NATIONAL BUREAU OF STANDARDS REPORT

4887

PERFORMANCE TESTS OF AN ELECTRO-AIR ELECTRONIC AIR CLEANER

by

Henry E. Robinson
Thomas W. Watson

Report to
General Services Administration
Public Buildings Service
Washington 25, D. C.

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *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 headquarters in Washington, D. C., and its major field laboratories in 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 reports and publications, appears on the inside back cover of this report.

WASHINGTON, D. C.

Electricity and Electronics. Resistance and Reactance. Electron Tubes. Electrical Instruments. Magnetic Measurements. Process Technology. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

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

Heat and Power. Temperature Measurements. Thermodynamics. Cryogenic Physics. Engines and Lubrication. Engine Fuels.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Nuclear Physics. Radioactivity. X-rays. Betatron. Nucleonic Instrumentation. Radiological Equipment. AEC Radiation Instruments.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. 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. Organic Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion.

Mineral Products. Ceramic Engineering. Porcelain and Pottery. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

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

Data Processing Systems. Components and Techniques. Digital Circuitry. Digital Systems. Analogue Systems. Applications 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.

Radio Propagation Engineering. Frequency Utilization Research. Tropospheric Propagation Research.

Radio Standards. High Frequency Standards Branch: High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Microwave Standards Branch: Extreme High Frequency and Noise. Microwave Frequency and Spectroscopy. Microwave Circuit Standards.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT 1000-30-4830

October 10, 1956

NBS REPORT 4887

PERFORMANCE TESTS OF AN ELECTRO-AIR
ELECTRONIC AIR CLEANER

by

Henry E. Robinson
Thomas W. Watson
Heating and Air Conditioning Section
Building Technology Division

to

General Services Administration
Public Buildings Service
Washington 25, D. C.

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

PERFORMANCE TESTS OF AN ELECTRO-AIR MODEL B-102 ELECTRONIC AIR CLEANER

by

Henry E. Robinson and Thomas W. Watson

1. INTRODUCTION

At the request of the Public Buildings Service, General Services Administration, the performance characteristics of electrostatic air cleaners were determined to provide information to assist in the preparation of new air filter specifications.

The test results presented herein were obtained on a specimen electrostatic filter unit submitted by its manufacturer at the request of the Public Buildings Service and included determinations of dust-arresting efficiency with three aerosols (atmospheric air, kerosene lamp smoke, and Cottrell precipitate), pressure drop, specific dirt load and cleanability of the specimen.

2. DESCRIPTION OF THE FILTER SPECIMEN

The cleaner was manufactured by the Electro-Air Cleaner Company, 1285 Reedsdale Street, Pittsburgh 33, Pennsylvania, and was of the electrostatic type. It was identified by the manufacturer as an "Electro-Air Electronic Air Cleaner," Model B-102, with one cell, rated velocity 333 feet per minute (1320 cfm total capacity). The power pack nameplate data furnished by the manufacturer were as follows:

Type B

Input: 60 cycles, 115 volts, 2 amp primary (maximum)

Output: 8,500 volts DC, 20 ma secondary

The test unit had a housing with transverse outside dimensions 24 x 22 7/8 inches and was 20 inches long. The unit was rated at 1320 cfm air delivery, which yields a nominal face velocity of 333 fpm, on the basis of a nominal transverse area of about four square feet.

The upstream and downstream faces had special flanges 30 inches square matching those of the duct of the test apparatus. The face openings were approximately 24 x 23 inches both upstream and downstream. The downstream face was adapted to receive a nominal 23 x 21 x 2-inch after-filter which for this unit was a 23 x 20 7/8 x 1 7/8-inch viscid impingement type air filter, manufactured by the Research Products Corporation of Madison, Wisconsin.

The filter cell of the unit was 23 13/16 inches in height, 22 9/16 inches in width, and 17 3/4 inches in length, and contained 57 aluminum plates (23 x 10 3/4 inches in dimension) spaced 3/8 inch apart on centers, presenting a total surface area of approximately 196 square feet.

The manufacturer furnished an adhesive (a water-emulsifying oil) designated as "Shell 368-S," with which the collector plates were oiled by spraying them from both the upstream and downstream faces. The after-filter was oiled in preparation for the test by spraying the media from the upstream and downstream faces with the same adhesive.

The power pack, connected to a 115-volt, 60-cycle supply, was adjusted by the manufacturer's representative to recommended settings prior to the tests; the ionizer and plate voltages that resulted were measured by means of an accurate electrostatic voltmeter.

3. TEST METHOD AND PROCEDURE

Efficiency determinations were made by the NBS "Dust-Spot Method" using the following aerosols: (a) outdoor air drawn through the laboratory without addition of other dust or contaminant; (b) kerosene lamp smoke; and (c) Cottrell precipitate. The test method is described in the paper, "A Test Method for Air Filters" by R. S. Dill (ASHVE Transactions, Vol. 44, P. 379, 1938). The test duct and arrangement are shown in Figure 1. A baffle made of two 3-inch wide slats was located in the duct about $3\frac{1}{2}$ ft downstream of the test assembly to intermix the air discharged from it.

For these tests, the unit was installed in the test duct and carefully sealed to prevent inleakage of air. The desired rate of air flow through the air cleaner was established and samples of air were drawn from the center points

of the test duct one foot upstream and eight feet downstream of the air cleaner assembly at equal rates and passed through known areas of Whatman No. 41 filter paper. For the atmospheric air and oil lamp smoke tests, the samples were drawn at equal rates through equal areas of filter paper (3/4-inch diameter spots). The downstream sample was drawn continuously during the test; the upstream sample was drawn intermittently in a number of one-minute periods uniformly distributed over the duration of the test, aggregating one-tenth of the downstream sampling period. Under these conditions an efficiency of 90 percent would be indicated if the upstream and downstream dust-spots on the filter papers had the same opacity, as indicated by the change in the light transmissions of the dust-spot areas before and after the sample was drawn, which were determined by means of a photometer using transmitted light. The filter papers used in the upstream and downstream positions were selected to have the same light transmission readings when clean. If the opacities of the dust-spots differed, the efficiency was calculated by means of the formula

$$\text{Efficiency, percent} = 100 \left[1 - \frac{t_1}{t_2} \cdot \frac{O_2}{O_1} \right] \doteq 100 - 10 \left(\frac{O_2}{O_1} \right)$$

where O_1 and O_2 were the opacities of the dust-spots upstream and downstream, respectively, and t_1 and t_2 were the aggregate times during which the upstream and downstream samples, respectively, were drawn.

For the efficiency tests with Cottrell precipitate as the aerosol, the samples upstream and downstream were drawn at equal rates and for equal times but unequal dust-spot areas were used to obtain opacities that were approximately equal. If the opacities of the dust-spots differed, the value of the efficiency was calculated by means of the formula above, with the ratio A_2/A_1 substituted for the ratio t_1/t_2, where A_2 and A_1 were the areas of the dust-spots downstream and upstream respectively.

The following procedure was employed in these tests. After the clean and oiled unit had been installed in the test duct, and all discoverable air leaks into its housing had been sealed, its input and output voltages were adjusted to recommended values by a representative of the manufacturer: (input 115 volts; ionizer and plates 8.4 kv). Three determinations of the efficiency of the clean unit were made at the rated velocity, using as the aerosol outdoor air drawn into the test duct through a nearby open window. A determination of efficiency with the unit not energized was also made. Following these, single determinations were made, using outdoor air, at velocities 20 percent greater, and 20 percent less, than the rated velocity.

Next, three efficiency determinations were made at rated velocity, using as the aerosol outdoor air with the addition of kerosene smoke generated by an open lamp flame near the inlet to the test duct.

Following these, three efficiency determinations were made at rated velocity, using as an aerosol outdoor air in which was dispersed Cottrell precipitate at a concentration of one gram per thousand cubic feet of air. When these had been obtained, the process was begun of loading the unit with a mixture of 4 percent cotton lint and 96 percent Cottrell precipitate, by weight, separately dispersed into the air stream. The lint used for this purpose was No. 7 cotton linters previously ground in a Wiley mill with a 4-millimeter screen; the lint was dispersed into the air stream through an aspirator operating at approximately 35 psi inlet air pressure. At suitable periods as loading progressed, the efficiency of the unit was determined using 100 percent Cottrell precipitate in outdoor air. In these tests, and during the loading process, the rate of feed of the dispersant was one gram per thousand cubic feet of air. The pressure drop and the ionizer and plate voltages of the unit were recorded at intervals during the tests. The dirt-loading process was continued until 899 grams of the lint and Cottrell precipitate mixture had been fed (i.e., 2/3 gram per cfm of unit rating).

At suitable periods as the dirt-loading process progressed, strips of transparent cellulose adhesive tape (3/4 inch wide) were stretched vertically across the test duct near its axis, with the adhesive side facing upstream. Tapes were located at three positions (1) 12 inches upstream, (2) 15 inches downstream, and (3) 8 ft downstream, of the test unit; the tapes at stations (1) and (3) were in the same longitudinal positions in the test duct as the inlets to the upstream and downstream sampling tubes. The adhesive surface of such a tape captured a sample of the particulate matter in the air flowing past it, and after suitable times of exposure to the aerosol, scrutiny of the tapes by eye and with a microscope afforded considerable information as to the vertical distribution, the nature, number, and size of the particles caught at the various stations. Photographic enlargements (10X) by transmitted light were made of sections of the tapes corresponding to a position at mid-height in the test duct.

The filter cell was removed from the test unit and cleaned by means of a stream of cold water from a high pressure hose nozzle, directed at and into the cell plates from both ends of the unit. The cleanability of the after-filter was determined separately, by the same means.

4. TEST RESULTS

A summary of the test data, giving efficiencies in percent with the three aerosols and the pressure drop of the complete unit including the after-filter, in inch W.G., at rates of air flow corresponding to various face velocities, is given in Table 1. A summary of the test data obtained in the dirt-loading test conducted at the rated face velocity of 333 fpm is given in table 2.

Photographs No. 1, 2, and 3 included in this report are 10X enlargements of the center 3/4 x 1-inch sections of cellophane tapes located at the three similarly numbered stations described under Test Method and Procedure. Tapes No. 2 and 3 were exposed at their respective stations simultaneously during the dirt-loading test for a period in which 124 grams of mixture were fed to the test unit. This exposure was during the interval in which the dirt-load increased from

40 to 164 grams, as shown in Table 2. Photograph No. 1 shows a tape exposed at station No. 1 for an equal length of time. After exposure, the tapes were carefully removed from the test duct for photographing and microscopic study.

Throughout the tests with atmospheric air, electrical sparking or flashing in the unit audible to the ear occurred, on the average, about once per hour. There was no observed instance of sparking or flashing during the tests with oil lamp smoke. However, during the Cottrell and lint loading test electrical sparking or flashing occurred intermittently, the frequency increasing from about 40 to 50 times per hour at the start to about 90 to 100 times per hour at the end of the loading test.

5. SUMMARY

A. Performance

The efficiency of the air cleaner in arresting the particulate matter existent in atmospheric air drawn through the unit varied considerably with the face velocity at which it was operated, as shown in Table 1. At the rated velocity (333 fpm), the average efficiency on atmospheric air (90.2 percent) and that on oil lamp smoke (91.2 percent) were very nearly the same. The efficiencies are reported to three significant figures obtained from the test data. In reporting thus, however, it is considered desirable to point out that an uncertainty on the order of one or two percent is possible in determining efficiencies, although in these results the differences between comparable efficiency values were consistently of a lesser magnitude.

As recorded in Table 2, the ionizer and plate voltage showed a decrease of about 2.5 kv at about 659 grams of load and a corresponding decrease in efficiency of approximately ten percent. However, at the beginning of the next test-day (at a load of 700 grams) the voltages and efficiencies were found to be at approximately their initial values and remained at a high level except for a one-minute period during the ten-minute efficiency determination at 886 grams of load.

In these two instances, the voltage was observed to vary as shown, the first value in each bracket being that at the start of the efficiency determination, and the last that at the end.

An efficiency determination made with atmospheric air at the end of the dirt-loading test indicated that the unit was approximately as efficient (within about one percent) on this aerosol when the unit was heavily laden with dirt, as when it was clean.

The greater part of the pressure drop through the complete unit was due to the resistance of the after-filter. It is noted in Table 2 that in the dirt-loading test, the pressure drop of the complete unit increased by 0.116 inch W.G. for a total dirt-load of 899 grams. This rise was due chiefly to an increase in the pressure drop of the after-filter, as a result of an accumulation of cotton lint and of comparatively large particles of Cottrell precipitate on its media.

B. Cleanability

The filter was subjected to the cleaning process des-described under Test Method and Procedure. No difficulty was experienced in thoroughly cleaning the ionizer and collector sections of the unit, using moderate care. The after-filter was also satisfactorily cleaned using the same procedure.

C. General

On completion of the dirt-loading test, the unit was removed from the test duct and examined. The ionizer assembly and bars, and the insulators were generally coated with a moderate layer of dust and lint. Dirt deposits were heaviest on the upstream edges and first two or three inches of the collector plates, the thickness of the deposits being up to about 1/32 inch. The heaviest deposits were observed on the leading edges of the negative plates. A continuous, but thinner, layer of dirt was deposited over the remaining area of the collector plates, extending to the aft edges. Considerable bridging of lint fibers from one collector plate to another, spanning the gap between them, was observed; such bridging appeared to be wholly from the center of the unit downstream to the aft edges of the plates.

The upstream face of the after-filter revealed considerable deposits of lint, somewhat concentrated in two horizontal strips each about five inches wide. The after-filter media was approximately uniformly darkened by a dust deposit on its upstream face.

The dirt (dust) deposits on the electrostatic unit and on the after-filter appeared to be well saturated with oil. After the unit had been removed from the test duct, the duct section downstream of the unit was carefully swept out with a fine brush. The amount of material obtained from this sweeping was 0.3 grams.

The cellophane tape samples obtained at stations (1), (2), and (3), as shown in Photographs No. 1, 2, and 3, respectively, indicate in a general way the performance of the complete unit. Photograph No. 1 shows many particles under five microns in actual size, and a distribution of larger particles up to a few as large as 400 microns, as well as many fibers of lint. (In these photographs 1/16 inch corresponds to an actual dimension of about 160 microns.) Photograph No. 2 for the tape 15 inches downstream of the unit, shows a few large particles up to about 150 microns in size, but very few fine dust particles considering their number upstream of the unit. Photograph No. 3, for the tape 8 ft downstream of the unit shows fewer of the larger particles of Photograph No. 2, which apparently settled out of the air stream. No significant amount of lint fibers is visible in either downstream tape photograph, or was observed by microscopic study of the tapes.

Comparison of the numbers of particles on the upstream and downstream tapes indicates, in an obvious way, a high order of efficiency for the unit in arresting Cottrell precipitate, as is also indicated by the discoloration test results presented in Table 2. The latter results show a considerably higher efficiency for the unit when Cottrell precipitate was being received in the air stream than when the aerosol was outdoor air or kerosene lamp smoke. The overall efficiency of the unit on particles of the sizes found in Cottrell precipitate appears therefore to be better than on the finer particles in outdoor air or kerosene smoke. Nevertheless, the downstream tapes, and the deposits on the after-filter, show that a few quite large particles of dust escaped beyond the electrostatic unit. Whether the large

particles were passed through the unit because they were not arrested at all, or were caught and later dislodged from the collector plates by electrical sparking, is not known from these tests.

As the photographs show, a few large particles passed unarrested through the after-filter. Assuming that one of the functions of the after-filter is to arrest as much as possible of the material escaping the electrostatic unit, the arrestance characteristics of the after-filter are of major importance in determining the presence or absence, in the air leaving the complete unit, of such particulate matter as is shown in the downstream tape photographs.

Table 1

Face Velocity	Inlet Aerosol*	Ionizer and Plate Voltage	Pressure Drop	Duration of Test	Efficiency
fpm		kv	inch W.G.	minutes	percent
333	A	0	0.178	30	4.8**
333	A	8.4	.178	180	90.0
333	A	8.4	.178	180	90.4
333	A	8.4	.178	180	90.2
266	A	8.4	.118	180	94.2
400	A	8.4	.255	180	86.1
333	S	8.4	.177	180	90.6
333	S	8.4	.177	180	91.2
333	S	8.4	.178	180	91.7
333	C	8.4	.178	9	98.6
333	C	8.4	.179	9	98.3
333	C	8.4	.179	10	97.7

*A = Particulate matter in atmospheric air at NBS.
S = Kerosene lamp smoke in atmospheric air.
C = Cottrell precipitate in atmospheric air (1 gram/1000 cf).
** Since unit was not energized, the efficiency was chiefly that of the after-filter.

Table 2

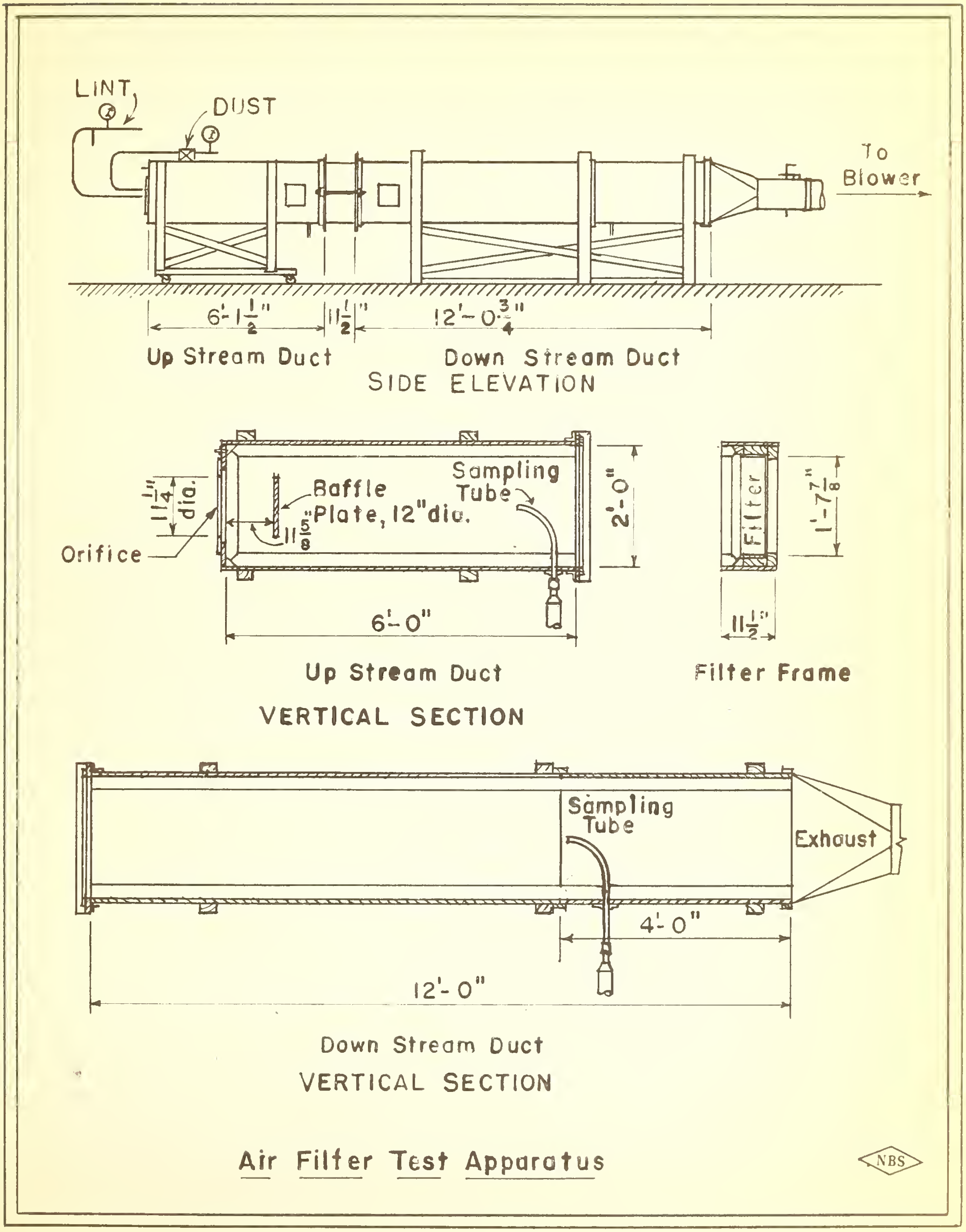
Face Velocity fpm	Dirt Load* grams	Ionizer and Plate Voltage kv	Output Current ma	Pressure Drop inch W.G.	Efficiency** percent
333	40	8.4	0.5	0.178	98.2 (Avg)
	54	8.4	.5	.180	98.7
	164	8.4	.5	.181	98.9
	333	8.4	.5	.182	98.5
	502	8.5	.5	.189	99.0
	659	(5.9)	.6	.212	88.8
		(6.2)	.6		
	700	8.5	.5	.220	98.4
		(8.5)	.5		
	886	(5.8)(a)	.6	.293	96.1
		(8.5)	.5		
	899	8.5	.5	.294	98.8
	899	8.5	.5	.293	89.2(Avg)(b)

* Average mixture: 3.9% lint, 96.1% Cottrell precipitate by weight.

** Efficiency determined with 100% Cottrell precipitate.

(a) Voltage decreased to 5.8 kv for one minute during 10-minute efficiency determination.

(b) Efficiency determined with aerosol "A" as in table 1, with the unit dirty.



LINT
DUST
To Blower
6'-1 1/2"
11 1/2"
12'-0 3/4"
Up Stream Duct
Down Stream Duct
SIDE ELEVATION
Sampling Tube
Baffle Plate, 12" dia.
11 1/4" dia.
11 5/8"
Orifice
2'-0"
6'-0"
Up Stream Duct
Filter
1'-7 7/8"
11 1/2"
Filter Frame
VERTICAL SECTION
Sampling Tube
Exhaust
4'-0"
12'-0"
Down Stream Duct
VERTICAL SECTION
Air Filter Test Apparatus
NBS

Figure 1

Photograph No. 1

Photograph No. 2

Photograph No. 3

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the front cover.

Reports and Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers and reports. Reports are issued to the sponsoring agency of a particular project or program. Published papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three monthly periodicals, available from the Government Printing Office: The Journal of Research, which presents complete papers reporting technical investigations; the Technical News Bulletin, which presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions, which provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: The Applied Mathematics Series, Circulars, Handbooks, Building Materials and Structures Reports, and Miscellaneous Publications.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($0.75), available from the Superintendent of Documents, Government Printing Office. Inquiries regarding the Bureau's reports and publications should be addressed to the Office of Scientific Publications, National Bureau of Standards, Washington 25, D. C.

NBS