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Environmental Protection Technology Series

EPA FABRIC FILTRATION STUDIES: 1. Performance of Non-woven Nylon Filter Bags

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: 1. PERFORMANCE OF NON-WOVEN NYLON FILTER BAGS

by

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PREFACE

This report is the first 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 four years by the Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina, 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 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 varied from about 20 to 40 percent for most of the testing.
4) The air to cloth ratio varied between 4.3 and 8.7 fpm*.
5) The dust loading varied between 1.5 and 3 grains/ft^3.
6) The test cycle consisted of a constant 20 minute feed, 1 minute delay, 2 minute shake cleaning, and 1 minute delay, regardless of the pressure drop across the bag.

*EPA policy is to use SI units only or to list both the common British unit and its metric equivalent. For convenience and clarity, non-metric units are used in this report. Readers more familiar with metric terms 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 contain:

1) Performance of Non-Woven Nylon Filter Bags (this report).
2) Performance of Non-Woven Polyester Filter Bags.
3) Performance of Expanded PTFE Laminate Filter Bags.
4) Aging Effects.
5) Bag Cleaning Technology.
6) Analysis of Particle Size Efficiency.

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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

F = fallout fraction (dust which goes directly to baghouse hopper without contacting bag)

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 filtration cycle (extrapolated from straight line portion of pressure drop trace) (in. H_2O)

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

Q = flow rate through filter, cfm

q_s = flow rate through sampling system, cfm

R = average dust feed rate, grams/min

S_E = effective drag, in. H_2O/fpm

S_T = terminal drag, in. H_2O/fpm

T = filtration time, min

V = filtration rate, fpm (air/cloth ratio)

W_D = mass of dust collected in sampling system, grams

ACKNOWLEDGMENTS

The Monsanto Company, St. Louis, Missouri donated all the spun-bonded polyester bags used in this study. They manufactured the fabric and assumed all costs of sewing and preparing the bags to fit the EPA test facility. Ralph DeBrunner of Monsanto supplied technical advice in regard to the fabric.

SECTION 1

INTRODUCTION

Fabric filtration is one of the major accepted methods of removing particulates from industrial effluent streams. Performance of fabric filters (or baghouses) is dependent on properties of the gas stream to be filtered, properties of the fabric used for the bags, and the modes of operation used for filtration and for bag cleaning. Important performance requirements are that the baghouse operate at the required efficiency, that pressure drop be kept as low as practicable, and that bag endurance be as great as possible. Efficiency is dictated by the job to be done, but pressure drop and bag endurance (within limits) are more in the nature of cost considerations.

Efficiency is often not a problem. Baghouses are inherently high-efficiency devices, as long as the fabric used is tight enough either to permit a good dust cake buildup on woven fabrics, or to prevent dust particles from blowing straight through non-woven fabrics. The formula used for calculating efficiency is:

$$E = 100\left[1 - \frac{(W_D)(Q)}{(R - FR)(T)(q_s)}\right]. \qquad (1)$$

Since efficiencies of bag filters are often greater than 99.9 percent, it becomes a little inappropriate to talk of efficiency. An alternative is to use outlet concentration:

$$C_o = \frac{(15.43\ \text{grains/gram})\ (W_D)\ (1000)}{(T)\ (q_s)}. \qquad (2)$$

Pressure drop through a bag filter increases as the dust load builds up on the fabric. For a given dust-fabric system at specific filtration conditions, a measure of pressure drop at the end of a cleaning cycle (or just prior to the filtration cycle) is given by the filter effective drags:

$$S_E = \Delta P_E / V. \tag{3}$$

The drag can also be measured at the end of the filtration cycle (just prior to cleaning) as:

$$S_T = \Delta P_T / V. \tag{4}$$

The increase in pressure drop as the filtration cycle progresses depends on the dust-fabric combination and the filtration conditions used. Because the dust cake or dust mass will build up in a characteristic fashion, a constant can be found for the system:

$$K = \left[\frac{(\Delta P_T - \Delta P_E)(A)^2 (7000 \text{ grains/lb})}{(Q)(T)(1-F)(R)(15.43 \text{ grains/gm})} \right] . \tag{5}$$

K applies only to the region in which pressure drop increases linearly with time. There is an initial "cake repair" period for each filtration cycle during which pressure drop builds at a decreasing rate. Although it was originally thought that K was a characteristic constant for any given dust, it is now realized that K is influenced by fabric construction and filtration conditions [Ref. 1]. Flow and pressure drop through fabric filters are discussed in the Handbook of Fabric Filter Technology [Ref. 2].

Bag endurance for a given fabric depends upon its resistance to the filtering environment and on the wear imposed by cleaning the fabric. Mechanical shake cleaning is usually used with woven fabrics; for pulsed-jet cleaning, a heavier felted material is preferred. A thorough discussion of cleaning and its effects on bag endurance is given in the Fabric Filter Cleaning Studies [Ref. 3].

A new type of fabric is now being investigated for use as a filter material. The fabric is non-woven, thinner than felted fabrics, and is formed by laying a web of filamentous material in a continuous set of processing steps which combine fiber formation, web formation, bonding, and fabric windup. The resulting "spunbonded" fabric can be made from such starting materials as polyamides, polyesters, or olefins. Spunbondeds are tough, strong, available in numerous weights, and much cheaper than woven fabrics of equivalent weight. Strength derives from the use of continuous filaments which are bonded at points of contact. The fabrics, if not given further treatment, are relatively stiff and parchment-like.

Figure 1 is a magnified view of some of the fabric used for the present work. This fabric is a spunbonded nylon 66, contains no binders, and is manufactured by Monsanto Company under the trade name Cerex®. It is the purpose of this work to investigate the performance of filter bags made of spunbonded nylon.

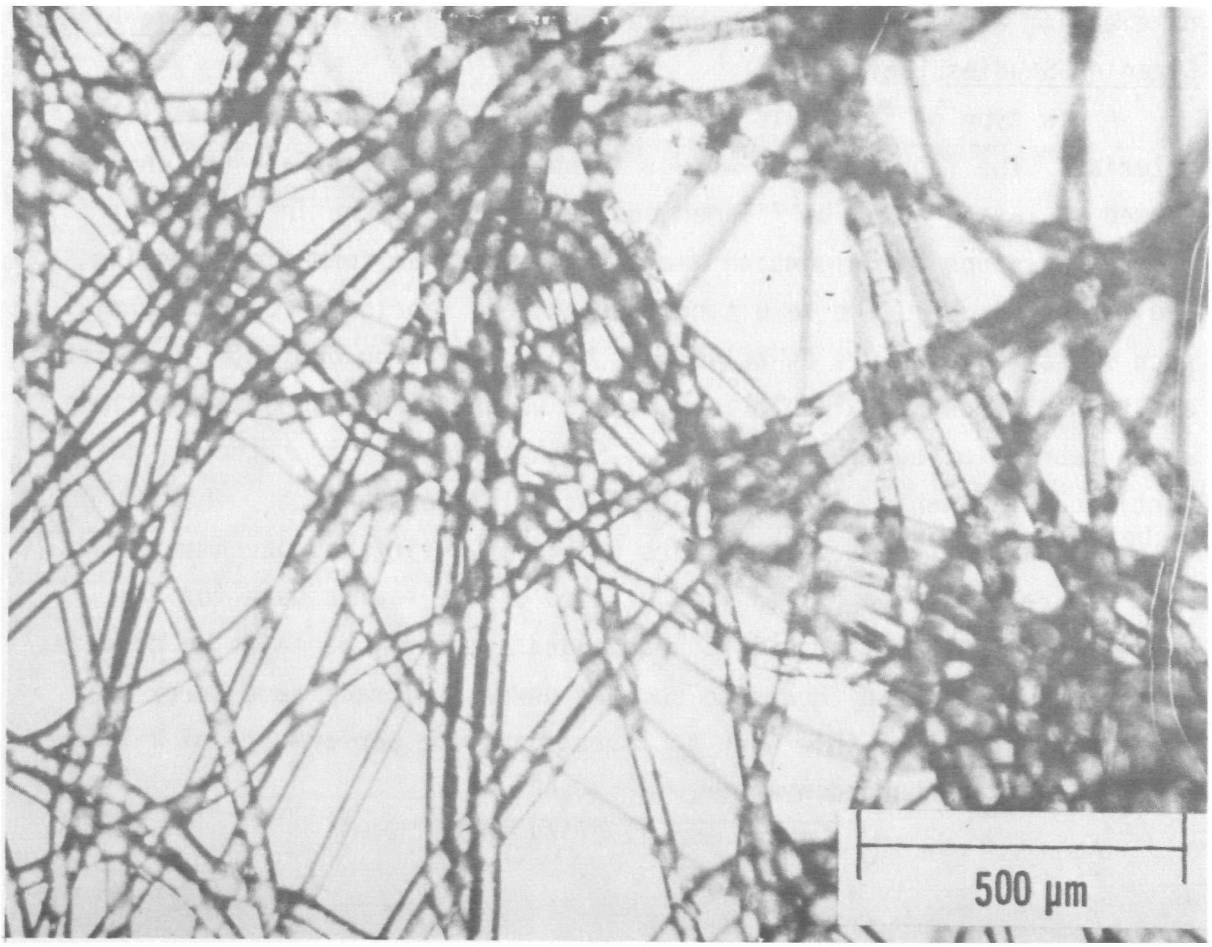

Figure 1. Cerex fabric photomicrograph. Fabric weight of 0.61 oz/yd^2.

SECTION 2

CONCLUSIONS

The following conclusions are based on a limited amount of data over a relatively narrow range of conditions:

1) On the basis of fabric weight, spunbonded nylons have higher efficiency, lower outlet concentration, lower specific cake resistance, and approximately equal effective drag when compared with woven nylon.
2) The heaviest bag tested (5.9 oz/sq yd) will withstand shake cleaning in excess of 8 million shakes. A lighter bag (2.9 oz/sq yd) will withstand in excess of 40 million shakes.
3) Assuming endurance is sufficiently good, spunbonded nylon filter bags would provide lower cost filtration when compared to woven nylon bags.

SECTION 3

EXPERIMENTAL METHODS

The test unit was a single-bag baghouse with dimensions as shown in Figure 2. The bags, approximately 3.5 in. in diameter by 62 in. long, had a total filter area of 4.6 sq ft. Inlet air of known humidity, temperature, dust loading, and quantity was admitted to the top of the bag, filtered, and passed out of the system. Pressure and flow were measured and continuously recorded, using 0-10 in. H_2O differential pressure cells: one was connected across the baghouse; another, across a flow venturi. Humidity was measured with wet and dry bulb thermometers; inlet dust feed rate was measured by weighing the dust feeder discharge over a known time interval. Efficiency and outlet concentration were measured by passing a known fraction of the baghouse effluent through a 0.45 μm millipore filter and weighing the accumulated dust. Sample flow rates were adjusted to give isokinetic flow. The dust used was flyash taken from utility boiler dust collection equipment and sized to eliminate large particles. Coulter analysis gave a mean particle diameter of 5.5 μm, with 10 percent less than 2.5 μm and 90 percent less than 12 μm.

For each bag tested there was an equilibrium period of 24 hours, after which performance was measured over three consecutive filtration-cleaning cycles. The standard cycle was 20 minutes of filtration followed by 1 minute of delay, 2 minutes of shake cleaning, and 1 more minute of delay. Shake conditions included an amplitude of 0.81 in. (stroke of 1.62 in.) and a frequency of 240 cycles per min. Fabric properties and filtration conditions are listed in Tables 1 and 2, respectively.

In addition to performance testing, two bags were put on an endurance cycle of 2 minutes feed and 15 minutes shake with 1 minute delay periods.

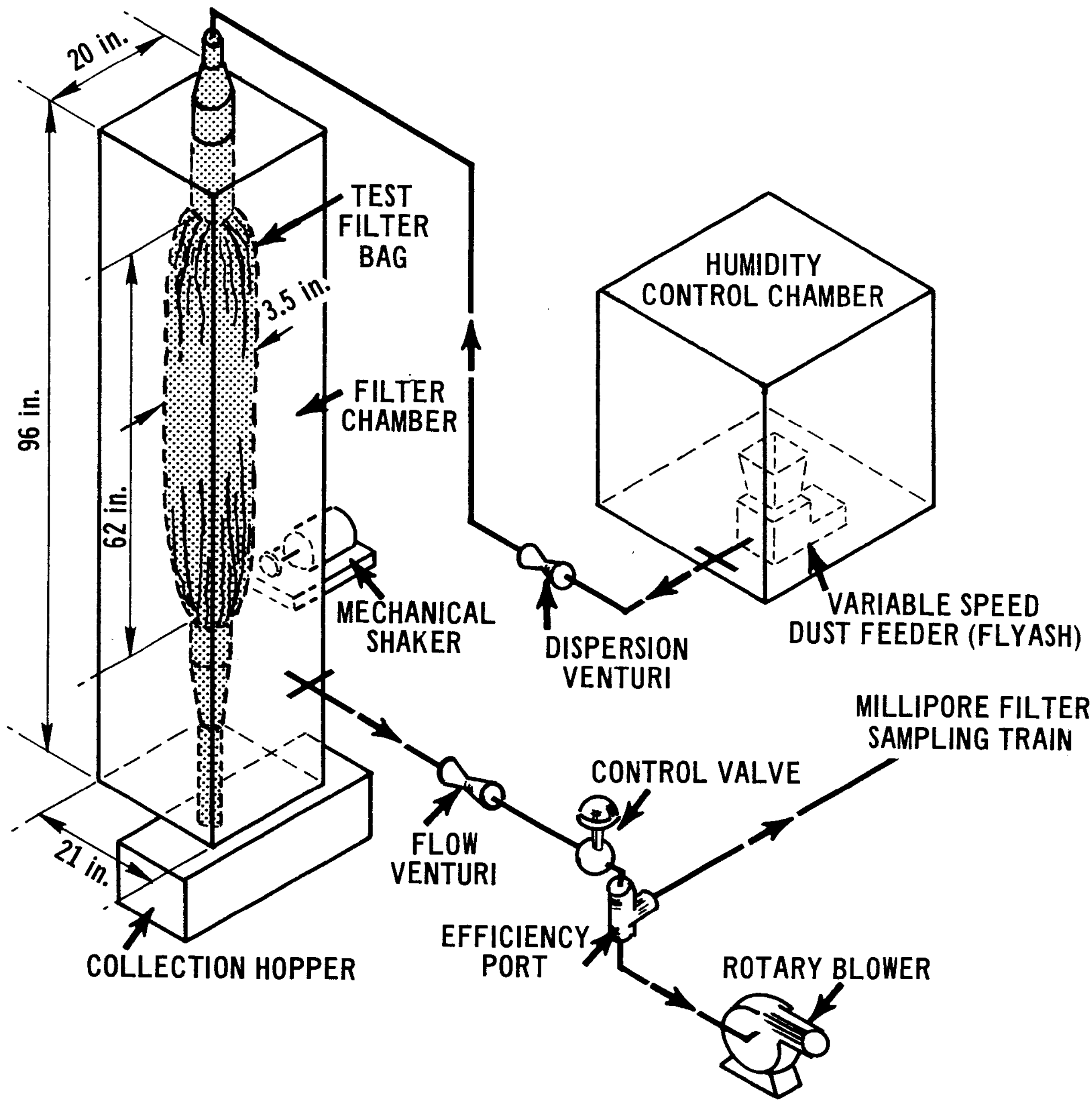

Figure 2. Test equipment used for evaluation of spunbonded nylons as fabric filter media.

TABLE 1. PROPERTIES OF SPUNBONDED NYLONS USED FOR EVALUATION AS FABRIC FILTER MEDIA[a]

Style	Nominal Fabric Weight (oz/sq yd)	Actual Fabric Weight[b] (oz/sq yd)	Thickness[c] (in.)	Air Permeability[d] (cu ft/min/sq ft)
5706-11	0.60	0.613	0.0035	791.0
578F-11	0.85	1.010	0.0043	614.0
5715-11	1.50	1.522	0.0067	383.0
5730-2F	3.00	2.862	0.0122	99.2
5740-2F	4.00	4.161	0.0157	65.6
4050-2F	6.00	5.870	0.0197	45.1

[a]Approximately 2 sq yd furnished for tests.

[b]ASTM D 1910-64

[c]ASTM D 1777-64

[d]ASTM D 737-69

TABLE 2. FILTRATION CONDITIONS USED FOR EVALUATION OF SPUNBONDED NYLONS AS FABRIC FILTER MEDIA

Condition	Air to Cloth Ratio (fpm)		
	4.3	6.3	8.7
Grain loading (grains/cu ft)	3.0	2.0	1.5
Relative humidity (percent)	---	20 to 40	---
Temperature (°F)	---	75 to 80	---

SECTION 4

RESULTS

Results will be discussed by performance parameters and the endurance test. Comparisons are made with the 4.1 oz/sq yd woven nylon fabric tested and reported previously [Ref. 4]. The woven nylon was a continuous-filament 2 x 2 twill with a 74 x 68 count.

4.1 EFFICIENCY AND OUTLET CONCENTRATION

Figures 3 and 4 dramatically show the effect of fabric weight on collection efficiency. There is apparently a threshold fabric weight for the test dust above which collection efficiency is good and below which it is not. Figures 5 through 8 show the progressive reduction in open pores available for passing dust as fabric weight increases. The 2.9 oz/sq fabric has very few open pores; the lighter fabrics have obvious openings through which dust can pass (the pores are too large for the dust to bridge). Outlet concentration is low for the 2.9 oz/sq yd and heavier fabrics, but much higher for the lighter open fabrics. Concentration was so high for the two lightest fabrics (0.61 and 1.0 oz/sq yd) that testing was discontinued. For the same weight of fabric, the non-woven fabric appears to be much more effective at trapping flyash particles.

4.2 SPECIFIC CAKE RESISTANCE

Figure 9 gives further evidence that fabric characteristics influence the manner in which a dust mass builds up on the filter. As fabric weight increases, so does specific cake resistance. For the same weight fabric, spunbonded nylon has a resistance of about 60 percent of the woven nylon.

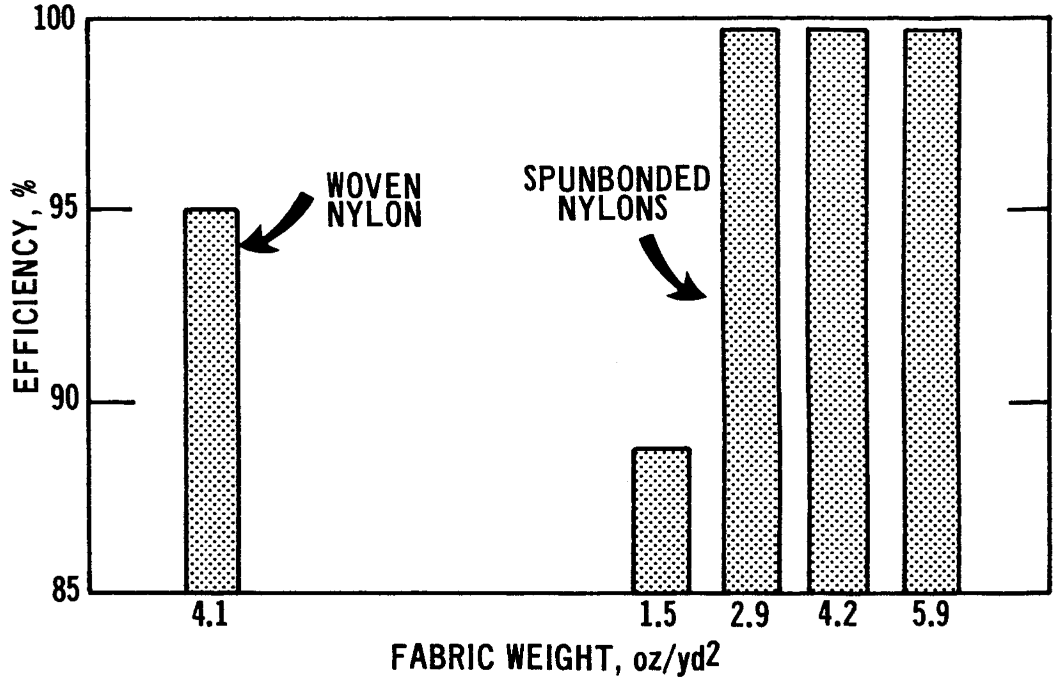

Figure 3. Dust mass collection efficiency of spunbonded nylons.

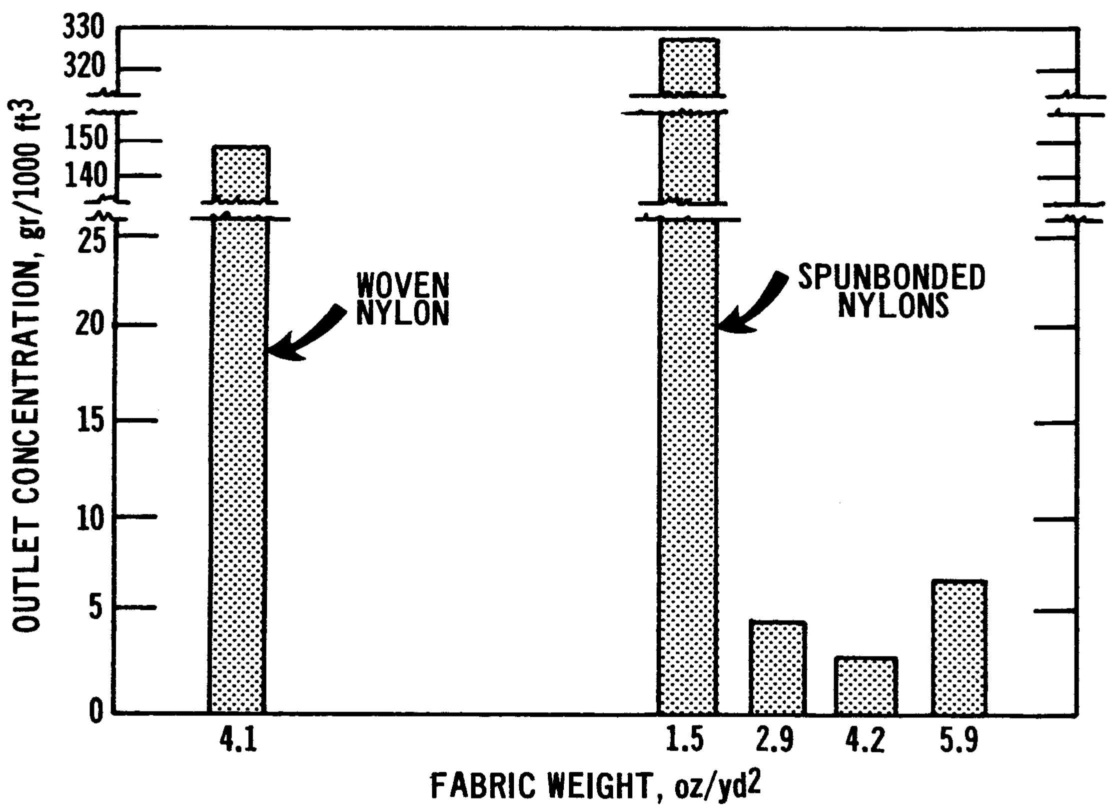

Figure 4. Outlet concentration for spunbonded nylons.

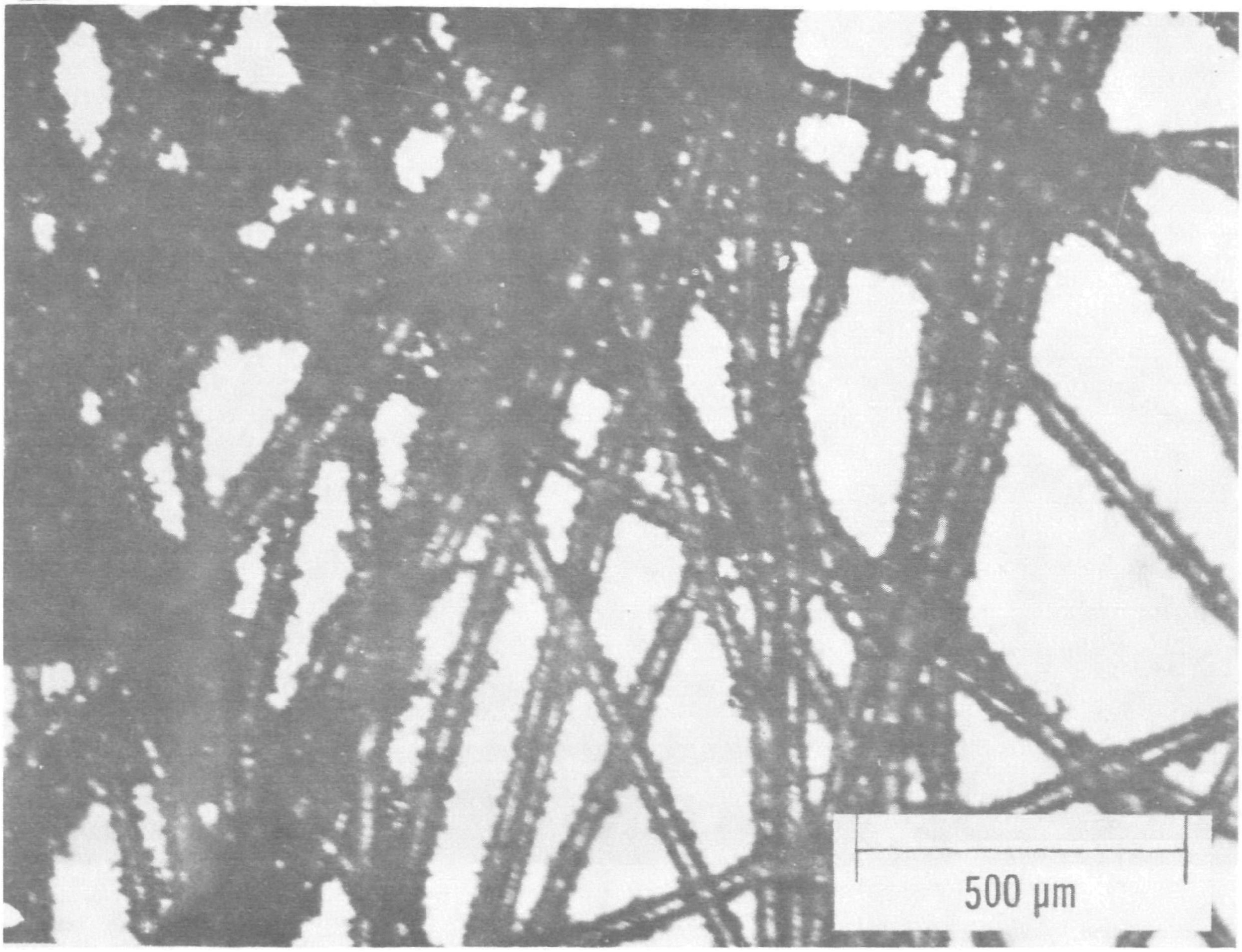

Figure 5. Photomicrograph of spunbonded nylon after filtration and cleaning, 0.61 oz/yd^2.

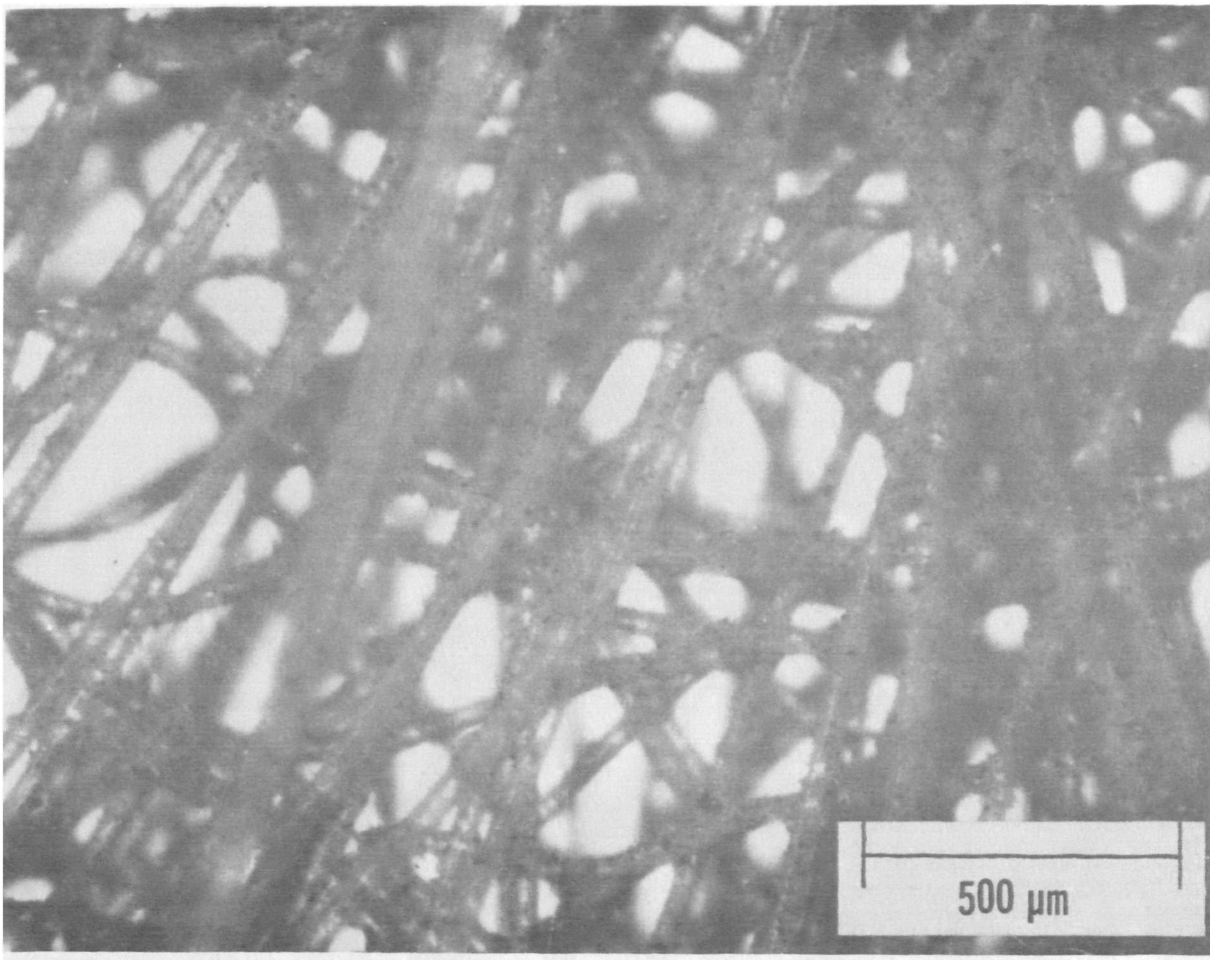

Figure 6. Photomicrograph of spunbonded nylon after filtration and cleaning, 1.5 oz/yd^2.

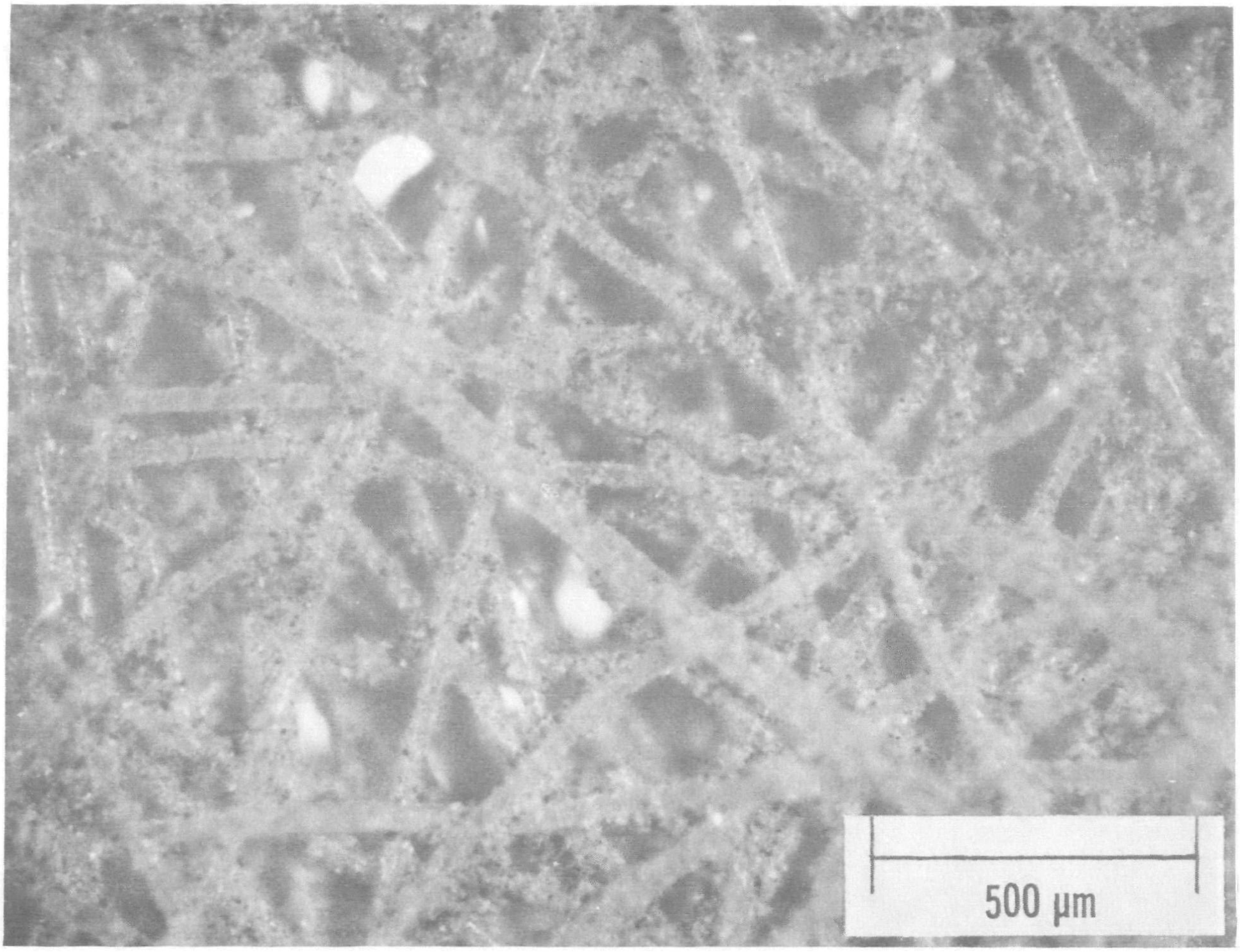

Figure 7. Photomicrograph of spunbonded nylon after filtration and cleaning, 2.9 oz/yd^2.

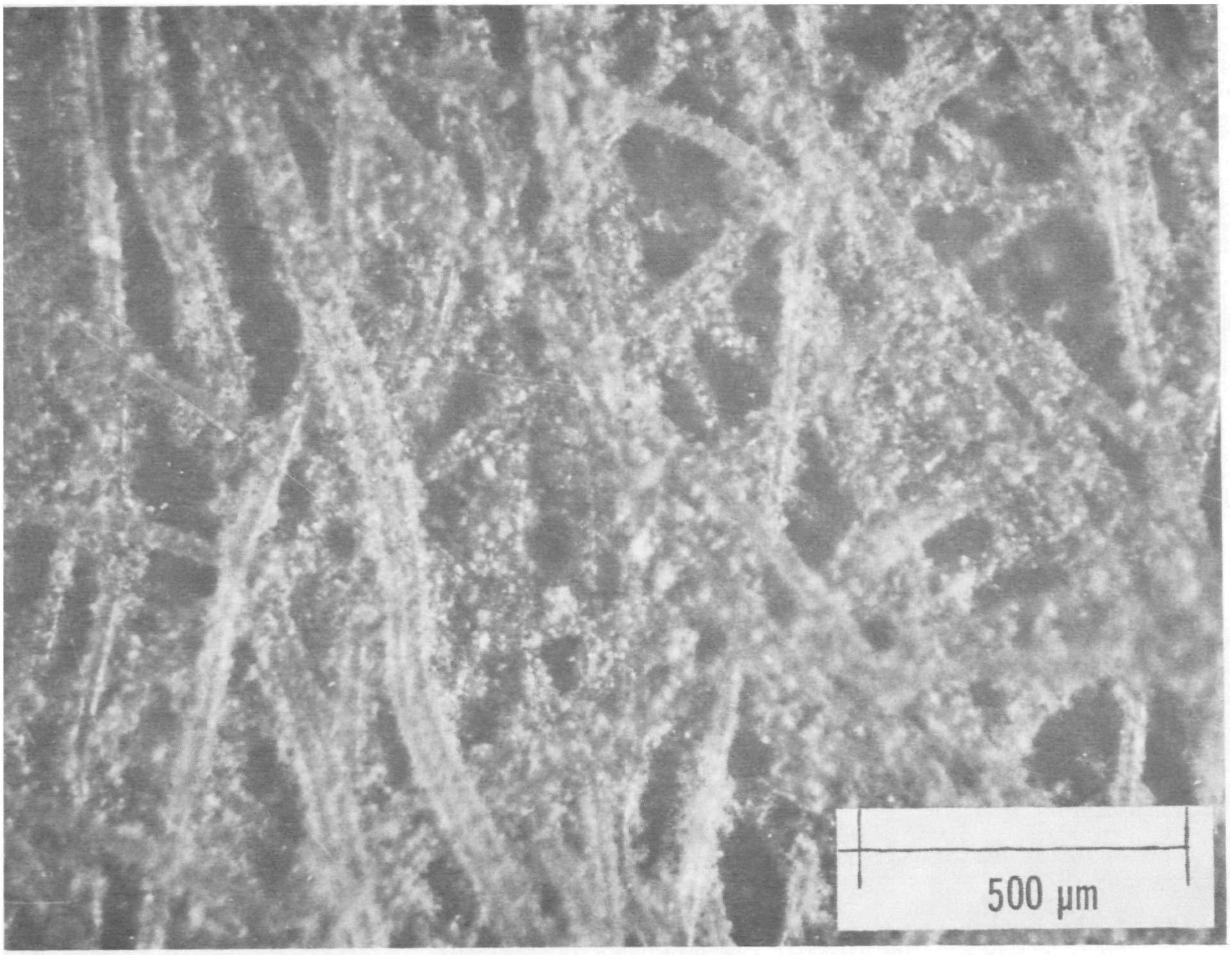

Figure 8. Photomicrograph of spunbonded nylon after filtration and cleaning, 5.9 oz/yd^2.

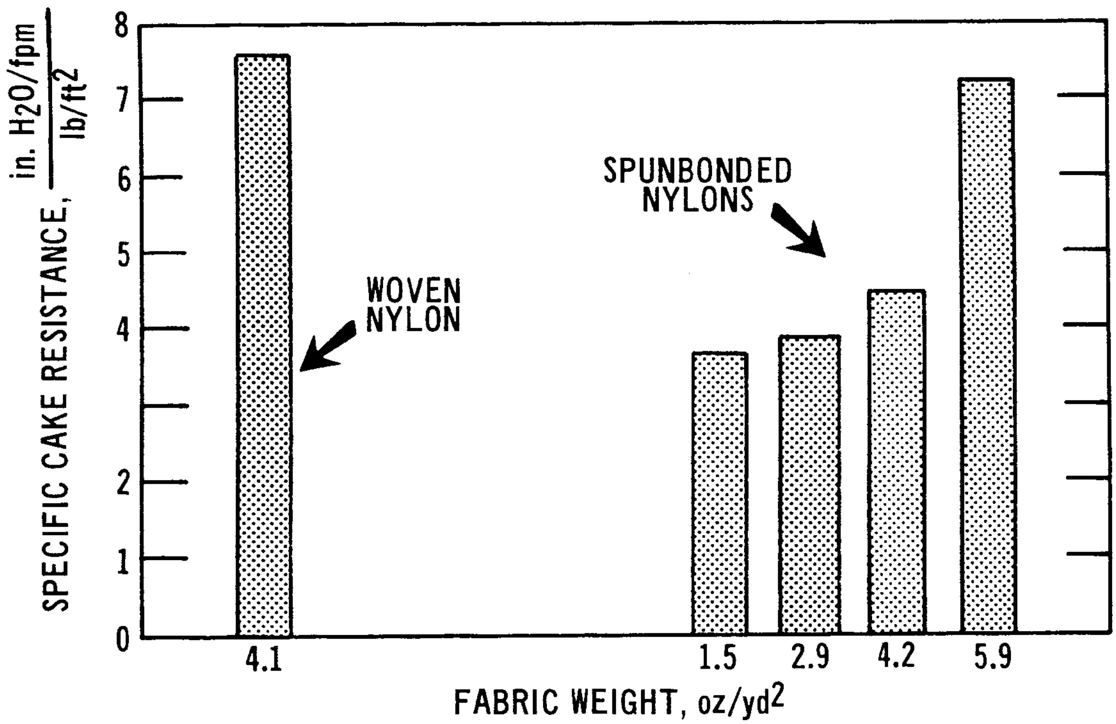

Figure 9. Specific cake resistance of flyash on spunbonded nylons.

4.3 EFFECTIVE DRAG

Effective drag of the spunbonded nylons also increases with fabric weight, as shown in Figure 10. This effect is expected as fabric thickness and air permeability also increase with fabric weight. The woven nylon has an effective drag about 80 percent of the spunbonded nylon. This lower drag of the woven fabric would be offset by the lower K shown for the spunbonded material. For the particular operating cycle used in this work, the terminal drag results had higher numerical values, but closely paralleled the effective drag results. The spunbonded fabrics had slightly lower terminal drag (4.2 percent) than the woven nylon.

4.4 ENDURANCE

The bag tested for endurance was periodically run for several cycles at the 20 minute filtration, 2 minute shake conditions in order to measure outlet concentration. Equipment repair was required at approximately 3.3 million shakes. Inspection showed a crack or fissure about 2 in. long on the bag surface, presumably at a point where the bag had been folded or creased in handling (the stiff nature of the material makes it difficult not to get such folds and creases). Further handling may have enlarged the crack, although there was no clear open space between the edges of the crack. Figure 11 shows changes in outlet concentration with number of shakes. Up to the point of equipment failure the outlet concentration decreased; however, Table 3 shows there was no significant change in terminal drag (or terminal pressure drop). Effective drag increased, but there was a compensating decrease in specific cake resistance.

After the equipment failure and subsequent bag handling, outlet concentration immediately increased, but then started decreasing again. The implication is that cracks in spunbonded bags tend to be "repaired" with continued usage. After 8.2 million shakes the bag failed. A second bag (2.9 oz/sq yd) failed at 40.5 million shakes with average outlet concentration of about 30 grains/1000 cu ft.

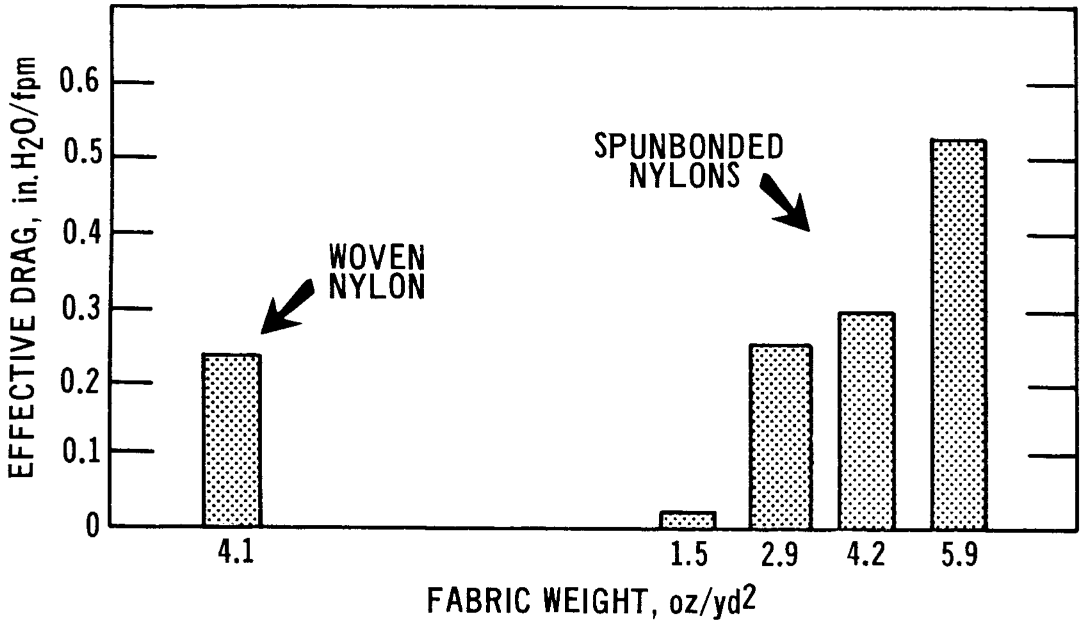

Figure 10. Effective drag of spunbonded nylons.

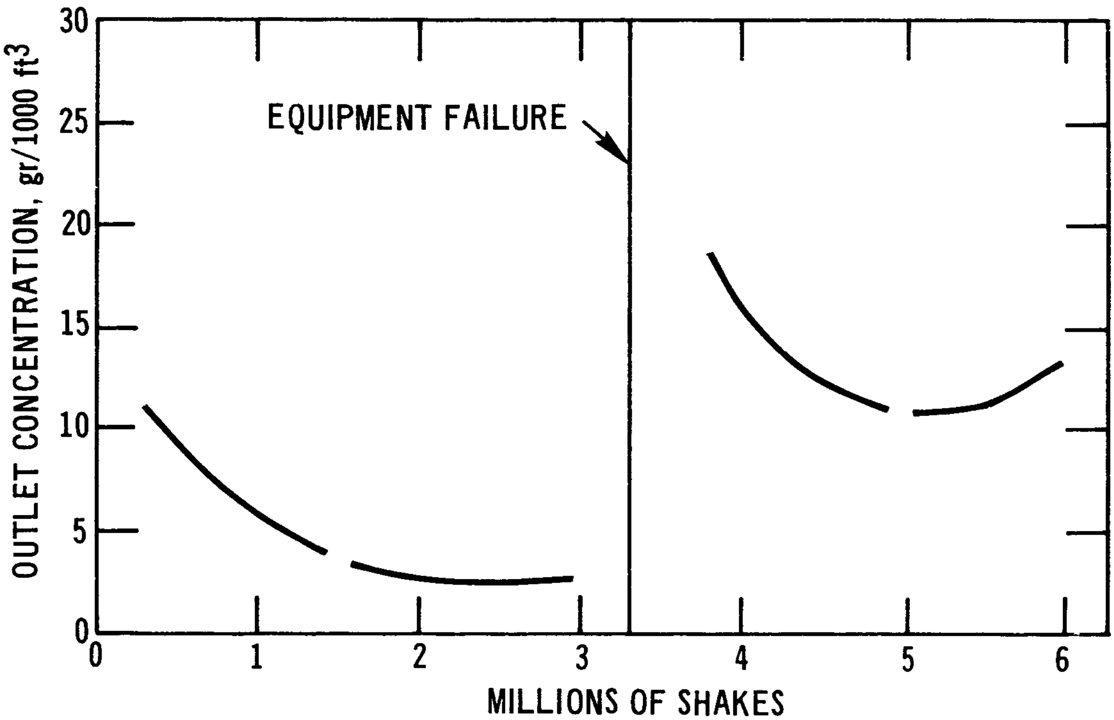

Figure 11. Outlet concentration versus number of shakes for 5.9 oz/yd^2 spunbonded nylon.

TABLE 3. PERFORMANCE OF SPUNBONDED NYLON[a] FILTER MEDIUM WITH NUMBER OF SHAKES

Characteristic	Number of Shakes (millions)					
	0.27	1.55	3.06	3.92[b]	4.97	6.05
Efficiency, %	99.63	99.84	99.91	99.37	99.64	99.54
Outlet Concentration (C_o), grains/1000 cu ft	11.30	4.50	2.80	19.00	10.80	13.50
Specific Cake Resistance (K), (in. H_2O/fpm)/(lb/sq ft)	7.70	5.20	4.80	7.90	6.90	8.00
Effective Drag (S_E), in. H_2O/fpm	0.51	0.54	0.65	0.75	0.80	0.79
Terminal Drag (S_T), in. H_2O/fpm	0.80	0.73	0.83	1.04	1.05	1.08
Terminal Pressure Drop (ΔP_T), in. H_2O	3.45	3.13	3.55	4.48	4.50	4.64

[a]Fabric weight = 5.780 oz/sq yd

[b]After equipment failure

4.5 HUMIDITY

All of the reported performance figures were collected for air at 20 to 40 percent relative humidity. It has previously been found that humidity affects flyash collection on nylon [Ref. 4], so attempts were made to correlate performance with humidity over the range of 10 to 60 percent. Results were inconclusive from the work that was done, but the ranges of values found for a 2.8 oz/sq yd bag were:

Efficiency:	99.34 - 99.87	percent
C_0:	4.7 - 19.7	grains/1000 cu ft
K:	3.5 - 4.6	(in. H_2O/fpm)/(lb/sq ft)
S_E:	0.29 - 0.52	in. H_2O/fpm

4.6 COSTS

Cerex is much cheaper than woven nylon. As of February 1973, the price of 4 oz/sq yd Cerex was $0.46/sq yd. One supplier quoted a quantity price of $1.60/sq yd for a heat-set, continuous-filament woven nylon, 3.93 oz/sq yd, approximately 74 x 68 count. Sewing costs for small lots of bags 5.5 in. in diameter by 71 in. long were quoted by one bag fabricator as $1.95 for woven nylon and $2.00 for the spunbonded nylon. For bags of this size, Cerex bags would cost about 70 percent of that of woven bags.

Further cost reduction with spunbonded bags is possible. Instead of being sewn, bags may be seamed ultrasonically or by various thermal techniques. Equipment is presently in use and commercially available for performing such operations.

4.7 INCREASED VELOCITY

In addition to testing at a filter velocity of 4.3 fpm, some testing was done at 6.3 and 8.7 fpm, but with constant dust feed rate (decreased grain loading). Table 4 shows the performance results. At the highest velocity, the lighter fabrics showed lower efficiency and higher outlet concentration than for the lowest velocity. This result may imply the formation of a more open cake allowing more seepage; however, values of the specific cake resistance and effective drag showed just the opposite effect. Presumably aerodynamic forces at the higher velocity were great enough to push more particles through the dust-fabric combination. For the heaviest fabric, the results were different: efficiency was nearly the same as for the 4.3 fpm, outlet concentration was lower, cake resistance increased by nearly 3 units, but effective drag decreased and terminal drag changed only marginally.

4.8 BAGHOUSE OPERATION

The stiff nature and resulting ease of creasing or cracking of the heavier weights of Cerex has been noted. Not enough experience has been gained during the present series of tests to tell if there would be any problems in industrial usage. The apparent cost and performance advantages of the fabric certainly warrant more testing in larger scale installations. On a fabric weight basis the spunbonded nylon has higher efficiency, lower outlet concentration, lower specific cake resistance, lower cost, and approximately equal pressure drop characteristics when compared with woven nylon. Endurance in the laboratory has extended to more than 6 million shakes without catastrophic failure.

TABLE 4. PERFORMANCE OF SPUNBONDED NYLON FILTER MEDIA AT THREE LEVELS OF FILTRATION VELOCITY

Characteristic	Fabric weight (oz/sq yd)			
	1.5	2.9	4.2	5.9
Efficiency, %				
*A/C = 4.3	88.68	99.84	99.90	99.79
A/C = 6.3	90.19	98.97	98.90	99.40
A/C = 8.7	86.09	99.31	99.40	99.75
Outlet Concentration (C_o), grains/1000 cu ft				
A/C = 4.3	328	4.7	3.1	7.0
A/C = 6.3	212	21.1	22.7	13.6
A/C = 8.7	201	10.0	9.4	3.7
Specific Cake Resistance (K), (in. H_2O/fpm)/(lb/ sq ft)				
A/C = 4.3	3.7	3.9	4.5	7.2
A/C = 6.3	1.5	6.4	4.3	4.7
A/C = 8.7	0.9	8.2	6.9	10.2
Effective Drag (S_E), in. H_2O/fpm				
A/C = 4.3	0.02	0.25	0.29	0.52
A/C = 6.3	0.04	0.42	0.34	0.42
A/C = 8.7	0.02	0.31	0.36	0.48
Terminal Drag (S_T), in. H_2O/fpm				
A/C = 4.3	0.15	0.44	0.46	0.79
A/C = 6.3	0.10	0.58	0.50	0.61
A/C = 8.7	0.05	0.61	0.63	0.85
Terminal Differential Pressure (ΔP_T), in. H_2O				
A/C = 4.3	0.66	1.91	1.99	3.43
A/C = 6.3	0.62	3.63	3.07	3.85
A/C = 8.7	0.47	5.30	5.39	7.38

*A/C = air to cloth ratio, fpm.

SECTION 5

LIMITATIONS

This work was done with only one test dust (redispersed flyash) and no variations were made in feed rate, cleaning conditions, or (with the exception of endurance testing) operating cycle. Lack of familiarity with the fabric undoubtedly caused operation at less than optimum conditions. Humidity control was imperfect and probably affected the results. Inaccuracies in flow rate measurement, used for all performance calculations, probably amounted to as much as 5 percent.

SECTION 6

REFERENCES

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4. Durham, J. F. and R. E. Harrington, "Influence of Relative Humidity on Filtration Resistance and Efficiency of Fabric Dust Filters," Filtration and Separation 8, July/August 1971, pp. 389-393.

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	4.45
foot	meter	3.05×10^{-1}
inch	meter	2.54×10^{-2}
mil	meter	2.54×10^{-5}
yard	meter	9.144×10^{-1}
grain	kilogram	6.48×10^{-5}
lb (mass)	kilogram	4.54×10^{-1}
oz (mass)	kilogram	2.83×10^{-2}
inch of water (60°F)	$newton/meter^2$	$2.49 \times 10^{+2}$
lb $(force)/inch^2$ (psi)	$newton/meter^2$	$6.89 \times 10^{+3}$
lb $(force)/foot^2$	$newton/meter^2$	$4.79 \times 10^{+1}$
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^2	3.39×10^{-2}
lb $(mass)/foot^2$	kg/m^2	4.88
in. H_2O/fpm	$\frac{newton\text{-}sec}{meter^3}$	4.90×10^4
$\frac{in.\ H_2O/fpm}{lb(m)/ft^2}$	$\frac{newton\text{-}sec}{meter\text{-}kg}$ (=1/sec)	10^4

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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

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16. ABSTRACT The report gives results of testing bags made of spunbonded nylon 66 in single-bag baghouses at flyash grain loadings of 1.5-3.0 grains/cu ft, at air-to-cloth ratios of 4.3-8.7 fpm, and at relative humidities of 20-40%. Results showed increased filtration efficiency with increased fabric weight. Compared to woven nylon of the same weight (4 oz/sq yd), spunbonded nylon was more efficient (99.89 vs. 95.02%), produced lower specific cake resistance (4.5 vs. 7.6 (in. H2O/fpm)/(lb/sq ft)), and had slightly higher effective drag (0.29 vs. 0.23 in. H2O/fpm). Endurance for a 2.9 oz/sq yd bag was over 40 million shakes. Spunbonded bag costs were estimated to be 70% of woven bag costs. Conclusions based on limited testing were that spunbonded nylon bags have higher efficiency, lower outlet concentration, lower specific cake resistance, and approximately equal effective drag when compared with woven nylon of the same weight. The heaviest bag tested will withstand shake-cleaning in excess of 8 million shakes. Assuming endurance is sufficiently good, spunbonded nylon filter bags would provide lower cost filtration when compared to woven nylon bags.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Air Pollution Control	13B
Filtration	Stationary Sources	11D
Dust Filters	Particulate	13K
Nylon 66	Baghouses	11E
Non-woven fabrics	Fabric Filters	
Dust	Spunbonded Fabrics	11G
Fly Ash	Collection Efficiency	21B

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