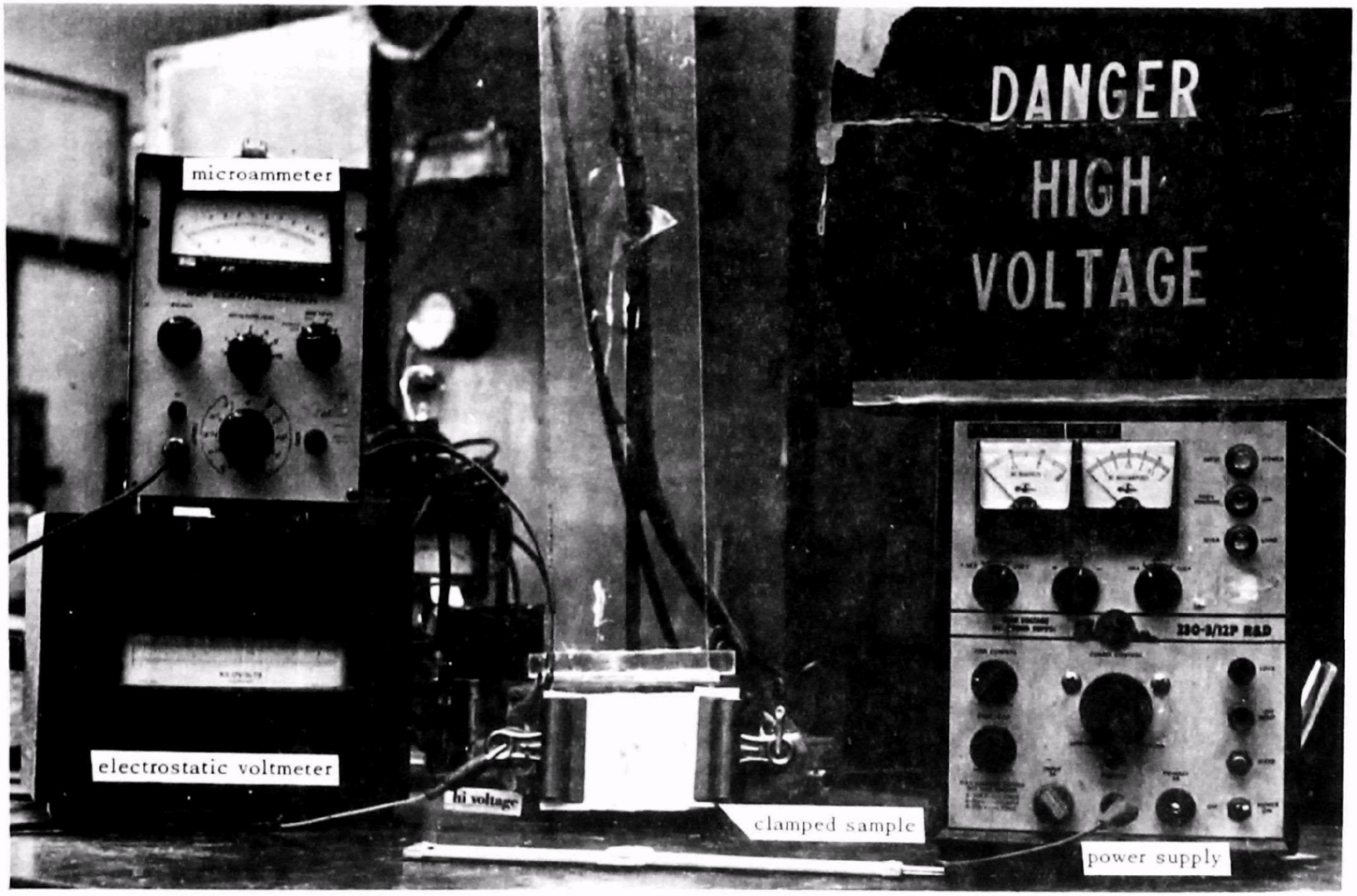


Figure 5 Fabric Resistivity Equipment

media are so often made with different surfaces, both of the clamp edges on one side, but on the same side, should be insulated. Reversing the clamps with insulated surfaces on a different side each time provides current values that allow calculation of R (Ω/□) directly for each surface.]

Resistivity values of about 10^{11} Ω/□ and less, indicate anti-static qualities, more or less significant, as shown for similar evaluations in the following Table:

TABLE 1. FABRIC RESISTIVITY[a] VS ANTI-STATIC RATING

Volume/vertical resistivity[b] (ohm-cm)	Surface/horizontal resistivity[c] (ohm)	Anti-static rating
[Material equilibrated at 70°F]		
$>10^{11}$	$>10^{13}$	Nil
$10^{10}-10^{11}$	$10^{12}-10^{13}$	Poor
$10^{9}-10^{10}$	$10^{11}-10^{12}$	Moderate
$10^{8}-10^{9}$	$10^{10}-10^{11}$	Fairly good
$<10^{8}$	$<10^{10}$	Good

[a] ASTM D257-61
[b] E. R. Frederick, Report to Mellon Institute, December 1, 1964 May 31, 1965
[c] D. Wilson, *J. Textile Inst.*, 54: T97 (1963), as measured between opposite edges of a 1-in. square or, for high resistance materials, between 2-in. electrodes, 0.2 in. apart.

It should be evident that since moisture can influence resistivity quite significantly, especially the resistivity of materials that sorb water, the measurements should be conducted under conditions of controlled temperature and humidity, preferably at moderate to low values (not over 50% RH).

Electrostatic Properties of Fabrics

Whenever two dissimilar materials (usually, at least one of which is an insulator) are rubbed together, one becomes electropositive, the other electronegative. This is one way particles and fabrics become charged.

Polarity variations among fabrics reflect inherent fiber differences that may be demonstrated from rubbing tests. The testing unit that we use is shown in Figure 3. By the rubbing method, a triboelectric series is obtained in which all fabrics may be listed from those that are very electropositive like wool, glass, and nylon, to those that are quite electronegative like the polyolefins, and especially, "Teflon." It will be apparent that by repeated rubbing trials, the series may be expanded to include any number of fabrics (Table 2). A variety of materials, including particulates, may be located in the same series. Other factors being equal, the greater the spread between materials in the series, the greater the interaction between the two materials.

The intensity of the electrostatic charge (together with any polarity differences) is considered to have a marked influence on the collection and is a function of surface (fiber, yarn, or fabric) roughness as well as of the inherent properties of the polymer. Other factors equal, the rougher the surface, the higher the generated charge. Rough fibers like wool, rough yarns like low twist spun yarns, and high cover fabrics like those that are napped, tend to develop higher charges than smooth surfaced materials such as those made from smooth (melt extruded) continuous filament fibers in low twist, pressed, calendered, or otherwise smooth fabrics.

Evaluation Procedure (Figure 3)--

- Triboelectrification and Measurement

1) Mount a clean and conditioned reference fabric on the 3 in. diameter wheel of the motor using the wedge to fix the overlapped ends in the slot of the wheel. (Do not permit fabric ends or wedge to extend above surface.)

2) Move the motor and other parts of the platform to the rear position.

3) Without soiling the conditioned test fabric, cut the sample to 3 in. width and 12 in. length and insert one end of the length in the center of the clamp at the base of the sample support.

4) Place the test fabric over both rods in the support frame and attach the clamp weight to the free end on the left-hand side.

5) Pull the motor support platform to the front position so that the reference fabric wheel is centered on the test fabric.

6) Zero the electrometer and ground off charges from the test fabric.

7) Extend the tensioning string from the sample support frame over the pulley rod of the frame at the far right of the test unit base and allow the weight to hang free. This will cause the test fabric to engage the reference fabric covered wheel.

TABLE 2. ESTIMATED* TRIBOELECTRIC POSITION OF SOME FILTER FABRICS

+8·
- 21 & 97 WOOL/NYLON, 21 [20%]
- 104 WOOL, HOM 8 [80%]
- 78 WOOL/NYLON [80%]

} APPROXIMATE LOCATIONS

+6-- NYLON 800 B (REFERENCE)
- 112 DACRON [80%]
- 102 WOOL, HOM 7 [85%]
- 23 WOOL/COTTON [100%]

+5·
- 122A DRALON T (DYED) NAP
- 15 DACRON [50%]
- 98 NYLON [45%]
- 122B DRALON T (DYED)

+4·
- 103 WOOL, HOM 6 [80%]
- 18 POLYESTER [90%]

+3·
- 110 NYLON, NAP [75%]
- 117 ACRYLIC, ZC [90%]
- 114 POLYESTER/GLASS [90%]

+2·
- 116 POLYESTER [75%]
- 6 KODEL [20%]
- 18 POLYESTER, NAP [25%]
- 93 DACRON [40%]
- 120 DRALON T [30%]

+1·
- 19 POLYESTER & PVA [45%]
- 9 50/50 DA/OR [35%]
- 77 GLASS [77%]
- 2 NOMEX [60%]

0·
- 118 POLYESTER [70%]
- 7 ACRYLIC, Z [40%]
- 107 DACRON, NAP [60%]
- 87 DRALON T [85%]
- 41 ACRYLIC, Z [25%]

−1·
- 12 ORLON [30%]
- 42 ORLON [60%]
- 10 75/25 DA/OR [40%]
- 3 DRALON T [30%]

−2·
- 16 DACRON SI [30%]
- 83 POLYPROPYLENE [50%]

−3·

−4-- DARLAN S546 (REFERENCE)
- 90 GORE (NOMEX BASE) [75]
- 37 TEFLON [0%]
- 65 KEVLAR [45%]

} APPROXIMATE LOCATIONS

−6·

*FROM TRIBOELECTRICIFICATION DATA BY PROPORTIONAL CALCULATIONS

[ ] = RELATIVE DISCHARGE RATE [LOSS (%) IN 2 MINUTES] AT 50% RH

NOTE: NUMBER PRECEDING EACH FABRIC IS AN ARBITRARY FABRIC REFERENCE NUMBER (SEE TABLE 4)

8) Turn on the motor switch momentarily (1 to 2 sec) and allow the reference wheel to stop. (Within the limits of about 100 to 500 rpm, the number of revolutions of the reference wheel is not critical).

9) Remove the weight attached to the test fabric support frame by lifting it over the frame to a resting position on the far left of the test unit (as in Figure 3B). This will remove the test fabric from contact with the reference fabric.

10) With the probe support in the far right position, move the motor base support to the rear until the probe holder reaches the center of the test fabric.

11) Slide the probe support to the far left position so that the probe contacts the rubbed test fabric.

12) Read the meter.

13) Slide the probe support to the far right position.

14) Slide the motor base support to the rear position.

15) Ground off the charges from the test fabric by rubbing ground wire over the entire rubbed area and beyond.

16) Repeat the above measurement at least four times, recording the fourth and fifth measurements as the true charge intensity.

- Triboelectrification and Discharge Rate Determination.

1) Repeat the operations indicated above through operation 9.

2) Allow the test sample to remain in this condition for a period of two min after the rubbing operation.

3) Slide the probe support to the far left position so that the probe contacts the rubbed but discharging test fabric.

4) Read the meter.

5) Two or three tests of this type are usually adequate for providing data to be used with that obtained in operation 12 for indicating the rate of charge dissipation.

6) The charge dissipation (percent) after two min equals 100 x [(data from operation 12) minus (data from operation 4 of this section)] divided by (data from operation 12).

Triboelectric Data for Some Filter Fabrics--
The direct influence of a fabric's electrical resistivity on electrostatic charging and the rate at which the charge decays is

TABLE 3. ELECTRICAL VARIATIONS IN SOME FABRIC FILTER MEDIA

No.	Fabric Type	Resistivity, Ω/□[a] @ Room Conditions (80°F/39% RH)	Resistivity, Ω/□[a] @ Room Conditions (after 150°F/16 h)	Relative Electrostatic Data [p.12][b] vs. nylon, volts	Relative Electrostatic Data [p.12][b] vs. darlan, volts	Relative Electrostatic Data [p.12][b] 2-min loss, %
2	Aramid, fil. (D.F.TW.) as received	7.0×10^{10}	—	- 0.5	+ 0.5	100
2	Aramid, fil. (D.F.TW.) wash-nonionic, rinsed well	5.0×10^{13}	--	-10.0	+ 3.0	30
30	Aramid, fil. (3 x 1 TW) as received	2.0×10^{10}	--	- 0.5	+ 1.0	100
30	Aramid, fil. (3 x 1 TW) wash-nonionic, rinsed well	2.0×10^{13}	--	- 6.6	+ 3.0	20
18	Polyester, sp. (2 x 2 TW) napped as received	8.3×10^{9}	7.4×10^{13}	- 1.3	+ 3.9	80
18	Polyester, sp. (2 x 2 TW) napped wash-nonionic, rinsed well	2.0×10^{12}	5.0×10^{14}	-10.0	+11.6	25
41	Acrylic, sp. (3 x 2 TW) as received	2.0×10^{11}	--	- 1.0	+ 1.0	100
41	Acrylic, sp. (3 x 2 TW) wash-nonionic, rinsed well	1.9×10^{13}	2.7×10^{14} (bone dry) (from oven) to 7.0×10^{13} (conditioned)	-10.0	+ 5.8	25

[a]AATCC Method 76-1972 (ANSI L14.112-1973-2/15/73)

[b]@ 70°F/50% RH

shown in Table 3. The data reported here are for only four commercial fabrics and indicate that just a modest reduction in surface resistivity (i.e. to 10^{10} Ω/□) can affect chargeability to a significant extent; thus confirming the relationship given in Table 1. The effect shown on resistivity and, thereby, on electrostatic charging of a wash-removed antistatic finish is evident. It can also be seen that the finish is not active when desiccated (note the change due to heating fabric #18) and is fugitive. Data such as these have been obtained for an exceptionally large number of commercial filter fabrics. If, therefore, electrostatic charges are as important in the filtration process as this report will attempt to show, the presence of such finishes must be known and, for most applications, removed prior to use. The easy-to-carry out resistivity test, therefore, would seem to be a necessary part of any filter media control program.

The results of rubbing tests conducted on some of the fabrics available for filtration evaluation, according to the procedure noted above, are included in Table 4. The relatively low resistivities of some as-received fabrics, most of which develop much higher values after laundering, clearly indicate the presence of a removable antistatic finish, most likely the fiber producer's treatment applied to enhance processing. That this finish is removable by laundering [or simply a hot (140°F) water rinse] is evident from the change in both resistivity (from 10^{10} to 10^{13} Ω/□ or higher values) and the triboelectrification data.

The triboelectric series provided in Table 2 is offered to illustrate the usefulness of the rubbing tests for establishing such a series. Because a proportional kind of analysis of these rubbing data was used to develop the Table, the positions should not be considered to be absolute. The real locations can be specified accurately only by using all of the samples as both the rubbed and rubbing materials.

While this restriction on the use of the series as given is not to be overlooked, it is interesting to speculate on some of the apparent similarities and anomalies shown. For example, the four acrylics, despite their obvious chemical difference, are located close together in the -0.2 to -1.5 region of the arbitrary scale. Dacron, on the other hand, shows a spread of from about +4.8 to -2.5 on this scale. Such wide differences in the triboelectric data for Dacron were shown earlier.[1] Also significant and undeniable, is the very electropositive character of the wool/nylon fabric and the extremely negative properties of Teflon and Kevlar. Actually, Kevlar appears to be the most electronegative fabric and it is also interesting because of its tendency to lose its charge faster than Teflon.

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[1]Frederick, E. R., *Chem. Eng.* 68:107 107-114 (June 1961).

TABLE 4. SOME PROPERTIES OF VARIOUS FILTER MEDIA

Fabric			Fiber			Construction			Electrical Properties			
No.	Mfr.	Style No.	Generic	Trade	Type	Yarn	Weave / Form	Perm. cfm/ft² @ 0.5" w.c.	Resistivity (Ω/□) as received, 70°-80°F/40-50%RH	Resistivity (Ω/□) as washed, 70°-80°F/40-50%RH	Rel. Triboelectric Pos. & [decay rate] 70°F/50%RH	Rub Voltages vs nylon/vs Darlan
1	JPS	D-8500-1	olefin	polyprop	fil.	fil.	plain	7	> 2×10^{14}	--	--	--
2	JPS	04-D8301	aramid	Nomex	fil.	fil.W / sp.F	d.f. twill	53	7×10^{11}	> 10^{14}	+ 0.6 [60]	-7/+6
3	JPS	55-90077	acrylic	Dralon T.	st.	sp.	3x1 twill	19	2×10^{13}	> 10^{14}	- 1.7 [30]	-10/+3
4	JPS	D-8328	aramid	Nomex	fil. & Tas.	fil.W / tex.F	d.f. twill & nap	45	4×10^{13}	4×10^{13}	+ 0.7	-3.4/+3
5	JPS	90074-57 (51b)	acrylic	Dralon T	st.-2½"	sp.	2x2 twill	30	2.4×10^{9}	4×10^{11}	--	--
6	JPS	04-D-8453 (½ Exp.)	polyester	Allied I-270 / Kodel	st.-1½"	sp.	1x3 twill W/F I-270 / Kodel	16.5	> 2×10^{14}		+ 1.9 [20]	-7.6/+11
7	JPS	90074-57 (6U)	acrylic	Zefran	st.-2"	sp.	2x2 twill	19	2×10^{10}	> 10^{14}	- 0.2 [40]	-8.3/+5
8	AF	S-574	acrylic	Orlon	st.	sp.		119	> 2×10^{14}	--	- 0.5 [30]	-7.5/+4
9	AF	2355	polyester / acrylic	50/50 Dacron / Orlon	st.	sp.		176	> 2×10^{14}	--	+ 0.7 [35]	-7.3/+6.5
10	AF	Ex	polyester / acrylic	75/25 Dacron / Orlon	st.	sp.		176	> 2×10^{14}	--	- 1.3 [40]	-10.8/+4
11	EId	2430	polyester (spun bonded)	Reemay	st.		non-woven (bonded)	416	> 2×10^{14}	--	+ 1.7	-2.7/+3.6
12	AF	S-575	acrylic	Orlon	st.	sp.		66	> 2×10^{14}	--	- 0.7 [30]	-6.6/+3.2
13	AF	WF-DB	wool	wool	st.		felt	22	5×10^{12}	1.4×10^{13} (either side)	∿ + 7	+0.9/+6.5
14	AF	2459	acrylic	Microtain	st.	sp.		61	> 2×10^{14}	> 2×10^{14}	--	--
15	AF	CS-1316	polyester	Dacron	fil.& st.	fil.W / sp.F	twill	39	> 2×10^{14}	> 2×10^{14}	+ 4.8 [45]	-1.3/+9.5
16	JPS	04-39703/5	polyester	Dacron (55)	fil.	fil.	twill	36	> 2×10^{14}	> 10^{14}	- 2.5 [30]	-7.5/+1.3
17	JPS	04-33141/1	olefin	Thiokol p.p.	st.-1½"	sp.	plain	61	2×10^{10}	--	--	--
18	JPS	80-D-8339	polyester	unbranded	st.-1½"	sp.	2x2 twill nap (one side)	38	1.6×10^{10}	> 10^{14}	+ 1.4 [25] (nap side)	-10/+11.6

(continued)

TABLE 4 (continued)

Fabric			Fiber			Construction			Electrical Properties			
No.	Mfr.	Style No.	Generic	Trade	Type	Yarn	Weave Form	Perm. cfm/ft^2 @ 0.5" w.c.	Resistivity (Ω/□) as received 70°-80°F/40-50%RH	as washed	Rel. Triboelectric Pos. & [decay rate] 70°F/50%RH	Rub Voltage vs nylon/vs Darlan
19	JPS	80-90067/71	polyester	unbranded & PVA	st.-1½"	sp.	3x1 twill	24	3×10^{13}	10^{14}	+ 0.4 [40]	-7.1/+5.6
20	AF	S-580	polyester	Dacron	st.	sp.	plain	68	8×10^{12}	$> 10^{14}$	- 1.7 [15]	-11.4/+3.5
21	AF	S-1414	wool/nylon	75/25 wool/nylon	st.	sp.	plain	35	2.8×10^{12}	3×10^{13}	∿ + 8 [20]	+1/+10
22	EId	F4xR-stat.	aramid	99/1 Nomex/S. Steel	st.	sp.		120	1×10^{8}		n.d. [100]	--
23	AF	B-Bu	wool/cotton	--	st.	sp.	plain	75	1×10^{12}	--	∿ + 7 [95]	--
24	AF	S-2353B	polyester	95/5 polyester/epitropic	st.	sp.		46	5×10^{7}	--	--	--
25	AF	S-1240	olefin	polyprop	st.	sp.		26	1×10^{10}	--	--	--
26	AF	S-610 (826)	acrylic	Orlon	st.	sp.		75	$> 2 \times 10^{14}$	--	--	--
27	EId	2470	polyester (spun bonded)	Reemay	st.	--	non-woven (bonded)	101	$> 2 \times 10^{14}$	--	--	--
28	JPS	S-632/54	fiberglass	Tritemp	fil.	fil.	2x2 twill	48	1×10^{11}	--	∿ + 5	--
29	JPS	S-401/38	fiberglass	Tritemp	fil.	fil.	3x1 twill	18	5×10^{11}	--	--	--
30	JPS	4-38325/2	aramid	Nomex	fil.	fil.	3x1 twill	31	3×10^{14}	$> 10^{14}$	- 0.9 [20]	-6.6/+3
31	JPS	F-4143-00 (1402)	aramid	Nomex	st.	--	felt (needled)	29	5×10^{11}	--	--	--
32	JPS	04-49832/15	polyester	Dacron	fil.	fil.	3x1 twill	17	$> 2 \times 10^{14}$	--	--	--
33	JPS	04-90055/3	polyester	Dacron T-55/T-56	fil./st.	fil.W/sp.F	3x1 twill	24	$> 2 \times 10^{14}$	--	--	--
34	JPS	80-D-8339/1	polyester	unbranded	st.-1½"	sp.	2x2 twill (singed)	--	5×10^{11}	--	--	--
35	AF	S-1152	polyester	Dacron	fil.	--		--	$> 2 \times 10^{14}$	--	--	--
36	JPS	D-8514	--	--	--	--	--	76	$\sim 6 \times 10^{12}$	--	--	--
37	JPS	4N-2281/1-2	p.t.f.e.	Teflon	fil.	fil.	3x1 twill	21	$> 2 \times 10^{14}$		∿ - 6 [0]	-8/-3.5

(continued)

TABLE 4 (continued)

Fabric			Fiber			Construction			Electrical Properties			
No.	Mfr.	Style No.	Generic	Trade	Type	Yarn	Weave Form	Perm. cfm/ft² @ 0.5" w.c.	Resistivity (Ω/□) as received 70°-80°F/40-50%RH	as washed	Rel. Triboelectric Pos. & [decay rate] 70°F/50%RH	Rub Voltage vs nylon/vs Darlan
38	JPS	04-D-8328/1	aramid	Nomex-Tas	fil./st.	fil.W / sp.F	twill	59	3×10^{12}	--	--	--
39	JPS	04-90051-5	aramid	Nomex-T450				25	$> 2 \times 10^{14}$	--	--	--
40	JPS	55-90078	acrylic	Dralon T	st.-2½"	sp.	3x2 twill	35	2×10^{11}	$> 10^{14}$	+ 2.0 [20]	-8.3/+12.5
41	JPS	55-90078/10	acrylic	Zefran	st.-2"	sp.	3x2 twill	28	2×10^{11}	2×10^{13}	- 0.3 [25]	-10/+5.8
42	JPS	55-90062/50	acrylic	Orlon, T-75	st.-2"	sp.	2x2 twill	42	3×10^{13}	$> 10^{14}$	- 0.3 [60]	-8.4/+4.9
43	JPS	80-90059/1	aramid	Nomex-T450	st.-2"	sp.	3x2 twill	36	$> 2 \times 10^{14}$	--	--	--
44	JPS	4-33106/1	olefin	polyprop (Brt. Alamo)	fil.	fil.	3x1 twill	20	$> 2 \times 10^{14}$	--	- 2.7 [15]	-6.5/+1
45	JPS	04-49815/77	acrylic	Dralon T	fil.	fil.	2x2 twill	28	$> 8 \times 10^{11}$	$> 10^{14}$	- 0.3 [50]	-7.5/+4.5
46	JPS	04-90108/1	acrylic	Dralon T	fil./st.	fil.W / sp.F	satin	11	$> 2 \times 10^{14}$	--	+ 0.4 [30]	-9.5/+7.5
47	EId	T1056-95 (+ Zepel)	aramid	Nomex (+ Zepel)	st.	--	felt (needled)	40	$> 2 \times 10^{14}$	--	--	--
48	AF	820 B	acrylic	Orlon	--	--	--	61	--	--	--	--
49	AF	869C-15	polyester	Dacron	--	--	twill	94	--	--	--	--
50	JPS	80D-8339/1	polyester	Dacron	--	--	--	86	--	--	--	--
51	JPS	04-90051/5	aramid	Nomex	--	--	twill	35	--	$> 10^{14}$	- 0.8 [25]	-12.5/+6
52	JPS	80-90059	aramid	Nomex	--	--	--	43	--	--	--	--
53	D(A)	659 NA	wool	wool	st.	--	felt (pressed)	--	--	--	--	--
54	AF	BB-BS	--	--	st.	sp.	plain	49	4×10^{10}			
55	AF	40/601	acrylic	Darlan	st.	--	felt (needled)	32	4×10^{10}	5×10^{10}	- 3.7 [30]	-14.7/+1
56	AF	136B	polyester	Dacron	st.	--	felt (needled)	44	2×10^{14}	--	--	--

(continued)

TABLE 4 (continued)

Fabric			Fiber			Construction			Electrical Properties			
No.	Mfr.	Style No.	Generic	Trade	Type	Yarn	Weave / Form	Perm. cfm/ft^2 @ 0.5" w.c.	Resistivity (Ω/□) 70°-80°F/40-50%RH as received	as washed	Rel. Triboelectric Pos. & [decay rate] 70°F/50%RH	Rub Voltage vs nylon/vs Darlan
57	AF	-D-282 (M-70079A)	acrylic	Orlon 42	st.	--	felt (needled)	28	2×10^{10}	--	--	--
58	AF	-D-184	wool	wool	st.	--	felt	30	4×10^{12}	--	--	--
59	AF	40/894	acrylic	Orlon	st.	--	felt (needled)	23	2×10^{13}	--	--	--
60	AF	40/306	acrylic	Orlon	st.	--	felt (needled)	47	8×10^{11}	--	--	--
61	AF	40/804	acrylic / polyester	75/25 Orlon / Dacron	st.	--	felt (needled)	29	$> 2 \times 10^{14}$	--	--	--
62	AF	E40/455 (anti stat)	polyester	Dacron (& a.s. fin.)	st.	--	felt (needled)	52	$\sim 6 \times 10^{8}$	--	antistatic [100]	--
63	AF	E40/804 (anti stat)	acrylic / polyester	75/25 Orlon / Dacron (& a.s. fin.)	st.	--	felt (needled)	19	$\sim 6 \times 10^{8}$	--	antistatic [100]	--
64	PG	Pot.	--	--	--	--	singed	53	$> 2 \times 10^{14}$	--	--	--
65	EId	181 III	aramid	Kevlar	fil.	fil.	3x1 twill	31	10^{14}	--	~ - 8 [45]	-7.3/-10.7
66	AF	S-237	wool	wool	st.	sp.						
67	AF	136B	polyester	Dacron	st.	--	felt (needled)	46				
68	AF	B.W.	wool	wool	st.	sp.	plain	44				
69	AF	GIW	wool	wool	st.	sp.	plain	54				
70	AF	2005	wool	wool	st.	sp.						
71	AF	S-225	wool	wool	st.	sp.	plain	46	10^{13}		+ 5.6 [75]	-0.3/+8
72	AF	-D-262 (M-82936A)			st.	--	felt (needled)					
73	AF	40/300	acrylic	Orlon	st.	--	felt (needled)					
74	AF	-D-602 40/449			st.	--	felt (needled)					

(continued)

TABLE 4 (continued)

Fabric			Fiber			Construction			Electrical Properties			
No.	Mfr.	Style No.	Generic	Trade	Type	Yarn	Weave / Form	Perm. cfm/ft^2 @ 0.5" w.c.	Resistivity (Ω/□) as received 70°-80°F/40-50%RH	Resistivity (Ω/□) as washed	Rel. Triboelectric Pos. & [decay rate] 70°F/50%RH	Rub Voltage vs nylon/vs Darlan
75	MSA-1	Resp. unt.	wool/acrylic	wool/acrylic	st.	--	felt	103	10^{11}		+	
76	MSA-2	Resp. & ZnR	wool/acrylic	wool/acrylic	st.	--	felt	67	3.8×10^{11}	--	very positive	--
77	AF	FG-G1	glass	glass				30	3.6×10^{13}			
78	AF	S-1414	75/25 wool/nylon	wool/nylon	st.	sp.	plain	33	9×10^{12}	--	∿ + 7 [80]	+1.3/+10
79	AF	2348	polyester	Dacron	st.	sp.	plain (napped)	79	6.6×10^{13}			
80	AF	868-B-6	polyester	Dacron	st.	sp.	twill	33	5×10^{14}			
81	AF	960	cotton	cotton	st.	sp.	satin	16	6.7×10^{8}			
82	AF	S-1441N	95/5 polyester/s. steel	95/5 Dacron/s. steel	st.	--	felt (needled)	39	2.1×10^{7}	--	n.d. [100]	--
83	AF	S-1290D	polyprop	--	st.	sp.	twill (napped)	73				
84	Hb	H06309	95/5 polyester/s. steel	95/5 polyester/s. steel	st.	--	felt (needled)	62	2×10^{7}	--	n.d. [100]	--
85	Hb	H06602	95/5 polyester/s. steel	95/5 acrylic/s. steel	st.	--	felt (needled)	26	2×10^{7}	--	n.d. [100]	--
86	R-?	R & H Imp. nat.	acrylic (+ H-a.s.)	Dralon T (& H-a.s.)	st.	--	felt (needled)	21	10^{9}	--	antistatic [100]	-1.6/+0.7
87	R-?	R & H Imp.-glazed	acrylic (+ H-a.s.)	Dralon T (& H-a.s.)	st.	--	felt (needled)	22	10^{9}	--	antistatic [100]	-0.8/+0.5
88	AF	2339	acrylic	Orlon	st.	sp.		28	1.3×10^{14}			
89	Gore	L10564	polyester (& Tef. lam.)	polyester (& Tef. lam.)	st.	sp.	felt & lam.			> 10^{14}	- 3.6 [55]	-14/+2.8
90	Gore	L10565	aramid (& Tef. lam.)	Nomex (& Tef. lam.)	st.	sp.	felt & lam.	--	--	> 10^{14}	∿ - 5 [75]	-2.3/-1
91	Gore	L10566	p.t.f.e. (& Tef. lam.)	Teflon lam.	st.	--	felt & lam.	--	--	> 10^{14}	--	--
92	AF	40/601	acrylic (dinitrile)	Darlan	st.	--	felt (needled)	35	5.6×10^{14}	--	--	--

(continued)

TABLE 4 (continued)

Fabric			Fiber			Construction			Electrical Properties			
No.	Mfr.	Style No.	Generic	Trade	Type	Yarn	Weave / Form	Perm. cfm/ft^2 @ 0.5" w.c.	Resistivity (Ω/□) 70°-80°F/40-50%RH as received	Resistivity (Ω/□) 70°-80°F/40-50%RH as washed	Rel. Triboelectric Pos. & [decay rate] 70°F/50%RH	Rub Voltage vs nylon/vs Darlan
93	AF	136B	polyester	Dacron	st.	--	felt (needled)	52	> 10^{14}	--	+ 1.5 [40]	-12/+14.3
94	Eld	(Herc.) S.N. 529-75 (XT0954)	p.t.f.e.	Teflon	fil.	fil.		32	> 10^{14}	--	--	--
95	JPS	Ram.	polyester 16 oz.	--	st.	--	felt (needled)	--			+ 0.9 [95]	-5.2/+5.1
96	AF	S-1414X	75 wool/25 nylon	75 wool/25 nylon	st.	sp.	plain	102	1.4×10^{12}	2.9×10^{13}	+ 5.7 [90]	-0.3/+11.9
97	AF	S-1414P	60 wool/40 nylon	60 wool/40 nylon	st.	sp.	plain	76	3×10^{13}	--	∿ + 8 [80]	+3.8/+14.3
98	AF	802B	nylon	nylon	st.	sp.	plain	42	3.7 x 10	--	+ 4.7	-2.3/+14.8
99	AF	40/300	acrylic	Orlon	st.	--	felt (needled)	--	--	--	--	--
100	AF	40/894	--	--	--	--	--	--	--	--	--	--
101	AF	--	wool	--	--	--	--	--	--	--	--	--
102	Hom	60306 nat.	wool	wool (#7)	st.	sp.		48	5×10^{13}	--	+ 5.5 [85]	-0.9/+17.5
103	Hom	908 nat.	wool	wool (#6)	st.	sp.		125	2×10^{14}	--	+ 3.9 [80]	-3/+11.5
104	Hom	970 nat.	wool	wool (#8)	st.	sp.		118	2×10^{14}	--	∿ + 8 [80]	+2.5/+11.5
105	AF	812	acrylic	Microtain	fil.	fil.	3x1 twill	31	1.4×10^{12}	--	--	--
106	U-J	AW155V0335	polyester	Dacron	fil.	fil.		31	3×10^{11}	--	+ 0.4 [90]	-1.9/+1.5
107	AF	S-197	polyester	Dacron	st.	sp.	plain (napped)	56	3.6×10^{12}	--	pl. -0.2 [50] nap -0.4 [60]	-8.8/+6.3 -15/+8.3
108	P & S	U-J	polyester	Dacron	st.	--	felt (singed b.s.)	66	9×10^{11} (used)	--	--	--
109	P & S	U-J	polyester	Dacron	st.	--	felt (singed b.s.)	56	3×10^{11} (used)	> 10^{14}	pl. -2.2 [25] singed -2.8 [25]	-13.5/+2.8 -15.5/+2.1
110	AF	802BC	nylon	nylon	st.	sp.	twill (napped)	32	1×10^{11}	--	pl. +3.7 [75] nap +3.1 [75]	-3.2/+11 -5/+12.5

(continued)

TABLE 4 (continued)

Fabric			Fiber			Construction			Electrical Properties			
No.	Mfr.	Style No.	Generic	Trade	Type	Yarn	Weave Form	Perm. cfm/ft² @ 0.5" w.c.	Resistivity (Ω/□) as received 70°-80°F/40-50%RH	as washed	Rel. Triboelectric Pos. & [decay rate] 70°F/50%RH	Rub Voltage vs nylon/vs Darlan
111	AF	961	cotton	cotton	st.	sp.	sateen (napped)	18	6.7×10^{8}	--	n.d. [100]	--
112	AF	C868B	polyester	Dacron	st.	sp.	twill	36	2.7×10^{11}	--	- 0.7 [65]	-8.6/+4.3
113	AF	S-2283NRMM	aramid/glass	87/13 Nomex/glass	st.		felt (needled) singed o.s.	25	1.9×10^{10}	--	pl. +1.5 [40] singed +3.9 [40]	-10.5/+13 -7.5/+28
114	AF	S-2473 NBR	polyester/glass	87/13 polyester/glass	st.	sp.	felt (needled) cal. o.s.	19	2.4×10^{11}	--	cal. +1.9 [90] pl. +2.4 [90]	-1.5/+2.2 -2.9/+5.2
115	AF	XD3766N	wool/acrylic	50/50 wool/acrylic	st.	sp.	felt (needled)	130	5.9×10^{10}	6.7×10^{13}	--	--
116	Carb	Ca-ST01-8	polyester	unbranded	st.	sp.	knit (seamless)	54	3×10^{13}	--	+ 1.9 [75]	-5.1/+7.3
117	Carb	Ca-SA02-8	acrylic	ZeA507	st.	sp.	knit (seamless)	99	1.4×10^{13}	--	--	--
118	Carb	Ca-ST02-8	polyester	unbranded	st.	sp.	knit (seamless)	50	1×10^{11}	--	+ 2.3 [90]	-4.5/+7.8
119	AF	810AL	acrylic	Microtain	st.	sp.	twill	46	1.3×10^{12}	$> 10^{14}$	--	--
120	AF	810LC	acrylic	Microtain	st.	sp.	twill	50	3×10^{13}	$> 10^{14}$	- 1.1 [75]	--
121	JPS	90112	acrylic	ZeA507	st.	sp.	(napped)	44	--	--	--	--
122	Carb	Ca-SAOX	acrylic	Dralon T (dyed ?)	st.	sp.	knit (seamless) napped	45	1.2×10^{10}	$> 10^{14}$	nap +5.1 [90] pl. +4.8	-0.4/+4.3 -0.5/+3.8
123	EId	4057-18-2	aramid	Nomex	st.	sp.	felt (scrimless)	47	$> 10^{14}$	--	--	--
124	EId	4057-18-10	aramid	Nomex	st.	sp.	felt (scrimless)	39	$> 10^{14}$	--	--	--
125	AF	S-547	acrylic	Darlan	st.	sp.	--	--	--	--	--	--
126	U-H	USS-H	polyester					37	7×10^{14}	--	--	--
127	AF	C-8171CF	acrylic	Microtain	st.	sp.	(napped)	47	2.8×10^{14}	--	--	--

(continued)

TABLE 4 (continued)

Fabric			Fiber			Construction			Electrical Properties			
No.	Mfr.	Style No.	Generic	Trade	Type	Yarn	Weave Form	Perm. cfm/ft^2 @ 0.5" w.c.	Resistivity (Ω/□) as received 70°-80°F/40-50%RH	Resistivity (Ω/□) as washed 70°-80°F/40-50%RH	Rel. Triboelectric Pos. & [decay rate] 70°F/50%RH	Rub Voltage vs nylon/vs Darlan
128	USF	25-830-030	aramid	Nomex (& Tef. fin.)	st.	--	felt (needled)	25	3.3×10^{12}	10^{14}	--	--
129	USF	4A25-831	aramid	Nomex	st.	--	felt (needled)	32	1.2×10^{12}	--	--	--
130	USF	4B25-838	aramid	Nomex (& Tef. fin.)	st.	--	felt (needled)	17	1.5×10^{12}	--	--	--
131	USF	2A16-140	acrylic	Homo acrylic	st.	sp.		31	$> 10^{14}$	--	--	--
132	USF	2B16-143	acrylic	Homo acrylic (& Tef. fin.)	st.	sp.		32	$> 10^{14}$	--	--	--
133	USF	3A25-591	polyester	unbranded	st.	--	felt (needled)	23	$> 10^{14}$	--	--	--
134	USF	3B25-644	polyester	unbranded (& Tef. fin.)	st.	--	felt (needled)	19	10^{10}	--	--	--
135	USF	1A15-011	polyester	unbranded (& sil.)	fil.	fil.		17	$> 10^{14}$	--	--	--
136	USF	1A15-014	polyester	unbranded (& Tef. fin.)	fil.	fil.		11	10^{13}	--	--	--
137	Troy	4582903-16 072-22p	polyester	Dacron	st.	--	felt (needled)		$> 10^{14}$	$> 10^{14}$	--	--
138	W-Ac	FIL-11	--	--	st.	--	felt (needled)	39	10^{11}	$> 10^{14}$	--	--
139	W-Ac	Kermel	--	--	st.	--	felt (batt)	260	10^{15}	--	--	--
140	W-Ac	F150	--	--	st.	--	felt (bonded)	v. high	6.9×10^{10}	2×10^{13}	--	--
141	AF	MC-2-811L	acrylic	Microtain (w/Tef. fin.)	st.	sp.	twill	40	6.9×10^{10}	3.6×10^{12}	h. cover -2.4 [75] plain -1.1 [80]	--
142	W-Ac	SR8166						96	4×10^{14}	--	--	--
143	Gore		p.t.f.e. lam on polyester	Teflon web on polyester	st.	--	felt & lam.	6-7	1.5×10^{13} Tef. 10^{17} felt	--	--	--
144	AF	S-1414X	wool/nylon	wool/nylon	st.	sp.	plain	50	2×10^{12}	--	--	--

(continued)

TABLE 4 (continued)

Fabric			Fiber			Construction			Electrical Properties			
No.	Mfr.	Style No.	Generic	Trade	Type	Yarn	Weave / Form	Perm. cfm/ft² @ 0.5" w.c.	Resistivity (Ω/□) as received 70°-80°F/40-50%RH	Resistivity (Ω/□) as washed 70°-80°F/40-50%RH	Rel. Triboelectric Pos. & [decay rate] 70°F/50%RH	Rub Voltage vs nylon/vs Darlan
144c	AF	S-1414XG	wool/nylon	wool/nylon (& 1.3% Cond. Graphite)	st.	sp.	plain	50	5×10^4	--	--	--
145	C-D		polyester		fil-W / sp-F	sp. cotton system	--	--	--	--	--	--
146	AF	S1472L	acrylic	Microtain	fil.& st	fil-W / sp-F	--	--	--	--	--	--
147	UF	5-19-77 5-19-77+G	polyester polyester & 0.6 cond. graphite	--	sp.	st.	--	--	--	--	--	--
148	UF	R-C (PG)	polyester	--	sp.	--	felt (glazed)	--	--	--	--	--
149	UF	R-C (P)	polyester	--	sp.	--	felt	--	--	--	--	--
150	UF	R-C (A)	acrylic	--	sp.	st.	--	--	--	--	--	--
151	Gore	4313.34	polyester (& Tef. lam.)	--	sp.	--	felt	--	--	--	--	--
152	AFI	21642	polyester	--	sp.	--	felt (glazed)	--	--	--	--	--
153	AFI	21611	polyester	--	sp.	--	felt (pressed)	--	--	--	--	--

Mfrs. = Manufacturers

AFI = Air Filters, Inc.
AF = Albany Int. or Globe Albany Corp.
Carb = The Carborundum Co.
D (A) = Day Co. (American Felt Co.)
EId = E.I. du Pont de Nemours & Co., Inc.
Gore = W. L. Gore & Assoc., Inc.
Hb = T. J. Heimbach GmbH & Co. (Duren, Germany)
Hom = Homestead Mills
JPS = J. P. Stevens & Co., Inc.
MSA = Mine Safety Appliance Co.
P & S = P & S Textiles, Inc.
R? = (Unknown European)
Troy = Troy Mills, Inc.
USF = United States Filter Corp.
W-Ac = Western Acadia, Inc.

Miscellaneous

a.s. = antistatic
f. = filling
fil. = filament
H-a.s. = Hyamine 3500 (antistat)
lam. = laminate
n.d. = not determined
p.e. = polyester
p.p. = polypropylene
p.t.f.e. = polytetrafluoroethylene
s. steel = stainless steel fibers
sil. = silicone (finish)
sp. = spun
st. = staple
tas. = taslan (bulked)
W=warp

Particulate Resistivity

The apparatus used to determine the resistivity of particulates has been described in detail by G. W. Penney.[2] The dust sample is equilibrated in the apparatus to an appropriate condition of dry and wet bulb temperature. The current obtained by the impressed voltage is determined by means of an electrometer and resistivity is calculated from the ohm's law relationship. The pressure on the samples is approximately 4.75 g/cm^2. Under these conditions, the determined resistivity (Ω-cm) is a function of the applied humidity, temperature, packing and voltage. (Table 5)

Electrostatic Properties of Particulates

Particles become charged, in fact White[3] states that it is almost impossible not to charge particles in the course of normal handling and processing. Whether the accumulated charge is positive or negative and will be retained for a significant time depends upon many conditions - inherent properties, the nature of the contacted material, the environment, etc. High resistivity insures charge retention but an easy-to-conduct and reproducible method for determining triboelectric (T.E.) locations is still needed. Experimentally, Penney has employed an impingement technique in which silica dust was evaluated for charge polarity and magnitude after being "bounced-off" eight different fabrics that had already been located in the T.E. series. These results (Table 14) indicated that this silica is located at about a -3 position in the scale of Table 2. The method offers significant promise and deserves further consideration.

PARTICULATE AGGLOMERATION OR POROUS CAKE FORMING TENDENCIES

For its potential value as a change that may occur during filtration, it is desirable to determine the relative agglomerating or porous cake forming tendencies as well as density changing characteristics of particulates. Clues to such changes may be obtained by a simple rolling test. In practice, the first stage of the test employs an apparent density type of evaluation, conducted by introducing a weighed and measured (usually 100 ml) volume of dust into a liter, wide mouth polyethylene bottle. The usual apparent density determination practice is used whereby the graduate is gently and uniformly tapped on a resilient base at each stage when the 25 ml, 50 ml, 75 ml, and 100 ml levels are reached. This procedure is applied to the dust before and after the rolling operation. The rolling may extend for any reasonable time but a constant period of about 30 min (or less) at a moderately slow speed (30 rpm) is preferred. Frequently, an increase in density occurs but, most important, the tendency for agglomera-

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[2]Penney, G. W., AIEE Transactions. 70 Section 1-201:1-3 (1951).

[3]White, H. J., Industrial Electrostatic Precipitation, Reading, MA, Addison-Wesley (1963).

TABLE 5. ELECTRICAL RESISTIVITY OF SOME PARTICULATES

Particulate	(Lot)	Temp., °F	RH, %	Applied Voltage, V	Amperage I, amp	Resistance R, ohm	Resistivity ρ = 15.71 R ohm-cm
Electric Furnace, U-D	(A)	70	35	--	--	--	6.5×10^{8}
Electric Furnace, U-D	(A)	240	v. low	--	--	--	2.8×10^{11}
Electric Furnace, U-D	(A)	200	v. low	--	--	--	9.3×10^{12}
Electric Furnace, U-D	(A)	150	v. low	--	--	--	1.2×10^{13}
Electric Furnace, U-D	(A)	125	v. low	--	--	--	5.0×10^{12}
Electric Furnace, U-D	(A)	100	v. low	--	--	--	2.5×10^{12}
Electric Furnace, U-D	(A)	85	v. low	--	--	--	1.7×10^{12}
Elec. Furn., s.s., U-J	(A)	77	42	1665	0.78×10^{-4}	2.1×10^{7}	3.3×10^{8}
Elec. Furn., s.s., U-J	(B)	77	42	1665	0.65×10^{-4}	2.5×10^{7}	4.0×10^{8}
Elec. Furn., s.s., U-J	(C)	73	33	1470	2.30×10^{-5}	6.4×10^{7}	1.0×10^{9}
Elec. Furn., s.s., U-J	(D)	73	33	1470	2.20×10^{-5}	6.9×10^{7}	1.1×10^{9}
Fly Ash, WP-S	(A)	73	33	72	1.35×10^{-2}	5.3×10^{3}	8.4×10^{4}
Ferromoly b-p., C-L	(A)	73	33	1490	0.59×10^{-4}	2.5×10^{7}	4.0×10^{8}
Moly-Met, R-S	(A)	73	33	1480	0.52×10^{-4}	2.8×10^{7}	4.4×10^{8}
P-6140 resin	(A)	73	33	1480	$< 10^{-12}$	$> 10^{15}$	$> 10^{15}$
Steel Grinding Dust, R-C	(A)	78	55	--	--	2.0×10^{7}	3.1×10^{8}
Steel Burning Dust, R-C	(A)	78	55	1000	4.20×10^{-7}	2.4×10^{9}	3.8×10^{10}
Steel Burning Dust, R-C	(B)	78	55	1750	10^{-6}	1.8×10^{9}	2.8×10^{10}

tion implies that a similar change may be expected to occur during filtration if a fabric of preferred electrostatic properties were used. (Table 6)

VISUAL EXAMINATIONS OF PARTICULATES (IN THE COURSE OF FILTER TESTS)

Visible examinations of the particles are made as they appear in the aerosol and as they appear after having been collected. The condition of the particulate at both locations is recorded photomicrographically (Figure 6). A sample of the incoming particulate suspension is obtained by drawing it from the mainstream onto the microscope slide in the settling chamber (F) of Figure 1. In practice, the air flow to this chamber is stopped when the microscope slide is inserted over the chamber port, the suspended dust in the cloud over the slide is then allowed to settle, thus providing a sample of the particles as they occur in the incoming aerosol. At the header, the collected particulate from the filter bag is also allowed to deposit on a microscope slide. Photomicrographs of the two samples provide a record of the material at the two locations and, by including a reference wire of known size in the picture, an estimate of particle and/or aggregate size is allowed.

REPRESENTATIVE AND EXPERIMENTAL FILTER FABRICS

Through the cooperation of fiber and/or fabric manufacturers, a broad spectrum of filter media have been obtained for the experimental studies (Table 4). This group of samples includes most of today's practical filter media. Identically sized test bags were prepared for use in the experimental collector. Separate swatches have been cut (3 in. x 12 in.) for triboelectrification tests and (6 in. x 8 in.) for permeability measurements. Resistivity data, verified by triboelectrification studies, have shown that many materials as-supplied had an antistatic finish. Several of the fabrics, although made from different fibers, also carried the same style number. Different kinds of acrylic fiber, for example, seem to be used interchangeably without differentiation.

Variations such as these in fabrics offered to bag makers and/or users, can have an adverse influence on filtration performance. Accordingly, one of the purposes of this report is to encourage fabric producers to add resistivity to the list of parameters included in filter fabric specifications and, of course, to indicate clearly the kind of fiber(s) used in the fabric. These characteristics of filter media are just as important as permeability, weight, etc. and need to be included in the information that relates fabric properties to performance.

EXPERIMENTAL FILTRATION STUDIES

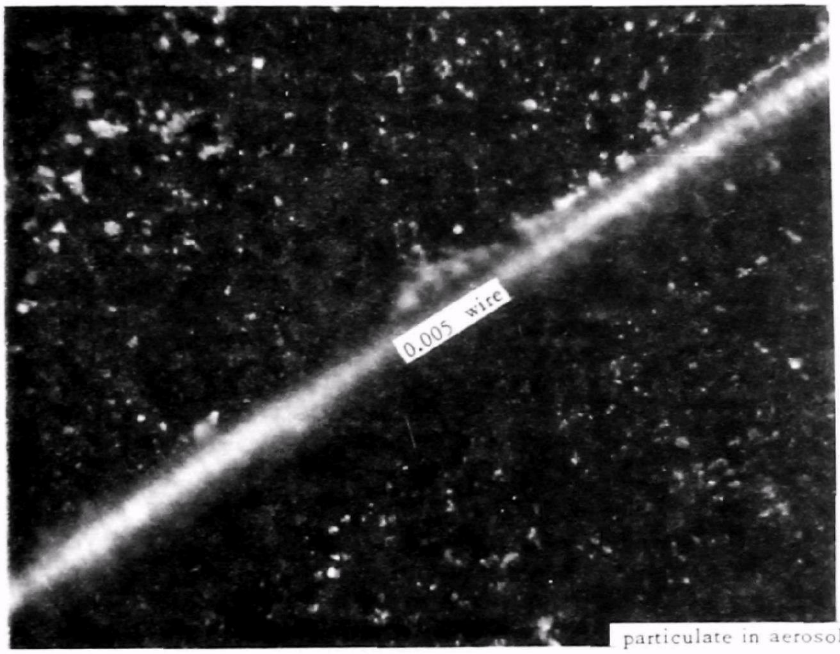
In the course of shake-down trials conducted on the bench-scale filter unit, a number of commercial particulates, including

TABLE 6. AGGLOMERATION AND APPARENT DENSITY CHANGES OF SOME PARTICULATES BY ROLLING

(Rolled in 1000 ml w.m. polyethylene bottle - 30 rpm/30 min)

Particulate	(Lot)	Tendency to Agglomerate Further	Weight g	Initial Vol. ml	Initial App. Den. g/ml	Final Vol. ml	Final App. Den. g/ml	∿ App. Density Change %
P·K-3085 resin	(A)	+	38.7	100	0.39	88	0.44	+13
P-6140 resin	(A)	+	46.7	100	0.47	92	0.51	+ 9
Ferromoly. b.p., CM-L*	(A)	+	131.8	100	1.32	80	1.66	+26
Moly-met, R-S*	(A)	+	90.5	100	0.91	73	1.24	+37
Elec. Furn., s.s., U-J*	(A)	+	24.6	100	0.25	92	0.27	+ 7
S.S. Burn., U-H*	(A)	+	106.6	100	1.07	86	1.24	+16
Steel Grinder, R-C*	(A)	+	170.0	100	1.70	94	1.82	+ 7
Steel Burn., R-C*	(A)	+	87.5	100	0.88	71	1.22	+39
Steel Burn., R-C*	(B)	+	83.5	100	0.84	78	1.07	+28
Steel Burn., R-C*	(C)[a]	+	80.0	100	0.80	60	1.33	+66
Silica, as rec'd., F-HH*	(A)	-[b]	120.4	100	1.20	106	1.14	- 6
Silica, as rec'd., F-HH*	(B)	-[b]	124.2	100	1.24	108	1.16	- 7
Silica, as rec'd., F-HH*	(C)	-[b]	118.9	100	1.19	102	1.16	- 2
Silica, used, F-HH*	(A)	-[b]	119.4	100	1.19	110	1.09	- 9
Silica, used, F-HH*	(B)	-[b]	136.9	100	1.37	108	1.27	- 7
Silica, used, F-HH*	(C)	-[b]	132.3	100	1.32	105	1.26	- 5
Silica, used, F-HH*	(D)	-[b]	121.1	100	1.21	105	1.15	- 5
Silica, as rec'd., PG-C*	(A)	-[b]	115.1	100	1.15	112	1.03	-11
Silica, as rec'd., PG-C*	(B)	-[b]	116.2	100	1.16	107	1.09	- 7
Silica, as rec'd., PG-C*	(C)	-[b]	119.7	100	1.20	107	1.12	- 7
Silica, as rec'd., PG-C*	(D)	-[b]	112.0	100	1.12	105	1.07	- 5

[a] Rolling carried out in 1000 ml glass bottle   [b] Tendency to deagglomerate evident   * Source code



80 magnifications

RELATIVE SIZES OF PARTICULATES

(A molybdenum based dust)

Figure 6 Particulates Before and After Fabric Contact

cement, flyash, shredded paper, and potato granules were examined to determine the performance characteristics and reliability of the equipment as well as to obtain information on the collectability of the dusts. An industrial problem manifested especially by poor fabric cleanability because of the substantial adhesion between the paper particles and the collecting fabric was verified experimentally and eliminated by making the particles, not the medium, antistatic. A cationic treatment of the shredded paper, an operation that might be carried out in the course of the manufacturing process, was shown to minimize the filter fabric cleaning problem.

Another serious problem experienced commercially in the filtration of potato particles was reproduced experimentally and found to be resolvable by heating the potato-dust aerosol to a temperature at which its relative humidity was below 15 percent. This particulate was shown clearly to be moisture sensitive. It had to be handled and filtered under relatively dry conditions in order to avoid particulate solvation, swelling, and tackiness.

The Collection of Flyash, WPP-S

The collectability of flyash (WPP-S) was found to vary considerably depending upon the nature of the different test filter media. Electrostatics, as well as construction features, provide an explanation. The studies were carried out at essentially constant conditions of dust loading, A/C ratio (5.4) and limiting pressure drop (6 in. w.c.). Significant differences were found among the eight tested fabrics in regard to collected solids, plug weight, plugged cloth pressure drop, and leakage (Table 7).

Variations in performance as a result of electrostatic effects are detectable when the influence of the fabrics' charge polarity and charge intensity are recognized. In making the analysis, the highly electropositive features of the wool/nylon fabric #21, for instance, must be noted. Also noteworthy are the moderately high charge but more electronegative properties of fabrics #40, #41, #44, and #42, and the very electronegative characteristics of the Teflon fabric (#37).

The fabrics (#40, #41, #44, and #42) in the middle region (-2.7 to +2.0) of the triboelectric series and especially the three that develop a high charge (#40, #41, and #42), collect the largest amounts of the flyash before reaching the limiting pressure drop of 6 in. w.c. Some of the high collectability indicated by fabric #44, a filament polypropylene, however, must be attributed to the fact that it leaked badly, never really forming an effective filter cake.

It is interesting to speculate further concerning the effect of electrostatic differences on the plugged cloth data shown for fabrics #40, #41, and #42. These fabrics, each made from a dif-

TABLE 7. EXPERIMENTAL FILTRATION OF FLY ASH, WPP-S

A/C = 5.4, ΔPc limit = 6 in. w.c., 75 - 85°F (∿ 60% RH) shake cleaning

Fabric							Filtration Parameters			
No.	Mfr.	Style	Yarn	Perm.	Rel. T.E. Pos. / Total rub Volt.	Fiber Type	Collected solids, g	Plug Wt. g	Plug ΔP in. w.c.	Relative Leakage
40	JPS	90078	sp.	35	+2.0 / 20.8	acrylic Dralon T	240	8	0.5	v. low
21	AF	S-1414	sp.	35	+8 / 11	75/25 wool/nylon	120	48	2.6	v. low
41	JPS	90078/10	sp.	28	-0.3 / 15.8	acrylic Zefran	200	26	1.0	v. low
15	AF	CS-1316	fil.	39	+4.8 / 10.8	polyester Dacron	130	20	1.8	mod. high
44	JPS	33106/1	fil.	20	-2.7 / 7.6	Olefin polyprop.	230	17	1.0	v. high
42	JPS	90062/50	sp.	42	-0.3 / 13.3	acrylic Orlon	230	16	0.8	v. low
37	JPS	4N-2281/1	fil.	21	∿ -6 / 11.5	Teflon	195	16	1.4	mod. high
28	JPS	S-632/54	tex. fil.	48	∿ +5	fiberglass	175	31	1.2	low

ferent acrylic and quite similar in construction, provide distinctly different plug weight-plugged cloth-pressure drop data that imply a preference for a moderately electropositive media, like #40 at +2.0 rather than the slightly electronegative media like fabrics #41 and #42, both of which are at a -0.3 triboelectric position. Most striking are the very significant and real differences in the plugged cloth features of these three filter fabrics. The bag made from fabric #40 retains about 8 g of flyash and shows a plugged cloth pressure drop of only 0.5 in. w.c. compared to the much higher values found for the other two acrylics. The comparatively low collectability provided by the highly positive wool/nylon #21 and Dacron #15 and even the glass #28 fabrics that also show a moderately high plugged cloth pressure drop and high plug accumulation, also suggest adverse effects produced by unfavorable electrostatic properties.

Following the preliminary trials, investigations were carried out to determine the collection properties of several selected but very different fabrics with a variety of polymeric and metallurgical dusts.

The Collection of Some Metallurgical Dusts

Particulate Emissions from Electric Arc Furnaces--

The large electric furnace baghouses that control emissions through an entire building evacuation system are quite prevalent and, too often, present energy related if not serious operational problems. The bags in these massive installations are large (mostly about 1 ft in diameter and 34 or 35 ft long), their numbers run into many thousands (sometimes more than 6000) and they handle as much as 1 3/4 million or more cubic feet of aerosol per minute. Most often, cake removal from these bags is accomplished by reverse air flow, a method that requires the use of an easy to clean fabric, usually considered to be a filament-like medium.

A number of these electric furnace baghouses, large and small, have experienced problems, some more serious than others. Excessive pressure drop, poor cleanability, and abnormally high energy demands have been reported.

The Collection of Electric Furnace Dust, U-D--At the very large plant of U-D, 5472 - 11 3/4 in. diameter by 34 ft long filament bags collect the particulate from 1 3/4 million ft^3/min emissions of an electric furnace shop at a pressure drop of 8 to 9 in. w.c. This level of flow resistance is considered to be excessive by ordinary filtration standards; a threat to high collection efficiency, too energy intensive, and excessively costly to operate at the reported $3000/day. Bag life is very good, but this excessive pressure drop and the attendant abnormally high energy demands, suggested that an experimental filtration study should be conducted to determine how other fabrics might perform and, possibly, how electrostatics might influence the process. Three polyester fabrics of different construction were selected for the first trials. One was made of filament type yarns, probably not too unlike that used in the bags in commercial service. The other two were made of staple yarns, one of which was napped. The results of the abbreviated study are summarized in Figure 7, and describe the pressure vs collected solid features of the three kinds of fabric through several cycles of operation at an A/C of 5.4 and to a limiting pressure drop of 6 in. w.c. Additional runs were made and the results are considered later, but the data presented here show clearly that the napped polyester fabric #18 far surpasses the performance of the filament yarn #15 and the unnapped staple yarn #16 fabrics. Only the relatively high plug weight (26 g) detracts from the outstanding collection properties of this napped polyester filter medium. (The potential danger of blinding problems in service must be considered.) It is also important to note that the fabrics of higher plug weight display lower plug pressure drop values.

The superior overall performance of the napped staple fiber, spun yarn fabric #18 and the better performance of the combination filament warp/spun filling fabric #15 compared to the all filament fabric #16 is noteworthy. While all three fabrics are polyesters and of about equivalent permeability (between 36 and 39), the significant differences in relative electrostatic chargeability among these fabrics would imply that different polyesters make up the three fabrics and, accordingly, that electrostatic polarity and intensity may offer a clue to filter fabric variability and therefore, to media specification. For example, on a triboelectric scale of 10 with nylon located at +6 and Darlan at -4, fabric #15 is located at +4.8, fabric #16 at -2.5, and fabric #18 at +1.4. Also important, perhaps even critical in this instance, is the intensity of the charges that develop on the different media. For example, fabric #18 charges triboelectrically to a total of 21.6 V (-10 V vs nylon and +11.6 V vs Darlan), fabric #15 to a total of 10.8 V and fabric #16 to a total of 8.8 V.

Additional runs were carried out on fabric #18 (through 26 cycles), the same fabric (#18) with 0.69% add-on of conductive graphite, fabric #20 (polyester, sp. 68 perm), fabric #31 (Nomex felt, 29 perm), fabric #40 (Dralon T, sp. 35 perm), fabric #41 (Zefran, sp. 28 perm), fabric #40 and #41 very lightly hand napped, and fabric #4 (Nomex fil. Taslan, napped 45 perm). Although the graphite finished fabric #18 was lowered in electrical resistivity to $10^7\ \Omega/\square$ (antistatic), only slight ($\sim$ 15%) improvement in plug reduction was achieved by this treatment. Hand napping was too ineffective to alter significantly the surface characteristics and performance of fabrics #40 and #41.

That the two acrylics, Dralon T and Zefran fabrics (#40 and #41) perform differently despite similarities in construction is evident from Figure 8. Although additional data for fabric #41 were obtained, these are not plotted in order to avoid crowding of the curves. For this fabric, a plug weight of 16.5 g was found

CONDITIONS - A/C = 5.4, ΔPc limit = 6 in. w.c., 150°F, shake (moderate) cleaning

LEGEND:	Run No.	Fabric No.	Fabric Type	Fabric Fiber	Fabric Perm.	Plug Wt. g	Rel. T.E. Position / Total Rub Voltage
	41	16	fil.W/fil.F	Da 55/Da 58 & Si.	36	3.6	-2.5/8.8
	40	15	fil.W/sp.F	Da	39	9.7	+4.8/10.8
	42	18	sp.W/sp.F	p.e. & nap.	38	26.9	+1.4/21.6

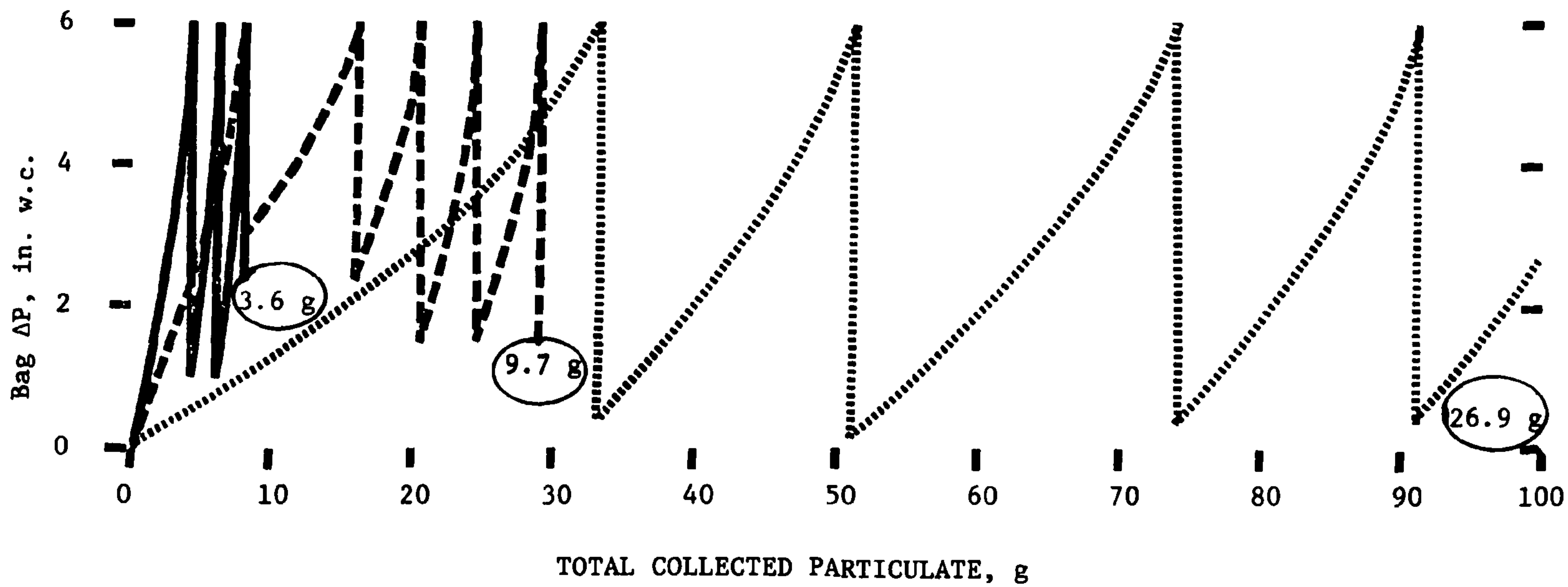


FIGURE 7. EXPERIMENTAL FILTRATION OF ELECTRIC FURNACE DUST, U-D (I)

CONDITIONS - A/C = 5.4, ΔPc limit = 6 in. w.c., 150°F, shake (moderate) cleaning

LEGEND:	Run No.	Fabric No.	Fabric Type	Fabric Fiber	Permeability cfm/ft² @ 0.5 in. w.c.	Plug Wt. g	Rel. T.E. Pos. Total Rub V
··········	45	40	sp.W/sp.F	Dralon T	35	6.7	+2/20.8
———	43	20	sp.W/sp.F	Dacron	68	38.5	-1.7/14.9
- - - - -	48	4	fil.W/tex F	Nomex	45	55.6	+0.7/6.4
—— ——	47	41	sp.W/sp.F	Zefran	28	9.6	-0.3/15.8

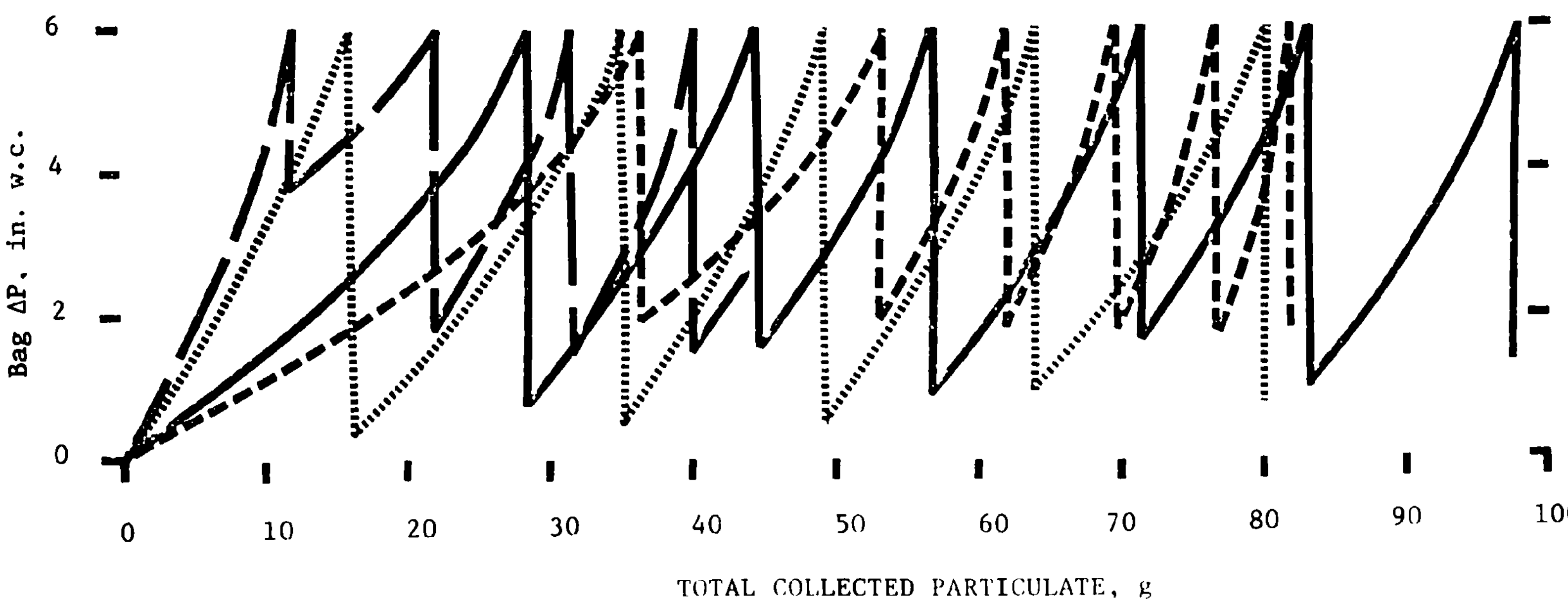


FIGURE 8. EXPERIMENTAL FILTRATION OF ELECTRIC FURNACE DUST, U-D (II)

after 10 cycles when the collected solids reached only 78.2 g. Thus, Zefran performed much less favorably than Dralon T and of course, neither fabric #20 (sp. Da) nor fabric #4 (fil. Tas Nomex) performed better than the Dralon T that showed a relatively low plug weight (6.7 g) and reasonably good collectability.

It would appear that if a napped fabric like #18 or possibly a napped variation of #40 would not become blinded, or if mechanical cleaning could be applied to limit plug concentration in commercial service with this electric furnace dust, an appreciable lowering of the bag pressure drop could be achieved to realize very significant savings in fan energy and thereby operating costs.

According to earlier speculations, much more reliability in selecting the preferred fabric to collect electric furnace dust should be allowed if the triboelectric location of the particulate were known. If, as suggested before, agglomeration at the collecting fabric surface is encouraged more and more as the charge polarity difference and intensity increases between the two materials, then knowing the T.E. series location of the dust as well as that of the fabric should permit considerable accuracy in specifying the preferred fabric. With this added information, it would be relatively easy to determine whether increased charge intensity was needed. Construction changes for more or less bulk to alter charge intensity in an appropriate way, or other changes to influence charge bleed-off as needed, could then be determined rapidly with certainly.

The Collection of Electric Furnace Dust, C-T--From a limited experimental filtration study, it becomes apparent that the filament like polyester fabric used at the C-T steel plant collected electric furnace dust in an inferior manner compared with several other fabrics (refer to Table 8). The cake that forms on this fabric, made of fine staple polyester fiber on the cotton system, tends to be highly resistant to air passage. Such a deposit leads to a rapid rise in pressure drop and to short cycling. On the favorable side, the deposited dust is removed quite readily from the relatively smooth-surfaced, low charge fabric, suggesting that reverse air cleaning should be effective. This feature is indicated in the data but again another very important observation regarding the plugged cloth pressure drop should be noted. Important variations occur between the plug ΔP values of the filament-like plant-used polyester medium and the other, especially the acrylic, media. Even though the quantity of plug (the dust retained on the plant-used polyester fabric after reverse air cleaning) is low, the resistance of this residue to air transfer is greater than that recorded for the very highly plugged (weightwise) acrylic fabrics. Whereas only four grams of plugged dust in the plant-used medium produces a pressure drop of 3.5 in. w.c., as much as 84 g of plugged dust in the acrylic fabric produce only a 2 in. w.c. resistance. These differences in plug as well as the variations in the collected dust in and on the two types of fabric indicate that the deposits differ substantially in porosity. It

TABLE 8. EXPERIMENTAL FILTRATION OF ELECTRIC FURNACE DUST, C-T

A/C = 6, ΔPc limit = 6 in. w.c., 130°-140°F, simulated reverse air cleaning

Fabric									Filtration Parameters						
									20 sec rev-air cleaning			40 sec rev-air cleaning			
									Cake	Plug		Cake	Plug		
No.	Mfr.	Style	Fiber	Yarn	Weave	Permeability cfm/ft² @ 0.5"	Resist. Ω/□	Rel. Triboelectric Position	Wt., g	Wt., g	ΔP in w.c.	Wt., g	Wt., g	ΔP in. w.c.	Relative Leakage
145	?	(C-T)	p.e.	fil.W / sp.F	3x1 tw (c.s.)	15	$> 10^{14}$	+	0.5	40	3.5	--	--	--	mod. high
18d	JPS	80-D8339	p.e.	sp.	2x2 tw napped	38	$3x10^{13}$	+ 1.4	2.1	high	2.1	2.8	59.5	1.5	mod. low
120	AF	810LC	acrylic	sp.	2x2 tw (w.s.)[2] napped	50	$> 10^{14}$	- 1.1	5.4	84	2.0	5.5	89	1.5	low
3c	JPS	55-90077	acrylic	sp.	3x1 tw (c s)[1]	19	$2x10^{13}$	- 1.7	4-5	38	2.5	4.5	42	1.8	low
3f	JPS	55-90077 & G	acrylic & cond. graph.	sp.	3x1 tw (c s)[1]	19	$2x10^{7}$	- 1.7 (antistat)	4-5	25	1.9	--	--	--	low
146b	AF	S-1472L	acrylic	fil.W / sp.F	3x1 tw (c s)[1]	40	$> 10^{14}$	- 1.0	3.6	54	1.5	4.8	44	1.0	mod. low
									spun side to dust						
146a	AF	S-1472L	acrylic	fil.W / sp.F	3x1 tw (c s)[1]	40	$> 10^{14}$	-1.0	4.5	36	1.3	5.0	46	1.2	mod. low
									filament side to dust						

[1]cotton system

[2]woolen system

is suggested that favorable electrostatic properties (polarity and intensity) contribute to the porous deposits (plug and cake) in and/or on the acrylic fabrics and that the absence of these preferred electrostatic features lead to the compact, highly resistant deposits in and on the plant-used, filament-like polyester medium.

If, after collectability, the plug pressure drop, not the plug weight, were the only other parameter of concern, it is evident that any of the acrylics, particularly fabric #146a, might be preferred for optimum performance. However, without information to indicate whether or not the residue might change phase or otherwise develop into a blinding type of plug to close-up the fabric, it would seem advisable to avoid excessively high levels of plug. Accordingly, more vigorous cleaning action (than reverse air) would appear to be the safest practice to adopt if a change to one of the high bulk acrylic fabrics were made for the collection of the C-T electric furnace dust. Combining shaker-type cleaning with a medium such as 3c, for example, would be a most reasonable recommendation for collecting this particulate commercially in an effective way.

The Collection of Electric Furnace (Stainless Steel) Dust, U-J-- Prompted by reports of collection problems with a stainless steel electric furnace (ssef) dust possibly related to electrostatics and reflected specifically by abnormally high pressure drop in an industrial, shaker-type baghouse, a filtration study was carried out. An evaluation of at least twenty (20) different media was carried out. Initially, comparisons were made of the more popular and relatively standard filter fabrics, but later other woven fabrics were examined together with knitted materials. The results indicated that the moderately electronegative and high charge intensity media, such as napped acrylic, napped cotton and napped polypropylene (in this order for increasing effectiveness) performed better than a variety of relatively electropositive polyester, nylon, and wool fabrics. Better performance was judged largely by better collectability as the test bags reached a pressure drop limit of 6 in. w.c. under equilibrium conditions at an A/C of 5.4.

Among the fabrics that performed best, the acrylics (Zefran or Dralon T) were considered to be the preferred practical choice for industrial service, inasmuch as problems could develop with the otherwise effective but more heat sensitive polypropylene and cotton media. However, when a 7.25 oz twill weave acrylic medium was recommended for use in the stainless steel electric furnace baghouse, the equipment vendor insisted that a knitted version be considered and samples were submitted for study. A Zefran knitted medium as well as a polyester knitted filter fabric were supplied and evaluated, filtrationwise, with the ssef dust. The knitted acrylic collected quite well and was found to surpass the performance of a polyester knit fabric. However, it was not acceptable because of excess leakage. Accordingly, a new, lower permeability (< 30) knit fabric was requested. Such a fabric was received as a 10+ ounce knit material. This bluish-grey knitted fabric displayed extremely high electropositive properties, essentially as positive as nylon and definitely not like Dralon T or Zefran in the triboelectric series. After proving in filtration tests that this was not a favorable medium for collecting ssef dust, it was rejected for use in the plant baghouse in deference to an acrylic medium, specified preferably as Dralon T for optimum stability, with the following other properties:

weight . . . . ∿ 7+ oz/yd^2

fiber . . . . staple

yarn . . . . spun

weave . . . . 3 x 1 twill

finish . . . . napped one side (dust side)

permeability . . . 15-25

The U-J baghouse collecting the emissions from this stainless steel electric furnace was reclothed with the recommended medium in May 1977 and has been functioning quite satisfactorily.

While the above specifications indicate that the preferred medium is one made on the cotton system, it should be apparent that a similar but heavier material made on the woolen system may be used, especially if durability and efficiency problems should develop in the shaker-type industrial baghouse.

<u>The Collection of Stainless Steel Burning Dust, U-H</u>--The emissions from a stainless steel burning (ssb) operation at the U-H Steel plant are evacuated to a baghouse. Serious problems in regard to both dust leakage to the atmosphere and excessively high pressure drop in the collector brought the issue to the attention of the writer.

In the course of the batch-like operations, the vendor-installed polyester bags showed a clean cloth pressure drop of about 2 in. w.c. at start up in a Torit collector. Soon (1 to 2 min) after the emissions entered the plant baghouse, the pressure across the bags increased to 10 - 12 in. w.c. and then progressively but more slowly during a subsequent 20 min period to 16 - 18 in. w.c.

The normal operating temperature (∿ 100°-120°F) is not excessive for a number of available filter media but a filament-like, light weight, combination yarn, polyester fabric with the filament side to the dust was supplied by the equipment vendor. The ssb dust is fine, relatively low in apparent density and magnetic, but visual examination and the rolling test indicated that it does agglomerate.

After the intermittent collection cycles of the baghouse, bag cleaning is applied by means of a 90 psi air jet employing six pulses. No information was provided concerning the A/C or dust loading conditions. The results of the initial filtration study carried out at A/C of 5.4 to a limiting pressure drop of 6 in. w.c. are summarized in Table 9. These data indicate that most of the tested media, regardless whether of high, low, or medium permeability, operated for only 30 to 40 sec, compared to the 20 sec cycle experienced with the vendor-supplied medium. Only a Teflon web (micro porous) laminated fabric (Gore-Tex L10564) performed significantly better. The filtration time for this fabric, all other parameters essentially the same, increased to 115 sec for an improvement of almost 500 percent.

Recognizing that even this extent of improvement might not be adequate, further examination of the fabrics was carried out at an A/C of 1.8 with the other parameters the same as before and reasonably constant. As expected, significantly longer filtration times were recorded to reach the same (6 in.) pressure drop with the filtration cycles extending from 20 to 25 min for the vendor-supplied and the usual media, and over 30 min for the microporous Teflon surfaced fabric.

On the basis of these limited data, the following recommendations were made at that stage of the study:

- lower the A/C ratio (increase capacity) substantially to 2 or less,
- provide an extra increase in capacity to have each compartment off-line for cleaning during the filtration period, and
- install the microporous Teflon surfaced (Gore) bags.

An examination of the data raises some interesting questions. For example, why does a low permeability fabric like #25a pass the stainless steel burning dust so seriously that the filtration test could not be continued while a relatively open (101 perm.) spun bonded fabric retained this dust and, in fact, collected it at least as well as the vendor-supplied, filament/spun yarn medium? Why too did the wool/nylon fabric, a relatively bulky material and very electropositive material with considerably fiber cover also leak badly? Why did the Teflon laminate-surfaced fabric collect 500 percent better than the vendor's fabric at the 5.4 A/C, but only 50 percent better at 1.8 A/C?

Obviously, the usually considered physical variations of the test fabrics provide no answers. If, however, the high intensity, very electronegative electrostatic charge features of Gore-Tex preferentially contribute to the formation of a porous cake; and if aerosol velocity and charge generation are proportional, then one reasonable explanation is available.

TABLE 9. EXPERIMENTAL FILTRATION OF STAINLESS STEEL BURNING DUST, U-H

(A/C = 5.4, ΔP limit = 6" w.c. - room temperature (~ 70°F), dust loading ~ 20 grains/ft³ - pulse-like cleaning)

Run No.	Fabric							Fiber			Filtration Data			
											A/C = 5.4		A/C = 1.8	
	No.	Mfgr.	Style No.	Yarn	Weave	Resist.[1] Ω/□	Permeability cfm/ft² @ 0.5" w.c.	Generic	Trade	Form	Filter Cycle-Sec.	Rel. Leakage	Filter Cycle-Min.	Rel. Leakage
141	126	Vendor (Torit) inst. ? supplied by U-H steel			fil. w/sp.F 3x1 twill c.s.[2]	7×10^{14}	37	polyester	?	fil. & st. (fil. to dust)	18-20	Mod.	20-25	Mod. Low
142	97	AF	S-1414P	sp.	plain w.s.[3]	3×10^{13}	76	75/25 Wool/Nylon	Wool/Nylon	st.	25-35	High	--	--
143	25a	A	S-1740	fil.	3x1 twill c.s.[2]	10^{10}	26	polyprop.	--	fil.	--	V. High	(excessive leakage)	
144	27b	Eld	2470	spunbonded		2×10^{14}	101	polyester	Reemay	st.	40	Low	22-24	Low
146	127	AF	C-817LCE	sp.	3x1 twill napped w.s.[3]	2.8×10^{14}	47	acrylic	Microtain	st.	30	Low	22-24	Low
140	111b	AF	961	sp.	satin napped c.s.[2]	6.7×10^{8}	17.5	cotton	cotton	st. (nap to dust)	30	Low	--	--
145	89	Gore	1.10566	sp. 3x1 twill base w.s.[3] w/Teflon laminate		$>10^{14}$	19.5	Teflon laminate on polyester base		st.	115	Low	31-37	Low

[1]at 50% RH, 70°F [2]cotton system [3]wool system

Further studies were carried out to compare the vendor-supplied filament-like polyester fabric and the microporous Teflon surfaced fabric (Gore-Tex L10564) at different dust loadings at both the 5.4 and 1.8 A/C ratios, mostly to a pressure drop limit of 6 in. w.c., but in some trials to a 3 in. w.c. limit. The aerosol temperature was also increased from the previous 65°F to 180°F in these later studies, in an effort to reproduce more exactly plant conditions.

The results are summarized as follows:

- at an A/C = 6 and particulate loading of ∿ 0.5 to 0.6 gr/ft^3, the Gore-Tex collected two to three times more dust than the vendor's polyester up to the 6 in. ΔP limit.
- at an A/C = 6 and particulate loading of ∿ 1 gr/ft^3, the Gore-Tex collected about six times more dust than the vendor's polyester up to a 6 in. ΔP limit.
- at an A/C = 6 and particulate loading of ∿ 2 to 3 gr/ft^3, the Gore-Tex collected about ten to eleven times more dust than the vendor's polyester up to a 6 in. ΔP limit.
- at an A/C = 6 and particulate loading of ∿ 7 to 8 gr/ft^3, the Gore-Tex collected about 30 to 40 percent more dust than the vendor's polyester up to a 6 in. ΔP limit.
- at an A/C = 1.8 and particulate loading of ∿ 6 to 7.6 gr/ft^3, the Gore-Tex and the vendor's polyester collected about the same quantity of solids up to a 6 in. ΔP limit.
- at an A/C = 1.8 and particulate loading of ∿ 1.5 gr/ft^3, the Gore-Tex collected over 80 percent more dust than the vendor's polyester up to a 3 in. ΔP limit.

The plugged cloth pressure drop of the Gore-Tex fabric remained lower, consistently, than that of the vendor's polyester and ranged from 0.4 to 0.6 in. w.c. (ΔPp), compared to the 1.4 to 2.5 in. w.c. (ΔPp) value found with the vendor's fabric when used at the 6/1 (A/C ratio) velocity. At the 1.8 A/C flow rate, the ΔPp values were 0.1 to 0.2 in. w.c. for the Gore-Tex and 0.2 to 0.8 in. w.c. for the vendor's filament-like polyester filter.

These data substantiate but extend the basic conclusions reached earlier regarding the relative effectiveness of the two fabrics. Only at the low A/C flow conditions with moderate dust loadings do the advantages fall off for the Teflon microporous membrane-coated fabric in collecting this stainless steel burning dust. There is also an indication that an optimum level of (ssb) dust loading exists for this unusual fabric in the region of 3 gr/ft^3 at the 6/1 A/C ratio flow condition.

It is desirable, if not important, to attempt an explanation for the superior performance of Gore-Tex as a filter medium for the ssb dust. Acceptance of the screening-type action indicated for this fabric in the EPA 600/2-76-168c (December 1976) report is certainly plausible, but this does not go far enough. If only screening were the filtration mechanism by which the microporous Teflon membrane fabric functioned, such fabrics would become universal, all-purpose filter media. All, or at least most dusts, therefore, should be collected in an effective and efficient manner by Gore-Tex. That this is not the case clearly suggests that other forces are at work.

Assuming the screening action to be predominant in Gore-Tex filtrations and that particulate agglomeration is also a common factor in the process (although it is variable and dependent upon the agglomerating tendencies of each aerosol), it seems likely that the electronegative and relatively high charge (-3.6/16.8 V) and moderately high discharge rate ($\sim$ 55%) features of this Gore-Tex fabric can play a significant and possibly controlling role in the filtration process.

According to my observations, the easy-to-agglomerate dusts, especially those located away from Gore-Tex in the triboelectric series, should respond to the electronegative Teflon surface by forming aggregates. Obviously, these larger agglomerated particles would be easily sieved out of the air stream, but because the rate of charge loss from the fabric is high, the collected solids would not be retained on the slick surface. As a result, some particulates are more effectively filtered than others by Gore-Tex. (A relatively clear indication of such differences is provided in the filtration results provided from the study of the two polymeric (P) dusts, referred to later in this report.)

The variations in filtration performance of Gore-Tex occurring as a result of different ssb dust loadings and different velocities are not so readily explained. Why, for instance, should Gore-Tex be so superior to the vendor's polyester at one level of dust loading and not at lower or higher loadings? Do the screening, charge generating and charge transfer features contribute significantly here too? A case could be made for velocity related frictional changes with resultant differences in charging and for particle-to-particle contributions as a function of concentrations and dust loading. Obviously, more study is needed in order to arrive at an acceptable explanation.

<u>The Collection of a Ferromolybdenum By-Product Dust, CM-L</u>--The filtration study of this (fmbp) dust was carried out in two phases. The results are considered here essentially as they were reported at the end of each stage to demonstrate that in the course of any such evaluation a representative variety of media should be examined and also that more than the common physical properties of the media and particulates must be considered. Reliable interpretations of performance differences cannot be accomplished with just

the usual information on fiber type, fabric construction, permeability and weight together with the usual particulate parameters of size and chemistry.

For the first five fabrics evaluated for collectability with this dust, as reported in Table 10, the major differences in performance can be attributed as much to construction variations (i.e. filament vs spun yarns) as to differences in electrical properties. The three spun yarn fabrics #102, #120, and #141, whether of 50 or 21 permeability, provide high collection efficiency mostly because they retain a high level of dust (after cleaning) that serves as a filter-aid. The filament yarn fabrics #37 and #44, on the other hand, retain less dust, are inherently less bulky, and leaked the dust quite seriously throughout the entire filtration cycle, especially at start-up. Observations such as this are not uncommon and the explanation is usually credited to the obvious physical differences. But the porosity differences in the non-removable (by the adopted cleaning method) dust (plug) in and/or on the two types of fabric must contribute to the differences in flow resistance. That these differences are significant is quite evident. Although the filament type fabrics retain one tenth or less as much plug as the spun yarn fabrics, they exhibit about the same air flow resistance as shown by the plugged cloth pressure drop. Obviously, the dust residues in the two types of media differ in porosity.

In subsequent filtration studies of the ferromolybdenum by-product dust (fmbp), five other fabrics were evaluated. The results are summarized in Table 11. From the results of these trials as well as from the rolling tests carried out on the dust, it became evident that this fmbp particulate agglomerated quite easily, especially in contact with the more electropositive, high charge intensity fabrics. As a result, the media that perform best are those that provide these properties. The electropositive fabrics #102, #144, and #111 perform well despite high electrostatic discharge rates, whether achieved by means of a conductive (graphite) finish or provided naturally (cotton). Quite possibly, the highly electropositive media are more effective in promoting agglomeration of this dust than those that are electronegative. This would suggest that this relatively easy-to-agglomerate ferromolybdenum by-product dust should be located about midway or at an electronegative position in the triboelectric series. Apparently, so long as the fabric used to collect this dust is quite electropositive, agglomeration proceeds well and collectability is quite good.

The addition of a high discharge rate finish [conductive graphite] does not detract from the performance of an otherwise favorable (electropositive) fabric, #144. On the other hand, neither the slightly negative material (acrylic as in #120) nor the very electronegative fabric (Teflon #37) performs well, despite favorable construction features. However, when the electropositive

TABLE 10. EXPERIMENTAL FILTRATION OF A FERROMOLYBDENUM BY-PRODUCT DUST, CM-L (I)

(A/C = 6, ΔPc limit = 6 in. w.c., 130°-140°F, 3-5 gr/ft³ loading, shake cleaning)

Run No.	Fabric						Filtration Parameters					
							Rel. Triboelectric			Plug		
	No.	Mfr.	Style	Type	Fiber	Permeability cfm/ft² @ 0.5"	Position	Rate of Charge Loss % (2 min)	Collected Particulates, g	ΔP in. w.c.	Wt. g	Relative Leakage
154	120 r[a]	AF	810LC	wov., sp.	acrylic (microtain)	50	- 1.1	75	∿ 16	0.8	∿ 45	low
155	120 n[b]	AF	810LC	wov., sp. napped	acrylic (microtain)	50	- 1.1	75	∿ 16	1.1	∿ 76	low
156	141[c]	AF	MC2-811L	wov., sp. TFE fin.	acrylic (microtain)	21	- 2.4	75	∿ 12	1.4	∿ 56	low
157	44	JPS	4-33106/1	wov., fil.	polyprop	20	- 2.7	10	∿ 23	0.7	4.5	v. high
158	37	JPS	4N-2281	wov., fil.	Teflon	21	∿- 8.0	0	∿ 12	0.9	4.6	v. high
159	102	Hom	60306 nat	wov., sp.	wool	50.5	+ 5.5	85	∿ 16	0.6	∿ 45	low

[a]normal cover surface [b]napped surface [c]high cover surface

TABLE 11. EXPERIMENTAL FILTRATION OF A FERROMOLYBDENUM BY-PRODUCT DUST, CM-L (II)

(A/C = 6 to ΔPc limit of 6 inches w.c., at 130°-140°F, 3-5 gr/ft³ loading, shake cleaning)

Run No.	Fabric						Filtration Parameters					
							Rel. Triboelectric			Plug		
	No.	Mfr.	Style	Type	Fiber	Permeability cfm/ft³ @ 0.5"	Position	Rate of Charge Loss % (2 min)	Collected Particulates, g	ΔPp in. w.c.	Wt. g	Relative Leakage
159	102 a	Hom	60306 nat.	woven, staple	wool	50.5	+ 5.5	85	∿ 16	0.6	∿ 45	low
160	120 h	AF	810LC & a.s. (D)	woven, staple & Downy	acrylic	50	∿ - 1	v. high	∿ 4	2.2	∿ 80	low
161	120 i	AF	810LC & a.s. (G)	woven, staple & cond. graphite	acrylic	50	∿ - 1	v. high	∿ 11	1.0	∿ 60	low
162	144e	AF	S-1414 & a.s. (G)	woven, staple & cond. graphite	75/25 wool/nylon	50	very +	v. high	∿ 22	0.5	∿ 40	low
163	144a	AF	S-1414	woven, staple	75/25 wool/nylon	50	very +	80	∿ 19	0.9	∿ 65	low
164	111e	AF	961	woven, staple napped	cotton	17.5	very +	high	∿ 18	1.0	∿ 60	low

characteristics are satisfied, then suitable construction and high electrostatic discharge rate features seem to further improve performance. [It should be apparent that these results substantiate other evidence indicating how antistatic qualities (i.e. conductivity through graphite finishing) do not eliminate charging but only cause the charge to bleed-off rapidly. The *Downy* (antistatic) finish would seem to impart tackiness that detracts from any favorable charge bleed-off feature that it might convey. Of course, it could not provide such properties at the elevated filtration temperature.]

The direct comparison provided by runs 161 and 162 (Table 11), indicating 100% better collectability by fabric #144c compared to fabric #120i, with both fabrics at the same permeability, tends to make a strong case for the influence of charge polarity and intensity, especially since, on a basis of weaves, the plain weave fabric (#144) should not be quite as effective as the twill weave fabric (#120).

The #44b fabric, a light-weight filament polypropylene (refer to Table 10), provides a high level of collectability but leaks seriously. The performance differences between this fabric and a negative (much more negative at ∿ -8) Teflon fabric, also in the filament construction, is not so easily explained unless the dust is located at a position in the triboelectric series quite near Teflon. Also of possible but lesser importance is the very low rate of charge decay of this fluorocarbon fabric.

The questions arising from these studies tend to be more numerous than the answers. It seems clear, however, that without such evaluations, no fair indication of filter media preferences can be given and, further, that construction parameters are not the only criteria upon which filter media must be specified.

<u>The Collection of a Steel Grinding Dust, R-C</u>--An effort was made, actually without even nearly adequate success, to collect the particulate products from a billet grinding operation by means of a pocket type filter. At least three different media were tried in the commerical collector designed for an A/C ratio of 3.9. All failed because they could not be cleaned of the tenaciously adhering dust by the relatively mild (∿ 3 psi) reverse air. After a conventional polyester felt (∿ 14 oz) did not respond to the reverse cleaning, a similar polyester felt with an exceptionally smooth (glazed) surface (permeability = 16 cfm/ft^2 at 0.5 in. w.c.) was tried. Even this extremely smooth surfaced fabric did not release the grinding dust and, as with the conventional felt filter media, the pressure drop in the baghouse increased so excessively (>> 10 in. w.c.) that the grinding emissions could not be collected and had to be vented. In the course of the field trials a relatively light weight (∿ 6 oz) woven acrylic fabric was tried. Although somewhat better performance may have been realized, even though moderate at best, this fabric was also discarded after only

limited service because of excessive fabric wear and inadequate cleanability.

Experimental filtration trials of the commercially tried - and several other - media, reaffirmed the poor cleanability of the grinding dust (refer to Table 12). Under the test conditions, the ultrasmooth polyester felt that failed in the commercial trial collected only 3.6 g of the grinding particulate during the very short (20 sec) filter test to the 6 in. w.c. pressure limit. All of the other trial media performed better and the more practical fabrics collected 8 to 10 times as much dust before reaching this limiting pressure drop.

While the better performance of bag #143 (Gore-Tex) might be attributed to the slick microporous Teflon surface, it should also be noted that this fabric is very electronegative and also develops a high level of charge in the triboelectric tests. Furthermore, if surface slickness were the all-controlling factor, the poor behavior of bag #148 and better performance of fabric #113e (singed 87/13 Nomex/β fiberglass felt) would be difficult to explain. Actually, singing of this fiber blend burns out the Nomex cover fibers to leave a high concentration of glass on the surface. This causes the electrostatic charge intensity to increase by 50 percent to an extremely high value and, at the same time, raises its position in the triboelectric series (refer to Table 2) from $\sim$ 1.5 to $\sim$ 3.9, reflecting the presence of a high concentration of the electropositive glass fibers. The relatively good behavior, collectionwise and in low plugged cloth pressure drop, of the highly electropositive wool fabrics (bags #58 and #75) also suggests that electrostatics influence the collection of this magnetic, moderately conductive (resistivity = 3×10^8 Ω-cm)dust. Incidentally, despite this noted conductivity by the bulk method referred to on page 11, a substantial layer of the collected particulate on the filter fabric provided only a very high (> 10^{14} $\Omega/\square$) measure of resistivity by the square method (page 10).

Although it was conceded that more study was needed, an immediate decision had to be made regarding filter medium requirements and even more basically, whether the pocket type baghouse was indeed a viable system for collecting this and a burning dust too. Accordingly, the pocket filter was fitted with the #113 Nomex/glass fabric, turning the singed surface to the dust side. After pretreating the filter with limestone dust, according to the user's specification, the system was placed into service. Start-up was uneventful and performance was quite adequate at least to an A/C ratio of 2.5. As the flow increased to the design A/C ratio of 3.9, however, the pressure drop increased to an excessive level. Again, as in previous trials, the dust caked onto the filter surface and could not be discharged by the mild reverse air cleaning pulses. As a result, the decision to change to another, more vigorous cleaning type collector was made and except for one or two remaining trials, the experimental filtration program was terminated.

TABLE 12. EXPERIMENTAL FILTRATION OF STEEL GRINDER DUST, R-C

(A/C = 6, ΔPc limit = 6 in. w.c., 130°-140°F, 10 pop cleaning operations)

Run No.	Fabric					Filtration Parameters						
	No.	Mfr.	Style	Permeability cfm/ft³ @ 0.5"	Resistivity Ω/□	Particulate Loading g/min	Collected Particulate g	Cake Wt. g	Filter cycle min:sec	Plug Wt., g	Plug ΔPp	Relative Leakage
171	148	U.F.	? p.e. wov. sp.	14	3×10^{11}	11	20.2	10	1:05	44	3.2	Moderate
172	147	U.F.	? p.e. wov. sp. & 0.6% cond. graph.	14	10^{7}	18	12	10	0:40	53	3.2	Low
173	143	Gore	Gore-Tex TFE on p.e. felt	6	1×10^{13}	20	35	20	1:45	15	1.6	V. Low
174	141	AF	MC2-811L - TFE fin. on acrylic	21	1.6×10^{10}	16	21	16	1:20	79	2.5	High
175	113e	AF	S2283NRMM 87/13 Nomex/β glass, singed	42	6.6×10^{9}	16	28 36[a]	34	1:45 2:15[a]	31	1	V. Low V. Low
178	113G	AF	same as 113e & 1.5% cond. graph.	42	10^{7}	15	34	27	2:15	42	1	V. Low
176	148	U.F.	? p.e. felt glazed	16	--	11	3.6	3.5	0:20	15	1.4	V. Low
177	58	AF	(D184) felt wool	30	5×10^{12}	16	33	28	2:05	116	1.1	V. Low
179	75	MSA	Resp.-unt. wool/acrylic	103	10^{11}	15	39[b]	30	2:35[b]	222	0.8	V. High
180[c]	113d	AF	same as 113e	42	6.6×10^{9}	13	28	25	2:10	33	1	Low

[a]Additional 10 shakes applied

[b]5 instead of 10 pop cleaning operations

[c]Run made after bag precoated with limestone dusts

In the course of other tests, some extremely interesting and potentially significant observations were made. For example, in the rolling tests, both the grinding and burning dusts deposited a tenacious, brown resin-like film on the contact surface. The dust had a distinct odor resembling a burned organic material. Furthermore, the grinder dust was shown by scanning electron microscopy to be made up of small but exactly spherical particles, and none were rough. Also, on the inside, clean air side of the pocket filter fabric, a dark brown, narrow line of about 1/2 in. in length occurred at each point of contact with the metal spring used to keep the pocket from collapsing. These marks were first thought to be burns, but closer examination showed no fused fibers and treatment with a petroleum solvent caused them to be removed almost completely.

These findings need verification and they raise other questions that should be answered. Nevertheless, some speculation is warranted even on the basis of the very limited information. For example, it seems that a component, possibly organic or a form of sulfur, and developing during both the processes of burning and the grinding of the billets, is common to both dusts, producing a very adhesive binder. This ingredient, assumed to be a material of high electrical resistivity with strong electrostatic activity, could migrate preferentially (because of the charge) or otherwise through the fabric to the grounded spreader wires inside the filter pockets producing the observed brown line marks. Certainly, the smooth spherical particles as shown in the SEM photo (Figure 9) of the grinder particles would have little tendency to bind mechanically to the fabric and account for poor cleanability. Even static adhesion between the particulate and fabric, especially when using a conductive medium, would not be as tenacious as shown in the filter trials. Some obvious questions arise from these real and not so real findings. Where, for example, would a common contaminant originate? Could it be that a protective coating is applied to the billets and that this, in course of heating, is transformed into a super binder? It is known that a flux is used in the burning operation and that the grinder wheels contain a phenolic binder. Certainly, some of both materials or their pyrolytic products get into the dust, but are these products so similar that they form the same kind of reddish brown film in the rolling tests and impart the adhesive properties? At this writing, no better data have been obtained and no further explanations have been made available. The questions remain unanswered.

The Collection of Polymeric Dusts

The Collection of Polymeric Dusts P·K-3085 and P·6140--

Two polymeric dusts, P·K-3085 , an aromatic copolymer, and P·6140, an alicyclic polymer mixture, were evaluated filtrationwise with several selected filter fabrics. The Teflon fabric used in the plant shaker-type collector served as the reference medium. It is not clear why a Teflon fabric is used in the plant collector

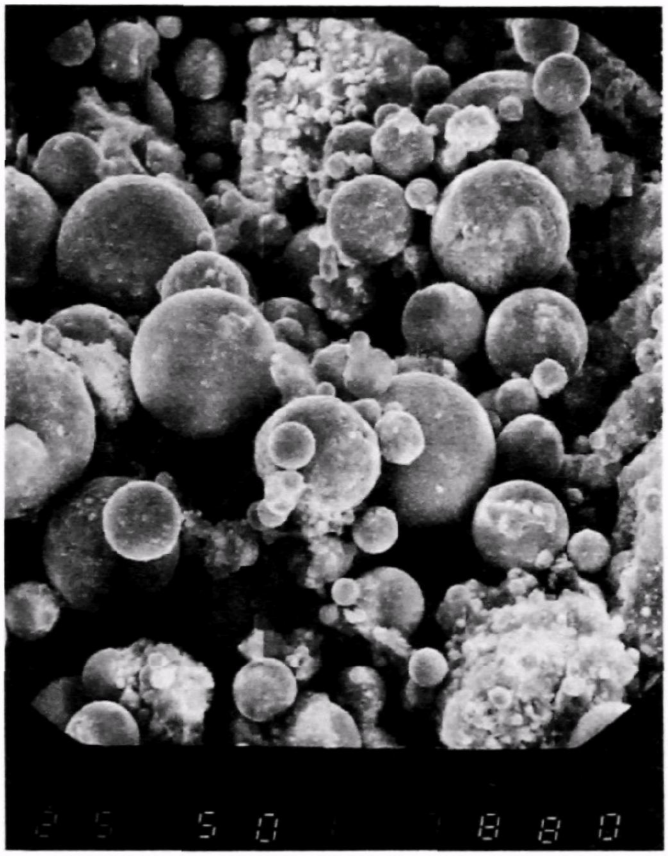


FIGURE 9. STEEL GRINDING DUST, X 500

by

SCANNING ELECTRON MICROSCOPE

that operates at ambient temperature and humidity, unless one or both dusts exhibit critically serious blinding properties or because the dusts are flammable.

Both dusts are flammable, thermoplastic and develop high levels of electrostatic charge. Resistivity measurements at 70°F/40%RH also indicate that both dusts have values greater than 10^{14} $\Omega/\square$. In the rolling test, the apparent density of P·K-3085 increased by about 13.7%, and that of P·6140 increased by 9% while both showed evidence of aggregation.

Serious leakage, especially during the cleaning operation, is the most critical problem experienced during the commerical filtration of these dusts. The resulting dust seepage leads to difficulties with plugged chambers, clogged pressure taps, and to the malfunctioning of shaker controls and the dust removal system.

The equipment specifications and operating conditions were given as follows:

- shaker-type collector designed for A/C = 5.3 and operated at 3.3,
- the maximum ΔP is 10 in. w.c. but operates at 2 to 4 in. w.c.,
- cleaning is accomplished by eccentric, horizontal mechanical shaking of 1-2 min,
- the filter cycle is 8 hr (to the 2 to 4 in. w.c.),
- the clean cloth ΔP is 2 in. w.c.,
- dust loading ranges from 0.9 to 1.4 gr/scfm.

The filter test results, although limited to an evaluation of seven media - three very electropositive fabrics, three very electronegative fabrics and a moderately positive fabric (refer to Table 13) permit some tentative conclusions of practical significance. While both of these polymeric dusts show the same high level of electrical resistivity ($> 10^{14}$ $\Omega/\square$), they differ appreciably in their aggregating and filtering properties. Of the two dusts, the P·6140 resin is the most critical, in regard to its ability to agglomerate and with respect to its overall collectability. With the P·K-3085 dust, all but the plant-used fabric performed well without leakage. The more critical-to-collect P·6140 dust is filtered best without leakage only by the high charge, electropositive fabrics.

It is especially interesting to note that the very electronegative Kevlar fabric #65 performs only slightly better than the other electronegative filters, including the plant-used Teflon #94. Actually, the Kevlar filter performed more like the Teflon

TABLE 13. EXPERIMENTAL FILTRATION OF POLYMERIC DUSTS P·K-3085 AND P·6140

A/C = 6, ΔPc limit = 6 in. w.c., 70-75°F, shake cleaning

Run No.	Fabric							Filtration Parameters						
	No.	Mfr.	Style	Fiber(s)	Permeability cfm/ft² @ 0.5"	Resist. Ω/□	Rel. Tribo. Position / Total Rub Voltage	Collected Particulate, g K-3085	Collected Particulate, g 6140	Plug Weight, g K-3085	Plug Weight, g 6140	Plug ΔP in. w.c. K-3085	Plug ΔP in. w.c. 6140	Leakage
111	71	AF	S-225	wool	46	10^{13}	+5.6 / 8.3	171	--	15.6	--	0.15	--	low
109	94	Eld	XT0954	Teflon	37	> 10^{14}	∿ -6 / 11.5	148	--	1.4	--	0.7	--	mod. high
106								--	71	--	6.2	--	1.2	v. high
110	89	Gore	L10564	Coretex Teflon lam. on p.e.	19.5	> 10^{14}	-3.6 / 16.8	207	--	9.3	--	0.7	--	low
105								--	88	--	8.4	--	0.7	low
108	96	AF	S-1414	75/25 wool/nylon	102	2.9×10^{13}	+5.7 / 12.2	190	--	30	--	0.1	--	slight
107								--	130	--	33	--	0.35	slight (cleaning)
112	78	AF	S-1414	75/25 wool/nylon	33	4×10^{12}	∿ +7 / 11.3	193	--	9.3	--	0.2	--	low
113								--	113	--	12.4	--	0.4	low
116	78a	AF	S-1414	75/25 wool/nylon + 0.9% Hyamine 3500	33	10^{8}	antistatic	--	102	--	13	--	0.5	low
114	18	JPS	D-8339	p.e. sp. & napped	38	> 10^{14}	+1.4 / 21.6	230	--	12.6	--	0.1	--	low
115								--	124	--	15	--	0.2	low
117	65	Eld	181 III	Kevlar fil.	31	10^{14}	∿ -8 / 18	--	96		5.4	--	0.8	high

and Gore #89 fabrics in regard to collected solids, plug retention, and plugged cloth resistance than the electropositive fabrics. In collecting the P·6140 dust, therefore, the more electropositive, high charging media perform far better than the electronegative materials. The outstanding performance of the high charge, only moderately high electropositive polarity, low dissipation rate polyester fabric #18 with this dust is noteworthy. For collecting the P·6140 dust without leakage, these results seem to suggest that the preferred medium is electropositive but not necessarily at the top level in the triboelectric series, capable of generating a high intensity of charge and with a relatively low rate of charge bleed-off. These features, presumably, are effective in encouraging suitable aggregation of the P·6140 dust on the collecting fabric. The same fabric should also be effective in collecting the P·K-3085 resin even though it seems to respond favorably to lesser extremes in charging.

The Collection of a Fine Polymeric Dust, RH-P--

A fine, high resistivity, very electrostatically active acrylic polymer dust that posed serious commercial collection problems was shown to behave similarly in experimental filtration studies. Only two among the first 14 tested media made of different fibers in a variety of constructions showed plug weights below the weight of the collected dust. Dust release from all of the tested bags was shown to be limited whether cleaning was attempted by shaking or by popping, the latter action being similar to that provided by pulse jet. The dust-fabric adhesion was so intense that plug weight/cake weight ratios ranged from 80-90/20-10 for all but the two test media noted above. The plug weight/cake weight ratio was substantially lower for one of these - a filament Teflon filter fabric, but dust leakage was critically serious throughout each filtration cycle. In these trials, only a Dralon T woven filter fabric performed at a relatively low plug weight/cake weight ratio without leakage. It is important to note that an almost identical filter fabric (with respect to weave and permeability), made of another acrylic (Zefran) at a different location in the T.E. series, held about 50 percent more plug and provided a 70 percent higher plug pressure drop with a high plug weight/cake weight ratio at 85/15. These performance differences are significant since the tests were conducted at the same 5.4 A/C ratio to a pressure drop limit of 6 in. w.c. under conditions of relatively constant dust loading and temperature (140 - 150°F).

Additional trials were carried out using 16 variations of needled (felt) fabrics, some of these were prepared with and without glazed filter surfaces and with and without organic-type anti-static treatments or included conductive fibers. The following conclusions were reached in the course of this phase of the study:

- glazing of the felt surface improved collectability. Both plug weight and plug pressure drop values were lowered when a glazed filter surface was used.

- a cationic antistatic finish (Hyamine 3500), whether used on the glazed or on the normal felt surface, improved collectability and reduced the plug weight in each case.

A single filter trial with the Dralon T fabric #3 from the first test series was carried out using the acrylic dust after this dust had been treated with the cationic Hyamine 3500 (antistatic) surfactant to a 1 percent add-on. The resistivity of the original test dust was reduced from > 10^{13} Ω-cm to 10^9 Ω-cm by the treatment, but this change had no beneficial effect on the collection process.

As a matter of interest, with a potential for explaining performance differences, is the observation that this acrylic dust with the antistatic treatment showed little tendency to disperse easily into a cloud. It was also shown to densify (by 20 percent) and become highly aggregated in the rolling test. The untreated dust, on the other hand, remained dusty or prone to dispersion, did not aggregate significantly and did not increase in density in the rolling test.

The overall results from the experimental studies may be summarized as follows:

- an acrylic fiber content filter performed better than fabrics made from other fibers,

- one acrylic, Dralon T, collected the polymeric acrylic dust better than another,

- a Dralon T felt functioned better than a woven Dralon T filter material,

- glazing this felt surface offered further improvement, and

- an antistatic finish applied to the glazed Dralon T felt provided additional advantages.

Subsequently, information obtained from the processor of the acrylic polymer dust indicated that the filter bags that performed best in commercial service were made from a European manufactured felt constructed with an acrylic fiber but treated by the user with a cationic (antistatic) finish. After relatively short periods (about one month) of plant use with different products, the bags were laundered and retreated with this finish before reuse.

Without knowing the location of this acrylic dust in the triboelectric series, it is not too safe to speculate regarding electrostatic effects. Nevertheless, the rolling test indicated that the dust did not aggregate or at least did not agglomerate easily. With its high level of electrostatic activity and this restriction on aggregation, especially in contact with a fabric of suitable charge and/or charge polarity, it seems reasonable to suggest that construction (felt for depth filtration and a glazed surface for enhanced cleanability) must be relied upon for the basic filtration needs, but that the preferred filter medium might be that having a location in the triboelectric series near the position of the dust. Such close proximity would be expected to limit electrostatic attraction or the adhesion between dust and fabric allowing, thereby, improved cleanability. In addition, the presence of the antistatic finish would also tend to enhance cleanability through its ability to promote rapid charge bleed-off.

The evidence, albeit circumstantial, implies that collectability of even those fine, electrostatically active dusts that resist aggregation may be achieved best by employing media with preferred electrostatic-as well as constructional-properties.

The Collection of Silica PG-C

Only a few particulates seem to resist aggregation and fail to respond to electrostatic charge induced agglomeration on a suitable filter medium. While silica does agglomerate, it seems to reach a state of limited aggregate stability. In fact, in the rolling test (Table 6), arbitrarily adopted as a guide to whether dusts will agglomerate, silica (at least the two varieties examined) actually seems to disperse somewhat into more "feathery" aggregates and consistently showed a reduction rather than an increase in density. In the collection of silica by fabric filtration, therefore, further agglomeration beyond a frail aggregate structure cannot be relied upon for optimizing filter performance. Fabric selection, in order to realize the best performance, seems possible on the basis of other operating parameters.

Since extended processing may tend to further disperse silica and almost any commercial method of handling this material can be expected to induce such a change, selection of the preferred medium will most likely have to be directed more to attain and maintain a high level of efficiency than to realize exceptionally low operating pressure drop. In other words, fabric construction would seem to have to be relied upon primarily to achieve a good pressure drop-collection relationship. But the electrostatic properties of the medium might be used to hold an effective filter-aid like cake on its surface at all times and, thereby, to enhance efficiency. This suggests that the polarity difference between the dust and the filter medium should be high in order to offer substantial attraction between the two materials and, further, that the discharge rate of the fabric should be sufficiently low to maintain the attractive forces for an adequate period of time to keep some of the dust on the surface of the fabric, even after the cleaning operation. Obviously, cleaning effectiveness may also have to be controlled at less than a maximum level.

According to the data reported earlier in Part A of this report by Professor Penney, some of which is reproduced in Table 14, silica should be located at about -3, between -2.5 and -3.6 on the arbitrary scale of our triboelectric series. In this location, a considerable electrostatic influence should be exerted on silica dust by a highly positive fabric like #97 (wool/nylon) or by a highly electronegative fabric like #65 (Kevlar), both of which are widely separated from the silica in the T.E. series. In a favorable construction, the wool/nylon and a Kevlar fabric might be expected to perform similarly, filtrationwise (refer to Table 14). The Kevlar fabric, however, displays a higher rate of charge dissipation (45% in 2 min) compared to the 20% value shown for the wool/nylon material. More serious, though, is the significant difference in the bulkiness of the two materials with the filament Kevlar fabric offering little more than screen-like properties compared to the high bulk, good cover, high charge features of the wool content medium. On all counts, then, the woven wool/nylon #97 should perform at high collection efficiency in shaker-type cleaning systems, and a felted wool should be best in a pulse- or reverse air-jet type system when collecting either of the two silicas.

Unfortunately, without a spun yarn Kevlar fabric more like the wool/nylon material in construction, it is not possible to prove without question the hypothetical relationship suggested above. Nevertheless, there are some important observations that appear to provide a measure of support. For example, although the wool/nylon #97 fabric leaked the silica dust quite seriously at first, the loss of silica through this filter bag became less and less with progressive runs, despite the vigorous shaking type cleaning operations. Even with such energetic cleaning (ten horizontal strokes through 1.5 in. displacement at the top cap), the plug pressure drop (ΔPp) increased from 0.2 in. to 0.6 in. w.c. after about eight (8) cycles and remained at that level until the test was terminated after eleven (11) cycles. Similarly, the plug weight increased from 19.3 g to a high and essentially constant value of $\sim$ 50 g. Although the Kevlar filter bag could not be carried through as many runs because of excessive leakage, the initial ΔP of 0.6 in. w.g. and, especially, the relatively high initial plug weight of 21 g (6 cycles) (high for a filament yarn fabric) would seem to reflect the attractive features of a fabric with a triboelectric charge polarity substantially opposite to that of the silica dust.

The filtration data (refer to Table 15) obtained in the collection of the same silica dust with a needled polyester felt, when compared with the above results, seems to substantiate the hypothesis. Certainly, compared to the filament yarn fabric or even the woven wool/nylon fabric, the data recorded for fabric #109 are most striking. Despite the fact that bags made of felt-like materials do not shake as well as the more flexible woven fabrics, the plugged cloth pressure drop value (ΔPp) for the poly-

TABLE 14. TRIBOELECTRIC POSITION OF SILICA, PG-C (RELATIVE TO SOME FABRICS)[a]

Fabric		Dust, Charge (Current, 1×10^{-9} a)
Identification	Rel. T.E. Position	Relative to Fabric
# 97 75 wool/25 nylon	∼ +8.0	-4.5
# 15 Dacron	+4.8	-1.4
# 9 50 Dacron/50 Orlon	+0.7	--
#16 Dacron (Type 55) & Silicone	-2.5	-1.1
←	∼ -3 Silica PG-C	→
#89 Gore-Tex Teflon on p.e.	-3.6	+0.9
#55 Darvan (felt)	-3.7	--
#37 Teflon	∼ -6.0	+3.8
#65 Kevlar	∼ -8.0	+4.2

[a] Penney, G.W. - Progress Report of October 15-November 15, 1976 to EPA Grant No. R803020

TABLE 15. EXPERIMENTAL FILTRATION OF SILICA, PG-C

(A/C = 6, ΔPc limit = 6 in. w.c., 130°-140°F, shake cleaning)

Run No.	Fabric								Filtration Parameters			
	No.	Mfr.	Style No.	Fiber	Type	Permeability cfm/ft^2 @ 0.5"	Rel. T.E. Position	Rate of Charge Loss % (2 min)	Av. Collected Particulates g	Plug Wt., g	Plug ΔPp	Relative Leakage
147	65	BId	181 III	Kevlar aramid	wov. fil.	31	∿ -8	45	130	21	0.6	high
148	97	AF	S-1414P	60/40 wool/nylon	wov. sp.	76	∿ +8	80	125	50	0.6	mod-low
149	109	P&S	U-J (used & washed)	Dacron p.e.	felt	56	-2.8	30	105	45	0.3	mod-low
150	16c	JPS	04-39703/5	Dacron p.e.	wov. sp.	26	-2.5	30	22	5	0.9	high
151	55	AF	40/601	Darlan acrylic	felt	32	-3.7	30	40	45	0.3	low

ester felt increased from an initial value of 0.1 in. to only 0.3 in. w.c. and the plug weight, again despite the fabric's comparatively very high bulk, increased from about 30 to only 45 g. The plug weight, although seemingly somewhat elevated, is really relatively low for a felt-like filter bag and yet it is below that found in the far more open (higher permeability), less bulky, wool/nylon bag of exactly the same filter area. In addition, compared to this polyester needled bag, the wool/nylon fabric collected about 15% more dust before reaching the same limiting pressure drop (ΔPc) of 6 in. w.c. Since some of this better collectability might be attributed to permeability difference, major emphasis must be placed on the plug weight and plugged cloth pressure drop data to provide a measure of evidence for the effectiveness of electrostatics in producing and retaining the attractive forces needed to form and hold a filter aid type of surface of silica on the fabric during each filtration cycle.

Also as given in Table 14 data, the #16 Dacron with a Silicone finish (this finish does not contribute significantly to the triboelectric properties) is located somewhat closer to silica in the T.E. series. As a result, the forces of attraction between the fabric and dust should be relatively low. Such appears to be verified by the filtration data that shows a low plug weight ($\sim$ 5g), high ΔPp and low collectability for this woven filter fabric .

Based on these results, it would appear that the efficient collection of silica dust in a shaker-type system may be accomplished best with a moderately heavy ($\sim$ 8 oz/yd^2), high cover, very electropositive, woven woolen fabric of about 30 to 40 permeability. If a pulse-jet type collector were to be used and similarly high efficiency were required, a wool felt of about 12 oz/yd^2 at a permeability of about 50 to 60 permeability might be recommended.

SUMMARY

Admittedly, many of the conclusions reached in the foregoing discussions relate electrostatic properties of filter fabrics with those of the particulates to explain collectability, cleanability or efficiency are developed largely upon circumstantial evidence. But any other fabric or particulate property fails completely to offer a more reasonable explanation. The basic premise of the electrostatic involvement hypothesis deals with particulate aggregation. Whereas this electrostatic charge-agglomeration reaction was first merely hypothesized, Professor Penney's work now removes some of the guesswork. His studies have demonstrated, for example, that "impact" charged particles form a "chain-like," porous or agglomerated deposit on a fabric without the use of high voltage either on the particulate or on the collecting surface. This observation serves to confirm the premise that natural charging can produce aggregates just as artificial charging (i.e. in an electrostatic precipitator) often leads to such a change in particulate qualities.

In another of Penney's tests, again without an external potential being impressed on the filter fabric, corona-charged particles (electronegative) also became deposited in a "chain-like" aggregated manner on just the electropositive fiber of a composite, two fiber filter. This filter is pictured in the photomicrograph (Figure 10)[3] showing a blend of two different (wool and acrylic) fibers, each of about 3 μm in diameter. The fact that one fiber remains clean while the adjacent fibers and only these electropositive fibers, collect the negatively charged particles as a porous aggregate is viewed as supporting evidence for the original hypothesis that stresses the effectiveness of high, often opposite charges in promoting the agglomeration of difficult-to-agglomerate particulates.

The other electrostatic-filter fabric relationships are more readily appreciated and justified. For example, that opposites attract and that as materials become more opposed their attraction increases is generally accepted. Less clear is the relative importance of charge intensity and triboelectric position in the

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[3]Penney, G. W., *J. Air Poll. Control Assn.*, 26:58 (1976).

FIGURE 10. AGGREGATED DEPOSIT OF PRECHARGED PARTICULATE ON A FILTER FIBER

aggregation process. But these and other charge-filtration relationships seem to provide the best explanation for many observed anomalies.

Rapid charge dissipation from a fabric or from a dust, too, may be realized if their entire surfaces are treated with a conductive finish. Much less effective, if at all effective in a fabric, is the use of conductive fiber elements. These fibers produce essentially no continuity over the fiber surface on the micro scale and, thereby, provide little benefit and certainly not the kind of overall charge dissipation offered by continuous conductive (cationic or graphite) finishes. Nevertheless, using the fugitive (organic based antistatic agents) in filtration processes that depend on such finishes for charge bleed-off, must be done with the knowledge that these agents, whether they depend upon the ionization of quaternary or hydroxy compounds for charge conductivity, must have moisture present for this function. Furthermore, both chemicals are temperature sensitive and the quaternary compounds are believed to form as intermediate product, an electropositive amine, in the "burning-off" process.

The value of antistatic treatments, sometimes even more effective on the particulate than on the filter fabric, seems to have been reasonably well demonstrated in some of the tests, and these revelations can have important implications. In considering antistatic finishes, it is important to note that such finishes do not eliminate electrostatic charging, but rather, they only provide a means for the generated charge to bleed-off very rapidly.

In the course of the experimental studies reported here, the considered effects of electrostatics on the filtration processes have been utilized to explain performance characteristics and to identify preferred media. Whenever particulates were capable of agglomerating, fabrics of high polarity differences and/or high charge intensities were employed to realize this effect. In at least one instance, a fabric capable of developing a high charge but at only a medium triboelectric position, produced the needed aggregation. In collecting another dust that did not seem to agglomerate to a stable aggregate, optimum filtration properties were achieved with a filter medium that was separated significantly from the particulate in the triboelectric series. Fortunately, the location of this dust in the triboelectric series had been established from the Penney studies. For the first time, the reliability of the dust-filter fabric relationship in the triboelectric series had been established. Accordingly, the analysis that prescribed such a difference for optimum performance would seem to be based on reliable evidence.

In at least one instance, the extent of improvement in filtration performance suggested for a supposedly better medium based on electrostatic properties, was inadequate. Further analysis of the overall problem now suggests that other factors may have had a completely overriding influence and critical fabric parameters, including the electrostatic, could never be altered favorably until these limiting conditions were eliminated.

Hopefully, this report of some fundamental and practically oriented studies, directed especially to considerations of electrostatic effects in fabric filtration, provides a contribution to the advancement of technology that allows otherwise unexplained filtration events to be solved better and and faster, even though not necessarily diagnosed with complete accuracy. Hopefully, too, other investigators will find this report sufficiently motivating to proceed further into this important area of fabric filtration.

TABLE 16. METRICATION OF SOME FILTER PARAMETERS

PROPERTY	METRIC UNIT	BRITISH UNIT	CONVERSION FACTOR (TO METRIC)
Width of cloth	mm	in.	25.4
Diameter of bags	cm	in.	2.54
Length of bags	m	ft	0.3048
Thread count	per cm	per in.	0.394
Thickness	μm	in.	25400
Unit mass of cloth	g/m^2	oz/yd^2	33.9
Density of material	g/m^3	lb/ft^3	16018
Permeability*	$l/s/m^2$ @ 200 Pa	cfm/ft^2 @ 0.5" w.c.	7*
Temperature	°C	°F	(F-32) 5/9
Pressure drop	mm w.c.	in. w.c.	25.4
Dust loading	g/m^3	gr/ft^3	2.288
Dust mass	g	gr	0.0648
Particle size	μm	in.	25400

*In metric practice, 20 mm is usual ΔP, but 200 Pa is being suggested. (Since permeability is not strictly proportional to ΔP, the factor of 7 is only approximate and must be established experimentally).

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16. ABSTRACT The report describes the construction and application of a bench-scale, single-bag, experimental filter. It also describes several complementary evaluation procedures and their data. Especially significant are the methods for, and results of, electrical determinations that are not normally applied to filter media and particulates. The effect of these electrical parameters on the collection process is used to explain performance variations. Results of several filtration studies on several industrial particulates (e.g., from a power plant, and from metallurgical and chemical processes) are reviewed in detail and explained on the basis of electrostatic properties. Flyash collection, for example, was favored by the use of mid-triboelectric position media and not by the highly electropositive or electronegative fabrics that are used for their high temperature properties. Three different electric furnace dusts tended to respond best (filtrationwise) with mid-triboelectric position fabrics, modified for different cleaning practices. Steel grinding and burning dusts offered very critical filtration characteristics that demanded control of aerosol flow and particulate loading, as well as special care in filter media selection. A ferromolybdenum by-product dust was collected best by very electropositive fabrics.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Air Pollution	Electrostatics	Air Pollution Control	13B	20C
Dust	Measurement	Stationary Sources	11G	14B
Aerosols	Electric Power Plants	Particulate	07D	10B
Fly Ash	Metallurgy	Fabric Filtration	21B	11F
Filtration	Chemical Industry	Triboelectric Measure-		07A
Fabrics	Electric Furnaces	ment	11E	13A

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