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EPA FABRIC FILTRATION STUDIES: 5. Bag Cleaning Technology (High Temperature Tests)

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EPA FABRIC FILTRATION STUDIES:
5. Bag Cleaning Technology
(High Temperature Tests)

by

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PREFACE

This report is the fifth 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 5 years by the Industrial Environmental Research Laboratory, Research Triangle Park, N. C., and previously by predecessor agencies. 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 baghouse operation in a carefully controlled laboratory setting that allowed measurement and comparison of bag performance and endurance.

The work reported in this paper was based on a laboratory simulation of high temperature baghouse operation, the only work in this series to use this apparatus. Cement dust was the only dust used here, whereas flyash was previously the only test dust used. Inlet dust loading was not measured and was not precisely controlled, since no performance parameter was monitored other than pressure drop across the bag. The primary purpose of the high temperature facility was to detect temperature induced bag failure or phenomena.

As in all previous reports, British units are used primarily. Their widespread use in the existing literature makes them the preferred choice in spite of EPA's policy to use metric units. Use of metric units would seriously inconvenience the majority of the intended reading audience. For those readers more familiar with the metric system a conversion table for changing the British units used in the report to their metric equivalents appears in Appendix B.

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

1) "Performance of Non-Woven Nylon Filter Bags," J. H. Turner, EPA-600/2-76-168a (NTIS No. PB 266271/AS), December 1976.
2) "Performance of Non-Woven Polyester Filter Bags," G. H. Ramsey et al., EPA-600/2-76-168b (NTIS No. PB 258025/AS), June 1976
3) "Performance of Filter Bags made from Expanded PTFE Laminate," R. P. Donovan et al., EPA-600/2-76-168c (NTIS No. PB 263132/AS), December 1976.
4) "Bag Aging Effects," R. P. Donovan et al., EPA-600/7-77-095a, (NTIS No. PB 271966/AS), August 1977.
5) "Bag Cleaning Technology (High Temperature Tests)," (this report).
6) "Analysis of Collection Efficiency by Particle Size."

ABSTRACT

The influence of high temperature operation (operation in an air flow whose temperature has been adjusted to the maximum continuous operating temperature recommended by the fabric filter manufacturer) on the selection of shake-cleaning parameters is the subject of this work. Two bags each of cotton and Dacron were operated in a laboratory baghouse using heated air passed through cement dust as the source of dirty air. The bags cleaned at high "g" forces (~5 g's) showed more deterioration in strength properties than those cleaned at 1.9 g's. The observations generally confirm the Dennis/Wilder analysis of mechanical cleaning and suggest that temperature is not a first order variable in the analysis of mechanical shake-cleaning. The cursory tests conducted here do not conclusively rule out temperature as an important parameter; they merely report that in this limited investigation it was not.

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LIST OF ABBREVIATIONS AND SYMBOLS

A = filtration area of fabric (sq ft)

C_o = mass outlet concentration (grains/1000 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)

W_R = cloth loading after cleaning (lb/ft^2)

W_T = cloth loading just prior to cleaning (lb/ft^2)

ACKNOWLEDGEMENT

The authors acknowledge, with pleasure, the comments and suggestions made by Richard Dennis of GCA Technology Division to improve this report.

SECTION 1

INTRODUCTION

Optimum parameters for shake-cleaning fabric filters have previously been studied, both theoretically and experimentally, by Dennis and Wilder [Ref. 1]. They showed that the residual dust remaining on a fabric filter after a shake-cleaning correlated with the reciprocal of the square root of the average bag acceleration during the shake-cleaning. The exact relationship varies with varying dust/fabric systems and also depends on other variables such as humidity, electrostatic charge and bag age.

The amount of residual dust, however, seems not to be related to the initial dust loading on the bag prior to the shake-cleaning.

Dennis and Wilder supported their theoretical models with measurements made while filtering flyash at room temperature. The fabrics they used included cotton sateen and Dacron. In the cursory work to be reported here the cleaning cycles recommended by Dennis and Wilder were repeated on cotton and Dacron in a test facility that allowed the fabric filters to be operated at their maximum recommended temperatures (180°F for the cotton; 275°F for the Dacron). The purpose of the work was to determine if the analysis of the shake-cleaning cycle previously confirmed for room temperature operation remained valid at the temperature maximums of each of the fabrics.

SECTION 2

CONCLUSIONS

The high temperature measurements reported in this paper are qualitatively consistent with the shake-cleaning analyses and room temperature measurements previously reported by Dennis and Wilder (D&W). Stronger conclusions in support of the D&W work are not justified because the dust used in the experiments reported here differed from that used by Dennis and Wilder (cement dust here vs. flyash) and the instrumentation was not as complete: bag tension, an important D&W parameter, was controlled only crudely; and the only performance parameter monitored here was pressure drop across the bag, a parameter treated only sketchily by D&W. Within these limitations, however, the importance of bag acceleration during cleaning was demonstrated and, as in the D&W model, shown to be a variable of first order importance in the shake-cleaning of fabric filters. No new, temperature-dependent phenomenon was identified to modify or upset the D&W analysis. Both bag performance, as measured by the pressure drop, and bag life, as measured by the physical properties of the fabric, depended more on the shake-cleaning action than on time at temperature. As in the D&W work, the dust loading of the cotton bags greatly exceeded that of the Dacron bags. Measurements of the absolute values of various properties of the used fabric, especially abrasion resistance, suggest that the Dacron bags would last longer. For both the cotton and the Dacron bags, shake cleaning at high "g" forces reduces bag strength (and presumably ultimate bag life) more rapidly than does low "g" cleaning. No direct measurements of bag life were made, however.

SECTION 3

BACKGROUND

The analysis of bag shake-cleaning carried out for EPA by Dennis and Wilder [Ref. 1] develops a theory of bag motion in terms of shake-frequency, stroke length and various bag properties including dimensions, elastic modulus and mounting tension. The inertial forces transmitted to the bag by the shaking force applied to one end of the bag must exceed the forces holding the dust at any specific region in order to effectively remove the dust. While the cleaning efficiency of a specific shake cycle depends upon the magnitude of the dust trapping forces as well as the motion of the bag, the Dennis/Wilder analysis concentrates primarily on the latter. The assumption is that tensile stress between the dust cake and the fabric is the only effective removal mechanism--the inertial forces perpendicular to the fabric surface during acceleration and deceleration separate the dust from the fabric, although shear force may assist in breaking adhesive bonds between dust and fabric.

In analyzing the bag motion Dennis and Wilder treat the bag like a vibrating string, oscillating in dampened harmonic motion. A displacement introduced by the shaker mechanism propagates along the bag to the end where it is reflected. At certain frequencies the reflected wave reinforces the applied displacements--these frequencies constitute resonant frequencies.

At all frequencies some dampening occurs and a minimal requirement for cleaning is that the applied shaking energy be sufficient to introduce a traveling wave that is not completely dampened before reaching the end of the bag. Otherwise no shake-cleaning would occur at the motionless end remote from the shaker mechanism.

Bag tension is an important variable in determining wave propagation and dampening. It varies along the length of the vertically suspended bag because of gravity, increases with time of filtration because of dust loading and varies with applied forces and bag motion during the shake-cleaning. Dennis and Wilder derived the following expression for relating the average bag amplitude, $\bar{Y}$, to bag tensions during shake-cleaning:

$$\bar{Y} = \frac{1}{\pi f} \sqrt{\frac{1}{M L \rho}} \sqrt{T_m (T_m - T_{i,m})} \tag{1}$$

where $\bar{Y}$ = the average amplitude of bag displacement (ℓ)

f = the shaker frequency (t^{-1})

M = the elastic modulus of the bag filter (m/t^2)

L = the bag length (ℓ) (between clamps)

ρ = the mass per unit length of the bag (m/ℓ)

T_m = the dynamic bag tension averaged at its midpoint ($m\ell/t^2$)

$T_{i,m}$ = the initial, average midpoint tension (static) ($m\ell/t^2$)

The value of $\bar{Y}$ calculated from Equation 1 underestimated the photographically measured* displacement amplitudes by about 30 percent [Ref. 1]. Equation 1 predicts that the average amplitude decreases with

*The procedure was to measure a maximum amplitude at a node and a minimum amplitude at an anti-node and average the two amplitudes to obtain an average amplitude.

increasing shake frequency. This relationship is not simple to confirm, however, because the tensions also vary with shake frequency, peaking in the vicinity of a resonance. Away from the resonances the bag tensions generally increase with increasing frequency partially cancelling the frequency-dependence of amplitude explicitly contained in Equation 1.

Once knowing the displacement at any point on the bag, the maximum acceleration, a_m, at that point is [Ref. 1]:

$$a_m = 4 \pi^2 f^2 Y \tag{2}$$

All points on the bag are assumed to move at the same frequency as the shaker arm.

Dennis and Wilder [Ref. 1] further showed that the residual dust loading of the fabric filter varied inversely as the square root of the average bag acceleration (Figure 1). The residual dust loading of the fabric is the dust remaining on the fabric after a specific shake-clean cycle as characterized by an average acceleration--the average of the maximum acceleration at all points of the bag. The residual dust loading is independent of the initial dust loading prior to the shake cleaning. To the first order the residual dust loading depends only on the average bag amplitude, ($\bar{Y}$), and frequency of the shaker, (f), assuming uniform bag tension at rest.

Figure 2 is a composite curve from Dennis and Wilder that summarizes this behavior. At the end of the filtration cycle the terminal drag is S_T and the cloth loading, W_T. The values of drag and cloth loading following a shake-cleaning are plotted for four different sets of shake-cleaning parameters (A to D). Although the inverse square root relationship between average acceleration and residual dust loading is not strictly followed, the residual dust loading clearly decreases with increasing bag acceleration.

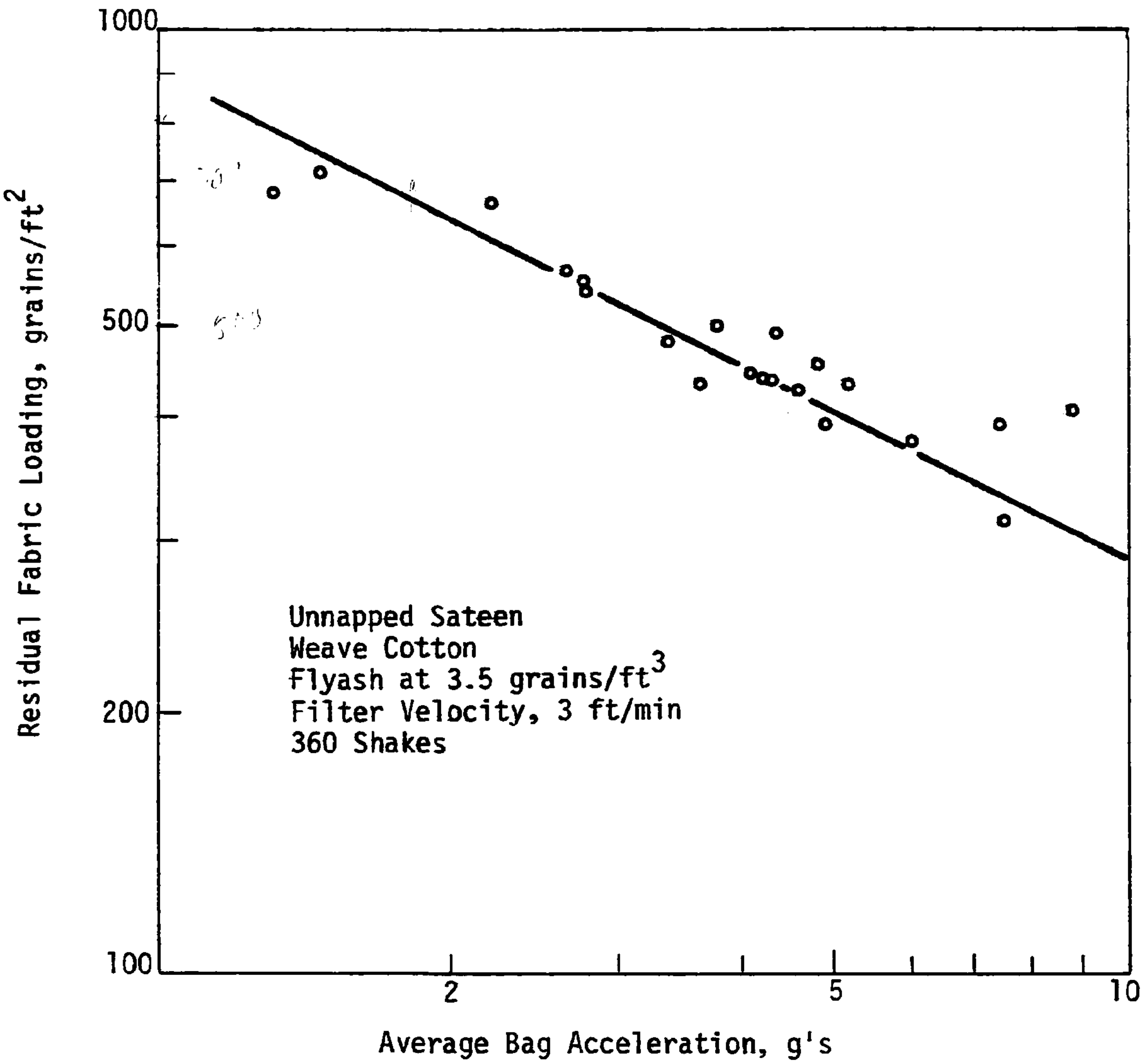

Figure 1. Residual fabric loading versus average bag acceleration (from Dennis and Wilder [Ref.1]).

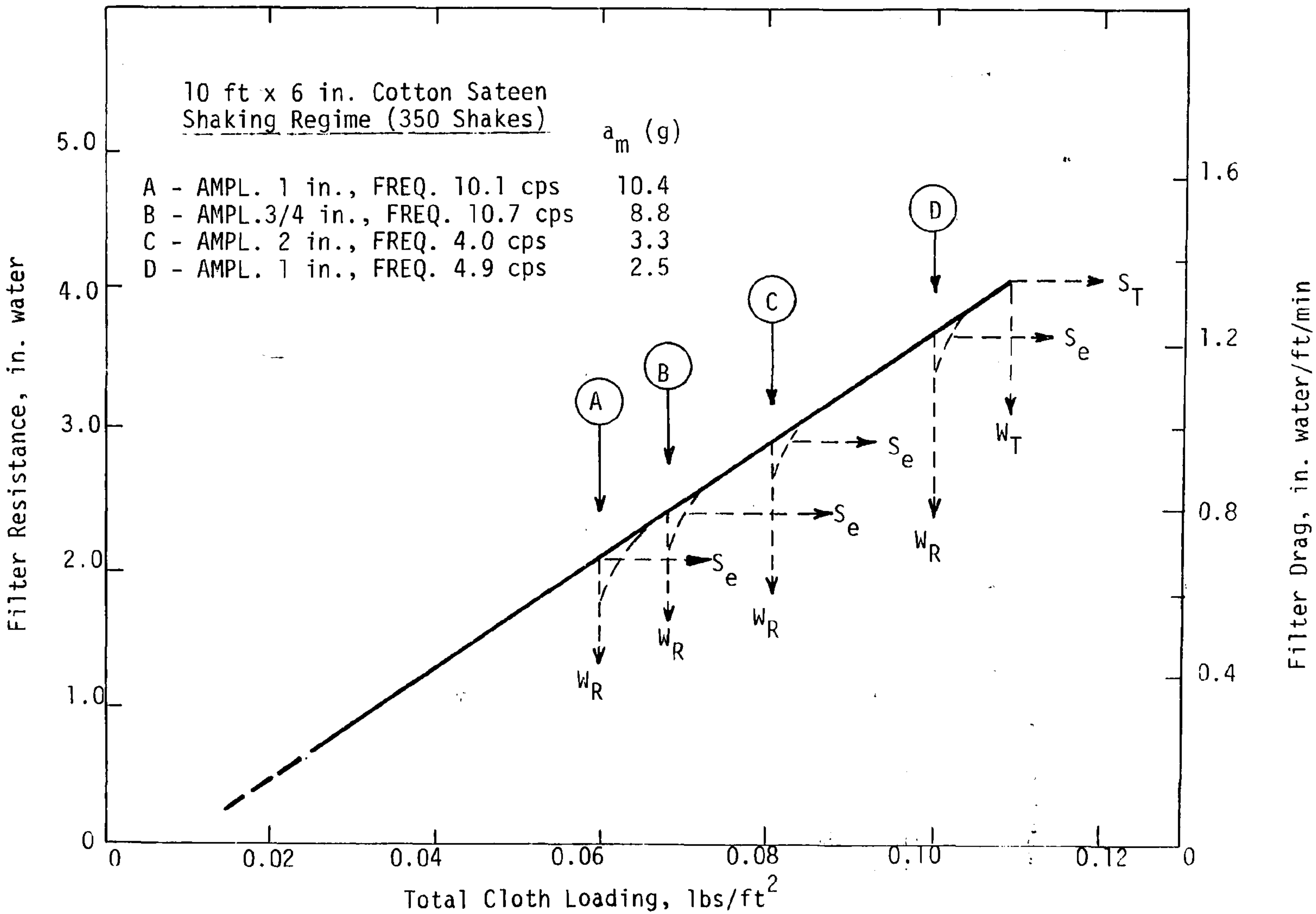

Figure 2. Cloth loading and filter drag characteristics for typical shaking regimes--composite curve (from Dennis and Wilder [Ref. 1]).

Total number of shakes is also a factor. Dennis and Wilder specify a minimum of 100 shakes for the observed relationships to be reproducible. By 200 shakes the residual dust has attained 80 to 95 percent of its 360 shake value and the optimum number becomes a compromise between the diminishing contribution to the cleaning and the linear increase in mechanical wear on the fabric.

Bag age also influences the observed relationship between the residual dust loading and the average acceleration during the shake-cleaning. The curves shown in Figure 3 compare residual dust as a function of total number of shakes for various new fabric filters and used bags of the same fabric (the "old", 0, designation in Figure 3). For all fabrics the residual dust loading decreased with bag age, perhaps because of "irreversible stretching in the [fabric] media" (Figure 4), and/or shedding of fibers that project across pores.

In summary, the general recommendations for shake-cleaning developed by Dennis and Wilder include:

1) Shaker parameters (amplitude and frequency of shake) selected so as to produce an average bag acceleration in the range 1.5 to 7 g's.
2) Total number of shakes between 200 and 400.
3) Control (and monitoring) of bag tension as a parameter in achieving No.1; in particular, adequate tension to ensure propagation of the oscillating motion along the entire length of the bag.

Other variables, such as dust type, fabric type, and bag age, influence the specific relationship between cleaning efficiency and shake-cleaning technique. Hence, the optimum shaker parameters cannot be specified <u>a priori</u> with complete confidence. Some trial and error will be necessary. The purpose of the work reported here is to observe the high temperature behavior of fabric filter bags, shake-cleaned in accordance with the general recommendations listed above. High temperature means the maximum temperature for continuous operation specified

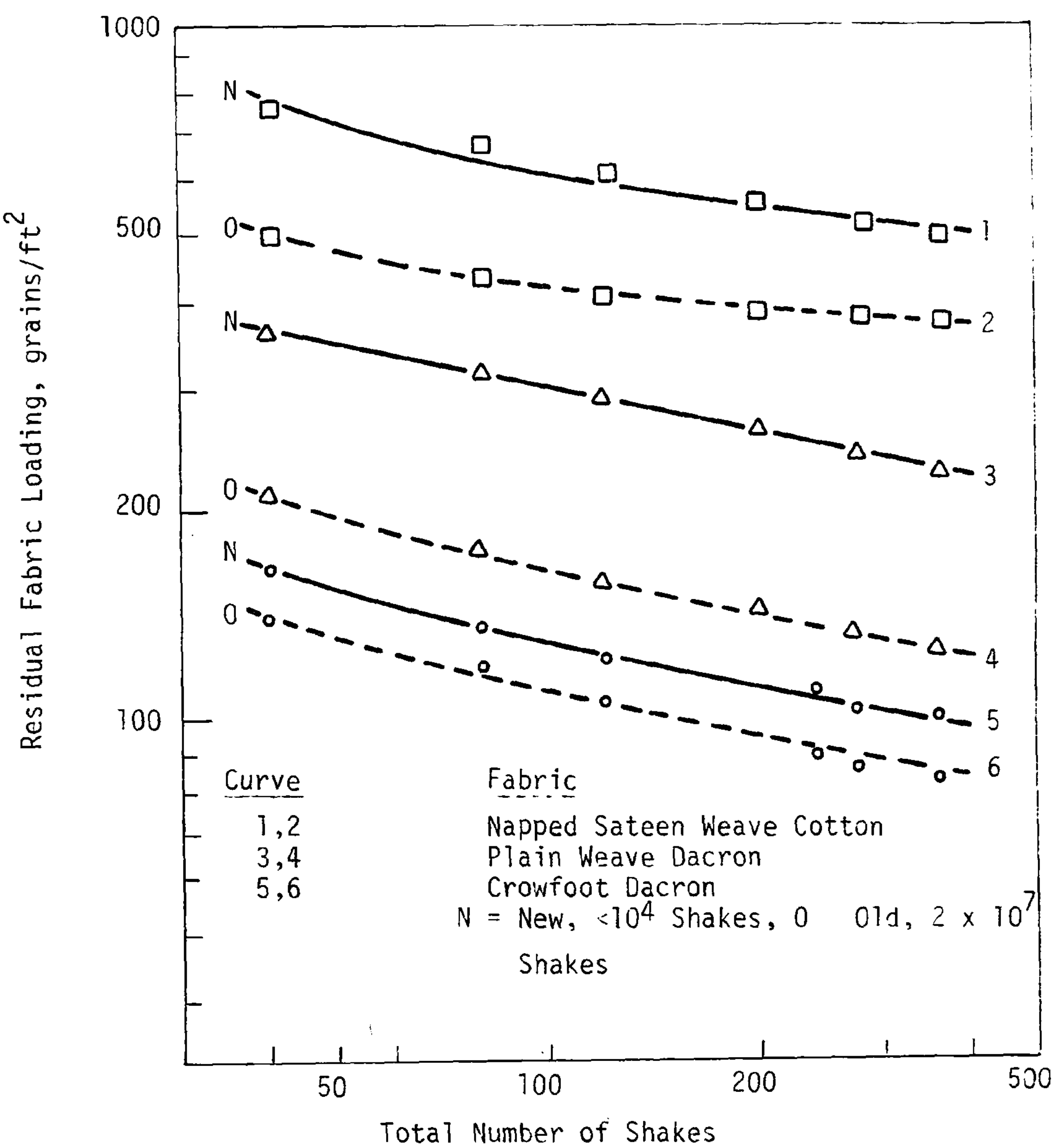

Figure 3. Residual fabric loadings for various fabrics with flyash aerosol (8 cps, 1 in. amplitude shaking) (from Dennis and Wilder [Ref. 1]).

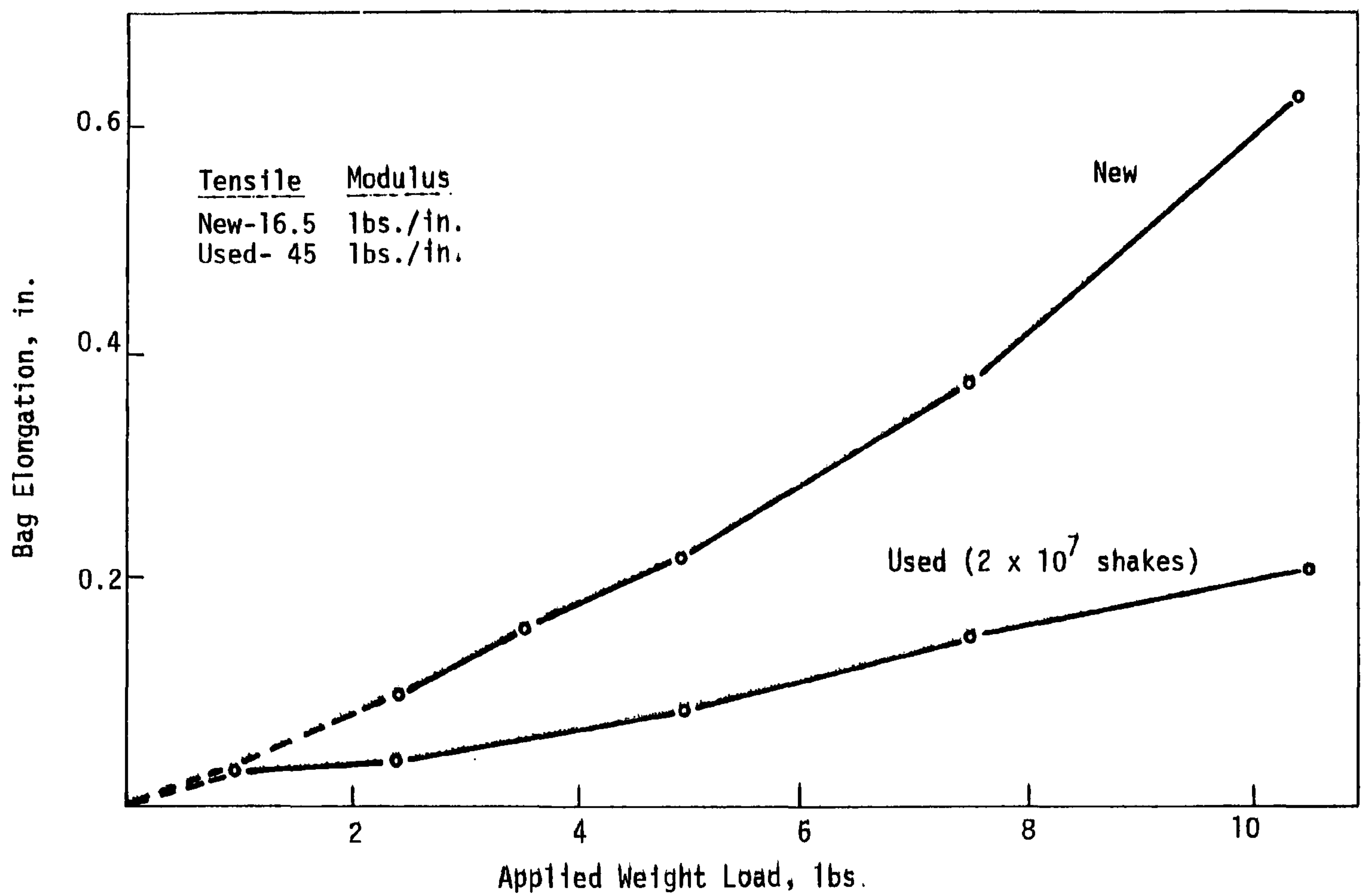

Figure 4. Tensile properties for a 10-foot by 6-inch sateen bag (from Dennis and Wilder [Ref. 1]).

by the fabric manufacturer. The investigations carried out attempted to determine if the general Dennis/Wilder recommendations apply also for high temperature operations or whether new forces and interactions dominate the problem.

SECTION 4

EXPERIMENTAL PROCEDURES

The apparatus used to carry out the high temperature evaluation consisted of a custom-assembled chamber sized to hold four bags (Figure 5). Cement dust, repeatedly entrained in the metered hot air flow entering the bag, was used for all tests. The entrained dust was then removed from the air flow by the fabric filter during the filtration cycle and shake-cleaned into the dust pot at the bottom of the bag during the cleaning cycle. During the next filtration cycle, the dust became re-entrained once more as the heated air entered the bag through various ports in the dust pot. The dust was thus continuously transferred from the dust pot to the fabric (the entrainment/filtration portion of the cycle) and then from the fabric back to the dust pot (the shake-cleaning portion of the cycle). The filtration period was always 75 secs; the shake-cleaning, 35 secs. No time delay separated these periods. Filtration ended and shake-cleaning began simultaneously; conversely, the shake-cleaning ended and the air flow for the next filtration period began at the same time.

Temperature of operation was controlled by passing the inlet air through a furnace heater, preset to the desired operating temperature. The actual temperature inside the baghouse was monitored by thermocouples located at various positions in the clean air side of the baghouse. The shaker arm was fabricated from hollow tubing which allowed pressure measurements to be made across the bag; that is, access to the inside of the bag for pressure measurements was through the shaker arm and the bag mount at the top. Since the inside of the bag is the dirty side of the air flow, the tubing became clogged with dust periodically.

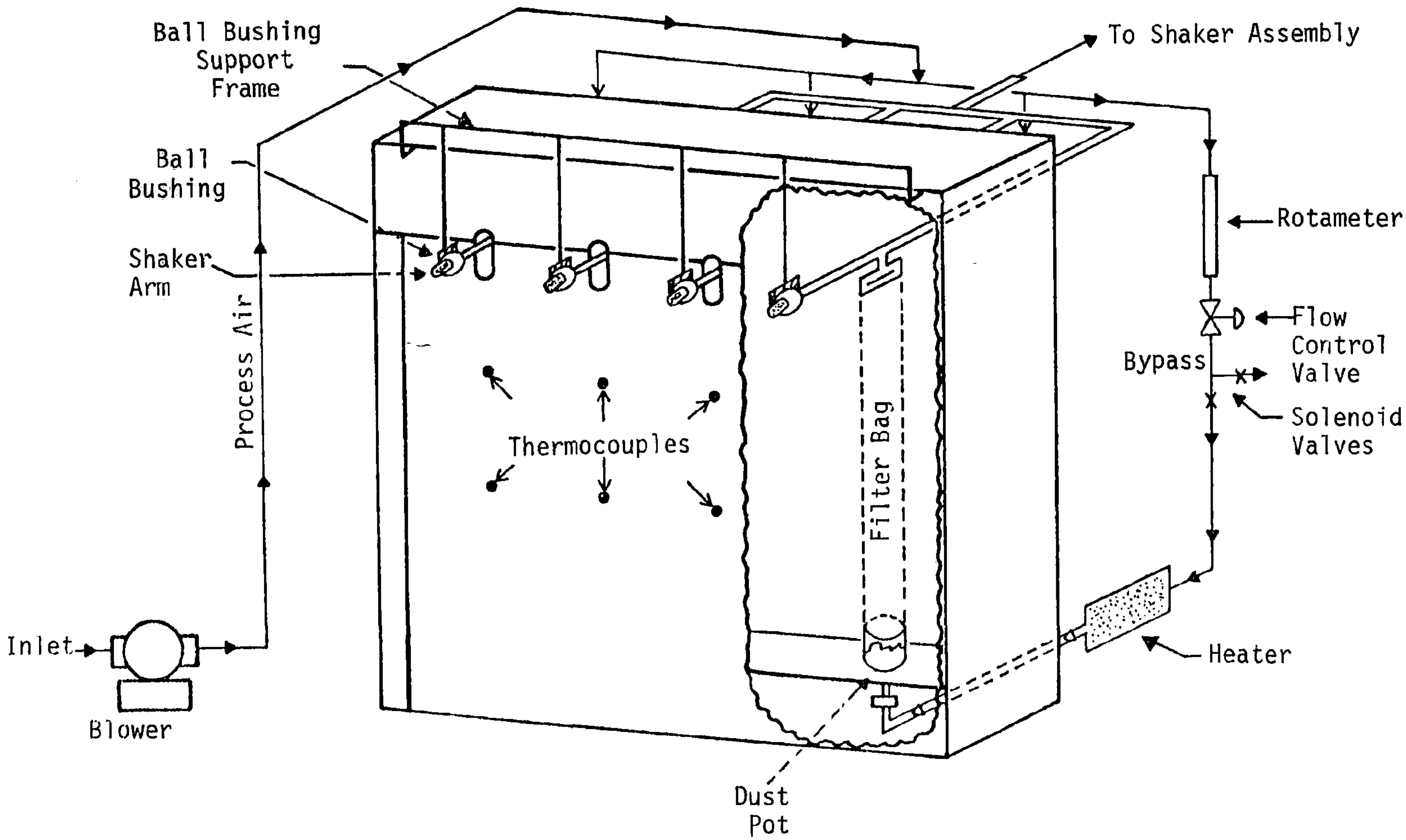

Figure 5. Laboratory baghouse for high temperature tests.

The variables of the shake-cleaning were controlled by a standard motor/cam arrangement not shown in Figure 5.

No performance characteristics (efficiency, outlet concentration, etc.) were measured other than pressure drop. The purpose of the test was to detect any major departure from room temperature behavior that high temperature operation would introduce.

All bags were 31.75 in. long and 5.5 in. in diamter, with a total bag area of 3.81 ft^2. Unlike the Dennis and Wilder work [Ref. 1] bag tension was not monitored continously; rather, it was adjusted initially by measuring the bag slack. After mounting the bag with zero slack, the tension was tightened or loosened by a fixed length to achieve the desired tension. This crude control of tension was deemed adequate for the confirmation of qualitative bag behavior.

Total air flow through the bag was determined by a rotameter in the feed line upstream of the furnace. This air flow was held constant throughout any given run at some value between 7.5 and 8.4 cfm, yielding an air/cloth ratio of about 2 fpm for all the tests reported here.

Inlet dust loading was not measured (nor were outlet concentration or bag efficiency). The dust feed mechanism, relying totally on air flow through settled dust, probabably produced non-uniformities in the inlet loading, as discussed in Section 5.

SECTION 5

RESULTS

Four runs, two with cotton bags and two with Dacron bags, were carried out using cement dust as the test dust. The independent variables of these runs are summarized in Table 1 along with the calculated total number of shakes and the maximum bag acceleration during the shake cycle. The total operating time was adjusted to achieve over 3 million shakes during each run regardless of the shaker rpm. The stroke is the total distance moved by the shaken end of the bag and is therefore twice the amplitude of the sinsusoidal wave motion of the bag—the amplitude, $\bar{Y}$, used in Equation 2 to calculate the maximum acceleration, was taken to be half the stroke. The operating temperatures were the maximum recommended by the manufacturers for the specific fabrics.

Unlike the Dennis and Wilder work [Ref. 1], bag dust loading was not measured *in situ*. Hence, the Dennis/Wilder correlation between residual dust loading and the inverse square of average bag acceleration during shake-cleaning (Figure 1) could not be confirmed directly. What was observed was the pressure drop across the bags at the time the shake-cleaning cycling commenced. This variable (actually the drag, $\Delta P/[A/C]$) has been shown previously to correlate qualitatively with the dust loadings, both residual and terminal, of a shake-cleaned bag operating on a fixed time sequence [Ref. 2] (a fixed time sequence is one in which the durations of the filtration period, the cleaning period and all other intervals of the operating cycle are constant in time). It was used in this work to investigate the role of acceleration during cleaning upon the dust loading of the bags.

Figure 6 is a plot of pressure drop for the two cotton bags; Figure 7, for the Dacron bags. The ordinate is pressure drop rather than drag,

TABLE 1. SUMMARY OF RUNS

Run No.	Bag No.	Fabric	Operating Time (hours)	Temp (°F)	Shake (rpm)	Stroke (in.)	Total Shakes ($\times 10^6$)	a_m (from Equation 2) [$\times 10^6$ in./min^2 (g)]	
37	6034-2	Cotton	703	180	240	2.36	3.22	2.68	(1.9)
	6034-3	Cotton	703	180	240	2.36	3.22	2.68	
38	6031-1	Dacron	704	275	240	2.36	3.23	2.68	"
	6031-2	Dacron	704	275	240	2.36	3.23	2.68	
	6031-3	Dacron	704	275	240	2.36	3.23	2.68	"
39	6031-4	Dacron	462	275	390	2.36	3.44	7.08	(5.1)
	6031-5	Dacron	450	275	390	2.36	3.35	7.08	"
	6031-6	Dacron	450	275	390	2.36	3.35	7.08	
	6031-7	Dacron	488	275	390	2.36	3.63	7.08	
40	6034-4	Cotton	460	180	370	2.36	3.25	6.38	(4.6)
	6034-5	Cotton	460	180	370	2.36	3.25	6.38	
	6034-6	Cotton	460	180	370	2.36	3.25	6.38	"

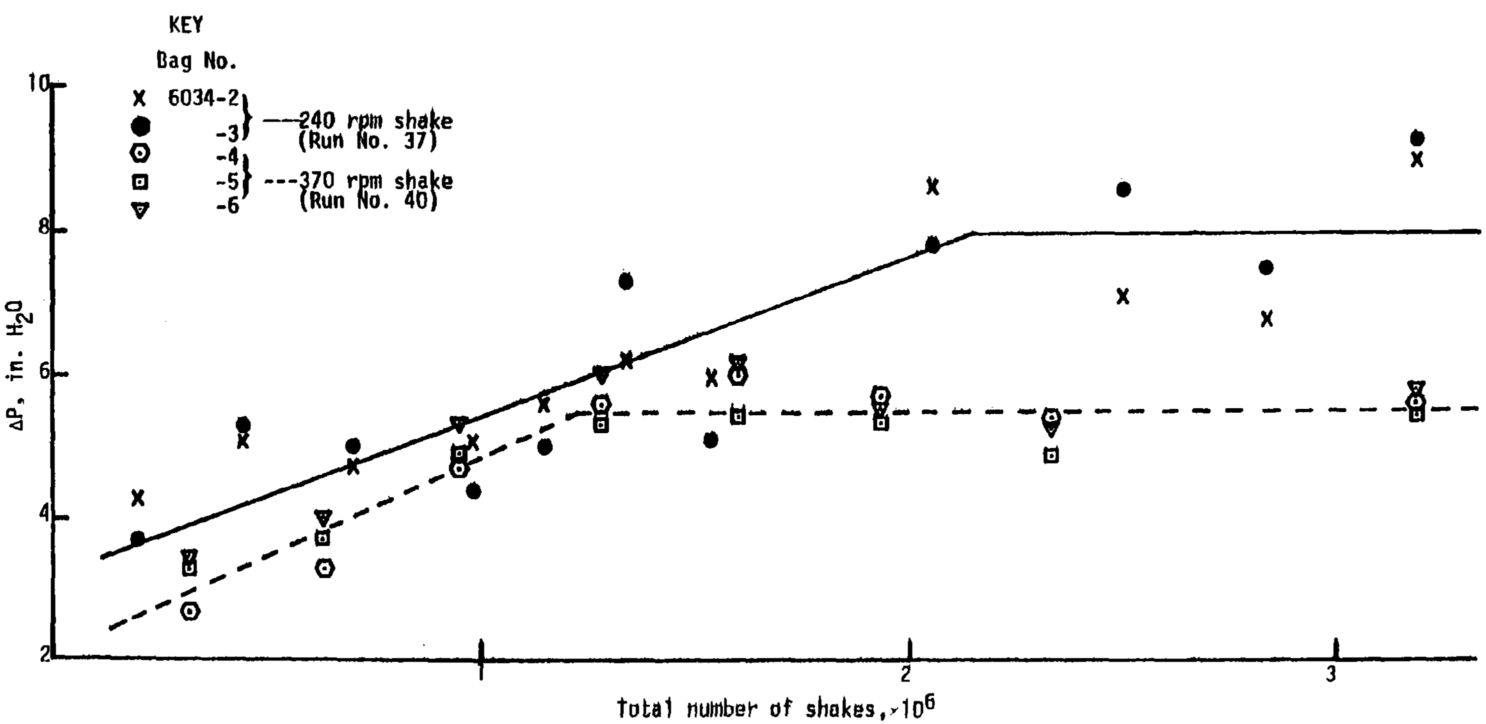

Figure 6. Pressure drops of cotton bags filtering cement dust at 180°F.

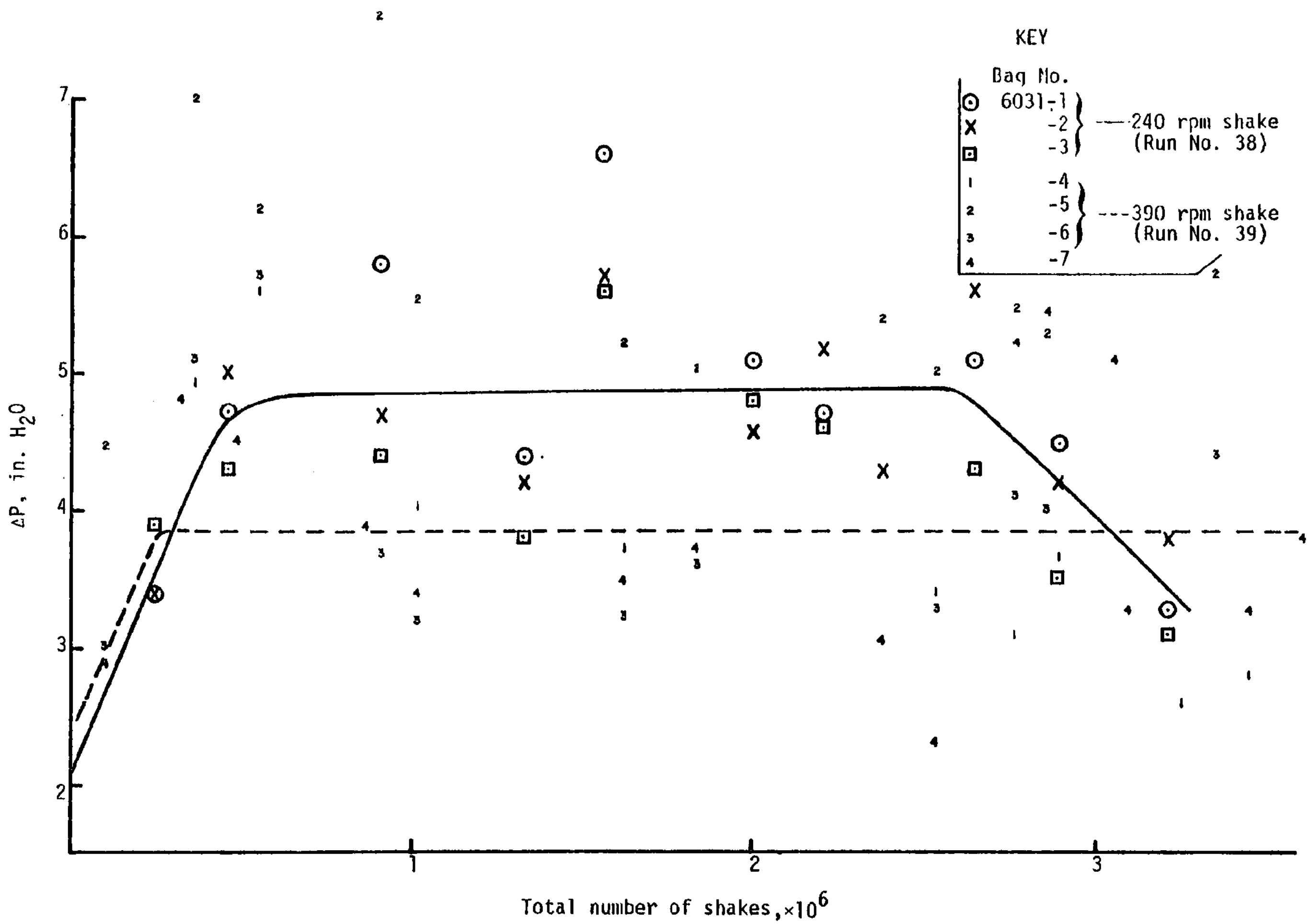

Figure 7. Pressure drops of Dacron bags filtering cement dust at 275°F.

since the gas flow was held constant for all these measurements. On a few measurements the air/cloth ratio varied--because of obstructions or other bag problems--but these were exceptions and were remedied immediately.

The data plotted in Figures 6 through 8 represent averaged pressure drops of 8 to 15 readings each. The curves, drawn by eye to fit the data, assume a simple linear behavior within two or three sequential time intervals and attempt to draw only first order distinctions between the compared curves.

The immediate conclusion from the plots of Figures 6 and 7 is that the runs carried out under higher "g" cleaning conditions operated at lower pressure drop, corresponding to a bag of lower dust loading. This conclusion is qualitatively consistent with the predictions of Dennis and Wilder; a stronger supporting statement is not made because the dust used here is different and the instrumentation was not as complete as theirs.

In Figure 7 there is a hint of a decrease in pressure drop for the data of run No.38, the Dacron run shake-cleaned at low "g". Thus turn-down in the curve suggests the onset of bag wearout [Ref. 2] after about 2.6×10^6 shakes. No such "wearout" suggestion is contained in the curve for run No.39 for which the ΔP data do not reflect any fall off to over 3.6×10^6 shakes. If total number of shakes is a valid measure of bag life, then the two curves represent different behavior. If, however, because of the elevated temperature of operation, operating time alone is a better measure of bag life, the two curves compare as shown in Figure 8. In Figure 8 the abscissa has been changed to operating time and the two curves may be consistent, since the operating time of the 390 rpm run is much less than the 240 rpm run--it simply may not have had sufficient running time to reach the wearout period. If the wearout mechanism is more temperature-dependent than shake-dependent, the display in Figure 8 is the more realistic presentation. Figures 6 and 7 assume that the number of mechanical shakes is the dominant variable by which to measure bag life.

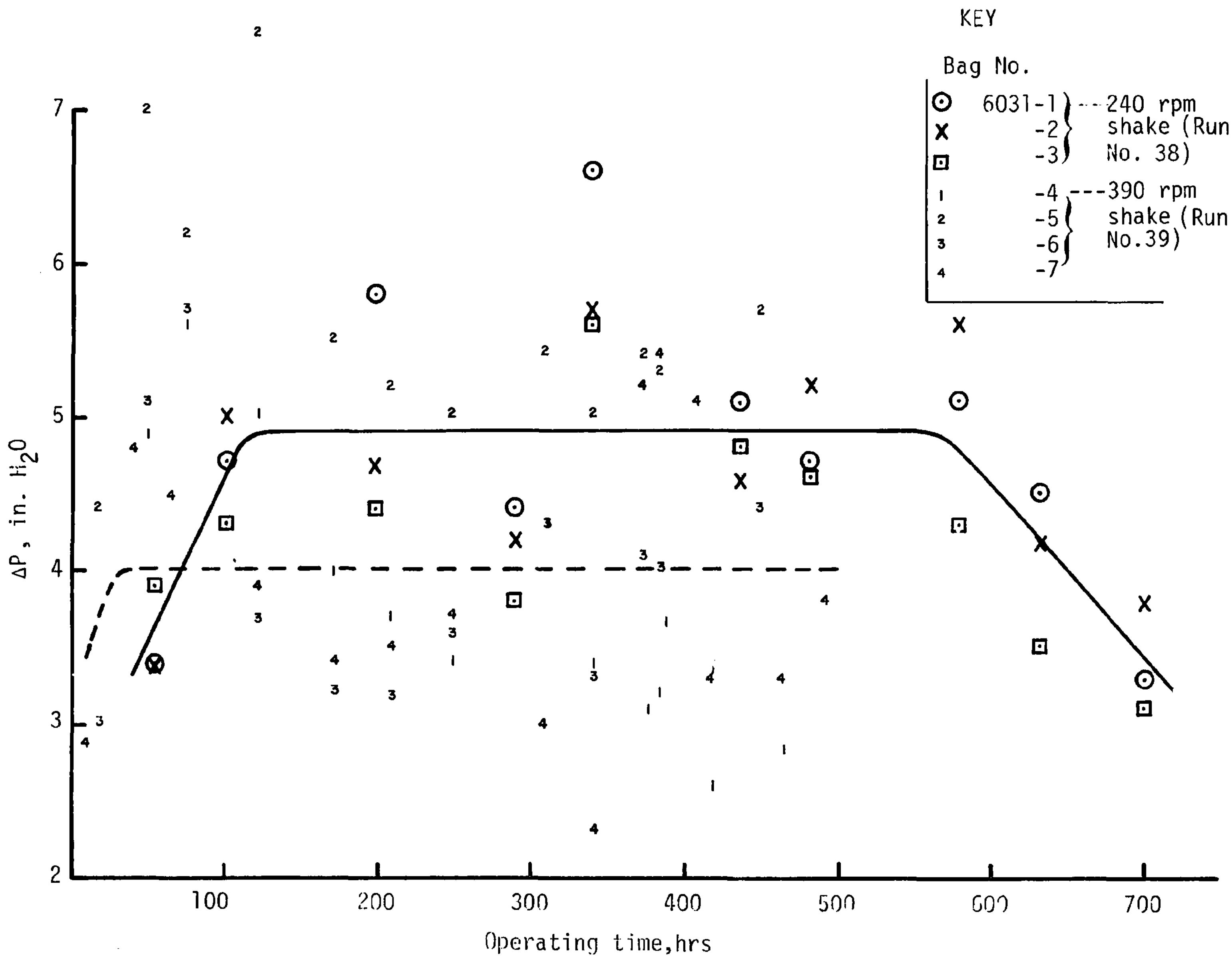

Figure 8. Replot of Figure 7 using total operating time as the abscissa.

The fact that the Figure 8 plot removes the minor inconsistency from the Figure 7 plot is the only evidence found in these investigations to suggest that time at temperature may be a significant variable. If valid this dependence does not conflict with the Dennis/Wilder observations; at most it adds another variable to consider in formulating a shake-cleaning schedule.

The measurements of pressure drop reflect large scatter. One major cause of variation in the measured pressure drops was the long, thin line through which the inside bag pressure was detected. Uncontrolled pressure drop along this line, because of obstruction and dust buildup, caused measurement errors that were characterized by gradual drifts to lower and lower values of measured pressure. When the line would subsequently be cleaned or blown clear, the indicated pressure drop would jump to a new, high value, introducing severe, unreal discontinuities into the record. This plugging problem was never solved but increased alertness for incipient blocks reduced its severity toward the end of the experiments.

An additional source of error arose because of non-uniformity in the re-entrainment of dust from the dust pot. The re-entrainment depended upon high velocity jets of incoming hot gas blowing through the dust. These jets could also become plugged, shifting the air flow to a higher positioned or less obstructed jet and pathway which then rapidly shifted the dust from its vicinity to that of the plugged jet port or ports. In any event the dust loading delivered to the bag would vary and become either erratic or dramatically reduced. Failure to spot this occurrence introduced additional error into the data.

The fabrics themselves are quite different in what appears to be the steady-state value of pressure drop. The higher of the two curves in Figure 7 (the Dacron fabrics) is less than the lower of the two curves in Figure 6 (the cotton fabrics). Residual dust loading following the shake-cleaning was not measured directly. The weight of the dust loaded bags was determined at the end of the test period by removing them from the baghouse and weighing them. They were then vigorously hand-shaken and reweighed. Table 2 summarizes these measurements. The striking observation is the large difference in dust loading between the cotton bags and the Dacron bags. The weight of a cotton bag plus its dust load was at least twice that of the new cotton bag. The Dacron bags gained only a small additional load when weighed dirty. These differences, although observed and noted by Dennis and Wilder, were not as pronounced for them. Because absolute values of dust loading are not predictable from the Dennis/Wilder work and must be determined independently for each new system, a quantitative comparison cannot be made. In any event, the cement dust/cotton bag data of Table 2 yields a value of terminal dust loading of 0.10-0.13 lb/ft^2, a range not too different from that given by Dennis and Wilder for the flyash/cotton system (Figure 2). The terminal dust loading of the cement dust/Dacron system, on the other hand, is on the order of only 0.003-0.005 lb/ft^2. Dennis and Wilder do not give any terminal dust loading for the flyash/Dacron system but their published residual dust loadings are an order of magnitude lower for the flyash/Dacron than for the flyash/cotton system.

The "after run" data listed in Table 2 cannot be classified as either the W_T or W_R (see Figure 2) values of Dennis and Wilder. These "after run" weights are those of the bags after removal from the baghouse at the completion of the test runs. The runs ended at some arbitrary time during a cleaning cycle and hence are more likely to be nearer their W_R value than their W_T value. Little difference in weight is evident between the two Dacron runs except for the anomalous no-weight gain of 6031-3. The cotton bag cleaned at low "g" does have a significantly higher dust loading than those cleaned at high "g"--in agreement with the predictions of Dennis and Wilder, if one chooses to interpret the "after run" weights as a basis for calculating residual dust loadings.

TABLE 2. BAG WEIGHTS

Bag No.	Run No. (fabric)	New, gm	After Run (dust loaded) gm	After hand-shaking, gm
6034-2	37	164		
6034-3	(cotton)	165	396	196
6031-1	38	177	185	
6031-2	(Dacron)	177	185	
6031-3		177	177	
6031-4	39	177	184	
6031-5	(Dacron)	177	183	
6031-6		177	183	
6031-7		177	184	
6034-4	40	164	348	202
6034-5	(cotton)	165	348	203
6034-6		165	354	202

The physical properties of the fabrics making up the filter bags were measured before and after the shake-clean test runs. The properties, determined by the procedures described in Appendix A, were carried out on fabric samples cut from the bags by the School of Engineering and Textiles, North Carolina State University [Ref. 3]. Their results are summarized in Tables 3 (cotton) and 4 (Dacron). The used fabrics measured include one sample from each run so that the six fabrics evaluated consisted of:

1) an unused sample of both the cotton and the Dacron fabrics;
2) one sample of each used fabric (6034-2 and 6031-2), operated for over 700 hrs at maximum rated temperature but shake-cleaned at the relatively mild maximum acceleration of 1.9 g's; and
3) one sample of each used fabric, operated for only 450+ hrs at maximum rated temperature but shake-cleaned with a maximum acceleration on the order of 5 g's.

The total number of shakes on all used fabrics was approximately the same ($\gtrsim$ million shakes, Table 1).

The major differences between the new fabric and the used fabrics of the same type were:

1) the used fabric is heavier (presumably because of residual dust);
2) it is less permeable to air; and
3) it exhibits reduced tongue tear strength.

In addition to the above differences the used cotton fabrics showed dramatically reduced abrasion resistance; the used Dacron fabric did not.

The shake-clean cycles themselves produced some differences, the high "g" cleaning action invariably proving more detrimental:

1) the ravel strip tensile strength (No.3, Tables 3 and 4) of both the cotton and the Dacron was significantly lower for the fabric cleaned with the high "g" cycle; and

TABLE 3. FABRIC PROPERTIES OF COTTON BAGS [Ref. 3]

Property	Typical New		6034-2 (703 hr, 1.9 g)		6034-4 (460 hr, 4.6 g)	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Weight, oz/yd^2	9.86	---	10.3	---	10.6	---
Construction: *						
Filling, ppi	60.3	0.45	60.7	0.45	60.3	0.45
Warp, epi	95.4	0.55	98.7	0.55	97.2	1.10
Strength-Ravel Strip Tensile:						
Filling, lb	110.6	4.25	115.4	17.25	51.3	4.11
Warp, lb	91.6	25.74	92.9	21.74	46.6	3.14
Elongation-Ravel Strip Tensile:						
Filling, %	14.8	0.54	15.8	0.31	15.7	1.74
Warp, %	17.0	2.35	18.2	2.42	19.2	3.01
Strength-Tongue Tear:						
Filling, lb	12.8	0.41	6.67	0.66	5.74	0.02
Warp, lb	10.9	0.37	5.32	0.54	5.27	0.22
Within Specimen Variability-Tongue Tear:						
Filling, lb	---	1.53		0.65	---	0.69
Warp, lb	---	0.37		0.22	---	0.31
Strength-Ball Burst, lb:	186.0	14.07	198	22.8	201.8	5.63
Air Permeability, ft^3/min/ft^2:	12.5	0.37	7.16	0.515	7.35	1.60
Abrasion Resistance, cycles:	43,642 35,250**	---	3,654 3,141**	2,611	4,374 4,336**	811
Residual Dust, % of initial wt:			29.1		21.7	

*Picks per inch and ends per inch.
**Geometric average.

TABLE 4. FABRIC PROPERTIES OF DACRON BAGS [Ref. 3]

Property	Typical New		6031-2 (704 hr, 1.9 g)		6031-7 (488 hr, 5.1 g)	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Weight, oz/yd^2	10.1	---	10.98	---	11.1	---
Construction:*						
Filling, ppi	47.9	0.10	49.3	0.447	48.9	0.74
Warp, epi	74.4	0.55	74.6	0.548	74.8	0.45
Strength-Ravel Strip Tensile:						
Filling, lb	131.6	21.33	162.1	7.72	109.1	23.74
Warp, lb	305.1	23.82	231.9	33.08	237.5	10.61
Elongation-Ravel Strip Tensile:						
Filling, %	41.9	4.68	39.3	1.49	26.6	5.12
Warp, %	51.6	1.37	42.2	5.23	35.4	0.92
Strength-Tongue Tear:						
Filling, lb	21.1	2.44	12.6	0.55	10.7	0.54
Warp, lb	34.1	3.46	18.1	3.66	16.6	2.45
Within Specimen Variability-Tongue Tear:						
Filling, lb	---	1.21		0.52	---	0.28
Warp, lb	---	0.82		0.31	---	0.17
Strength-Ball Burst, lb:	438.2	20.87	403	11.0	285.2	40.92
Air Permeability, ft^3/min/ft^2:	29.44	5.48	17.6	2.32	12.32	1.76
Abrasion Resistance, cycles:	86,205 84,120**	21,854	70,688 64,420**	30,682	277,068 259,900**	100,299
Residual Dust, % of initial wt:			2.6		11.9	

*Picks per inch and ends per inch.
**Geometric average.

2) the elongation (No.4, Table 4) and the ball burst strength (No.7, Table 4) of the Dacron cleaned at high "g" were significantly lower than those of the Dacron cleaned at low "g" forces.

The abrasion resistance of the high "g" Dacron sample was anomalously high (No.9, Table 4) and may reflect a major physical change in the fabric surface, caused, perhaps, by heat generation during abrading. For whatever reason, the fabric surface of this sample became extremely smooth and polished during the abrasion test, the only sample of those tested to do so and, hence, the only sample to exhibit an increase in abrasion resistance [Ref. 3].

None of the bags was tested to failure and all appeared to be in good condition following the test cycle--at least to the eye. The physical properties of the fabric, however, do not rule out a correlation between shaker parameters and bag life. All fabric properties that deteriorated did so more rapidly when the "g" forces increased during the cleaning cycle. The samples that were operated at high temperature for a longer time, but at lower "g" cleaning conditions, retained more of their new fabric properties. The data justify only this qualitative statement, however.

REFERENCES

1. Dennis, R. and J. Wilder, "Fabric Filter Cleaning Studies," EPA-650/2-75-009, NITS No. PB 240372/AS, January 1975, GCA Technology Division.

2. Donovan, R. P., B. E. Daniel and J. H. Turner, "EPA Fabric Filtration Studies: 4. Bag Aging Effects," EPA-600/7-77-095a, NTIS No. PB 271966/AS, August 1977, EPA/Industrial Environmental Research Laboratory, Research Triangle Park.

3. Letter Reports, W. C. Stuckey, North Carolina State University, to J. H. Turner, EPA/Industrial Environmental Research Laboratory-Research Triangle Park, January to July 1973.

APPENDIX A

TEST PROCEDURES FOR FILTER BAG PROPERTIES [Ref. 3]

A. Weight Per Square Yard--(oz/sq yd)

1) Rip seams of bag to obtain rectangular piece.
2) Measure full length and full width of three separate pieces to nearest sixteenth of an inch. Determine average of each dimension.
3) Weigh full piece of fabric to nearest 0.1 gram.
4) Calculate weight in ounces per square yard.

B. Construction--Thread Count

1) Count warp yarns (ends) in a 3-inch length at five different places.
2) Count filling yarns (picks) in a 3-inch length at five different places.
3) Calculate average warp ends/inch and average filling picks/inch.

C. Tensile Strength and Elongation--Ravel Strip Method

1) Mark five 1-1/2 x 6 inch specimens on the fabric in both the warp and filling directions so that no two warp specimens contain the same warp yarns, nor any two filling specimens contain the same filling yarns. Mark the longer dimension of each specimen parallel to the yarn component to be tested for strength or elongation.
2) Cut all specimens from the base fabric and ravel equally on both sides from the 1-1/2 to a 1-inch dimension.
3) Break the specimens using the Instron tester with the following test conditions:
    a) "D" cell--200 lb Full Scale Load (FSL)
    b) Clamp surfaces--1-1/2 x 1-1/2 inches
    c) Gage length: 3 inches
    d) Crosshead speed: 0.6 inches/minute
    e) Chart speed: 3 inches/minute

4) For each specimen, record the breaking load in pounds and elongation in inches.

5) For both warp and filling yarn components, calculate average breaking load in pounds and average elongation in percent.

D. Tongue Tear Strength

1) Mark five 3 x 8 inch specimens in both the warp and filling directions. Mark the 3-inch dimension parallel to the yarn component to be tested for tear resistance. Mark so that no two specimens contain the same yarn component to be tested.

2) Cut all specimens from the base fabric. Cut into the 3-inch side of each specimen, 1-1/2 inches from each end (i.e., in the center of the 3-inches). Extend the cut into the body of the specimen 3-inches, to make two strips or tongues on the specimen.

3) Tear each specimen on the Instron, mounting one tongue in one clamp and the other tongue in a second. (The specimen tears when the two clamps are separated.)

4) Operate the Instron so that the clamps separate 3 inches greater than the initial gage, resulting in a 1-1/2 inch tear in the specimen. Use the following test conditions:

   a) "C" cell--20 lb FSL
   b) Clamp surfaces--1-1/2 x 3 inches
   c) Gage length: 3 inches
   d) Crosshead speed: 2 inches/minute
   e) Chart speed: 2 inches/minute

5) Determine tearing strength for each specimen by dividing the chart for the 1-1/2 inch tear into five equal sections and reading the highest peak in each section. The average of the five peaks is the tearing strength of that particular specimen.

6) Calculate average warp and filling tearing resistance.

E. <u>Ball Burst Strength</u>

1) Mark and cut from fabric five 4-inch diameter specimens so that no two specimens include the same warp and filling yarns.
2) Use Scott Model J pendulum tester with 300 pound capacity for burst tests.
3) Calculate and report average strength in pounds.

F. <u>Air Permeability</u>

1) Use Frazier instrument and make five tests by randomly positioning the fabric over the chamber opening. (No cutting of specimens is necessary.)
2) Use No. 4 nozzle (3 mm) or whatever is necessary, and adjust surface pressure on fabric to 0.5 inch on the inclined manometer for each determination prior to reading the vertical manometer.
3) Calculate average air flow in cu ft per sq ft of fabric per minute.

G. <u>Abrasion Resistance</u>

1) Cut five 3-3/4 inch diameter specimens so that no two specimens include the same warp and filling components.
2) Abrade until failure, using a Schiefer abrasion tester with a square cut tungsten abradent blade, a 5-lb head weight, and a 1-inch diameter sample pedestal.
3) Calculate and report geometric mean of number of cycles to failure.

APPENDIX B

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}
lb (force)	newton	4.45
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)	$newton/meter^2$	$2.49 \times 10^{+2}$
$lb/inch^2$ (psi)	$newton/meter^2$	$6.89 \times 10^{+3}$
$lb/foot^2$	$newton/meter^2$	$4.79 \times 10^{+1}$
foot/min (fpm)	meter/sec	5.08×10^{-2}
$foot^3$	$meter^3$	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^2	3.39×10^{-2}
$grains/ft^3$	kg/m^3	2.29×10^{-3}
$grains/1000\ ft^3$	g/m^3	2.29×10^{-3}
°F	°K	$°K = \frac{5}{9}(°F + 459.67)$

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7. AUTHOR(S) B.E. Daniel, R.P. Donovan (RTI), and J.H. Turner		8. PERFORMING ORGANIZATION REPORT NO.
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16. ABSTRACT The report gives results of a laboratory study to determine the influence of high temperature operation (operation in an air flow whose temperature has been adjusted to the maximum continuous operating temperature recommended by the manufacturer) on the selection of fabric filter shake-cleaning parameters. Two cotton and two Dacron bags were operated in a laboratory baghouse, using heated air passed through cement dust as the source of dirty air. The bags cleaned at high 'g' forces (about 5 g's) showed more deterioration in strength properties than those cleaned at 1.9 g's. The observations generally confirm the Dennis/Wilder analysis of mechanical cleaning and suggest that temperature is not a first order variable in the analysis of mechanical shake-cleaning. The cursory tests conducted here do not conclusively rule out temperature as an important parameter; they merely report that, in this limited investigation, it was not.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Air Pollution	Cleaning	Air Pollution Control	13B	13H
Filtration	High Temperature	Stationary Sources	07D	
Air Filters	Tests	Fabric Filtration	13K	14B
Fabrics	Cements	Bag Filters	11E	13C, 11B
Cotton Fabrics		Baghouses		
Polyester Fibers		Shake Cleaning		

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