NATIONAL BUREAU OF STANDARDS REPORT

6908

PERFORMANCE CHARACTERISTICS OF SOME VISCOUS-IMPINGEMENT AND THROW-AWAY TYPES OF AIR FILTERS

by

Carl W. Coblentz and Paul R. Achenbach

Report to

Office of the Chief of Engineers
Bureau of Yards and Docks
Headquarters, U. S. Air Force
Washington 25, D. C.

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Performance Characteristics of Some Viscous-Impingement and Throw-away Types of Air Filters

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1. Introduction

The performance of a group of panel air filters of the cleanable viscous-impingement and throw-away types of 1- and 2-inch nominal thickness was determined to provide information for preparation of new specifications for air filters, to assist in the proper application of these devices, and to permit an economic comparison of cleanable and disposable types of equipment. This investigation was carried out as a part of the Tri-Service research and development program at the National Bureau of Standards.

The performance of the individual filters with respect to arrestance, pressure drop, dust-holding capacity, and cleanability has been described previously in separate reports. This report summarizes and compares the data obtained on 16 viscous-impingement type and 6 throw-away type filters.

2. Description of Test Specimens

The test specimens were designated as types A through L and marked with the suffix 1 or 2 to indicate their nominal thickness in inches. The actual thickness of the nominal 1-inch filters ranged from 7/8 inch to 1 inch, whereas that for the nominal 2-inch filters ranged from 1 13/16 inches to 2 inches. The cleanable viscous-impingement filters were manufactured and furnished by 6 different manufacturers and the throw-away filters were manufactured and furnished by 4 different manufacturers.

The eight types of cleanable viscous-impingement filters were made of corrosion-resisting material, either aluminum or galvanized steel, with the frames and filter media always composed of the same metal. The steel filters had media made of wire whereas the aluminum filters used layers of perforated sheets. The four types of throw-away filters had glass fiber media and cardboard frames.

The adhesives used on the cleanable filters were furnished by the respective manufacturers and were soluble in water. The throw-away type filters were furnished with an adhesive, believed to be Tricresyl phosphate.

3. Test Method and Procedure

All of the cleanable filters and a part of the throw-away filters were tested at both 360 ft/min and 540 ft/min face velocity. The air flow rates were determined as the product of the net face area and the face velocity. Since all filters tested had a nominal size of 20 x 20 inches, the actual air flow rates corresponding to the two values of face velocity were all close to 800 cfm and 1200 cfm, respectively.

The cleanable type filters were immersed in the adhesive furnished by the manufacturer and left to dry in the laboratory at least 16 hours before being weighed and installed in the test apparatus. The initial pressure drop of each filter was determined for both face velocities after which the arrestance of the clean filter at the air velocity desired for that test was determined with the NBS "Dust Spot Method" as described in the paper, "A Test Method for Air Filters" by R. S. Dill (ASHVE Transactions, Vol. 44, p. 379, 1938).

The arrestance determinations were made with laboratory air into which Cottrell precipitate had been injected and diffused at a ratio of 1 gram per 1000 cu ft of air. The sampling air was drawn from the center points of the test duct one foot upstream and eight feet downstream of the filter at equal flow rates and passed through known areas of Whatman No. 41 filter paper. The change of opacity of these areas was determined with a photometer which measured the light transmission of a part of the area on each sampling paper before and after the sampling period. The two sampling papers used for each arrestance measurement were selected to have the same light transmission readings when clean. In order to obtain similar increases of opacity on both samplers, different size areas were used upstream and downstream of the filter. The arrestance, A (in percent), was calculated by the following formula:

$$A = \left(1 - \frac{S_D}{S_U} \times \frac{\Delta D}{\Delta U}\right) \times 100$$

where S_D and S_U are the downstream and upstream areas, and ΔD and ΔU the observed changes in the opacity of the downstream and upstream sampling areas, respectively.

Whereas the arrestance determinations were made with Cottrell precipitate only, cotton lint was added during the loading process in a ratio of 4 parts by weight to every 96 parts of Cottrell precipitate, including that amount used for arrestance measurements. Arrestance determinations were made at the beginning and at the end of the loading period of each filter and at several intermediate load conditions.

The pressure drop across the filter under test was recorded after each increment of 20 grams of dust had been introduced into the test duct, and the test was terminated when the pressure drop reached 0.5 in. W.G. at the lower air flow rate and 0.8 in. W.G. at the higher air flow rate.

The cleanable viscous-impingement type filters were washed with hot water using a hose until the effluent water appeared clean and then were allowed to dry. After drying, the filter was re-oiled, weighed and installed in the test apparatus for determining any change in pressure drop and for a second loading, after which the cleaning procedure and the determination of the pressure drop were repeated.

4. Test Results

The data obtained on arrestance, dust holding capacity, pressure drop, and cleanability for the two types of air filters are summarized in Tables 1 to 4 and a part of the data is shown graphically in Fig. 1 to 4.

The "Dust Load" shown in these tables and graphs is the dust holding capacity of the filters, or the dust received by the filter, at the selected final pressure drops of 0.5 and 0.8 in. W.G. for face velocities of 360 and 540 ft/min, respectively. It is the weight of Cottrell precipitate and lint introduced into the test apparatus divided by the net face area of the filter and diminished by the percentage of dust fallout upstream of the filter. This fallout was determined by weight at the conclusion of the test by sweeping out the test duct.

The "Average Arrestance" in the tables and graphs is the average of the arrestance values obtained during the period in which the capacity dust load was accumulated. It was determined graphically from a curve drawn through the plotted values of arrestance versus dust load for each filter test.

The values shown in Tables 1 to 4 for weight increase and pressure drop increase after the second cleaning are cumulative; that is, they are changes from the initial values for the clean filter.

Tables 1 and 2 show that the average arrestance of the one-inch cleanable filters ranged from 47 to 69 percent at a face velocity of 360 ft/min with an average of 56 percent for all specimens, and ranged from 47 to 73 percent at a face velocity of 540 ft/min with an average of 59 percent for all specimens.

The arrestance did not increase for all of the filters at the higher air velocity; it remained constant for two filters and decreased for one other. The average arrestance of one of the one-inch throw-away filters decreased significantly, from 58 to 46 percent, and that of another remained about constant as the face velocity was increased from 360 to 540 ft/min.

The dust load of the one-inch cleanable filters ranged from 85 to 362 g/sq ft at the lower face velocity and from 78 to 690 g/sq ft at the higher face velocity, indicating a wide disparity among the eight different models. The variation in dust load for the specimens of the throw-away type was much less than for the cleanable filters. The average dust load of the two types of filters was comparable for the 1-inch thick media, but in the 2-inch filters the cleanable type had a higher dust-holding capacity.

A graph of average arrestance versus dust load for the eight models of cleanable filters shows a general inverse relationship between these two variables. However, the correlation is not good enough to warrant developing a mathematical expression for it.

Tables 1 and 2 show that the initial pressure drop increased less than 0.01 in. W.G. after two cleanings for most of the viscous-impingement filters and several of the filters showed no measurable increase in pressure drop after two cleanings at the lower face velocity. The weight change after two cleanings ranged from a loss of 12 grams to a gain of 123 grams, with an average gain in weight of 34 grams for all specimens. This average weight gain was about 6 percent of the average total dust load on the filters. In the worst case, that of specimen E-1, the weight increase after two cleanings was about 27 percent of the dust load for the lower face velocity and 31 percent of the dust load for the higher face velocity.

Tables 3 and 4 show that the average arrestance of the two-inch cleanable filters ranged from 58 to 66 percent with an average of 60 percent for all specimens at a face velocity of 360 ft/min, and ranged from 57 to 74 percent with an average of 65 percent at a face velocity of 540 ft/min. All except one of the cleanable filters increased in average arrestance as the face velocity was increased. The average arrestance of the one 2-inch throw-away filter tested at both face velocities decreased from 74 to 71 percent as the face velocity was increased from 360 to 540 ft/min.

The dust load of the two-inch cleanable filters ranged from 110 to 468 g/sq ft at the lower face velocity and from 92 to 775 g/sq ft at the higher face velocity. The ratio of the maximum to the minimum values of dust load for the eight specimens was about the same for the two-inch filters as for the one-inch specimens.

The arrestance values obtained for the two-inch throw-away filters was appreciably higher than for the cleanable filters.

Tables 3 and 4 show that the initial pressure drop increased 0.021 in. W.G. at the lower face velocity and 0.035 in. W.G. at the higher face velocity, on the average, after two cleanings. One filter showed a decrease in pressure drop after two cleanings and two filters, specimens B-2 and E-2, showed an increase much higher than the average. The weight increase after two cleanings ranged from 0 to 385 grams, with an average of 145 grams for all specimens. This average weight gain was about 12 percent of the average total dust load on the filters. In the two worst cases, specimens B-2 and E-2, the weight increases after two cleanings were 64 and 49 percent of the total dust loads for the two filters, respectively.

Small variations in weight, in either direction, would be expected after cleaning and re-oiling as a result of variations in oil drainage, but this does not account for the large changes in weight shown in Tables 1 to 4. Variations in oil drainage probably accounts for the decreases in weight shown in the tables as compared to the initial weight of the specimens.

The average values of the dust load and arrestance for the two types and two thicknesses of filters are summarized in Table 5 for face velocities of 360 and 540 ft/min. This summary shows that the average arrestance of the 2-inch cleanable filters was 4 to 6 percent higher than that of the 1-inch filters of the same type, whereas the average arrestance of the 2-inch throw-away filters was 11 to 13 percent higher than that of the 1-inch filters. Table 5 also shows that the arrestance of the cleanable filters increased, on the average, with increased face velocity, whereas it decreased for the throw-away types with increased face velocity. It should be noted that the number of throw-away filters tested was considerably less than the number of cleanable filters, so the average values obtained on the former type are perhaps less representative of all available models than for the latter type.

Table 5

Summary of Average Performance

Nominal Thickness of Filters, inches	Face Velocity, ft/min	Dust Load, g/sq ft		Mean Arrestance, %	
		Cleanable	Throw-away	Cleanable	Throw-away
1	360	200	200	56	65
1	540	254	249	59	60
2	360	279	187	60	78
2	540	325	264	65	71

Table 6 was prepared to show the general nature of the arrestance curve plotted against dust load for each filter tested. Filters A, D, E, F, G, and J showed a continuous rise in arrestance from the beginning to the end of the loading period for both face velocities and both filter thicknesses, whereas filter B showed this same characteristic in the 1-inch thickness, filters K and L showed this rising characteristic in the 2-inch thickness, and filter C had this characteristic at a face velocity of 360 ft/min for both thicknesses. Filter C revealed minimum arrestance values at 20 and 30 percent of full dust load for the 1- and 2-inch thicknesses, respectively. Filter H had a rather flat arrestance curve at the higher face velocity, but the curve drooped a little near full dust load. The arrestance curve for filter I, in the 1-inch thickness, sloped downward continuously throughout the loading of the filter.

The current Federal Specification for cleanable viscous-impingement type air filters, F-F-300, dated October 1957, specifies a 2-inch thick filter with the following performance characteristics at a face velocity of 350 ft/min;

(a) Initial arrestance, 45% minimum
(b) Dust load at 0.4 in. W.G. pressure drop, 250 g/sq ft minimum
(c) Pressure drop increase after 1 cleaning, 0.01 in. W.G. maximum.

Table 6 indicates that all of the filters, A to H inclusive, had a minimum arrestance in excess of 45% at 360 ft/min face velocity. Figure 3 shows that the dust load of filters C, E, G, and H was in excess of 250 g/sq ft at a pressure drop of 0.5 in. W.G. An examination of the curves for these filters showed that the dust load requirement was also met at a pressure drop of 0.4 in. W.G.

The other filters of this type did not meet the dust load requirement. Table 3 shows that filters A, D, and E exceeded the specified maximum increase in pressure drop of 0.01 in. W.G. after one cleaning. Thus, of the eight specimens tested, only specimens C, G, and H met all three requirements of Federal Specification F-F-300.

The current Federal Specification for throw-away type filters, F-F-310, dated October 1957, specifies one-inch filters or two-inch filters with the following characteristics at a face velocity of 370 ft/min.

Nominal Filter Thickness	1-inch	2-inch
Arrestance, Minimum	60%	70%
Dust Load at 0.5 in. W.G., Minimum	115 g/sq ft	115 g/sq ft

Figure 1 shows that only filter J met both requirements in a 1-inch thick filter, and all four specimens, I through L, met both requirements in a 2-inch thick filter.

5. Discussion and Conclusions

It seems more logical to specify the arrestance of air filters on the basis of the average value during the loading of the filter rather than the initial value for a clean filter, since most filters improve in arrestance as the load increases and the change of arrestance with load is gradual. Furthermore, where a considerable number of suppliers is available and the performance of the different models covers a wide range, it should not be necessary to set the requirements so low that all can comply.

The results of this series of tests indicate that, on the average, a 2-inch thick filter of the cleanable viscous-impingement type had about 5 percent higher arrestance and from 25 to 30% greater dust-holding capacity than a 1-inch thick filter of the same type in the range of face velocity from 360 to 540 ft/min. These average values do not apply to every model tested, because some 2-inch thick filters had lower arrestance than the corresponding 1-inch filter.

The two models of 1-inch throw-away type filters used in these tests revealed arrestances and dust-holding capacities generally comparable with those obtained for the cleanable filters of the same thickness. The 2-inch throw-away type filters had higher arrestances than any of the cleanable filters and a lower dust-holding capacity, on the average, than the cleanable filters at a face velocity of 360 ft/min, but the same comparison was not true at the higher face velocity. The principal

difference between the two types of filters was the relation of arrestance to face velocity. An increase in face velocity was accompanied by an increase in arrestance, on the average, for the cleanable filters, but the reverse was true for the throw-away filters in two out of three cases.

The data obtained on cleanable viscous-impingement filters during this series of tests are considered to be sufficiently comprehensive to serve as a basis for revising the Federal Specification requirements and providing requirements for both 1-inch and 2-inch filters. Estimates could probably be made from these data on the relative merits of 1-inch and 2-inch cleanable filters for various applications. Data on additional models of throw-away filters are needed before any revision of the Federal Specification on this type of filter could be suggested.

At the same time, it should be remembered that either type of filter can readily be modified by the manufacturer with respect to media density, pressure drop, thickness, and type of adhesive, accompanied by a change in performance. Thus, it cannot be assumed that the performance data observed during a given series of tests will be applicable over a long period of time unless the design of the filter is known to be unchanged. For example, a cleanable filter made for similar duty by the same manufacturer as one of the present test specimens, but with a different model number, was tested at the National Bureau of Standards about a year prior to this series of tests. In the present series, this filter had a very low dust-holding capacity, but in the earlier test the dust-holding capacity was comparable to other models. A careful examination of the construction of the filters revealed that a small change in the arrangement of the filter media had increased the arrestance somewhat, but had very considerably reduced the dust-holding capacity. Conversely, an earlier design of one of the throw-away type filters reported herein, was tested less than a year ago and found to have a very low arrestance. The filter was redesigned and retested with the resulting performance being incorporated in this summary.

The determination of acceptable cleanability should probably be based on more than one loading and cleaning of a filter, and probably should be based on weight gain rather than increase in pressure drop. Changes in pressure drop of a few thousandths of an inch of water cannot always be determined with certainty in such laboratory procedures. It will be noted in Table 1 that filter E-1 gained 65 grams in weight, which was approximately 14% of the total dust load, after the first cleaning, accompanied by a pressure drop increase of only

0.005 in. W.G.; and in Table 3, filter C-2 gained 212 grams in weight, which was about 26% of the total dust load, after the first cleaning, accompanied by a pressure drop increase of only 0.003 in. W.G. Experience with the specimens tested indicates that a more reliable indication of cleanability would be established after two or three cleanings than after one cleaning.

Table 1

Performance of 1-inch Air Filters at 360 ft/min Face Velocity

Filter Designation	Initial Pressure Drop	Dust Load	Average Arrestance	Weight Increase After First Cleaning	Weight Increase After Second Cleaning	Pressure Drop Increase After First Cleaning	Pressure Drop Increase After Second Cleaning
	in. W.G.	g/sq ft	%	g	g	in. W.G.	in. W.G.
Cleanable Viscous-Impingement Filters							
A-1	0.075	85	60	- 6	2	0.002	0.000
B-1	0.055	202	56	38	40	0.007	0.005
C-1	0.040	316	48	12	57	0.000	0.003
D-1	0.105	152	56	18	15	0.001	0.000
E-1	0.055	180	60	65	123	0.005	0.030
F-1	0.022	187	54	30	18	-0.001	0.000
G-1	0.070	113	69	22	30	0.000	0.000
H-1	0.055	362	47	-10	-12	-0.005	0.000
Average	0.060	200	56	21	34	0.001	0.005
Throw-Away Filters							
I-1	0.100	208	58				
J-1	0.086	191	72				
Average	0.093	200	65				

Table 2

Performance of 1-inch Air Filters at 540 ft/min Face Velocity

Filter Designation	Initial Pressure Drop in. W.G.	Dust Load g/sq ft	Average Arrestance %	Weight Increase After First Cleaning g	Weight Increase After Second Cleaning g	Pressure Drop Increase After First Cleaning in. W.G.	Pressure Drop Increase After Second Cleaning in. W.G.
Cleanable Viscous-Impingement Filters							
A-1	0.155	78	67	- 6	2	-0.005	0.000
B-1	0.125	227	61	38	40	0.009	0.009
C-1	0.087	386	48	12	57	0.002	0.014
D-1	0.235	168	55	18	15	0.000	0.003
E-1	0.125	158	68	65	123	0.015	0.060
F-1	0.055	200	49	30	18	0.009	0.009
G-1	0.143	124	73	22	30	-0.005	0.003
H-1	0.120	690	47	-10	-12	-0.008	-0.003
Average	0.131	254	59	21	34	0.002	0.012
Throw-Away Filters							
I-1	0.145	325	46				
J-1	0.156	173	73				
Average	0.151	249	60				

Table 3

Performance of 2-inch Air Filters at 360 ft/min Face Velocity

Filter Designation	Initial Pressure Drop	Dust Load	Average Arrestance	Weight Increase		Pressure Drop Increase	
				After First Cleaning	After Second Cleaning	After First Cleaning	After Second Cleaning
	in. W.G.	g/sq ft	%	g	g	in. W.G.	in. W.G.
Cleanable Viscous-Impingement Filters							
A-2	0.080	110	61	85	85	0.035	0.030
B-2	0.070	240	59	90	385	0.010	0.080
C-2	0.060	326	60	212	197	0.003	0.010
D-2	0.096	240	58	-	83	0.011	0.020
E-2	0.046	296	60	175	360	0.014	0.025
F-2	0.040	233	59	10	10	-0.005	-0.001
G-2	0.045	315	66	38	42	0.001	0.007
H-2	0.105	468	56	-12	0	0.000	0.000
Average	0.068	279	60	85	145	0.009	0.021
Throw-Away Filters							
I-2	0.121	124	79				
J-2	0.107	255	74				
K-2	0.147	125	81				
L-2	0.101	172	77				
Average	0.119	169	78				

Table 4

Performance of 2-inch Air Filters at 540 ft/min Face Velocity

Filter Designation	Initial Pressure Drop in. W.G.	Dust Load g/sq ft	Average Arrestance %	Weight Increase After First Cleaning g	Weight Increase After Second Cleaning g	Pressure Drop Increase After First Cleaning in. W.G.	Pressure Drop Increase After Second Cleaning in. W.G.
Cleanable Viscous-Impingement Filters							
A-2	0.225	92	65	85	85	-	-
B-2	0.170	250	74	90	385	0.020	0.155
C-2	0.146	290	62	212	197	0.006	0.022
D-2	0.190	294	61	-	83	0.020	0.030
E-2	0.128	293	68	175	360	0.023	0.036
F-2	0.075	270	59	10	10	-0.008	-0.003
G-2	0.117	318	70	38	42	0.010	0.010
H-2	0.240	775	57	-12	0	-0.005	-0.005
Average	0.161	325	65	85	145	0.012	0.035
Throw-Away Filters							
I-2*							
J-2	0.196	264	71				
K-2*							
L-2*							

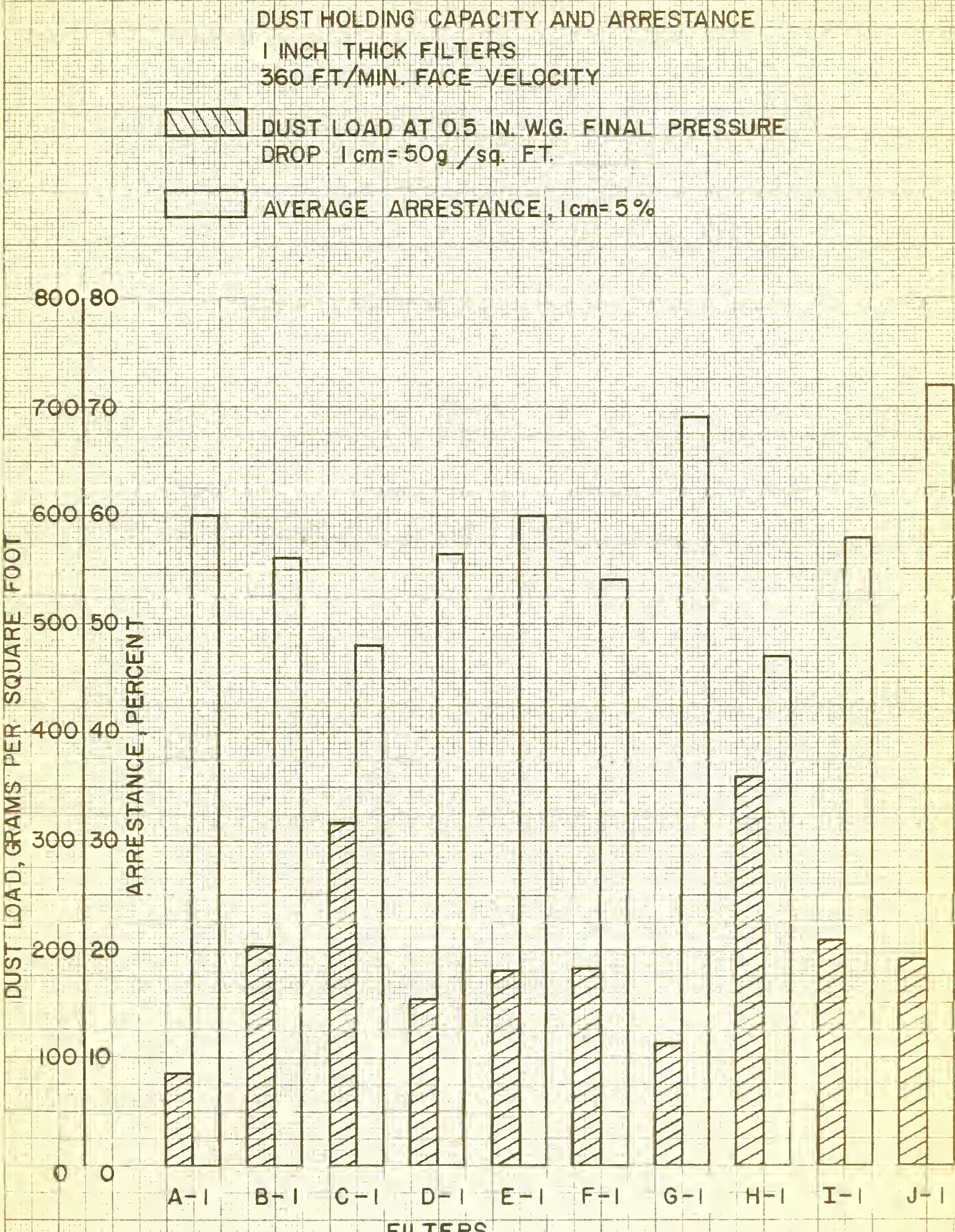
* Not tested at 540 ft/min face velocity.

Table 6

Maximum and Minimum Arrestance Values and
the Percent of Dust Load at Which They Occurred

Thickness of Filter		1 inch				2 inches			
Face Velocity, ft/min		360		540		360		540	
Filter Specimen	Arrestance	A	L	A	L	A	L	A	L
A	max.	70	100	78	100	76	100	72	100
	min.	52	0	64	0	55	0	64	0
B	max.	63	100	66	100	68	100	79	60
	min.	50	0	56	0	52	0	64	0
C	max.	50	100	61	100	65	90	70	100
	min.	47	0	41	20	53	0	57	30
D	max.	62	100	63	100	65	100	65	100
	min.	51	0	51	0	53	0	56	0
E	max.	71	100	81	100	71	100	81	100
	min.	50	0	51	0	52	0	57	0
F	max.	77	100	56	100	75	100	65	100
	min.	42	0	43	0	49	0	50	0
G	max.	79	100	80	100	79	100	81	100
	min.	60	0	62	0	59	0	60	0
H	max.	53	70	48	50	62	100	59	90
	min.	38	0	45	100	48	0	56	100
I	max.	60	0	55	0	86	100	-	-
	min.	54	100	38	100	73	0	-	-
J	max.	78	100	79	100	78	100	77	100
	min.	58	0	63	0	61	0	59	0
K	max.	-	-	-	-	85	100	-	-
	min.	-	-	-	-	74	0	-	-
L	max.	-	-	-	-	82	100	-	-
	min.	-	-	-	-	69	0	-	-

A is the arrestance of Cottrell precipitate.
L is the percent of full dust load at which the maximum or minimum arrestance occurred.


DUST HOLDING CAPACITY AND ARRESTANCE
1 INCH THICK FILTERS
360 FT/MIN. FACE VELOCITY
DUST LOAD AT 0.5 IN. W.G. FINAL PRESSURE DROP 1 cm = 50g /sq. FT.
AVERAGE ARRESTANCE, 1 cm = 5 %
DUST LOAD, GRAMS PER SQUARE FOOT
ARRESTANCE, PERCENT
0 100 200 300 400 500 600 700 800
0 10 20 30 40 50 60 70 80
A-1 B-1 C-1 D-1 E-1 F-1 G-1 H-1 I-1 J-1
FILTERS
FIG. 1

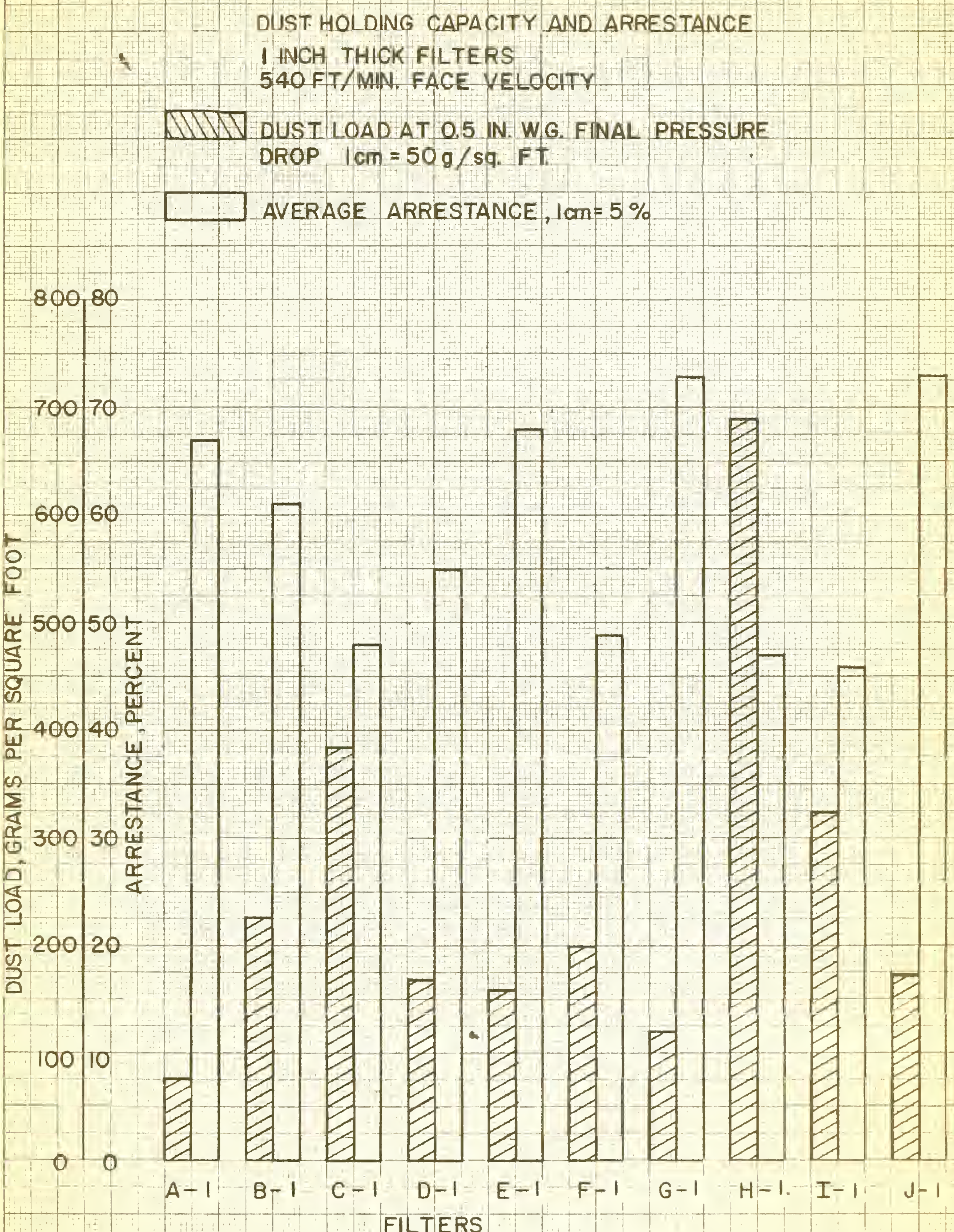

DUST HOLDING CAPACITY AND ARRESTANCE
1 INCH THICK FILTERS
540 FT/MIN. FACE VELOCITY
DUST LOAD AT 0.5 IN. W.G. FINAL PRESSURE DROP 1cm = 50 g/sq. FT.
AVERAGE ARRESTANCE, 1cm = 5 %
DUST LOAD, GRAMS PER SQUARE FOOT
ARRESTANCE, PERCENT
800 80
700 70
600 60
500 50
400 40
300 30
200 20
100 10
0 0
A-1
B-1
C-1
D-1
E-1
F-1
G-1
H-1
I-1
J-1
FILTERS

FIG. 2

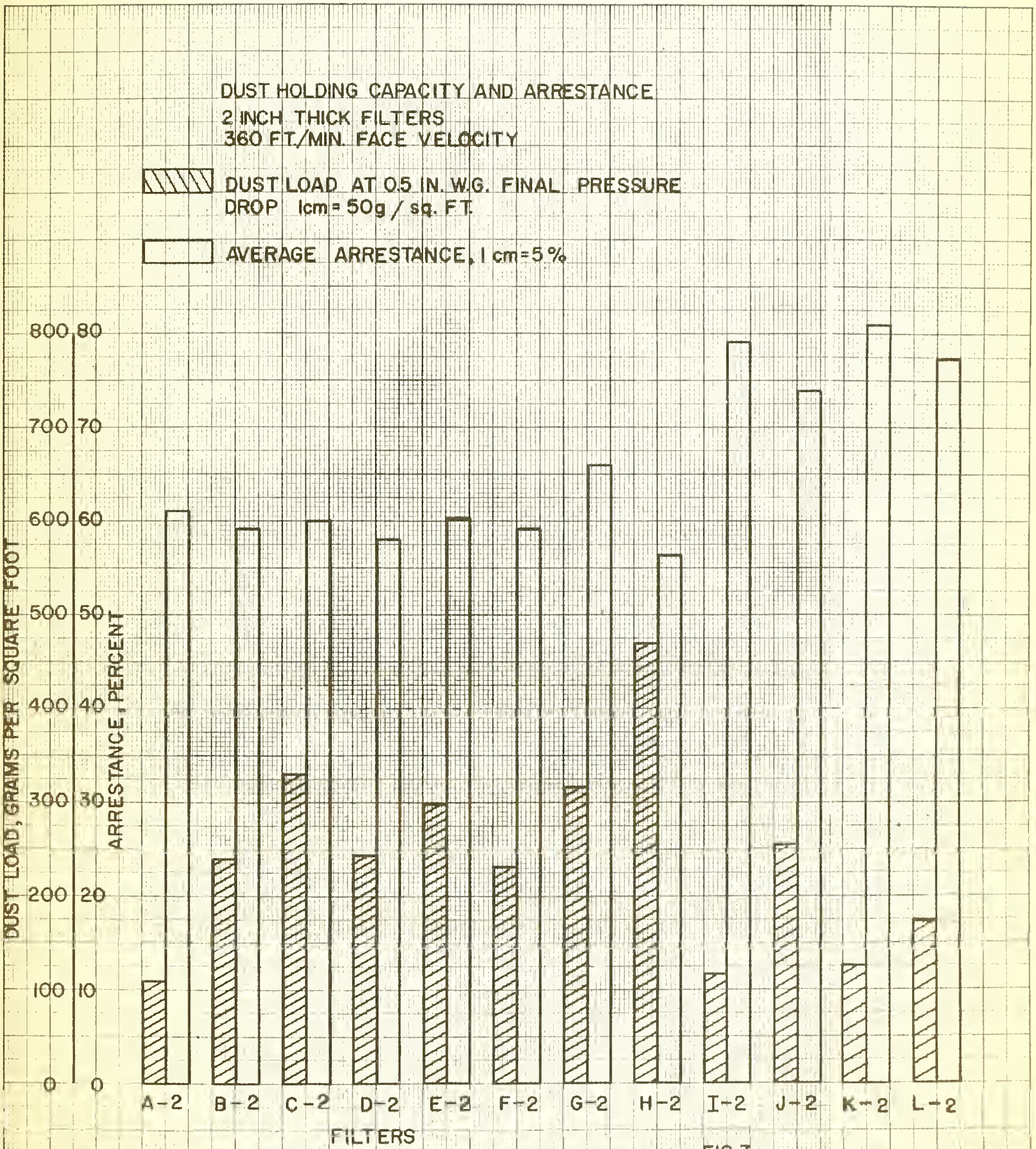

DUST HOLDING CAPACITY AND ARRESTANCE
2 INCH THICK FILTERS
360 FT./MIN. FACE VELOCITY
DUST LOAD AT 0.5 IN. W.G. FINAL PRESSURE DROP Icm = 50g / sq. FT.
AVERAGE ARRESTANCE, I cm = 5 %
DUST LOAD, GRAMS PER SQUARE FOOT
ARRESTANCE, PERCENT
0 100 200 300 400 500 600 700 800
0 10 20 30 40 50 60 70 80
A-2 B-2 C-2 D-2 E-2 F-2 G-2 H-2 I-2 J-2 K-2 L-2
FILTERS

FIG.3

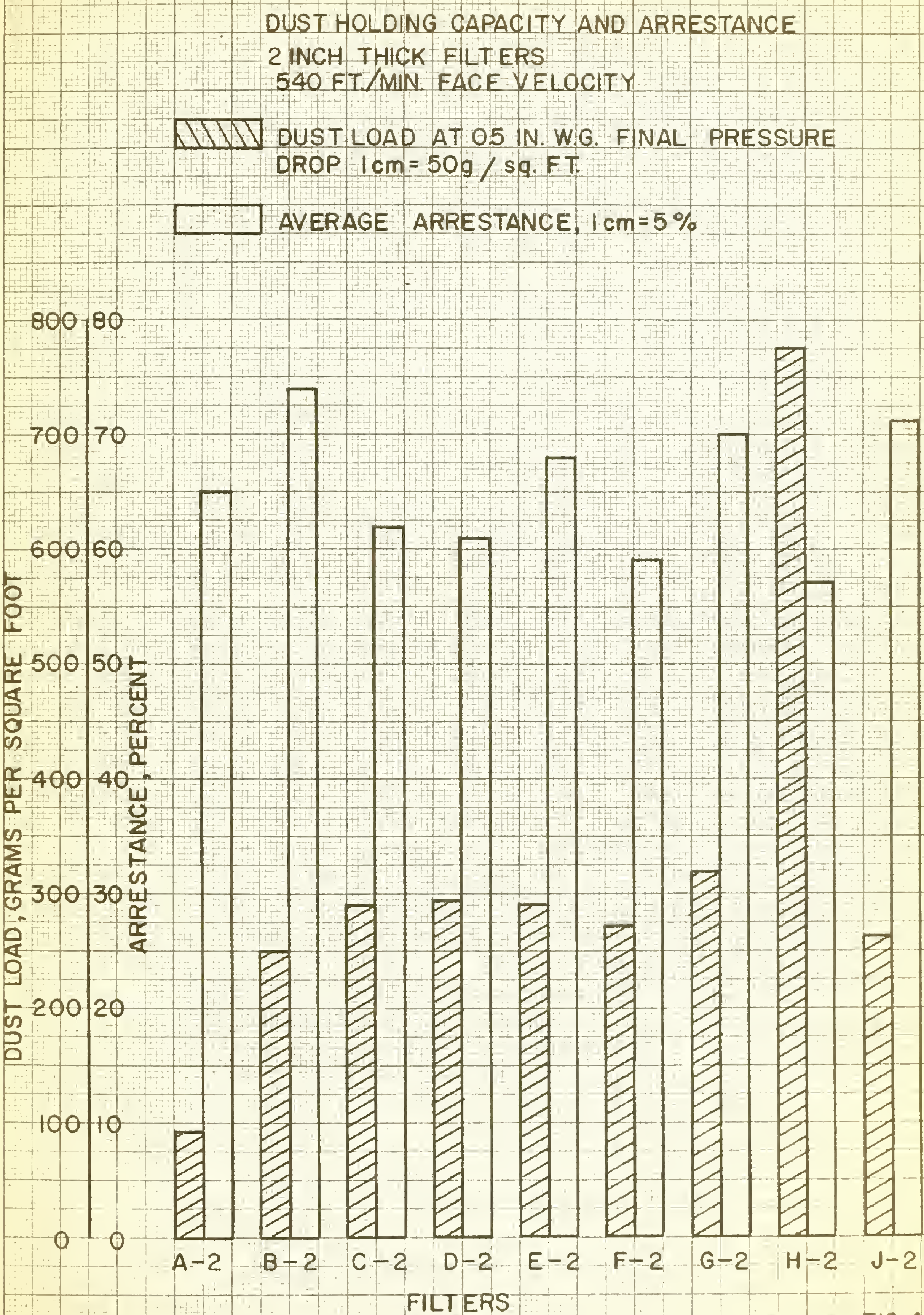

DUST HOLDING CAPACITY AND ARRESTANCE
2 INCH THICK FILTERS
540 FT./MIN. FACE VELOCITY
DUST LOAD AT 0.5 IN. W.G. FINAL PRESSURE DROP 1cm = 50g / sq. FT.
AVERAGE ARRESTANCE, 1 cm = 5 %
DUST LOAD, GRAMS PER SQUARE FOOT
ARRESTANCE, PERCENT
800 80
700 70
600 60
500 50
400 40
300 30
200 20
100 10
0 0
A-2
B-2
C-2
D-2
E-2
F-2
G-2
H-2
J-2
FILTERS

FIG. 4

U.S. DEPARTMENT OF COMMERCE
Frederick H. Mueller, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.

Electricity and Electronics. Resistance and Reactance. Electron Devices. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Photographic Technology. Length. Engineering Metrology.

Heat. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology. Molecular Kinetics. Free Radicals Research.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Physics. Radiation Theory. Radioactivity. X-rays. High Energy Radiation. Nucleonic Instrumentation. Radiological Equipment.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Air Conditioning, Heating, and Refrigeration. Floor, Roof, and Wall Coverings. Codes and Safety Standards. Heat Transfer. Concreting Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Application Engineering.

- Office of Basic Instrumentation.
- Office of Weights and Measures.

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships. VHF Research. Radio Warning Services. Airglow and Aurora. Radio Astronomy and Arctic Propagation.

Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Research. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation Obstacles Engineering. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Electronic Calibration Center. Microwave Physics. Microwave Circuit Standards.

Radio Communication and Systems. Low Frequency and Very Low Frequency Research. High Frequency and Very High Frequency Research. Ultra High Frequency and Super High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Systems Analysis. Field Operations.

NBS