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Environmental Protection Technology Series

EPA FABRIC FILTRATION STUDIES: 3. Performance of Filter Bags Made From Expanded PTFE Laminate

Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

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EPA FABRIC FILTRATION STUDIES:
3. PERFORMANCE OF FILTER BAGS
MADE FROM EXPANDED PTFE LAMINATE

by

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PREFACE

This report is the third in a series of reports, entitled EPA Fabric Filtration Studies, which summarize the results of EPA laboratory testing of new baghouse fabric materials and present the conclusions of specialized research studies in fabric filtration. These tests have been carried out over the past 4 years by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, N. C. Related work by predecessor agencies predates the present series. The purpose of these investigations was to evaluate the potential of various new fabrics as baghouse filters and to obtain data for use by the fabric filtration community. The testing consisted of simulating a baghouse operation in a carefully controlled laboratory setting that allowed measurement and comparison of bag performance and endurance. The simulation discussed in this paper covered only a very narrow range of operating conditions:

1) Redispersed, classified flyash (mass median diameter between 5 and 6 μm) entrained in air was the only dust used.
2) All filtering was done at room temperature.
3) Humidity was varied from about 30 to 70 percent.
4) The air to cloth ratio was varied between 4:1 and 10:1.
5) The inlet dust loading was held in the vicinity of 3 grains/ft^3 (6.9 g/m^3)*.

*EPA policy is to use metric units only or to list both the common British unit and its metric equivalent. For convenience and clarity, to the anticipated reading audience, British units are used in this report. Readers more familiar with the metric system may use the factors in the Appendix to convert to that system.

Extreme caution should be used in extrapolating the results reported here to the substantially different conditions that occur in all field applications. The usefulness of the present results is primarily as an initial screen of candidate fabrics for baghouse applications.

The projected EPA Fabric Filtration Studies series will consist of the following reports:

1) "Performance of Non-Woven Nylon Filter Bags," J. H. Turner (in press)
2) "Performance of Non-Woven Polyester Filter Bags," G. H. Ramsey et al., EPA-600/2-76-168b, June 1976
3) "Performance of Expanded PTFE Laminate Filter Bags" (this report)
4) "Bag Aging Effects"
5) "Bag Cleaning Technology"
6) "Analysis of Collection Efficiency by Particle Size"

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LIST OF ABBREVIATIONS AND SYMBOLS

A = filtration area of fabric (sq ft)

C_o = mass outlet concentration (grains/100 cu ft)

E = mass collection efficiency (percent)

K_2 = true value of specific cake resistance (in. H_2O/fpm)/(lb/sq ft)

K_2' = measured value of specific cake resistance (in. H_2O/fpm)/(lb/sq ft)

ΔP_E = pressure drop across bag at time zero of filtration cycle (in. H_2O)

ΔP_T = pressure drop across bag at end of filtration cycle (in. H_2O)

S_E = effective drag (in. H_2O/fpm)

S_T = terminal drag (in. H_2O/fpm)

A/C = air/cloth ratio (fpm)

ACKNOWLEDGMENTS

All fabric filters used in this study were donated by W. L. Gore and Associates, Inc., Rt. 213, North Elkton, MD 21921. It is also a pleasure to acknowledge the constructive criticism and advice provided by Mr. Edward De Garbolewski of that organization.

SECTION 1

INTRODUCTION

This paper summarizes a laboratory evaluation of filter bags made of Gore Tex.* Gore Tex is expanded polytetrafluoroethylene (PTFE) deposited as a thin, fibrillated film (shown in Figure 1). The filters evaluated here for baghouse applications consisted of this fibrillated film deposited on a 2/1 twill fabric woven from spun staple Nomex** fiber. A cross-section through the composite fabric is shown in Figure 2. The coarse woven fibers are the Nomex substrate, one side of which is covered with the thin PTFE film. This Gore Tex/Nomex composite is but one of a family of Gore Tex laminates. Other readily available backing materials include woven polyester and Gore Tex expanded PTFE itself. All backing scrims are highly porous. Their chief function is to provide strength for the composite fabric.

Measured properties of the Gore Tex/Nomex fabric are listed in Table 1. The high tensile and burst strengths are characteristic of a woven fabric. Permeability is low which might suggest pressure drops and drags somewhat higher than desired for bags made from this material. As will become evident, this potential shortcoming does not, in fact, exist; the dust/fabric system investigated here allowed economical baghouse operation, more like the best of the previously investigated systems than the poorest [Refs. 2,3].

Among the properties specified by the manufacturer as being of particular interest for baghouse applications are the chemical inactivity of the PTFE ("resists acids, alkalies, weathers well; and is non-flammable")

*Tradename of W. L. Gore and Associates, Inc.
Elkton, MD 21921
**Tradename of E. I. DuPont Company, Inc.

and its temperature stability ("very stable from -350 to 500°F"). It is a good thermal and electrical insulator and its surface has a low affinity for water. To fully realize these advantages, however, the fabric must be an all Gore Tex laminate--Gore Tex PTFE film on a Gore Tex PTFE backing. All the laminates evaluated in this study were of the Gore Tex/Nomex type, whose chemical and physical properties are governed primarily by the Nomex. The film side of the Gore Tex/Nomex fabric feels slick and smooth--like any PTFE coated surface; the reverse however, shows no influence of the PTFE film.

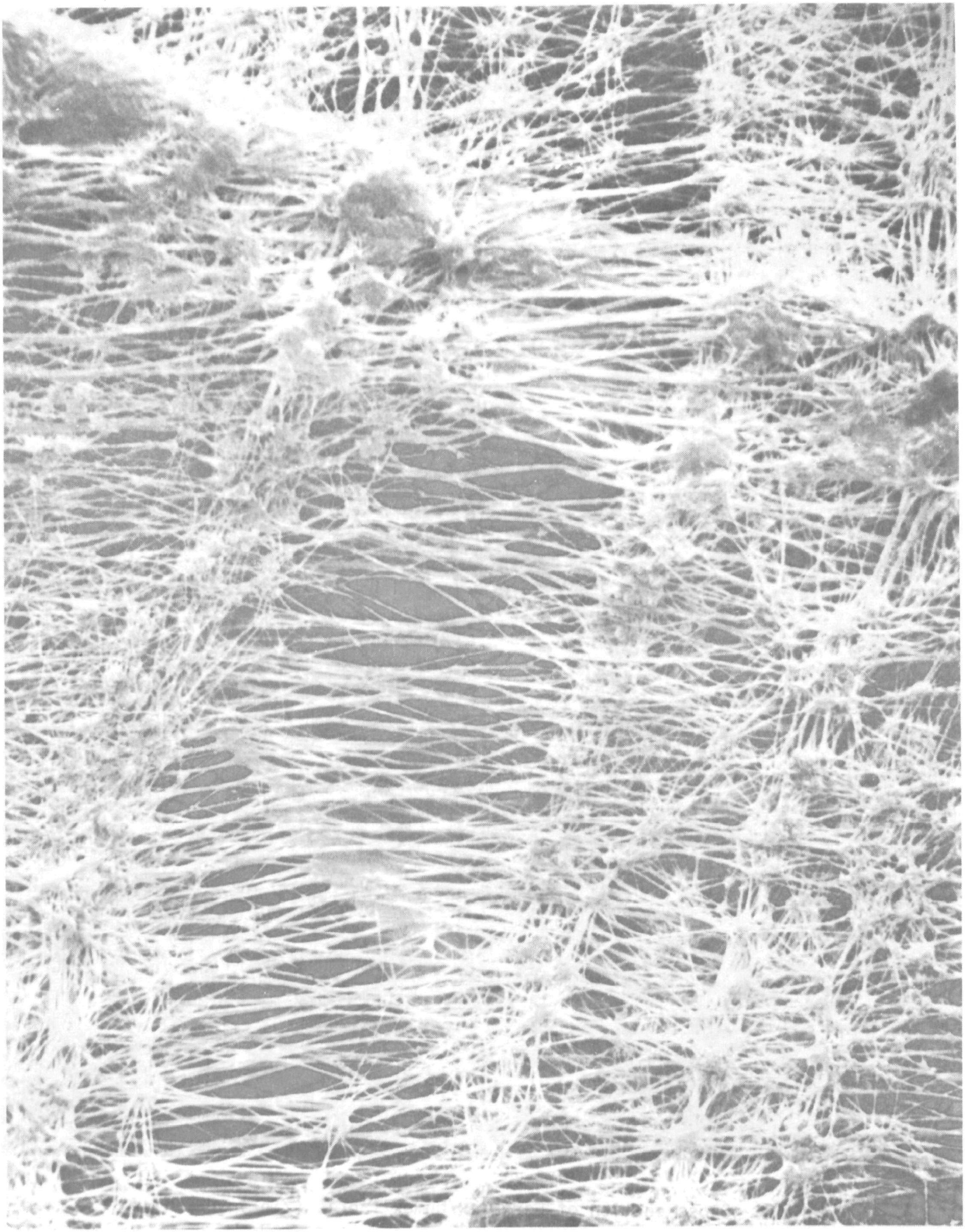


Figure 1. Gore Tex film (2150X) [Ref.1].

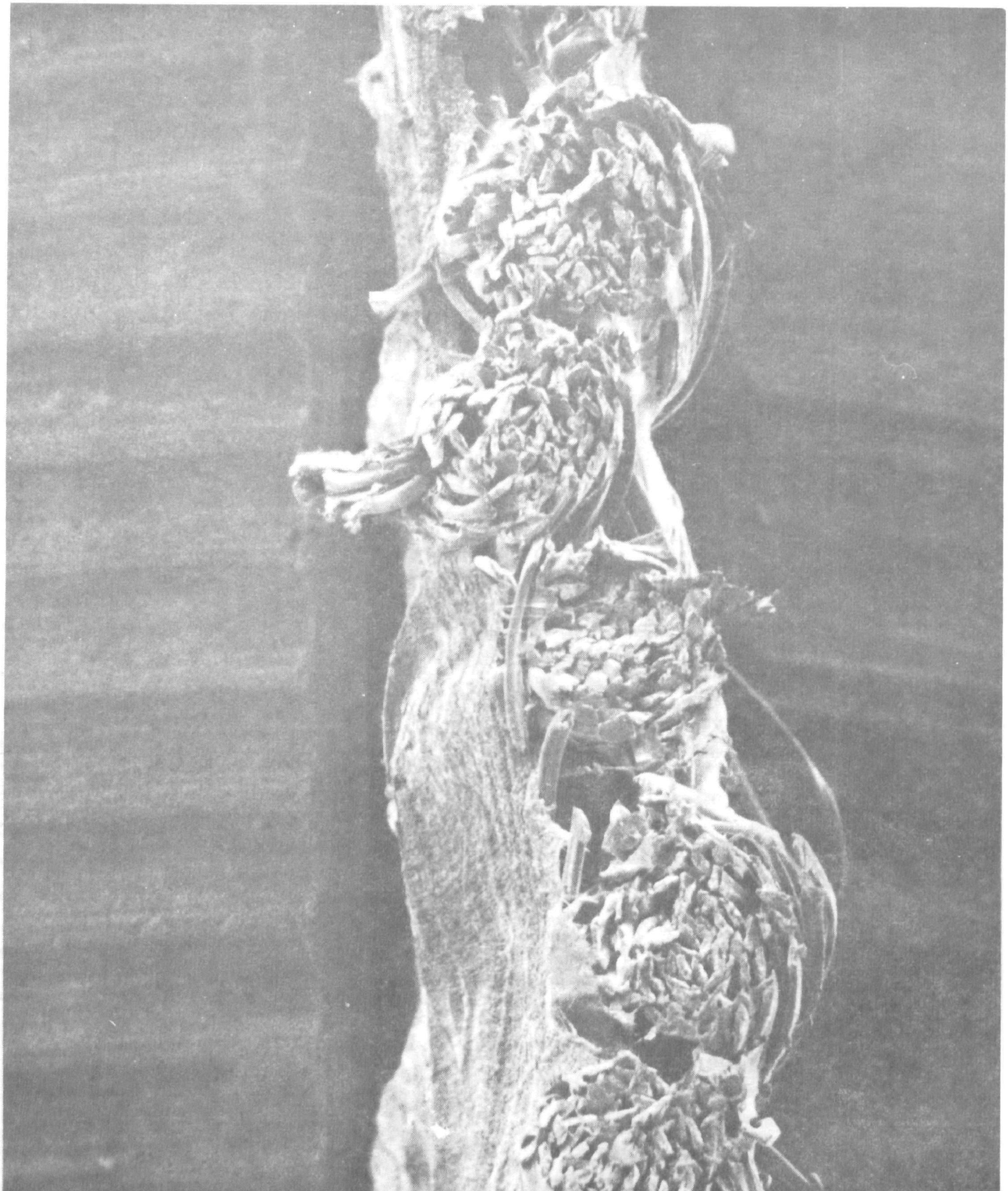


Figure 2. Cross-section of Gore Tex/Nomex fabric (215X) [Ref.1].

TABLE 1. MEASURED PROPERTIES OF GORE TEX/NOMEX*

Weight/unit area [oz/yd^2]	5.90
Thickness [mils]	12.3
Grab Tensile [lbs/in.]	
Warp	217
Filling	121
Grab Elongation [%]	
Warp	31.7
Filling	27.8
Tongue Tear [lbs]	
Warp	6.73
Filling	6.30
Mullen Burst [psi]	233
Frazier permeability at 0.5 in. H_2O press. diff. [$ft^3/min/ft^2$]	10.6

*ASTM test methods carried out by FRL, An Albany International Company, Route 128 at Route 1, Dedham, MA 02026 [Ref.1].

SECTION 2

CONCLUSIONS

Laboratory evaluation of bag filters made from Gore Tex/Nomex (a fibrillated film of polytetrafluorethylene supported by a woven lattice of Nomex) shows that:

1) The Gore Tex/Nomex bag filters exhibit very high filtration efficiency (~99+ percent), low outlet concentration (less than 4 grains/1000 ft^3), acceptable effective and terminal drags and acceptable cake resistance. Their filtration efficiency was the highest of any bag filters evaluated in this series.
2) Other than showing an increase in pressure drop across the bag, performance is insensitive to variations in air/cloth ratio between 4 fpm and 10 fpm. Outlet mass concentration and cake resistance did not vary significantly over this range of air/cloth ratios.
3) Conclusions based on data acquired with a particle counter disagreed with the conclusions based on mass weighings, as stated in 2, in that the total number concentration of outlet particles increased with air/cloth ratio (it was almost twice as great at an air/cloth ratio of 10 fpm as it was at an air/cloth ratio of 4 fpm). In addition the size distribution of the outlet particles shifted slightly toward the larger particles with increasing air/cloth ratio.
4) Bag efficiency and the other performance parameters did not vary significantly with relative humidity over the 30 percent to 70 percent range.

◇ ΔP_T (avg.)

5) Optical counter data suggest that the dominant dust/ fabric interaction is sieving. This conclusion is also supported by scanning electron micrographs of the fabric surface, revealing structure and dimensions that are comparable in size to or smaller than the median diameter of the test flyash.

6) Modifications in the test cycle showed that acceptable cleaning could be obtained by short (4 sec) periods of shaking. Reducing the shake cleaning time by a factor of 30 (from 2 min to 4 sec) produced increases of about 50 percent in the pressure drops (ΔP_E and ΔP_T). Reducing the delay times between the filtration and the shake cleaning increased both the pressure drops and the number density of particles in the outlet (optical counter data). A delay time of 5 secs was clearly inadequate; the optimum delay is a tradeoff between downtime (no filtering) and energy costs of filtering at high average pressure drop.

7) The one sample endurance-tested failed after 11 million shakes, making it comparable in endurance to the spunbonded bags but less durable than the woven bags. The failure time in this test depended strongly upon mounting technique; the bag failure occurred in the vicinity of the cuff clamps.

Bag filters made from Gore Tex/Nomex appear particularly well suited for applications requiring high efficiency filtration. The chemical inactivity and broad temperature range of operation characteristic of PTFE (both properties cited by the manufacturer) make Gore Tex/Gore Tex and, to a lesser degree, Gore Tex/Nomex filter bags suitable over a wide spectrum of applications and perhaps the optimum solution for certain filtering problems such as the control of fine hazardous or toxic particulate emissions. The dimensions and structure of Gore Tex laminate fabric suggest that it would be a particularly effective fabric for filtering submicron particles because many of the PTFE fibers are of submicron diameter as would be required for efficient filtration of submicron dusts according to classical filtration theory.

SECTION 3

EXPERIMENTAL METHODS

The series of evaluating tests is similar to those previously carried out on Cerex* [Ref. 2] and Reemay** [Ref. 3] filter bags. As before, the tests were conducted in a single compartment baghouse containing only one bag (Figure 3). The Gore Tex/Nomex bags were sewn so as to present the PTFE coated side of the fabric to the dirty gas flow. The nominal bag area was 8.5 sq ft for operation at an air/cloth ratio of 4 fpm. To achieve air/cloth ratios higher than 5 fpm, the bottom of the test bag was coated with a thin film of Silastic***, thereby reducing the filtering length of the bag and the bag area. At a constant total flow through the baghouse, the air/cloth ratio varies inversely with the bag area. The higher air/cloth ratios (up to 10 fpm) were achieved primarily by reducing the bag area and only secondarily by altering the total gas flow.

The performance parameters measured were filtration efficiency, outlet concentration, effective and terminal drags and specific cake resistance. The only dust used was powerplant flyash, classified to remove oversized particles. By Coulter counter analysis, 10 percent by weight of the flyash was less than 4 μm in diameter; 90 percent was less than 16 μm; and the median diameter was between 5 and 6 μm.

The dust loading was held constant throughout all testing, the feed rate varying with the total flow to produce a constant dust loading at all air/cloth ratios. Outlet concentration and filtration efficiency were determined by isokinetically sampling the outlet and weighing the sample collected on a Millipore filter. The size distribution of the particles in the outlet gas was also determined using a Climet particle

*Tradename of Monsanto.
**Tradename of DuPont.
***Tradename of Dow Corning, Inc.

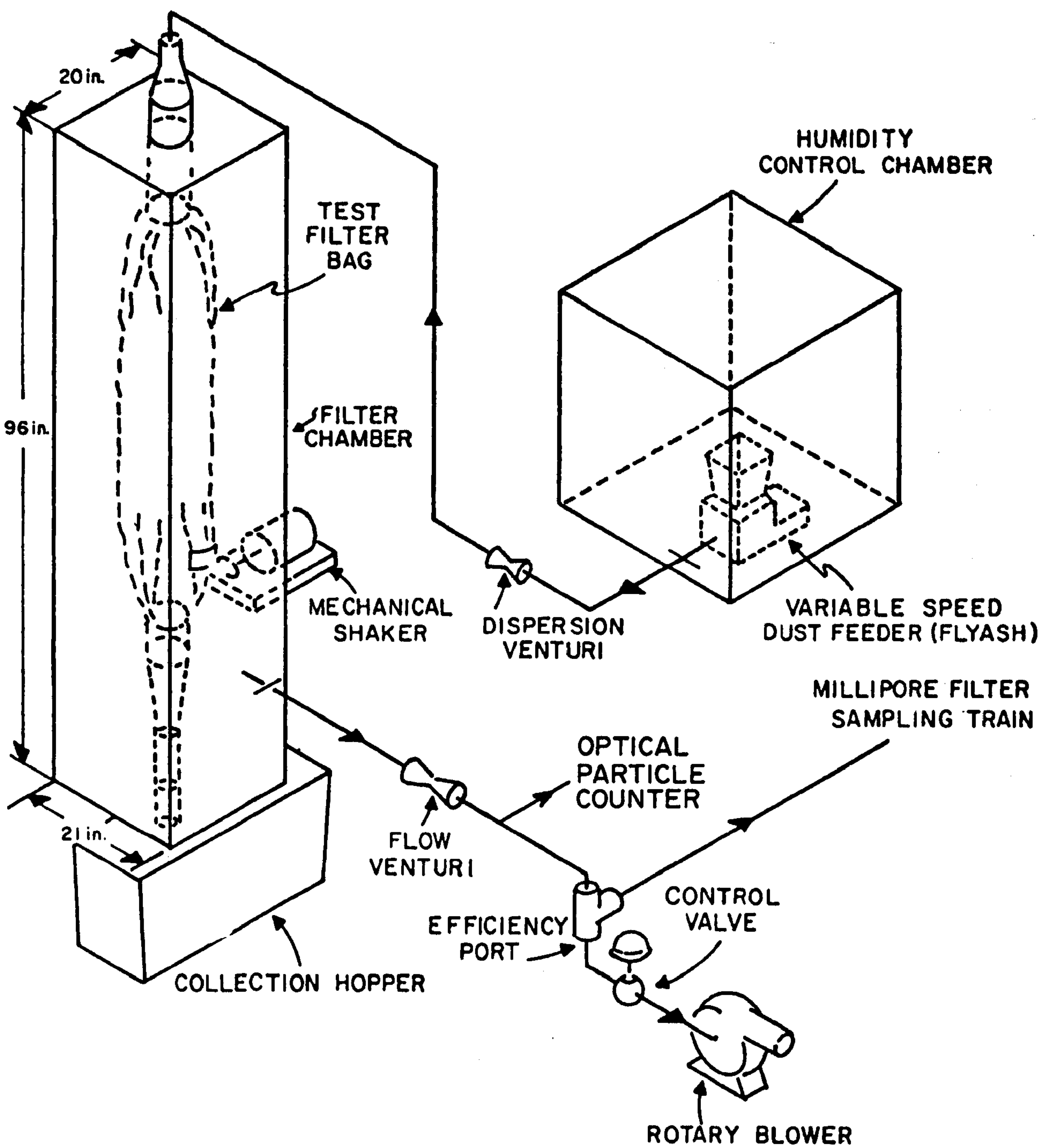


Figure 3. Test apparatus.

counter, a forward light scattering instrument. Climet data, taken at the limit of the counter's capability, were used as secondary measures of performance only; efficiency and outlet concentration were based exclusively upon the Millipore sampling as described in Reference 3.

The effect of relative humidity upon the performance parameters was checked by varying the relative humidity in a random manner between 30 percent and 70 percent. The equilibrating time between humidity changes was 48 hours. The relative humidity of the gas being cleaned was measured both before filtration and after filtration, using wet-bulb/dry-bulb thermometers. All the standard performance parameters were measured as a function of humidity; the size distribution of particles in the outlet was also determined by the Climet counter as a function of filtration time at each value of relative humidity.

Bag endurance was measured on one sample using the number of the shake cleaning cycles to failure as a measure. The operating cycle for the endurance test consisted of 15 minutes of shake cleaning (240 rpm, 1-7/8 in. stroke) followed by 1 minute delay, then 2 minutes of dust feed followed by a 1 minute delay before resuming the 15 minute shake. Periodically the cycle was switched to the standard 20 minute filtration cycle for measuring bag performance (20 minutes filtration, 1 minute delay, 2 minutes shake, 1 minute delay). In both cases the maximum harmonic acceleration during shaking was about 2.1×10^6 in./min^2 (~1.5 g's).

SECTION 4

RESULTS

The filtration efficiency of all Gore Tex/Nomex bags tested was very high, regardless of the air/cloth ratio. Similarly, the outlet concentrations were very low. Figure 4 shows outlet concentration as a function of air/cloth ratio. Over the range of 4 fpm to 10 fpm, no dependence on the air/cloth ratio exists, the scatter in the values being typical of these low concentrations.

Other performance parameters are plotted in Figures 5 and 6 as a function of air/cloth ratio. Comparative data points (at 4 fpm only) are shown for a woven polyester fabric, a spunbonded nylon fabric and a spunbonded polyester fabric. The specific cake resistance, the effective drag and the terminal drag (not shown) of the Gore Tex/Nomex fabric are either similar to or lower than those of woven polyester and spunbonded nylon bags but higher than the values of the best spunbonded polyester bags [Refs. 2,3]. This means that fan operating power is greater for the Gore Tex/Nomex bags than for the spunbonded polyester bags but is comparable to or less than the power requirements of woven polyester bags or spunbonded nylon bags.

When used to filter flyash, Gore Tex/Nomex bags show very little performance dependence upon humidity (Figure 7). This lack of humidity dependence is different from that of many fabric/dust systems in which the filtration efficiency normally improves at high humidity [Ref. 4].

A second striking difference in the interaction between Gore Tex/Nomex and flyash is the relative stability of mass filtration efficiency during the filtration cycle. Most fabrics exhibit low efficiency immediately after cleaning [Ref. 5]. As the filter cake builds up, efficiency improves. Most of the particles passing the filter do so in the first half of the filtration cycle. The number of particles in the

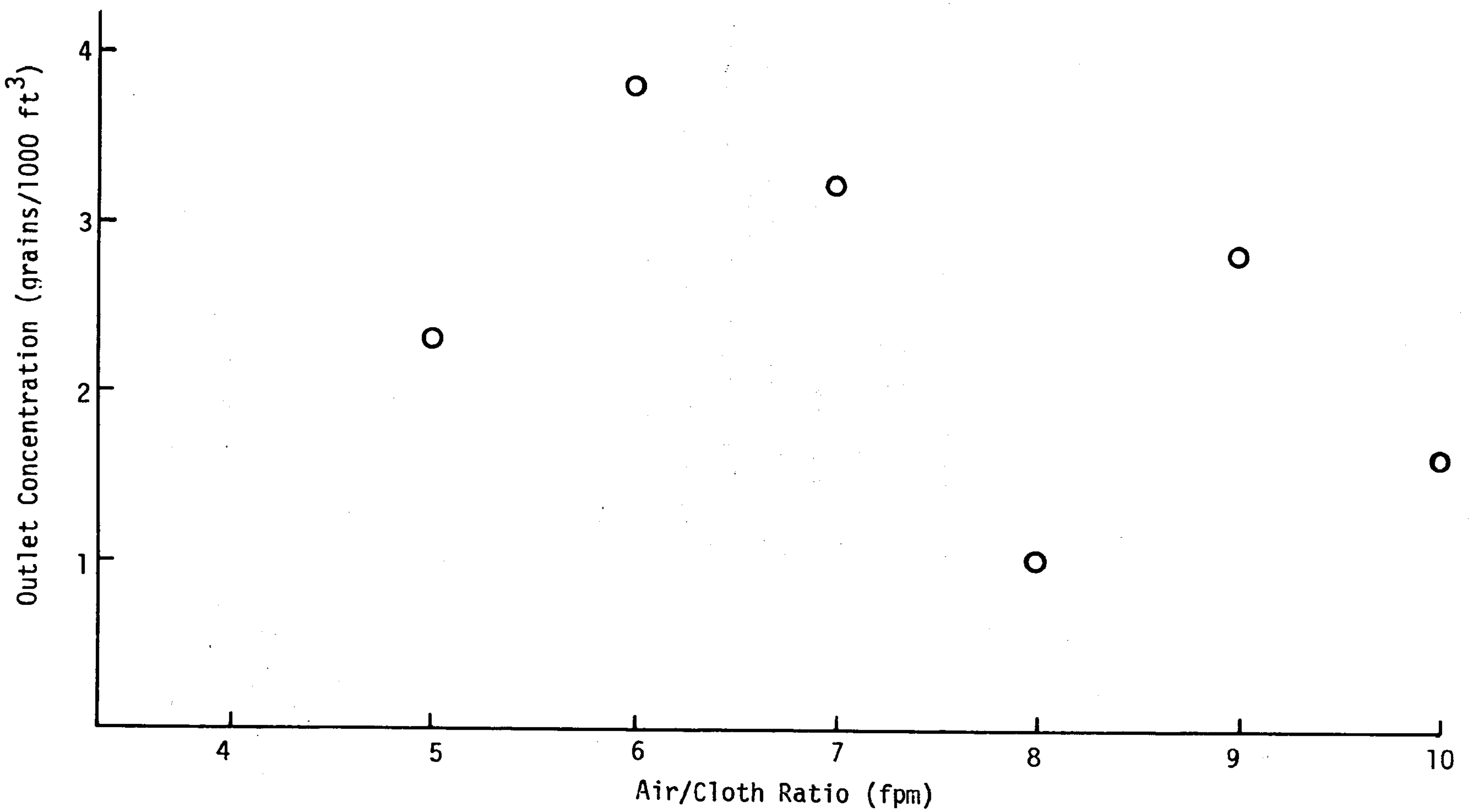


Figure 4. Outlet concentration as a function of air/cloth ratio.

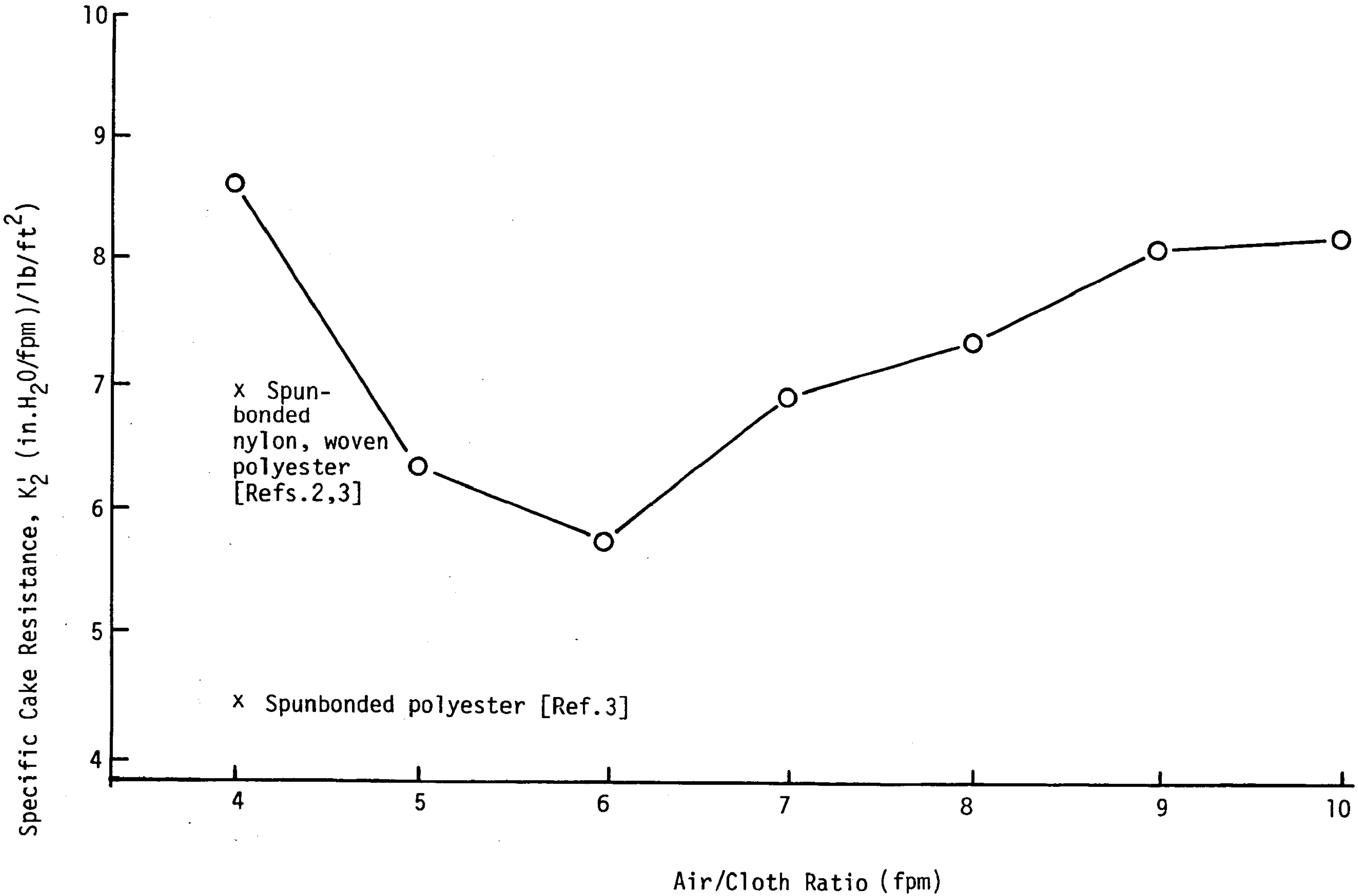


Figure 5. Measured cake resistances.

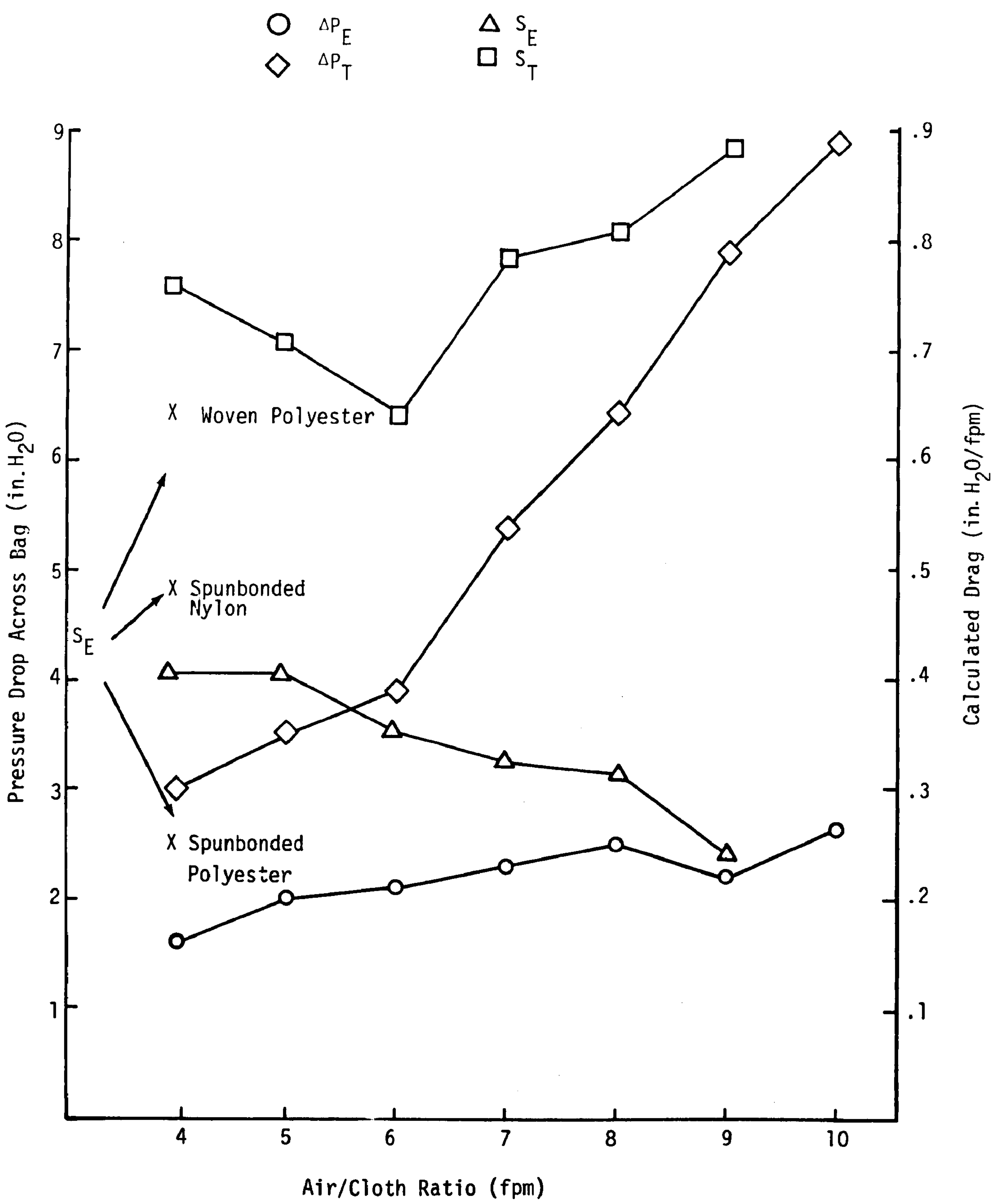


Figure 6. Pressure drops and calculated drags as a function of air/cloth ratio.

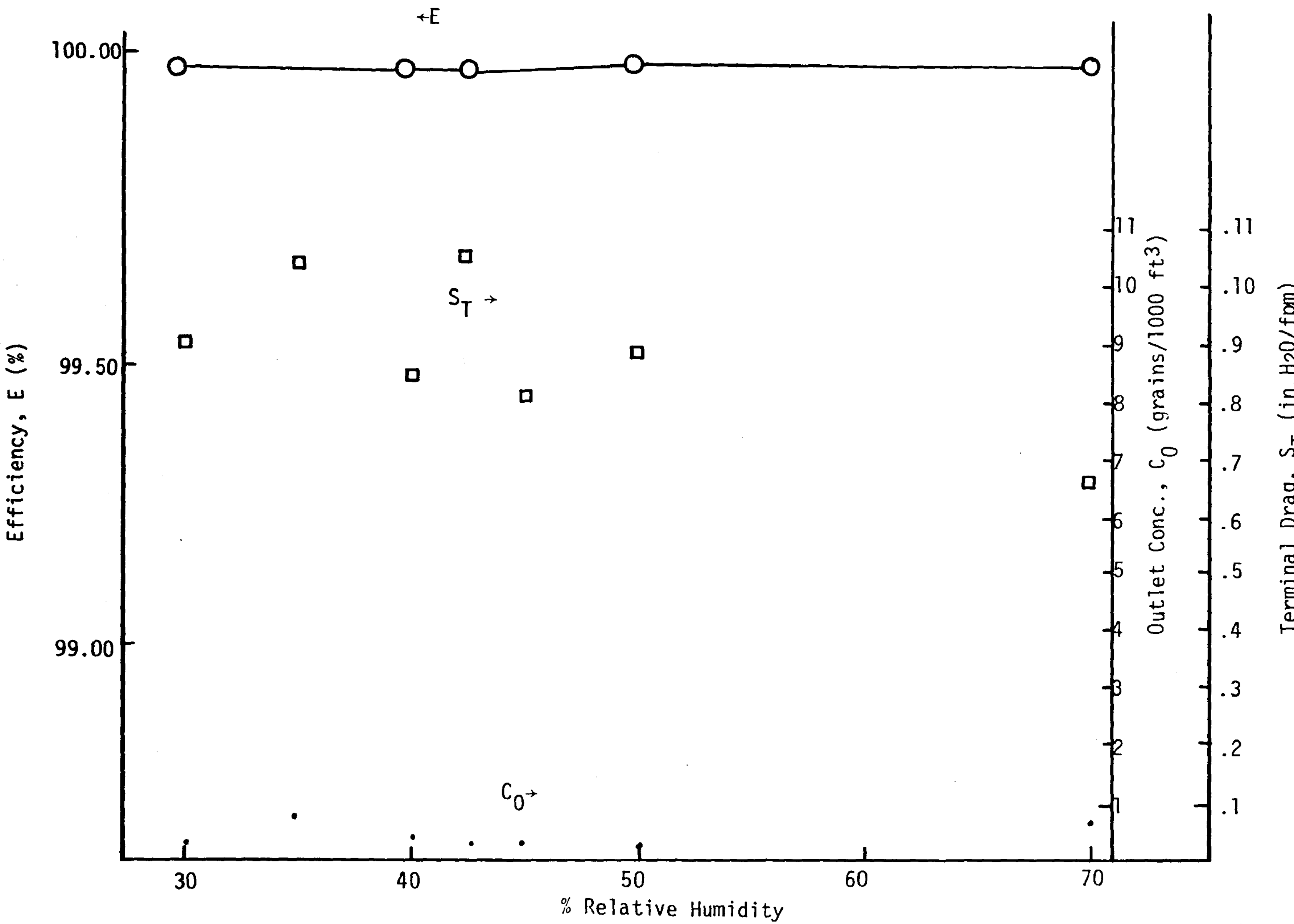


Figure 7. Humidity dependence of filtration efficiency and outlet concentration.

filter outlet varies with time (measured from the end of the previous cleaning cycle) as shown in Figure 8. This plot is for a spunbonded polyester fabric filter [Ref. 3].

Similar measurements made on Gore Tex/Nomex filter bags reveal a very different behavior (Figure 9). At an air/cloth ratio of 4 fpm the concentration of particles passing through the filter remains essentially constant throughout the filtration cycle.

This result suggests that the Gore Tex layer itself rather than the filter cake dominates the dust/fabric interaction.

Filter cake buildup still occurs with the Gore Tex/Nomex, as evidenced by the increase in pressure drop during the filtration cycle. Since the increase in pressure drop is not accompanied by an increase in filtration efficiency, the role of the filter cake may be to plug the Gore Tex layer rather than to serve as a filtering medium. In any event the peaks in the concentration of penetrating particles, characteristic of previous bags tested [Ref. 3 and Figure 8], are greatly reduced for particles filtered through Gore Tex/Nomex bags.

A pronounced pulsing effect occurs at high air/cloth ratio. Figure 9 compares plots of particle concentrations in the outlet versus filtration times for two air/cloth ratios. At an air/cloth ratio of 9 fpm numerous peaks in particle outlet concentration appear at various times during the filtration cycle. One hypothesis is that these peaks correlate with filter cake sloughing off the bag. This sloughing action consists of substantial portions of the filter cake falling off or becoming dislodged by vibration of the air flow, resulting in a sudden release of particles through the bag. At the lower air/cloth ratio of 4 fpm no pronounced peaks occur and presumably the sloughing is less abrupt.

Two observations conflict with this model of dust cake "sloughing action:"

1) According to this model the dust cake plays a measurable role in the filtration process (the loss or sloughing of dust cake is hypothesized to produce the bursts of penetrating particles). The data of Figure 9a suggest the opposite-- that the dust cake has little effect on filtration efficiency.

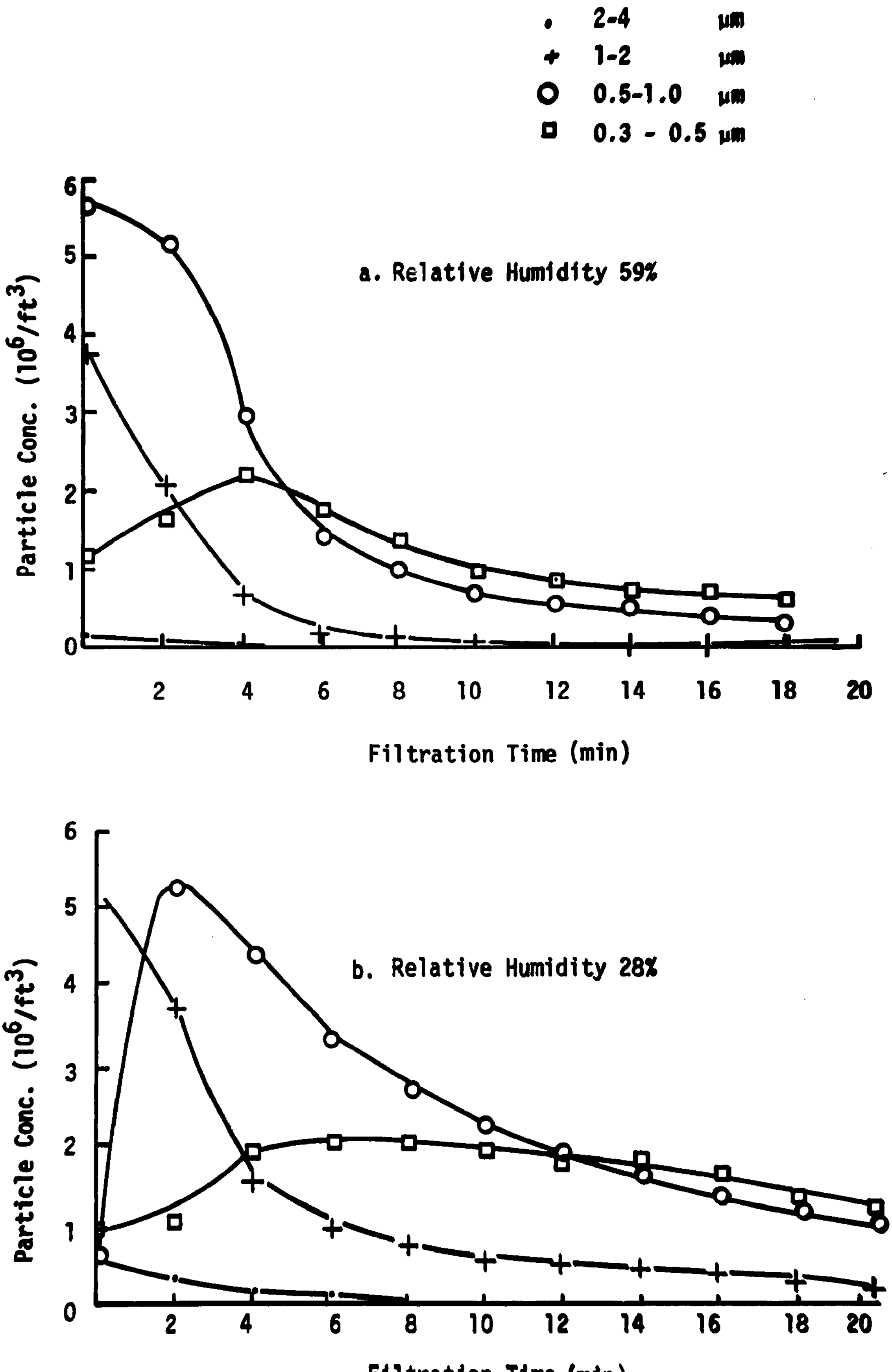


Figure 8. "Standard" time dependence of particle concentration during filtration cycle (Polyester spunbonded fabric).

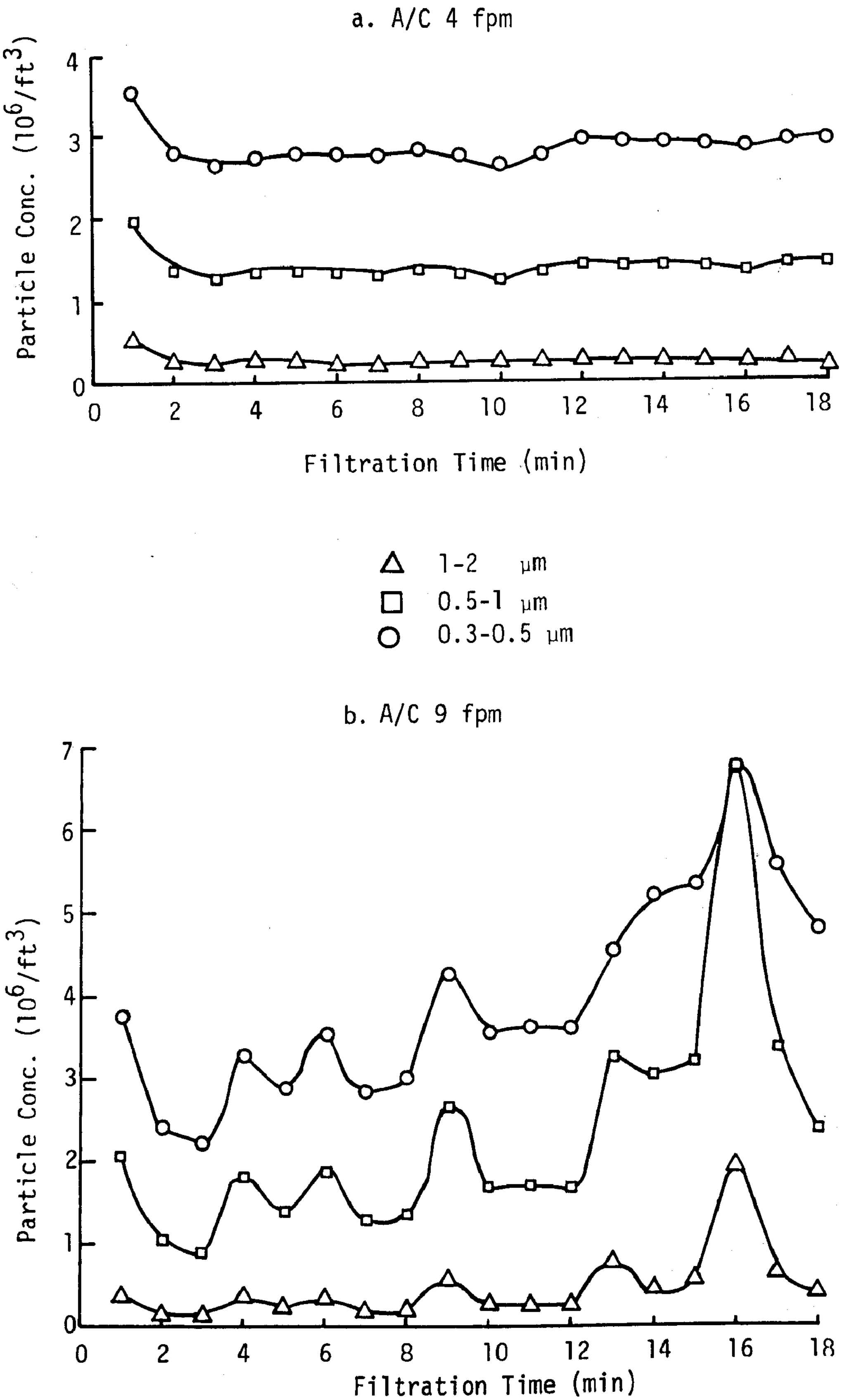


Figure 9. Time dependence of flyash particles penetrating Gore Tex/Nomex bags.

2) If the dust cake is continually sloughed, the increase in pressure drop across the bag should be limited to a fixed value representative of the "effective" dust cake layer that never gets removed. A special cleaning cycle should be unnecessary because the sloughing action constitutes a naturally occurring cleaning step itself. Neither of these conclusions is true--pressure drop builds up continuously across the bag and the bag is not self cleaning.

Dust cake accumulation is, admittedly, far less evident on these bags than other bags tested in this series. Its absence, however, implies not so much sloughing as simple inability of the dust to adhere to the PTFE film. This lack of dust adherence ("good release properties") has been noted by others [Ref. 6] and proclaimed by the manufacturer as an important advantage for using Gore Tex laminates as fabric filters [Ref. 7].

The increased concentration of penetrating particles at high air/cloth ratio evident in Figure 9 is amplified in Figure 10. Each datum point of Figure 10 represents the average of the 18 or 19 individual counts taken at 1 minute intervals throughout the 20 minute filtration cycle--for example, the 9 fpm data of Figure 10 are simply the average of all the individual measurements shown in Figure 9b. As the air/cloth ratio increases, the number of penetrating particles in all size ranges increases. Those in the larger two sizes increase a little more than the smallest size range (Figure 11). The 0.3 to 0.5 μm class makes up 66 percent of the total number at an A/C of 4 fpm but only 57 percent of the total at an A/C of 10 fpm; conversely the 0.5 to 1.0 μm particles contribute 29 percent of the total at an A/C of 4 fpm but 35 percent when A/C ≈ 10 fpm. The breakdown of the total penetrating particle population, classified into three size ranges, is given as a function of air/cloth ratio in Figure 11. The small shift to larger-sized penetrating particles at high A/C agrees qualitatively with impactor data previously reported by McKenna et al. [Ref. 6] using Gore Tex/Nomex bags on an industrial boiler.

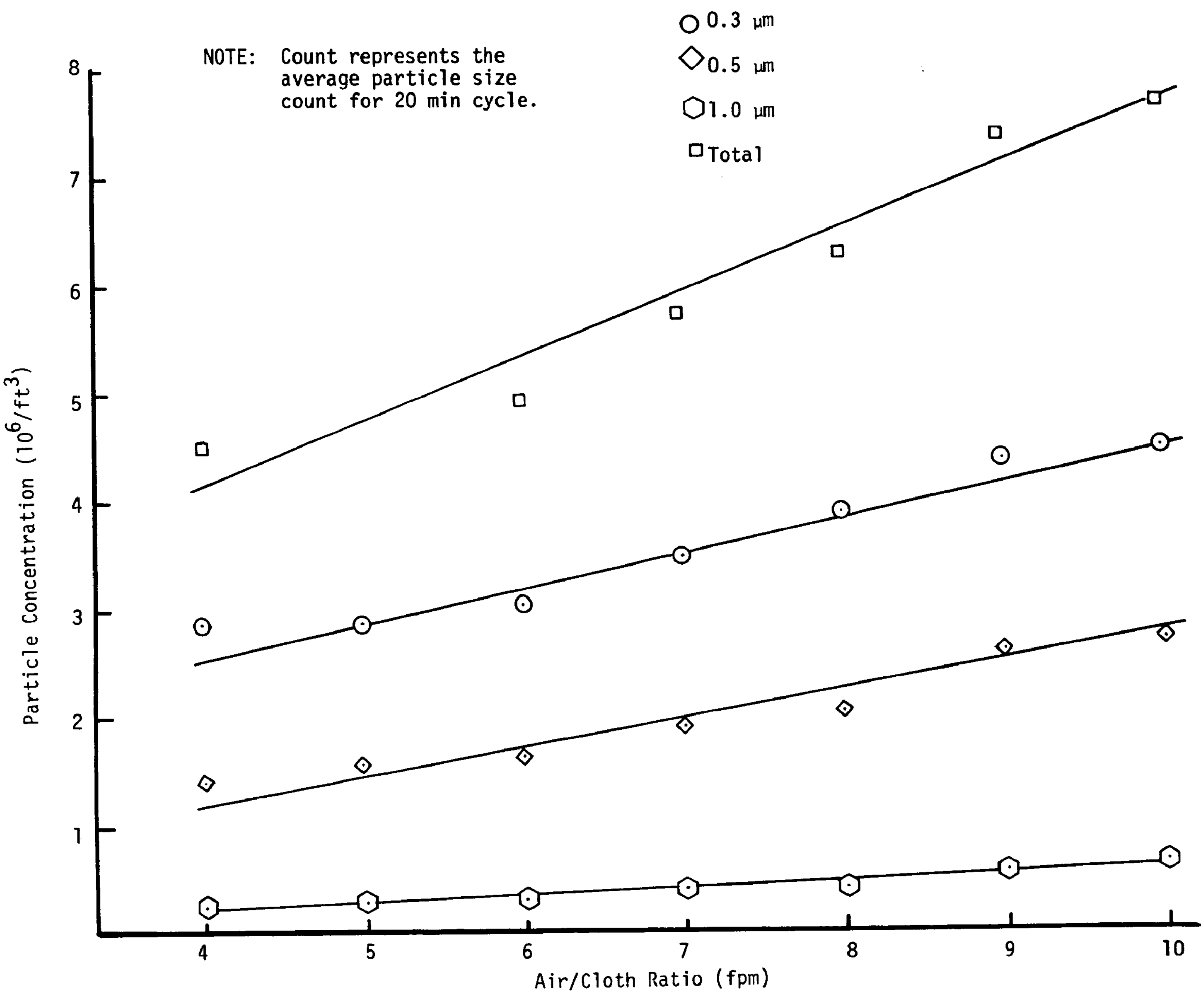


Figure 10. Concentrations of penetrating particles as a function of air/cloth ratios.

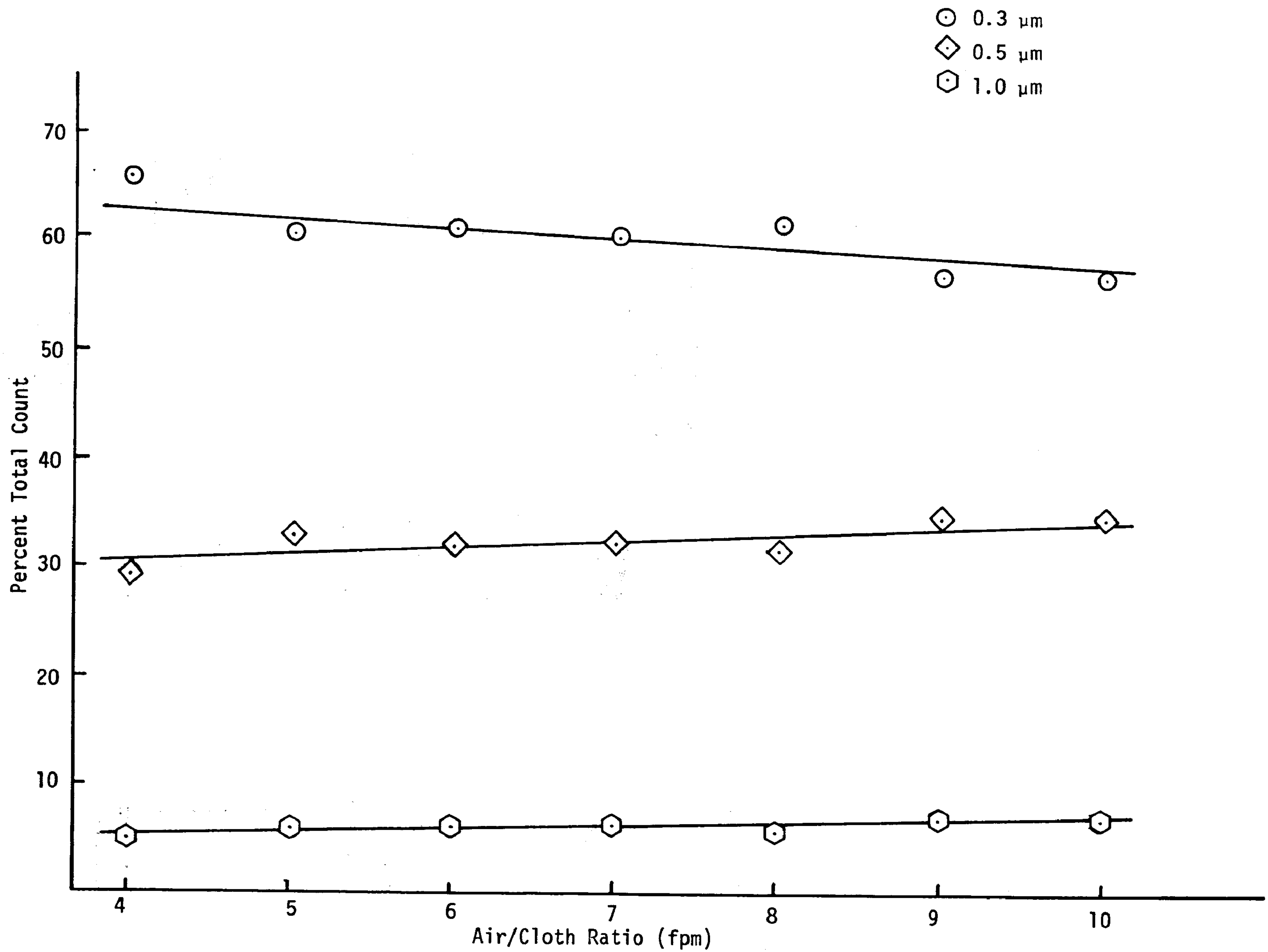


Figure 11. Size distribution of penetrating particles at various air/cloth ratios.

MODIFIED CLEANING CYCLES

Because of the unusual interaction between the flyash and the Gore Tex/Nomex bags and to further investigate the dust release properties of this system, two modifications in the standard cleaning cycle were investigated:

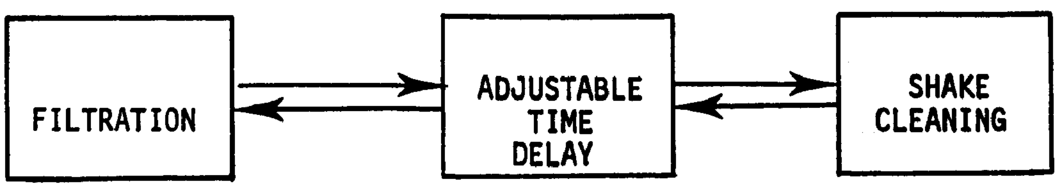
1) Reduction of the shake cleaning period to 4 secs instead of the standard 2 minutes.
2) Reduction of the delay between the end of the feed cycle and the beginning of the shake cleaning cycle to various times less than the standard 1 minute.

Successful operation at reduced shake cleaning and/or delay times implies more economical field operation in that less time and energy are required for bag cleaning.

Variations in Delay Time and Shake Cleaning Time

Modifications in the delay time were studied using the 4 second shake cleaning period exclusively. Two time delays are built into the standard sequence: one between the end of the filtration cycle and the beginning of the shake cleaning; and the other between the end of the shake cleaning and the resumption of the filtration that starts the next sequence. Both of these delays originate from the same timer so that a change in one delay always means a similar change in the other.

The standard test cycle is a fixed time test cycle consisting of 20 minutes filtering, 1 minute delay, 2 minutes shake cleaning (at 4 cycles/sec for a total of 480 complete shakes) and finally another 1 minute delay before beginning the next 20 minute filtering cycle. The sequence of steps is:



Standard Cycle:	20 minutes	1 minute	2 minutes
Modified Cycle:	20 minutes	1 minute to 5 seconds	4 seconds

Figure 12 shows the effect of reducing shake cleaning and delay times at an A/C of 4 fpm. The initial and final pressure drops characteristic of the standard cycle are plotted at the extreme left. The bars just to right--those labelled with delay time equal to 1 minute--show the effect of reducing the shake cleaning cycle to 4 secs (16 shake cycles total). Cleaning is not as effective with the 4 sec shake cycle in that both ΔP_E and ΔP_T are nearly 50 percent larger but, considering that the shake cleaning time period has been reduced by a factor of 30, this magnitude of increase in the pressure drops may be surprisingly small. The conclusion is that the 480 cleaning shakes of the standard cycle remove only fractionally more dust cake than do the 16 shakes of the modified cycle. This effect is analogous to that found by Walsh and Spaite [Ref. 8] for cotton sateen and flyash, but the miniumum number of cleaning strokes required is reduced by a factor of 4 over that reported by Walsh and Spaite.

The remaining data graphed in Figure 12 show the effect of shortening the delay times. During the delay periods, gas flow through the bag stops and the system simply rests, allowing suspended dust to settle. An identical delay period separates the change from filtering to cleaning and from cleaning back to filtering.

In general, as the delay time is shortened, both the initial and the final pressure drops increase, suggesting that, at shortened delay times, either the dust is not as efficiently dislodged from the bag surface or that more and more of the dust dislodged by the shaking becomes retrapped on the bags rather than deposited in the hopper or both. Any forward air flow during the shake cleaning dramatically reduces the ability of the shake cleaning action to dislodge the trapped surface dust. If the delay time between the cessation of the filtration period and the beginning of the shake cleaning is not sufficient to allow the pressure differential across the bag to decay to essentially zero, the dust dislodgement effectiveness of the short, 4 sec shake cleaning may be greatly reduced.

The effectiveness of the shake cleaning can also be compromised by insufficient delay between the shake cleaning and the resumption of filtration. Ideally the cleaning action shakes the dust off the bags to

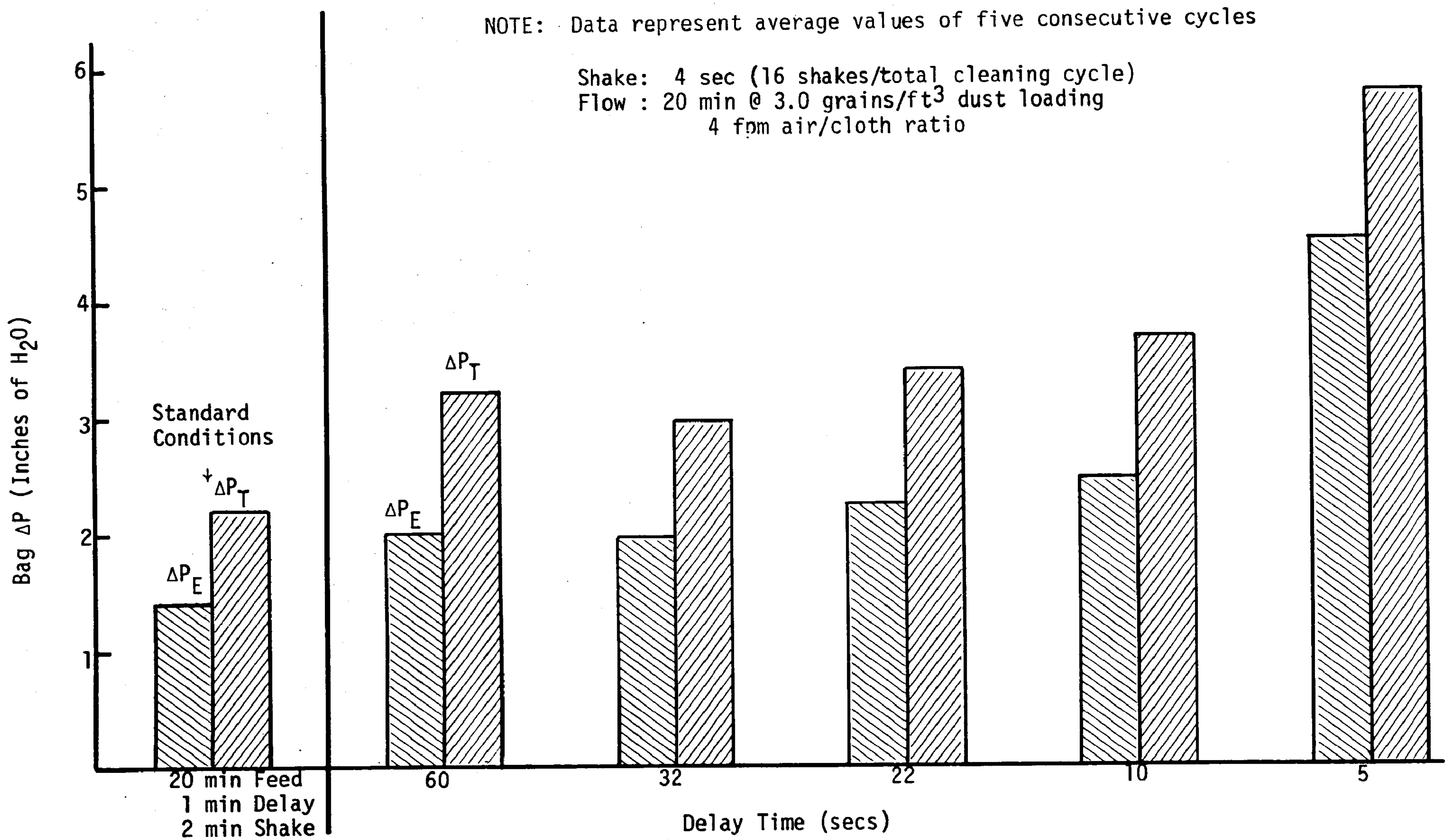


Figure 12. Pressure drops during modified cycle (4 sec cleaning, variable delay time).

form a dense cloud of agglomerated particles which gradually settle into the collection hopper. If, however, the gas flow of the filtration cycle is resumed before the dust cloud has completely or even mostly settled, those particles and agglomerates still in suspension are rapidly swept back onto the bag.

Regardless of which delay action dominates, the data of Figure 12 show that with only a 5 sec delay, the effective cleaning of the modified cycle is greatly reduced.

The data graphed in Figure 12 represent average values of five consecutive cycles at each delay time. As evident in Figures 13 and 14, which plot sequential values at each delay time, the pressure drops at 5 secs delay are actually worse than indicated in Figure 12 in that they have not reached an equilibrium value even after the sixth consecutive cycle. The pressure drops at 10 secs delay and longer appear to have reached a steady state value (or nearly so) after five sequential cycles.

Clearly, 5 secs delay time is too short and thwarts the cleaning action. There is little difference in pressure drops between the 60 sec delay and the 32 sec delay. Twenty-two sec delay causes increased pressure drops and 10 sec delay even greater.

The Climet data generally support the conclusion that shortening the time delay results in higher dust loads on/in the fabric filter and greater penetration through the fabric. Typical penetration data, as gathered by the Climet counter, are shown in Figure 15. The bars represent the average total number density of particles measured during the last cycle of each modified sequence carried out at the delay time indicated. A particle measurement was generally made every minute during the 20 minute filtration cycle. The value graphed in Figure 15 is the average of the 18 to 20 measurements of total particles made at 1 minute intervals during the filtration step. The values of total particles did not change much with time--the values recorded 1, 2, or 3 minutes after the filtration cycle began were essentially the same as those measured 17, 18 or 19 minutes into the 20 minute filtration period. This lack of time dependence for the Gore Tex/Nomex fabric filters was described previously and depicted by the data of Figure 9a for operation at an A/C of 4 fpm.

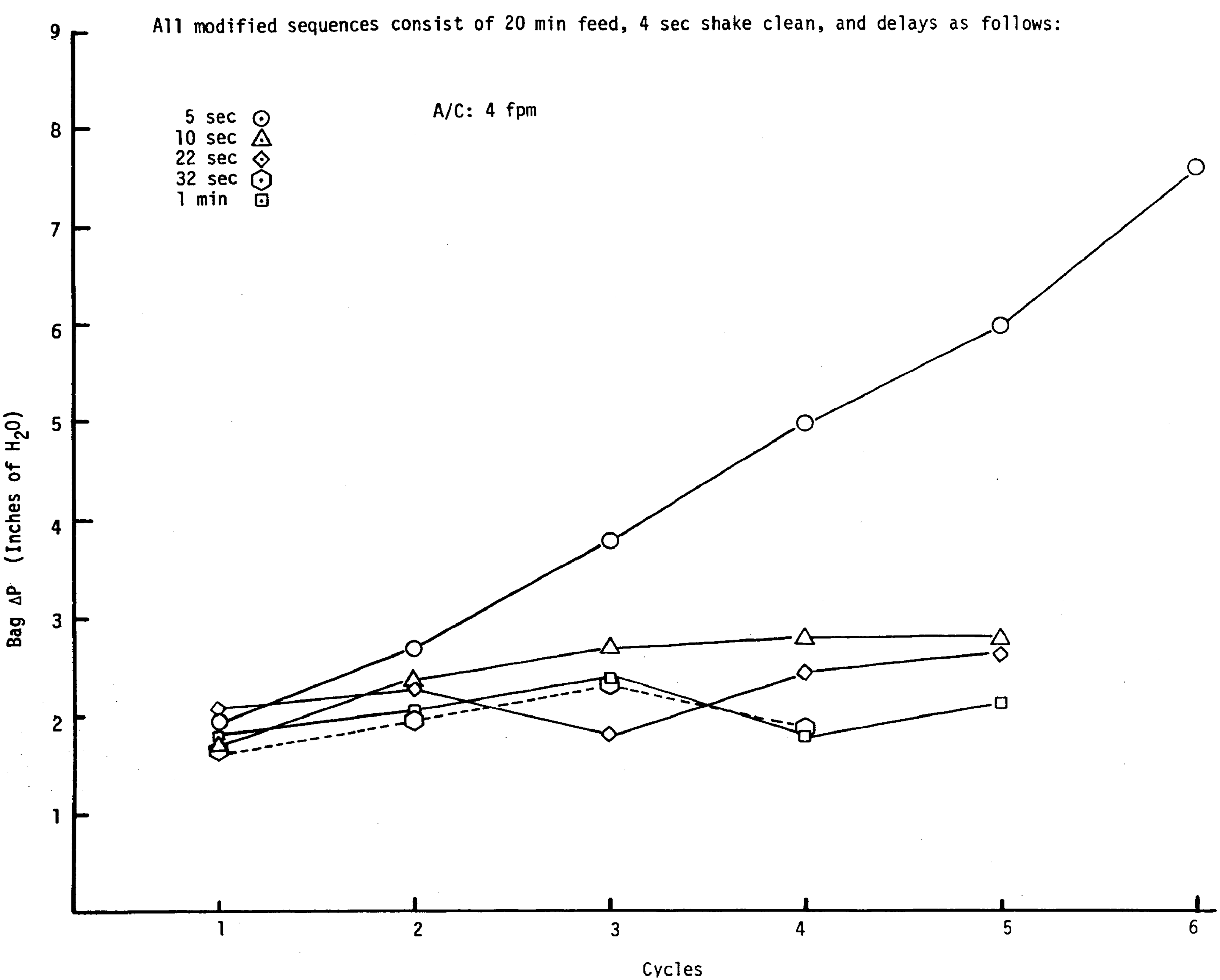


Figure 13. Initial pressure drops for modified sequences.

All modified sequences consist of 20 minute feed, 4 second shake clean and delays as follows:

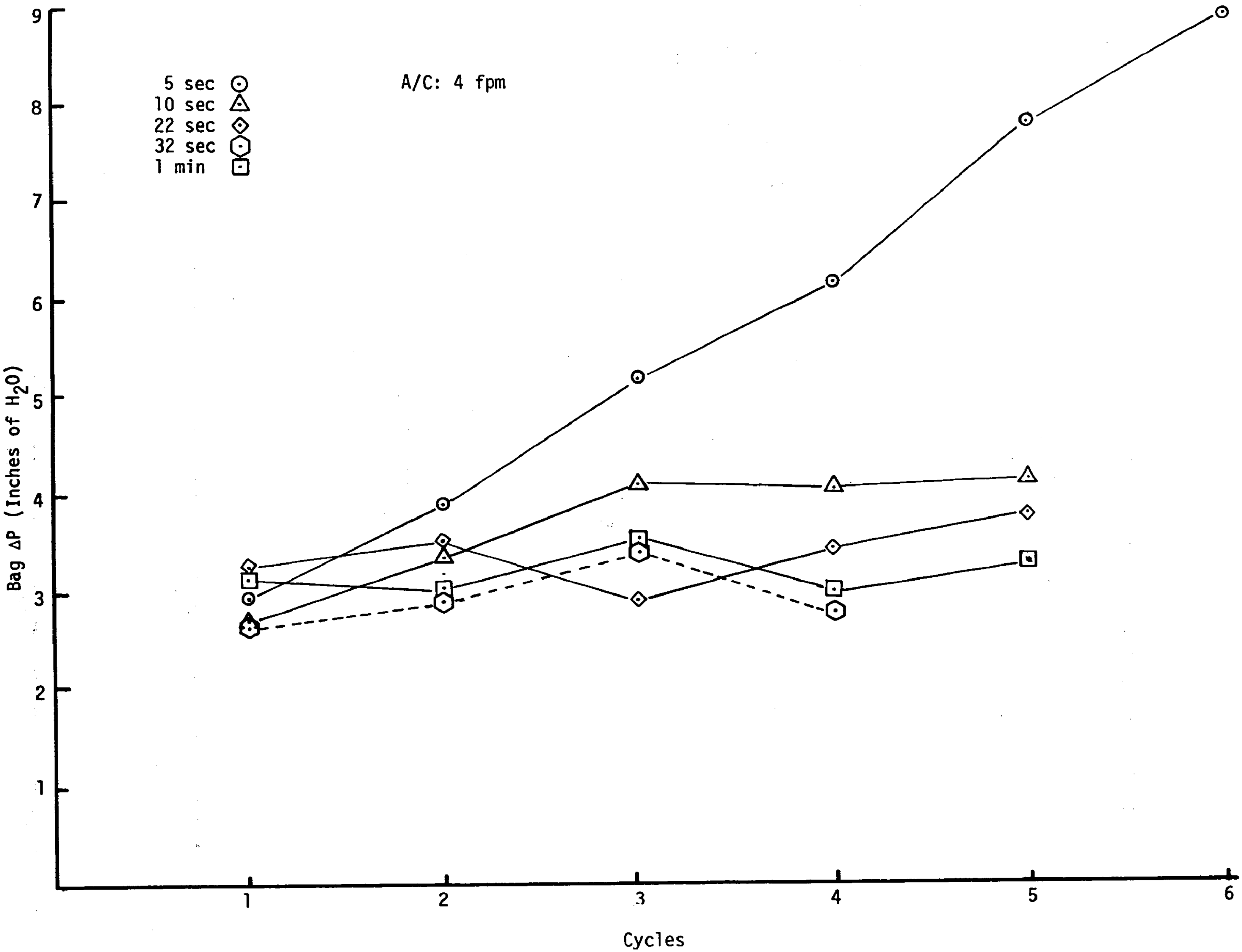


Figure 14. Final pressure drops for modified sequences.

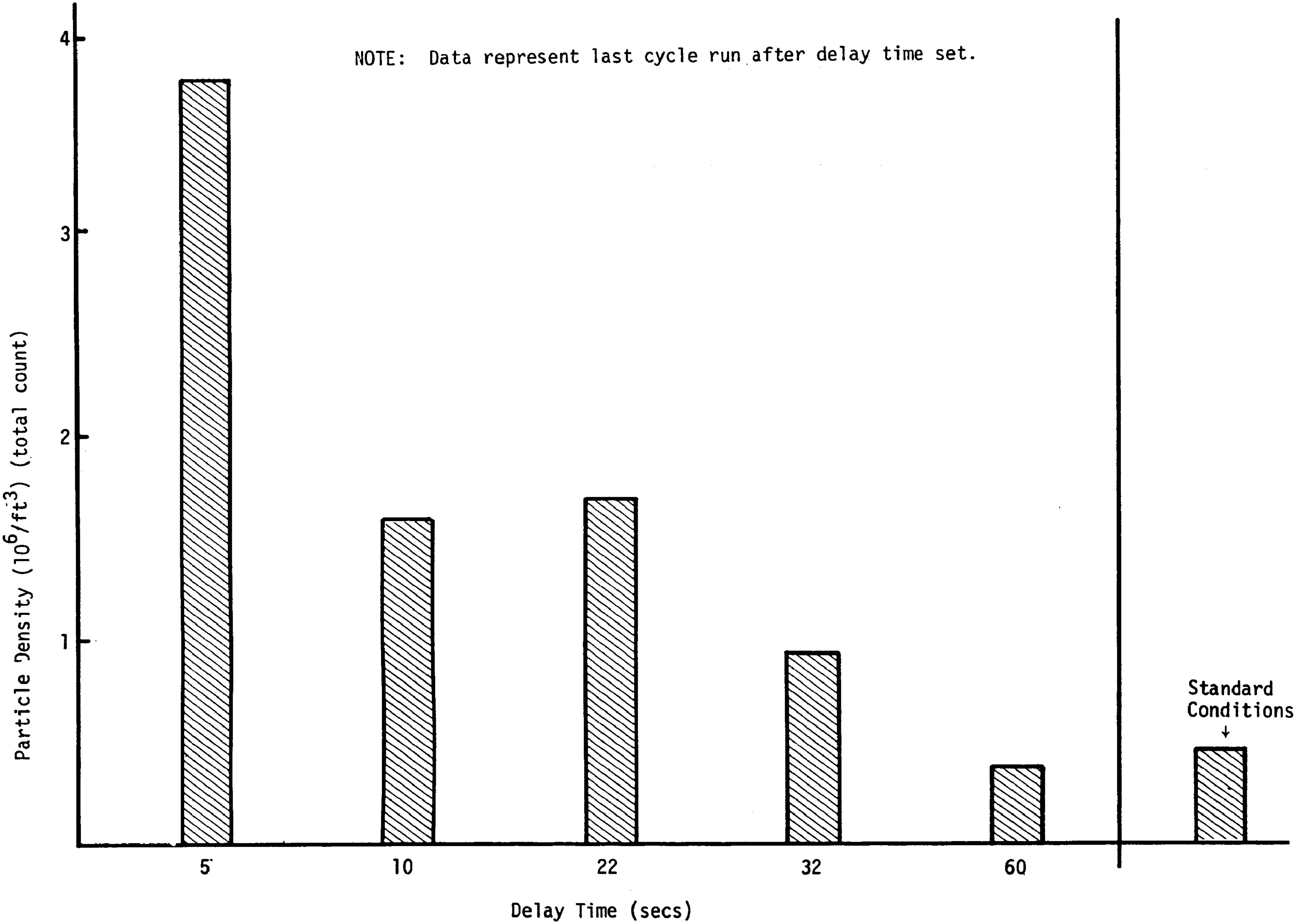


Figure 15. Average total number density of particles during last filtering cycle of modified sequence.

Climet data were taken during each of the five or six consecutive cycles run at a given delay time. The numbers graphed in Figure 15 represent the average of those measured during the last cycle only. For the 5 sec delay, the average value during the last cycle differed substantially from the average of all cycles, increasing in time somewhat similarly to the pressure drops at 5 sec delay, previously plotted in Figures 13 and 14. Far more particles penetrated through the fabric during the 6th cycle of the 5 sec time delay sequence than during the 1st or 2nd. This increase of particle penetration with time was not true for cycles using a 10 sec or longer delay time, again being similar in behavior to the pressure drop data presented in Figures 13 and 14.

The size distribution of the penetrating particles changed only slightly with delay time, shifting toward larger particle penetration during the 5 sec delay cycle (Figure 16). The magnitude of the shift is a 5 percent effect.

Variations in Filtration Time

Variations in the length of the filtration cycle were also investigated. Holding the delay time at 1 minute (the delay time of the standard cycle) and the shake cleaning step at 4 sec (the cleaning time of the modified cycle), the length of the filtration cycle was varied between 5 and 40 minutes. Figure 17 plots the measured pressure drops over this range. The major effect of increasing the length of the filtration cycle is to increase the final pressure drop. The cleaning/delay cycle restores the initial pressure drop for all filtration cycle times, as is evident from the unchanging values of ΔP_E. These measurements show that the 4 sec shake cleaning with 1 minute delay would lend itself nicely to an operating sequence based on a fixed pressure drop to initiate cleaning.

ENDURANCE TEST

For the endurance test the air/cloth ratio was held at 4 fpm throughout all filtration. The outlet concentration measured during the periodic checks of performance parameters is plotted in Figure 18. The first

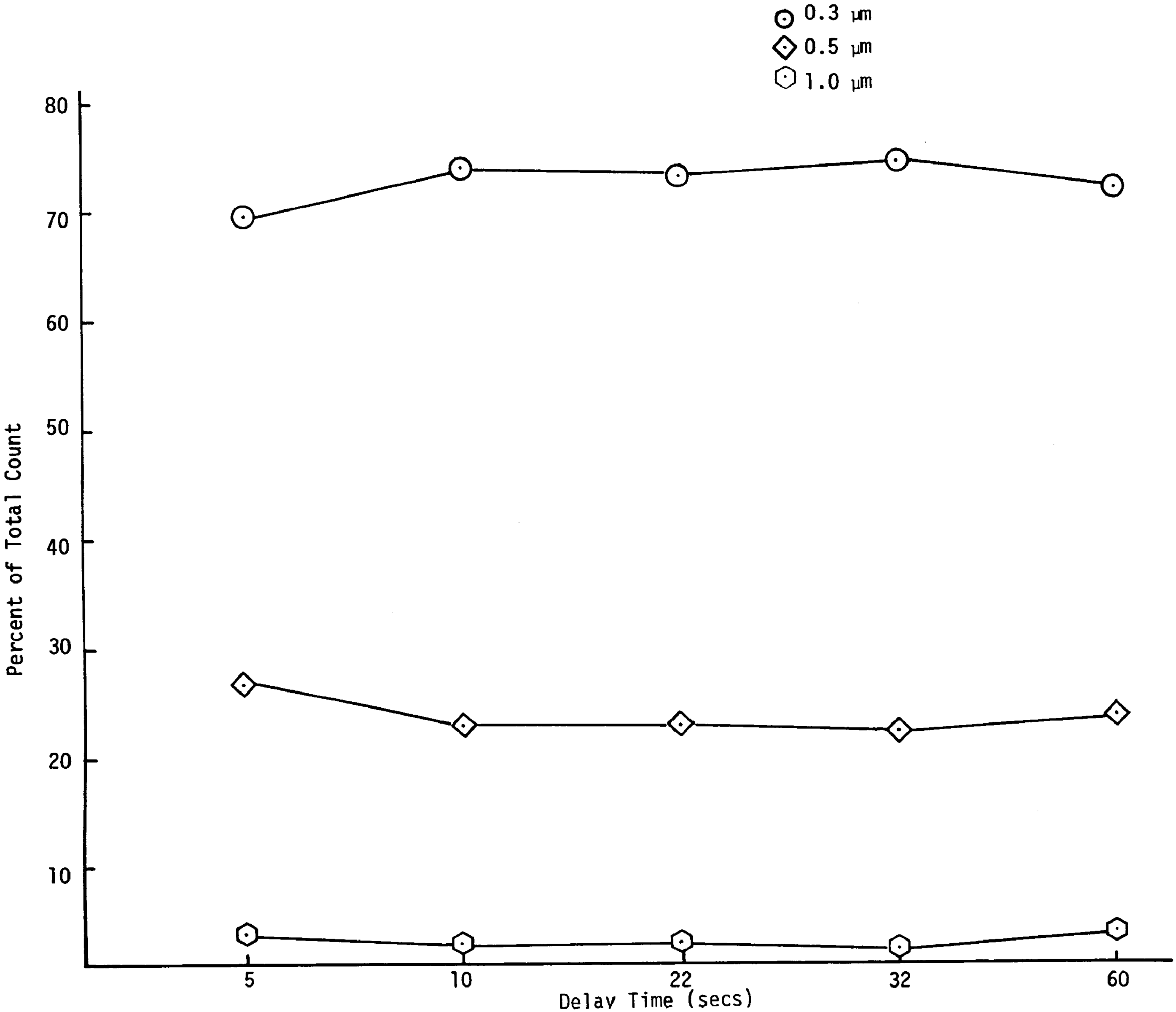


Figure 16. Size distribution of penetrating particles at various delay times.

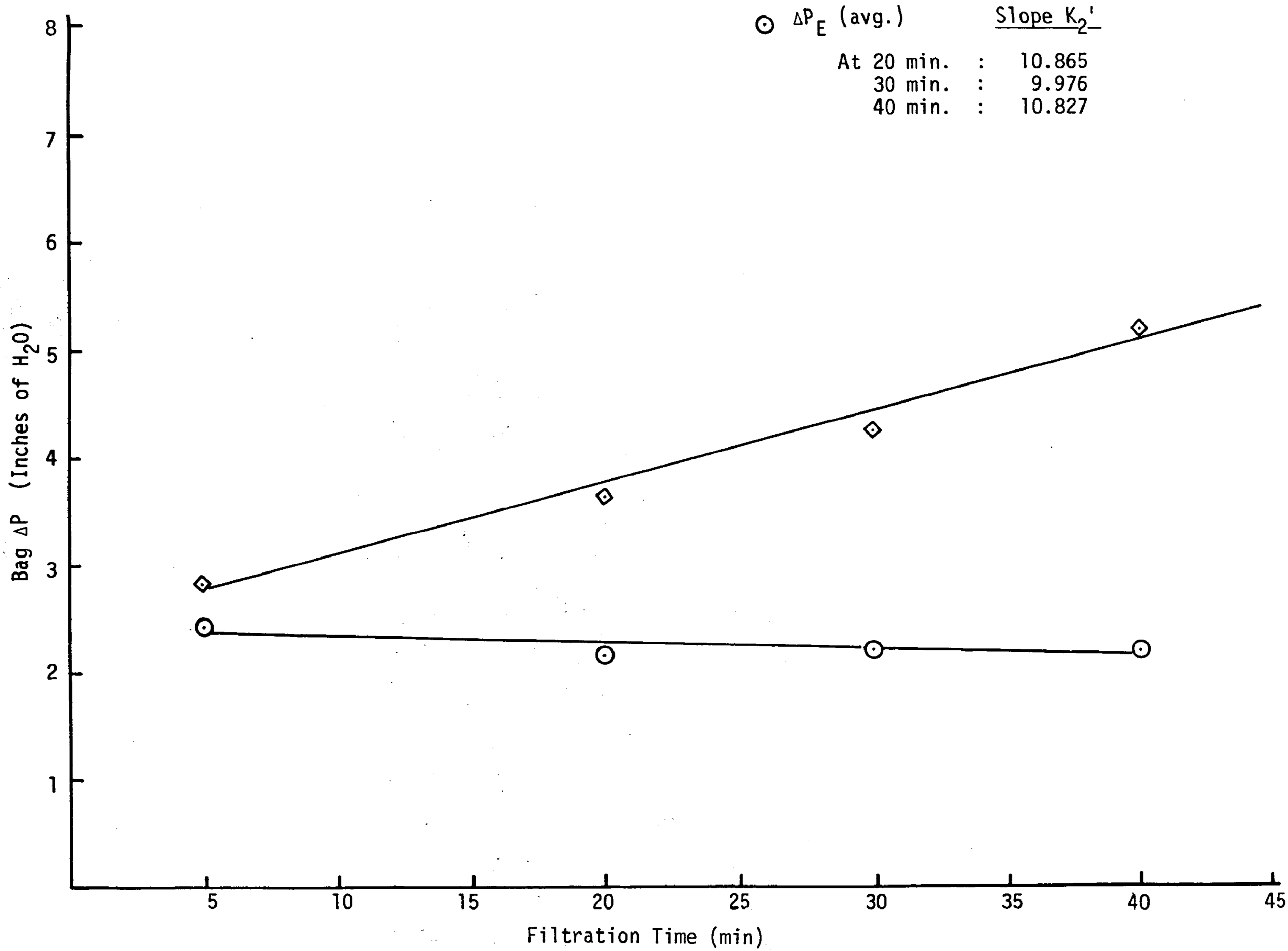


Figure 17. Pressure drop as a function of filtration time.

evidence of performance degradation appeared after 4.5 million shakes. Two small tears formed on the bag where it was clamped to the bottom support cone. The outlet concentration increased but leveled off at 12 to 14 grains/1000 ft^3 until two new tears developed at the top of the bag, causing the outlet concentration to jump significantly. These new tears were also in the vicinity of the cuff, this time the top cuff. From Figure 18, the bag failure can be seen to occur between 10 and 11 million shakes.

The endurance measured in this test depended primarily on mounting, similar to the conclusion reported by McKenna et al. [Ref. 6] when using Gore Tex/Nomex in a pilot scale baghouse on an industrial boiler. The bag failure here stemmed from fabric abrasion against the support cones at either end. The bag fabric remote from the mounts was in good condition with only slight evidence of wear or thinning. Superior mounting methods could greatly increase the measured life of the bag.

The similarly measured, shake endurance of woven polyester bags was 54 million; of 3 oz/yd^2 Reemay bags, 3.5 million shakes; and of 6 oz/yd^2 Reemay bags, 22 million shakes [Ref. 3]. The heaviest weight Cerex bag tested exceeded 6 million shakes without catastrophic failure [Ref. 2]. Translating the number of mechanical-shakes-to-failure into bag life is complicated by the influence of other bag properties upon the frequency of cleaning. While the spunbonded fabrics [Refs. 2,3] and the Gore Tex/Nomex fabric do not tolerate as many shakes as woven polyester bags, their lower values of drag and specific cake resistance mean that they will not have to be shaken as often so that they could conceivably last longer in a given field application.

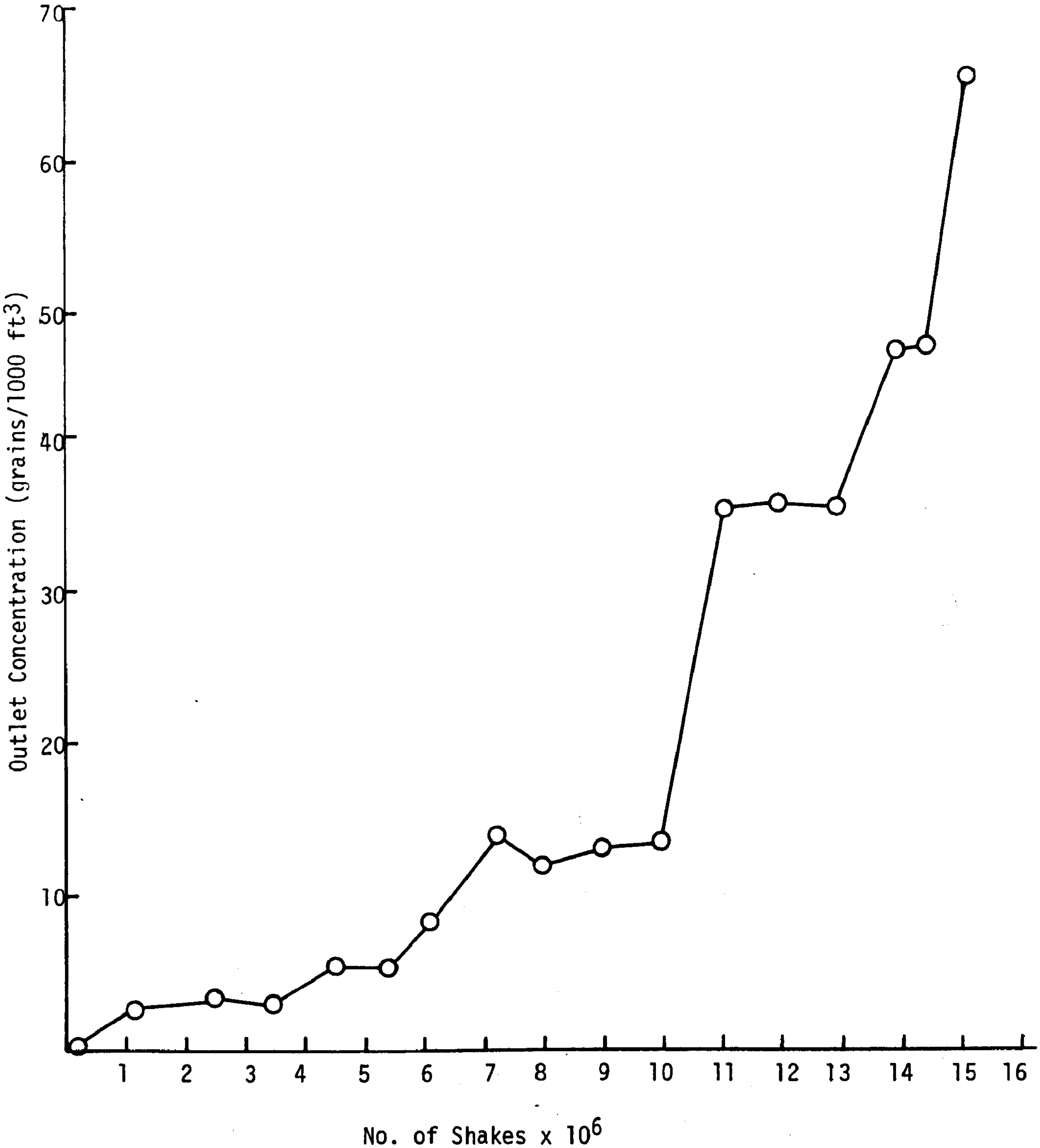


Figure 18. Endurance data for Gore Tex/Nomex bag filter.

SECTION 5

DISCUSSION

The particle counter data reveal some distinctive properties of the interaction between flyash and fabric filters made of Gore Tex/Nomex. Particle concentrations according to three optical sizes, as shown in Figure 9 for two air-to-cloth ratios, do not vary in time in the same manner as they do for a fabric filter that utilizes the dust cake for additional particle capture and removal. As previously discussed, when the dust cake plays the dominant role in the filtration process, filtration efficiency is lowest immediately after the cleaning cycle and increases as the dust cake rebuilds during the subsequent filtration cycle, being the highest immediately before the next cleaning cyle. Figure 9 shows that the Gore Tex/Nomex fabric does not behave this way. At an A/C of 4 fpm, the particle concentrations are roughly constant throughout the filtration cycle; at A/C = 9 fpm (Figure 9b), the particle concentrations actually increase as filtration proceeds, exhibiting peaks of penetrating particles superimposed upon a slowly rising background.

The hypothesis of dust cake sloughing was rejected as an explanation because the dust cake appears not to dominate the filtration process even though its buildup causes an increase in pressure drop across the bag.

The results presented in the previous section are qualitatively consistent with a model in which the fibrillated film of PTFE (Figures 1 and 19) removes most of the flyash by sieving. Referring to the scanning electron micrograph of Figure 19 (printed at 6450X, meaning a 1-in. length in the micrograph represents about 4.0 μm in reality), the structure and dimensions of the fibrillated film makes sieving of 5 to 6 μm median diameter flyash appear highly likely, since few passageways in the film

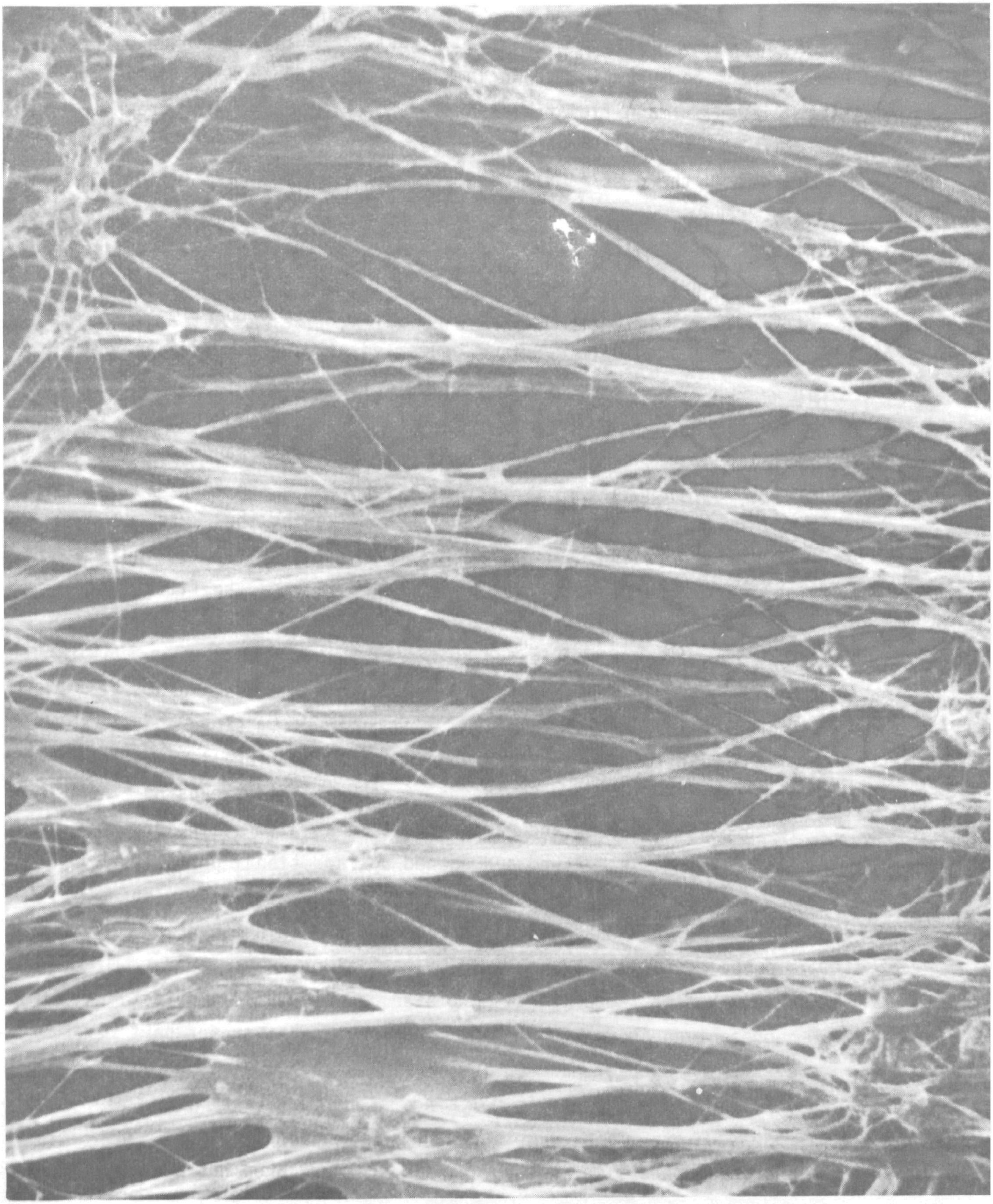


Figure 19. Close-up of fibrillated film of Gore Tex/Nomex (6450X) [Ref.1].

are as large as 6 μm. These dimensions contrast markedly with those of the Reemay fabric, for example, shown in Figure 20 at 645X, a full order of magnitude lower in magnificiation than the Gore Tex/Nomex micrograph in Figure 19. The gross differences in fiber dimensions and spacings make differences in the dust/fabric interaction not only plausible but highly likely.

Accepting sieving as the primary dust removal mechanism then leads to the following consequences:

1) The particle trapping depends primarily on the properties of the fibrillated Gore Tex film deposited, like a fine spider web, across the woven Nomex lattice (Figure 21).
2) The dust cake that collects does not improve filtration efficiency over the 0.3 μm to 1 μm particle size range although it increases the pressure drop across the fabric by blocking spaces and passageways--by plugging the sieve.
3) The shake cleaning removes the dust cake, thereby unplugging the filter and reducing the pressure drop across the filter. The efficiency of filtration, depending only on the Gore Tex film, remains unaffected by the cleaning.
4) At high gas flow--high air-to-cloth ratios--the dust cake increases in quantity, plugging more of the film sieve and giving rise to high pressure drops across the fibrillated film. These high pressure drops stretch the film, causing it to open its pores and perhaps rupture at discrete points. As the film is stretched and opened up, additional particles pass through the sieve. The peaks in penetrating particles (Figure 9b) are characteristic of pore stretching to pass a pulse of particles, followed by partial or complete relaxation to the original pore size. Ruptured filaments represent an increased pore size and could account for part of the increase of penetrating particles with time as depicted in Figure 9b. Rupture is not a necessary feature of the model, however, since increased pressure drop alone means increased pore size in the film and pressure drop has been

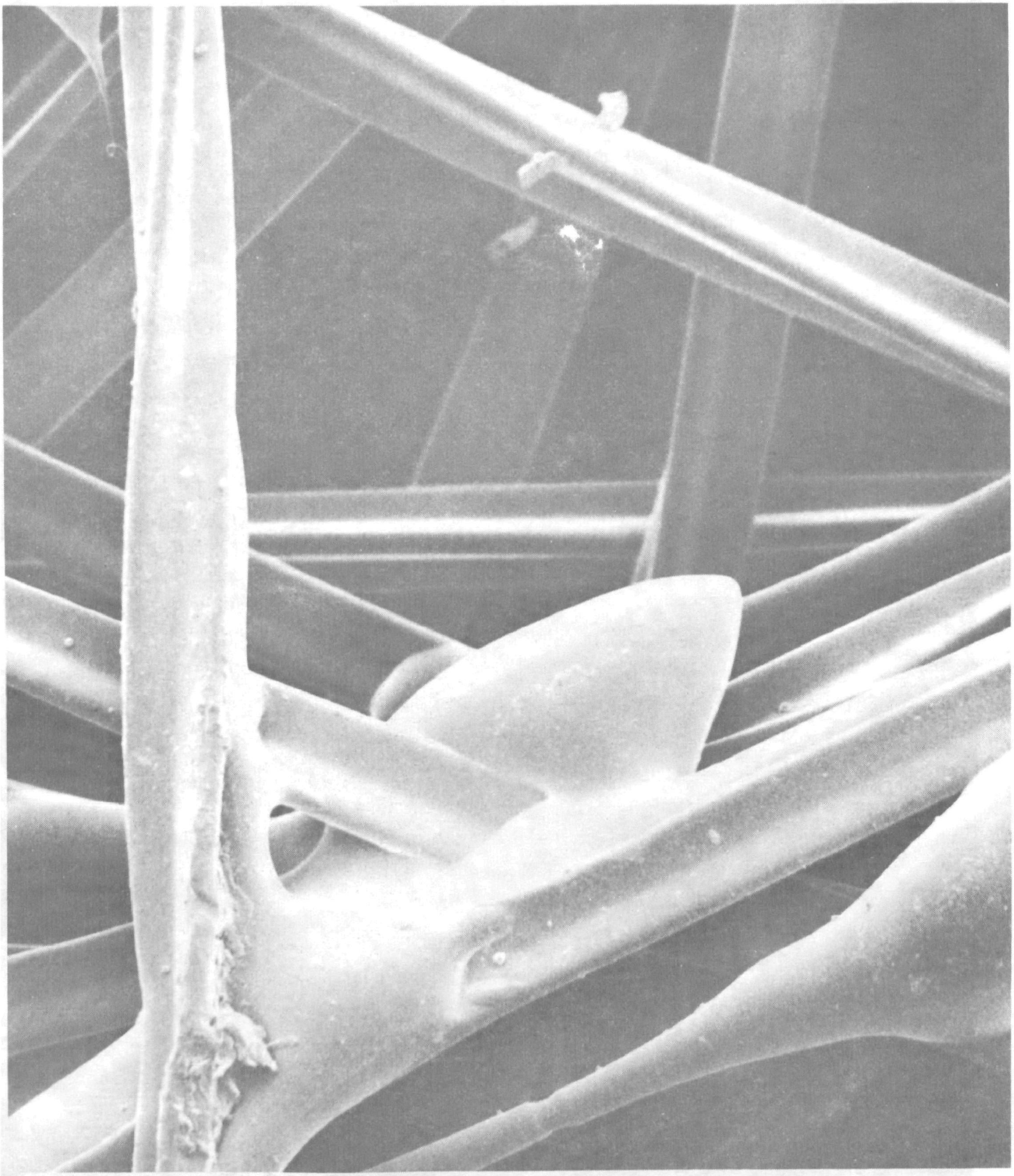


Figure 20. Spunbonded polyester (Reemay*) (645X) [Ref.1].

*Registered tradename of E. I. Dupont Co., Inc.

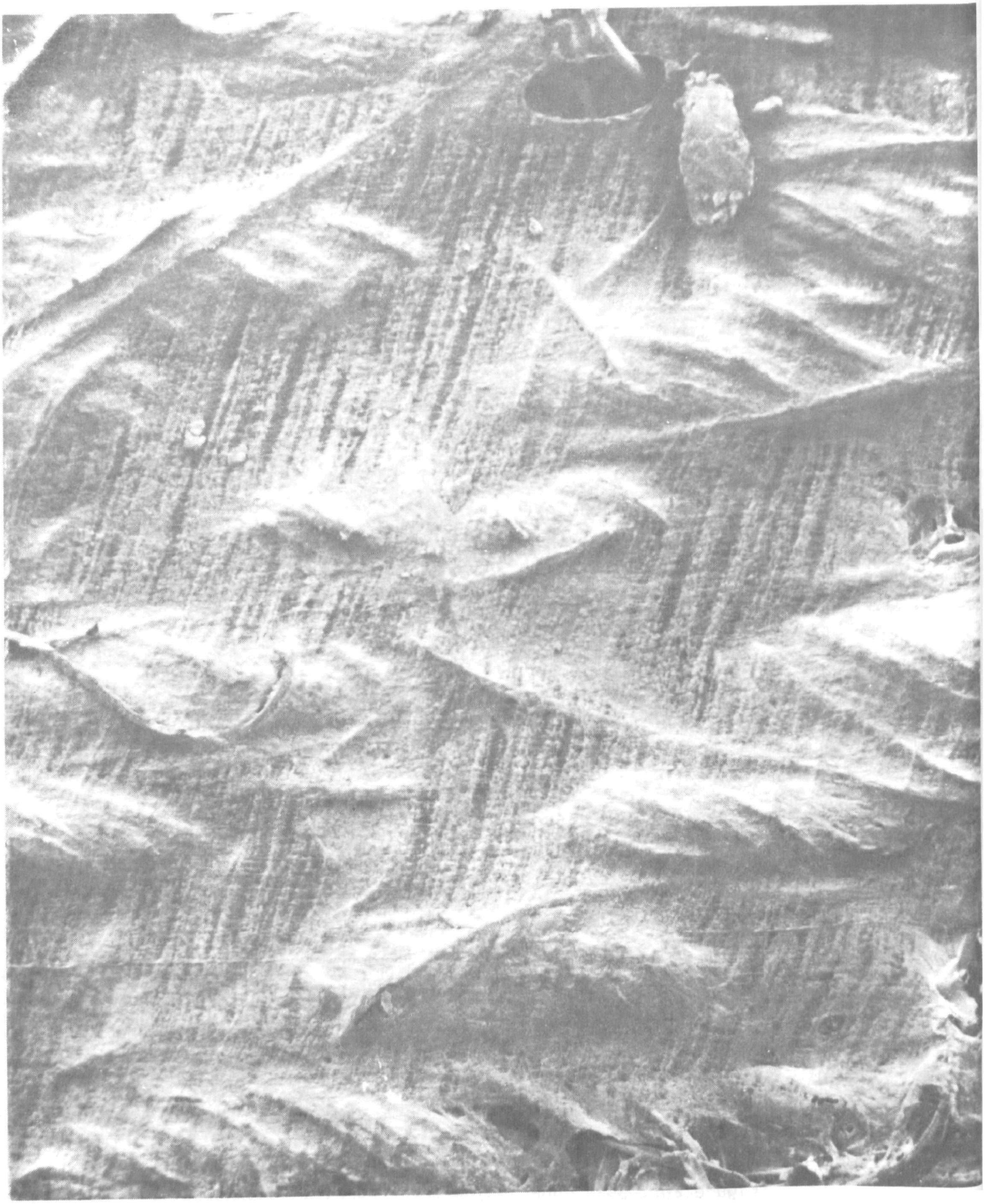


Figure 21. Gore Tex/Nomex at 108X [Ref.1].

shown to build up throughout the filtration cycle (Figure 17) and with increasing A/C (Figure 6).

The sieving model just described is based almost exclusively on data from the optical counter. These data are not always supported by the measurements of outlet concentration based on total mass collected on a Millipore filter (Figure 4). In Figure 4 outlet concentration (C_0) appears insensitive to A/C; if anything it decreases with increasing A/C. The Figure 4 data, however, reflect very low values of outlet concentration--all are below 4 grains/1000 ft^3. Errors in this measurement become very large at C_0 values below 10 grains/1000 ft^3. Therefore these data may not be significant.*

The sieving model, including pressure-drop-induced stretching of PTFE, explains most of the major features of both the optical and the mass data. Lack of sensitivity to relative humidity, as portrayed in the mass data of Figure 7, is consistent with sieving as the primary filtration mechanism. Humidity affects particle agglomeration and sticking coefficient, neither of which is critical for sieving. The increase in the number of penetrating particles with A/C, as shown in Figure 10, is consistent with pore stretching because of the higher pressure drop occcurring at high A/C (Figure 6). Pore stretching can also account for the slight shift to larger sized penetrating particles at high A/C (Figure 11). In all modified cycle testing (Figures 12-17) anything that produced increased pressure drop across the bag also caused an increase in the number density of penetrating particles and a shift to larger sized penetrating particles (compare Figures 13 through 16).

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*In general quantitative correlation of optical counter number data with Millipore mass data has not been good throughout these experiments. Sampling ports are located differently for the two measurements (Figure 3). Isokinetic flow is used for the mass data while a fixed total flow, adjusted to be near isokinetic by varying the sampling nozzle dimensions, is used for the optical measurements. The measurements depend on different particle populations (the Millipore data measures total mass; the optical counter, number density over a narrow size range) and particle properties so that quantitative correlation would not necessarily be direct and simple. Qualitative correlation should be expected but does not exist between measurements of C_0 vs A/C (Figure 4) and particle penetration vs A/C (Figures 9, 10).

While the sieving explanation seems to account for the present observations, it is still tentative and speculative. Further testing using a finer dust (a dust composed primarily of submicron particles) would provide valuable additional data. With these finer particles, sieving should become less important and the role of the dust cake more similar to that in the previous dust/fabric systems studied in this series [Refs. 2,3].

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APPENDIX

CONVERSION FACTORS

To Convert From:	To	Multiply By:
$foot^2$	$meter^2$	9.29×10^{-2}
$inch^2$	$meter^2$	6.45×10^{-4}
$yard^2$	$meter^2$	8.36×10^{-1}
$grains/foot^3$	kg/m^3	2.29×10^{-3}
$grains/1000\ ft^3$	g/m^3	2.29×10^{-3}
lb (force)	newton	4.49
foot	meter	3.05×10^{-1}
inch	meter	2.54×10^{-2}
mil	meter	2.54×10^{-5}
yard	meter	9.14×10^{-1}
grain	kilogram	6.48×10^{-5}
lb (mass)	kilogram	4.54×10^{-1}
inch of water (60°F)	$newton/meter^2$	2.49×10^{-2}
$lb/inch^2$ (psi)	$newton/meter^2$	6.89×10^{-3}
$lb/foot^2$	$newton/meter^2$	4.79×10^{-1}
foot/min (fpm)	meter/sec	5.08×10^{-3}
$foot^3$	$meter^3$	2.83×10^{-2}
$inch^3$	$meter^3$	1.64×10^{-5}
$yard^3$	$meter^3$	7.65×10^{-1}
oz/yd^2	kg/m^3	3.39×10^{-2}

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/2-76-168c		

4. TITLE AND SUBTITLE	5. REPORT DATE / 6. PERFORMING ORGANIZATION CODE
EPA Fabric Filtration Studies: 3. Performance of Filter Bags Made From Expanded PTFE Laminate	5. December 1976 6.
7. AUTHOR(S) Robert P. Donovan (Research Triangle Institute), Bobby E. Daniel, and James H. Turner	8. PERFORMING ORGANIZATION REPORT NO. IERL-RTP-233
9. PERFORMING ORGANIZATION NAME AND ADDRESS See Block 12.	10. PROGRAM ELEMENT NO. EHE624 11. CONTRACT NA--Inhouse Report
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711	13. TYPE OF REPORT AND PERIOD COVERED Inhouse Final; 10/74-10/75 14. SPONSORING AGENCY CODE EPA-ORD

15. SUPPLEMENTARY NOTES IERL-RTP project officer for this inhouse report is J.H. Turner, 919/549-8411 Ext 2925, Mail Drop 61.

16. ABSTRACT The report, third in an EPA Fabric Filtration series, gives results of an evaluation of fabric filters made of an expanded polytetrafluoroethylene (PTFE) film supported on a woven Nomex scrim--the Gore Tex/Nomex fabric. Filtration efficiency was very high and other performance parameters (drag and effective cake resistance), acceptable. The one fabric bag tested for endurance failed prematurely near the bag cuff; even so, it gave evidence of acceptable bag life. Because of the small fiber dimensions and spacings of the PTFE film, the dominant mechanism for particle removal appears to be sieving. This mechanism is not usually the dominant filtering mechanism for fabric filters; consequently, the Gore Tex/Nomex fabric exhibits some properties that are different from those of other fabrics evaluated in this series. The most important difference is in the role of the dust cake which, for the system reported here, is not a major factor in determining efficiency. Filtration efficiency is as good or better with little or no dust cake on the filter (such as at the beginning of a filtration cycle) than it is after a cake has had a chance to form (such as at the end of the filtration cycle). Thick dust cakes were simply not seen on this fabric, however. This conclusion applies only to the flyash used in these experiments. Finer dusts may behave differently.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Air Pollution	Fly Ash	Air Pollution Control	13B	21B
Dust	Caking	Stationary Sources	11G	07A,13H
Filtration		Polytetrafluoroethylene	11D	
Dust Filters		Particulate	13K	
Fabrics		Fabric Filters	11E	
Tetrafluoroethylene Resins		Baghouses	11E	
		Sieving		

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	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

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