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Determining the Properties of Fine Particulate Matter

POWER TEST CODES

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
United Engineering Center
345 East 47th Street New York, N.Y. 10017

Determining the Properties of Fine Particulate Matter

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FOREWORD

IN November, 1954, a group of engineers from among the leading utilities and equipment manufacturers discussed the need of standardized methods and measuring equipment to determine the size of small particulate matter such as is found in dust and smoke. It was suggested that the ASME Power Test Codes Committee undertake the preparation of such a test code. In addition to the utilities, the chemical and other industries had problems on particle sizes and were interested in the development of such a test code.

PTC Committee No. 28 on the Measurement of Small Particulate Matter was organized in April, 1955, and charged with the development of a test code. The Committee has made maximum use of the work being done by other organizations in the field such as the American Society for Testing and Materials and the Air Pollution Control Association.

The Committee has attempted to establish test standards for the determination of all of those properties of fine particulate matter which are involved in the design and evaluation of dust separating apparatus. This includes such properties as terminal velocity distribution, particle size, bulk electrical resistivity, surface area, loss on ignition, etc.

The Committee was successful in obtaining the cooperation of the U.S. Public Health Service, Department of Health, Education and Welfare, which made the facilities of its Robert A. Taft Sanitary Engineering Center available. A research project was conducted to develop and prepare "standard samples" of sub-sieve-size material for calibration of those instruments used for the determination of terminal velocity distribution. These "standard samples" will be made available for use in conjunction with the Test Code.

This Code was approved by the Power Test Codes Committee on April 27, 1964. It was approved and adopted by the ASME Council as a standard practice of the Society by action of the Board on Codes and Standards on September 15, 1964.

July, 1965

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Test Code for

DETERMINING THE PROPERTIES OF FINE PARTICULATE MATTER

CONTENTS

SECTION 0, INTRODUCTION

0.1 This Code is intended to define the test procedures to be used for the determination of those physical and chemical properties of dust which are involved in the design and evaluation of Dust Separating Apparatus.

0.2 For the purpose of this Code "dust" is defined as the particles of gas-borne solid matter having terminal velocities greater than 0.1 inch per minute in air. The larger gas-borne particles (having terminal velocities greater than 1000 inches per minute) which are the product of combustion of solid fuel are usually referred to as "cinders," but come under the general heading of dust. Smoke, as distinguished from dust, is the result of incomplete or arrested combustion of the volatile constituents of fuels and usually consists of particles having terminal velocities less than 0.1 inch per minute. Soot is composed of agglomerated smoke particles. The term "fly ash" is not used in this Code, although several of the test methods make reference to other standard methods developed for the testing of fly ash.

0.3 Unless otherwise specified, all references to other codes refer to ASME Power Test Codes.

SECTION 1, OBJECT AND SCOPE

1.01 The object of the test shall be to determine various physical and chemical properties of dust. This Code provides procedures for determining these properties and defines the terminology to be used in stating these properties.

1.02 Modifications of the test procedures contained in this Code or the determination of special data outside the scope of this Code shall be made only after written agreement of all parties to the test regarding details of the test, methods of computation, and terminology to be used in reporting results – all of which shall be completely described in the test report.

1.03 This Code excludes the methods to be employed in obtaining the samples of dust to be tested. It shall be assumed that the samples of gas-borne dust taken from a duct shall be taken in accordance with the Test Code for Determining Dust Concentration in a Gas Stream (PTC 27-1957). It is recommended that samples should not be obtained from a large bulk of material in a hopper, silo, or from a similar location. If it is necessary to take samples from such a location due to the design of the particular unit being tested, the samples shall be taken by such procedures as will insure their being representative of the whole. In either case, the methods to be employed shall be defined in a written agreement between all parties to the test.

1.04 Should the specific directions given in this Code for any particular measurement differ from those given in other ASME Power Test Codes for similar measurements, the instructions of this Code shall prevail unless otherwise agreed by the parties to the test.

SECTION 2, DESCRIPTION AND DEFINITION OF TERMS

2.01 This Code specifies the test procedures to be employed in the determination of certain physical and chemical properties of dust. These properties and other terms used in connection with their determination are defined by the following:

2.02 Terminal Velocity. The equilibrium velocity, expressed in inches per minute, associated with a given particle when the drag force produced by the particle freely falling through dry air at 68 F and 29.92 in. Hg abs is equal and opposite to the force of gravity acting on the particle to produce the motion.

2.03 Terminal Velocity Distribution. The tabular or graphical presentation of data showing the per cent by weight of those particles in a dust sample having terminal velocities less than various indicated values.

2.04 Specific Gravity. The weight per unit volume of a particle or a group of particles in a dust sample relative to that of pure water at 4 C, expressed as a decimal fraction. Only that volume actually occupied by the particles is to be considered, not the voids between the particles as they rest together.

2.05 Sieve Analysis. The tabular or graphical presentation of data showing the per cent by weight of those particles which are able to pass through the openings of various indicated sizes of sieves. Unless otherwise specified, sieve numbers shall refer to the U.S. Standard Sieve Series.

2.06 Bulk Electrical Resistivity. The resistance to current flow, expressed in ohm-centimeters, through a dust sample contained in a cubic volume one centimeter on a side when exposed to an electrical potential equivalent to 90 per cent of the breakdown voltage of the sample applied uniformly across two opposite faces of the cube. Unless otherwise specified, this property shall be determined when the sample is in equilibrium with air at a temperature of 300 F and at a humidity of 5 per cent by volume.

2.07 Breakdown Voltage. The electrical potential, expressed in volts per centimeter, which will produce a change in the physical characteristics of a dust sample accompanied by sudden increase in current flow through the sample beyond that occurring at a slightly lower potential. Unless otherwise specified, this property shall be determined under the same conditions as those for the determination of Bulk Electrical Resistivity.

2.08 Moisture Content. The loss in weight of a dust sample, expressed in per cent, occurring when the sample is dried in free air at a temperature of 105 C.

2.09 Loss on Ignition. The loss in weight of a dried dust sample, expressed in per cent, occurring when the sample is ignited in free air at a temperature of 800 C.

2.10 Water Soluble Content. The loss in weight of a dried dust sample, expressed in per cent, occurring when the sample is elutriated with boiling water at atmospheric pressure and then redried.

2.11 Water Soluble Sulfate Content. The sulfate content of a dried dust sample, expressed in per cent by weight, which can be removed from the sample by elutriation with boiling water at atmospheric pressure. Unless otherwise specified, the sulfate content shall be calculated as sulfuric acid (H_2SO_4).

2.12 Bulk Density. The density, expressed in pounds per cubic foot, of an uncompressed dust sample.

2.13 Specific Surface. The surface area per unit weight of a dust sample, expressed in square centimeters per gram.

2.14 Those abbreviations and symbols involved in the conduct of specific tests are defined in the test instructions.

SECTION 3, GUIDING PRINCIPLES

3.01 The tests to be conducted on a sample of dust shall be those which furnish data regarding the physical and chemical properties of the material which are pertinent to the design and evaluation of the performance of Dust Separating Apparatus.

3.02 Items on Which Agreement Shall be Reached. The parties to a series of tests on a sample of dust shall reach agreement on the following items, and the agreement shall be in writing:

(a) The physical and/or chemical properties to be determined by the tests

(b) The tests to be employed in the determination of these properties

(c) Details as to any modifications of the test procedures

(d) The source of the sample

(e) The methods to be employed in obtaining the sample in cases of deviation from, or for points not covered by, Test Code for Determining Dust Concentration in a Gas Stream (PTC 27-1957)

(f) Selection of the laboratory for making any tests on the sample if equipment and trained personnel for conducting these tests are not available to parties of the agreement

(g) Tolerances, if any, to be applied.

3.03 Tolerances. This Code does not specify tolerances to be applied to the test results. However, in the description of each test, the limits of accuracy of the test are stated as well as the range of results which shall be considered acceptable when duplicate tests are performed on different specimens of the sample. If multiple tests are to be performed on a given sample by a laboratory, the method of reporting the composite results shall be established by agreement of all parties concerned.

3.04 Reports. The report of tests on a sample of dust need only include those items relative to the tests upon which agreement has been reached plus the actual test results. However, full details as to the conduct of the tests and the data taken during the tests shall be made available to any party to the agreement upon request.

SECTION 4, TEST METHODS

4.01 The following test methods shall be employed to determine those physical and chemical properties of dust defined in Section 2 of this Code.

4.02 – METHOD FOR THE DETERMINATION OF TERMINAL VELOCITY DISTRIBUTION

Apparatus:

1. Centrifugal Classifier, conforming to the description in the Appendix, see Figs. 1 and 2.
2. Chemical Balance.
3. Scoop, spatula, soft brush, large sheets of glazed paper.
4. Sieve, 100 mesh (U.S. Sieve Size).

Procedure:

1. Dry the sample in a drying oven at a temperature of 105–110 C to constant weight. Cool in a desiccator. Weigh out a portion of the dried sample of approximately 10 grams. Record the weight to the nearest 0.01 gram as W_s. See Note 3.
2. Screen the weighed sample through the 100 mesh sieve. Weigh the portion of the sample passing through the sieve. Record the weight as W_o.
3. Insert the largest throttle spacer, Throttle *A*, under the grading member of the Centrifugal Classifier and secure.
4. Transfer the portion of the sample weighed in Step 2 to the feed hopper. Replace the hopper cover and secure.
5. Start the rotor motor. When the rotor reaches maximum speed, start the nitrogen flow. See Note 4. Turn on the vibrator and brush motor. The vibrator may be controlled by the rheostat.
6. After approximately five minutes of operation, switch off the brush motor and the vibrator. Turn off the nitrogen flow. Remove the cover from the feed hopper. Estimate the quantity of sample that has been fed into the classifier and ascertain whether the feed rate is within limits. See Note 5. If the adjustable slide and the brush have been properly positioned, the feed rate can be adjusted to the correct value by means of the vibrator rheostat.
7. Replace the cover on the feed hopper. Start the nitrogen supply. Turn on the vibrator and the brush motor. Adjust the vibrator to obtain correct feed rate.
8. Continue operation until the feed hopper is empty. Switch off the brush motor and the vibrator. Turn off the nitrogen flow. Switch off the rotor motor and stop the rotor by gently applying the brake.
9. Swing the cover casing up out of the way. Remove the knurled locking ring. Raise the upper rotor assembly out of the lower section and place it on a large sheet of clean glazed paper.
10. Brush the adhering dust to the bottom of the catch basin. Detach the catch basin. Collect the dust from the catch basin plus any that spills on the glazed paper and weigh. Record the weight as W_a.
11. Reassemble the catch basin and the upper rotor assembly and secure the knurled locking ring. Replace the throttle spacer with the next smaller size, Throttle B.
12. Transfer the sample weighed in Step 10 to the feed hopper. Repeat Steps 5 through 10, recording the weight of sample as W_b. See Note 5.
13. Repeat Steps 5 through 12 for each of the remaining throttles, using as feed the residue from the preceeding run. Record the weights as W_c, W_d, W_e, etc.

Calculations:

1. Calculate the Weight Per Cent Smaller Than Indicated Size corresponding to the Terminal Velocity values for each throttle as follows, using the terminal velocity values obtained for each throttle during calibration of the Centrifugal Classifier.

$F_a = 100\,(W_o - W_a)/W_s$, and

$F_b = 100\,(W_o - W_b)/W_s$, and

$F_c = 100\,(W_o - W_c)/W_s$, etc., where

F_a, F_b, F_c, etc. = fraction of sample in weight per cent, having terminal velocities less than U_a, U_b, etc.

U_a, U_b, U_c, etc. = Terminal Velocity values in inches per minute, assigned to Throttles *A, B, C,* etc.

W_s = weight of sample.

W_o = weight of that portion of the sample passing through 100 mesh sieve.

W_a, W_b, W_c, etc. = weights of sample remaining after fractionation using Throttles *A, B, C,* etc. respectively.

2. The data obtained above should be plotted on logarithmic probability graph paper, the logarithm of the Terminal Velocity (in inches per minute) versus the Weight Per Cent Smaller Than Indicated Size. A typical curve is shown in Fig. 3 in the Appendix.

Notes:

1. Prior to conducting any terminal velocity distribution analyses in accordance with this Code, the Centrifugal Classifier should be installed and calibrated in accordance with the procedure described in the Appendix. The calibration should be checked periodically by testing a portion of material previously tested which has a known terminal velocity distribution.
2. Clean the Centrifugal Classifier thoroughly before each test, making sure that no films remain which would cause dust particles to adhere to the surface of the apparatus.
3. Particular care should be taken to insure that the 10 gram sample used in this test is representative of the gross sample in respect to particle size.
4. The nitrogen gas pressure should not exceed one-half inch of mercury as registered on the manometer. Higher pressures will tend to blow the sample out of the cup section in the upper rotor. This will contaminate the sample on the stop ring. If this condition exists, it will be indicated by a fine coating of material on the lock ring.
5. The sample need not be inspected during the subsequent runs (Steps 6 and 7) once the proper feed rate has been obtained. A feed rate of approximately 1 gram per minute is desirable. With higher feed rates, the sample may not be properly deagglomerated. If sufficient gross sample is available, the correct feed rate can be established on a portion of the material prior to the actual test on the 10 gram sample. Otherwise the feed rate should be determined by using a sample having similar characteristics.
6. All weights should be recorded to the nearest 0.01 gram.

4.03 – METHOD FOR THE DETERMINATION OF SPECIFIC GRAVITY

References:

1. ASTM Designation C 188-44, "Method of Test for Specific Gravity of Hydraulic Cement."

Apparatus and Reagents:

1. Le Chatelier Flask, conforming to the dimensions shown in Fig. 11.
2. Funnel, long stem (approximately 150 mm).
3. Constant temperature Water Bath.
4. Chemical Balance.
5. Kerosene or Naphtha, water free, having a specific gravity not lighter than 62 degrees API.
6. Thermometers, small spatula, and scoop.

Procedure:

1. Using the long stem funnel, fill the flask with kerosene or naphtha to a point on the stem between the zero and the 1 ml mark.
2. Immerse the flask in the constant temperature water bath maintained at or about room temperature. Place the thermometer in the liquid in the flask. When the temperature of the liquid is the same as that of the bath, remove the thermometer and determine the volume of the liquid. Record the volume as V_1. See Note 1.
3. Dry approximately 100 grams of the sample in a drying oven at a temperature of 105–110 C. Cool in a desiccator. Weigh out a portion of the dried sample of approximately 50 grams. Record weight as W_s.
4. Introduce the dried sample (which should be at room temperature) into the flask with a small spatula or scoop. Take care to avoid splashing and see that the sample does not adhere to the inside of the flask above the liquid. Add sample in small increments to prevent trapping air bubbles in the liquid-sample mixture. If the proper amount of sample has been added, the level of liquid will be between the 18 and the 24 ml marks. See Note 2.
5. Place the stopper in the flask and roll the flask in an inclined position to free entrapped air from the mixture. Continue until no air bubbles rise to the surface. See Note 3.
6. Immerse the flask in the constant temperature water bath and insert the thermometer. When the liquid in the flask is at the same temperature as that of the bath, remove the thermometer and determine the volume of the liquid. Record the volume as V_2.

Calculations:

1. Calculate the Specific Gravity to the nearest 0.01 as follows:

$$\text{Specific Gravity} = W_s/\Delta V \rho_{H_2O}\text{, where}$$

W_s = weight of sample, in grams

$\Delta V = V_2 - V_1$ = displaced volume, in ml

ρ_{H_2O} = density of water, in grams/ml at 4 C = 1.00.

Notes:

1. The flask shall be immersed in a constant-temperature water bath, maintained at about room temperature, for a sufficient interval before making either of the readings so as to avoid variations greater than 0.2 C in the temperature of the liquid in the flask. All readings shall be checked until they are constant to ensure that the contents of the flask have reached the temperature of the water bath. Be extremely careful when removing the thermometer from the flask prior to reading the liquid volume. A loss of as little as two drops of liquid will induce an error in the calculated specific gravity of the order of 0.01 unit.
2. If, after sample addition, the liquid level is higher or lower than the graduated center portion of the flask, a smaller or larger portion of sample must be used.
3. It is advisable to use a rubber pad on the table top when filling or rolling the flask.

4.04 – METHOD FOR THE DETERMINATION OF SIEVE ANALYSIS

References:

1. ASTM Designation E 11-60T, "Tentative Specifications for Sieves for Testing Purposes."

Apparatus:

1. Sieves, U.S. Standard Series, 8 inches in diameter, conforming to Ref. 1, 60 mesh, 100 mesh, 200 mesh, and 325 mesh.
2. Balance, having a capacity of at least 50 grams and a sensitivity of 0.05 grams.
3. Brush, ½ in. to ¾ in. wide, with soft bristles.
4. Glazed paper.

Procedure:

1. Weigh out a 50 gram portion of the sample to the nearest 0.1 gram. Record weight as W_s.
2. Place sample on the 60 mesh sieve, with the pan attached, and attach cover. Hold the sieve in one hand in a slightly inclined position so that the sample will be well distributed over the sieve, at the same time gently striking the side about 150 times per minute against the

palm of the other hand on the upstroke. Turn the sieve every 25 strokes about one sixth of a revolution in the same direction. Continue the operation until not more than 0.05 grams of sample pass through the sieve in one minute of continuous sieving. Each time, before weighing the material passing through the sieve, tap the side of the sieve with the brush handle in order to remove any material adhering to the wire cloth.

3. When the sieving has been finished, remove the cover of the sieve and carefully remove the residue remaining on the sieve to a tared container. Invert the sieve over a piece of glazed paper and clean the wire cloth by brushing the under side. Add the material thus removed from the wire cloth to the residue removed from the sieve.

4. Weigh the portion of the sample retained on the sieve to the nearest 0.1 gram. Record weight as W_{60}.

5. Place the material passing through the 60 mesh sieve on the 100 mesh sieve. Continue sieving in a similar manner, using successively each of the selected sieves in the order of decreasing size of opening, and recording the weight of that portion of the sample retained on each sieve. Use the appropriate subscripts – W_{100}, W_{200}, etc.

Calculations:

1. Calculate Screen Analysis, in weight per cent smaller than indicated mesh size, to the nearest 0.5 per cent as follows:

$$\text{Weight per cent smaller than 60 mesh} = 100\,(W_s - W_{60})/W_s$$

$$\text{Weight per cent smaller than 100 mesh} = 100\,(W_s - W_{60} - W_{100})/W_s$$

$$\text{Weight per cent smaller than 200 mesh} = 100\,(W_s - W_{60} - W_{100} - W_{200})/W_s$$

$$\text{Weight per cent smaller than 325 mesh} = 100\,(W_s - W_{60} - W_{100} - W_{200} - W_{325})/W_s$$

Notes:

1. The dust sample should be pre-dried for one hour in a drying oven at a temperature of 105–110 C. Cool sample in desiccator to room temperature prior to performing the above test procedures.

2. Washers, slugs, or shot shall not be used on the sieves.

3. Mechanical sieving devices may be used by mutual consent of all parties concerned. When these devices are used, their thoroughness of sieving shall be tested by using the hand method for comparison. If such a device is used it should be so stated in the report of the test results.

4. When the quantity of sample available for analysis is limited, the test may be conducted using smaller diameter sieves by mutual consent of all parties concerned. When using the smaller 5 inch diameter sieves, a 20 gram sample portion should be used instead of the 50 gram stated above.

5. By mutual agreement of all parties concerned, other mesh size sieves may be used. Calculate the test results in the same manner, using the appropriate subscripts when recording the weight of sample remaining on each sieve.

6. See Table 4 in the Appendix for specifications of U.S. Standard Series Sieves. This table is reproduced from Ref. 1.

4.05 – METHOD FOR THE DETERMINATION OF BULK ELECTRICAL RESISTIVITY

References:

1. Air Pollution Control Association, "Approved Standard Method for the Determination of Bulk Electrical Resistivity of Dry Particulates."

Apparatus:

1. High-Voltage Conductivity Cell. See Note 2.

2. Electric Oven, temperature and humidity controlled. See Note 3.

Procedure:

1. Place the sample in the cup of the conductivity cell by means of a spatula. Level by drawing a straight edge blade, held vertically, across the top of the cup. See Note 4.
2. Gently lower the disk electrode onto the surface of the sample. It should rest freely on the sample surface without binding in its support. The guard ring may be attached physically to the movable disk electrode by means of suitable high temperature insulators, e.g., mica, silica, or alumina, or it may be mounted and guided separately. See Note 5.
3. Resistivity measurements shall be made at a temperature of 300 F and a humidity of 5 per cent by volume unless otherwise specified. See Note 6. Mount the conductivity cell in the electric oven and establish the equilibrium temperature and humidity.
4. In making a measurement, the voltage applied to the cell should be raised from zero in a series of small steps and the current through the sample layer observed for each voltage step up to the point of electrical breakdown of the sample layer. Before making the actual resistivity measurement the breakdown voltage of the sample should be determined by at least three observational runs in which the voltage is raised gradually to the breakdown point. The sample layer should be remixed and releveled after each run in order to break up any spark channels that may have been forced through the sample layer. An entirely new sample is preferred for each run if possible. Record the breakdown voltages as V_{B-1}, V_{B-2}, V_{B-3}, etc. Calculate the average breakdown voltage, V_B.
5. Determine the resistivity of the sample in the range of 85 to 95 per cent of the average breakdown voltage. Since the voltage-current characteristics of most samples will be non-linear, the resistivity shall be calculated using correspondence values of voltage and current. Record the voltage and current readings as E_1 and I_1, E_2 and I_2, etc.

Calculations:

1. Calculate the Bulk Electrical Resistivity to three significant figures as follows:

Bulk Electrical Resistivity,

$$\text{in ohm-cm} = \frac{E \times A}{I \times L}, \text{ where}$$

E = voltage applied to conductivity cell (85 – 95% of V_B), in volts.

I = current corresponding to voltage E, in amperes.

A = cross-section area of disk electrode, in square centimeters.

L = thickness of sample layer between electrode, in centimeters.

V_B = average of V_{B-1}, V_{B-2}, V_{B-3}, etc. = breakdown voltage, in volts.

2. The value of the breakdown voltage should be reported along with the value of the Bulk Electrical Resistivity.

Notes:

1. This method is applicable only for dust samples which have a bulk electrical resistivity in excess of 1×10^7 ohm-cm.
2. The electrical resistivity of the sample shall be determined by means of a high-voltage conductivity cell having the basic dimensions shown in Fig. 7 in the Appendix. An acceptable method of construction is shown in Fig. 8. The electrical circuit for the determination of the resistivity is shown in Fig. 9.
3. For measurements at elevated temperatures and controlled humidity, the conductivity cell is mounted in an electric oven with thermostatic temperature control and good thermal insulation to maintain uniform internal temperature. Humidity may be controlled by any one of several conventional means, including circulation of pre-conditioned gas through the oven, injection of a controlled amount of steam, temperature controlled circulating water bath, or by certain chemical solutions which control vapor pressure. To provide intimate contact between the humidified gas and the dust sample in the conductivity cell it is desirable to circulate the humidified gas directly through the dust layer. This should be done by using sintered stainless steel electrodes of 25 micron porosity. An acceptable method for humidity control and measurement is shown in Fig. 10 in the Appendix.

4. It will be noted that this method of filling may introduce slight variations in the packing of the sample in the cup. However, tests indicate that this effect is relatively small for the large majority of dust samples encountered in practice.

5. In general the latter arrangement is to be preferred since there will be a free air gap between the guard ring and the movable disk electrode with no possibility of current leakage between the two. The annular spacing of approximately 1/32 inch between the guard ring and the movable disk electrode is ample provided the mechanical supports or guide means are accurately made. The details for accomplishing this are not shown as this is a matter of convenience in mechanical design rather than a fundamental factor.

6. The conditions for equilibrium of temperature and moisture content of the sample with that of the temperature and humidity controlled atmosphere in contact with it shall be determined by the requirement that resistivity measurements be reproducible within 10 per cent when determined by two successive measurements made 15 minutes apart. Further, since the particle conductivity usually depends on the past treatment of the particle as well as the temperature and humidity equilibrium reached under given conditions, it is preferable to determine the resistivity by raising the oven temperature to the value desired rather than by first overheating the oven and then cooling it to the desired temperature.

4.06 – METHOD FOR THE DETERMINATION OF MOISTURE CONTENT

References:

1. ASTM Designation C 311-57T, "Methods of Sampling and Testing Fly Ash for Use as an Admixture in Portland Cement."
2. ASTM Designation D 271-48, "Methods of Laboratory Sampling and Analysis of Coal and Coke."

Apparatus:

1. Drying Oven. See Note 1.
2. Desiccator.
3. Chemical Balance.
4. Combustion Crucibles with Covers. See Note 2.
5. Crucible Tongs and Spatula.

Procedure:

1. Dry the empty crucible and cover in the drying oven at a temperature of 105–110 C. Cool crucible and cover in the desiccator for 30 minutes and weigh to the nearest 0.001 gram. Record weight as W_1.
2. Using the spatula, place approximately 1 gram of the sample into the crucible. Cover the crucible quickly and weigh at once. Record weight as W_2.
3. Remove cover and quickly place the crucible into the preheated drying oven. Return the cover to the desiccator. Close the oven at once and heat the sample for 1 hour at a temperature of 105–110 C. Open the oven and quickly cover the crucible. Cool the covered crucible and its contents in the desiccator for 30 minutes and then weigh. Record weight as W_3.

Calculations:

1. Calculate the Moisture Content to the nearest 0.1 per cent as follows:

$$\text{Moisture Content, in } \% = \frac{W_L}{W_s} \times 100, \text{ where}$$

$W_L = W_2 - W_3$ = weight loss in drying, in grams.

$W_s = W_2 - W_1$ = weight of sample, in grams.

Notes:

1. Drying oven should be designed to maintain a temperature of 105–110 C. Natural or forced convection of clean, dry air must be provided to remove moisture from samples drying in the oven.
2. Combustion crucibles having a large surface area on base and a capacity of 10 to 30 ml, with matching aluminum covers, should be used. Crucibles and crucible covers which comply with ASTM Designation D 271-48 are suitable.
3. Make sure, by proper mixing, that the sample used in this test is representative of the gross sample.

4.07 – METHOD FOR THE DETERMINATION OF LOSS ON IGNITION

References:

1. ASTM Designation C 311-57T, "Methods of Sampling and Testing Fly Ash for Use as an Admixture in Portland Cement."
2. ASTM Designation D 271-48, "Methods of Laboratory Sampling and Analysis of Coal and Coke."
3. ASTM Designation C 114-53, "Standard Methods of Chemical Analysis of Portland Cement."

Apparatus:

1. Drying Oven.
2. Desiccator.
3. Chemical Balance.
4. Combustion Crucibles with Covers. See Note 1.
5. Muffle Furnace.
6. Crucible Tongs and Spatula.

Procedure:

1. Dry approximately 5 grams of the sample to constant weight in the drying oven at a temperature of 105–110 C. Store the dried sample in the desiccator.
2. Ignite the empty crucible to constant weight in the muffle furnace at a temperature of 800 ± 50 C. Cool crucible in the desiccator. Place cover on the crucible and weigh to the nearest 0.001 gram. Record weight as W_1.
3. Using the spatula, place approximately 1 gram of the dried sample into the crucible. Cover the crucible quickly and weigh at once. Record weight as W_2.
4. Remove the cover and place the uncovered crucible and its contents into the preheated muffle furnace. Return the cover to the desiccator. Ignite the uncovered crucible and its contents, with free access for air, to constant weight at a temperature of 800 ± 50 C. Remove the crucible and cool in the desiccator. Cover with the crucible cover and weigh. Record weight as W_3.

Calculations:

1. Calculate the Loss on Ignition to the nearest 0.1 per cent as follows:

$$\text{Loss on Ignition, in }\% = \frac{W_L}{W_s} \times 100, \text{ where}$$

$W_L = W_2 - W_3$ = weight loss on ignition, in grams.

$W_s = W_2 - W_1$ = weight of sample, in grams.

Notes:

1. Combustion crucibles having a large surface area on base and a capacity of 10 to 30 ml, with matching aluminum covers, should be used. Crucibles and crucible covers which comply with ASTM Designation D 271-48 are suitable.
2. Make sure, by proper mixing, that the sample used in this test is representative of the gross sample.
3. The term "constant weight" for the 5 grams of dried sample denotes a loss in weight of less than 5 milligrams per hour. For the crucible and the 1 gram dried and/or ashed sample, the term "constant weight" denotes a loss in weight of less than 1 milligram per hour.

4.08 – METHOD FOR THE DETERMINATION OF WATER SOLUBLE CONTENT

Reference:

1. Air Pollution Control Association "Approved Standard Method for the Determination of Water Soluble Content of Fly Ash."

Apparatus and Reagents:

1. Chemical Balance.
2. Desiccator.
3. Beaker, 400 ml.
4. Wash Bottle.
5. Gooch Crucible, with asbestos mat.
6. Vacuum Flask.
7. Graduated Cylinder, 250 ml.

Procedure:

1. Dry approximately 5 grams of the sample in a drying oven at a temperature of 105–110 C for

one hour. Cool and store the dried sample in a desiccator.

2. Weigh out a 1.0 gram portion of the dried sample. Record the weight to the nearest 0.001 gram as W_1. Using a wash bottle with a fine stream of water, carefully wet and transfer the sample to a 400 ml beaker. Increase the volume of water to approximately 125 ml.
3. Boil gently for 15 minutes. Remove from heat and wash down the cover glass and the walls of the beaker with hot water.
4. Using a vacuum, filter through a predried, weighed Gooch crucible containing an asbestos mat. Catch the filtrate in a clean, properly trapped vacuum flask. Carefully police all particles from the beaker and wash the beaker and crucible well with hot water. Record the crucible weight before filtration as W_2.
5. Dry the crucible in an oven at 105–110 C for one hour. Cool in desiccator and weigh rapidly. Record weight as W_3.

Calculations:

1. Calculate the Water Soluble Content to the nearest 0.1 per cent as follows:

$$\text{Water Soluble Content, in } \% = \left[1 - \frac{W_R}{W_s}\right] \times 100,$$

where

$W_R = W_3 - W_2$ = weight of insoluble portion of sample, in grams.

$W_s = W_1$ = weight of sample, in grams.

Notes:

1. This method can be combined with that for the determination of Water Soluble Sulfate Content. Carry out the procedure for that method, following the instructions in the Notes for combining the two methods.
2. All water used in this method shall be either distilled or demineralized.

4.09 – METHOD FOR THE DETERMINATION OF WATER SOLUBLE SULFATE CONTENT

Reference:

1. Air Pollution Control Association, "Approved Standard Method for the Determination of Water Soluble Sulfate Content of Fly Ash."

Apparatus and Reagents:

1. Hydrochloric Acid, Concentrated, Reagent Grade.
2. Barium Chloride Solution, 100 grams per liter.
3. Chemical Balance.
4. Desiccator.
5. Beakers, 400 ml.
6. Wash Bottle.
7. Buchner Funnel and Vacuum Flask.
8. Filter Paper, Whatman No. 42 or equivalent.
9. Graduated Cylinder, 250 ml.
10. Pipettes, 3 ml and 10 ml.
11. Thermometer.
12. Gooch Crucible, with asbestos mat.

Procedure:

1. Dry approximately 5 grams of the sample in a drying oven at a temperature of 105–110 C for one hour. Cool and store the dried sample in a desiccator.
2. Weigh out a 1.0 gram portion of the dried sample. Using a wash bottle with a fine stream of water, carefully wet and transfer the sample to a 400 ml beaker. Increase the volume of water to approximately 125 ml. Record the sample weight to the nearest 0.001 gram as W_1.
3. Boil gently for 15 minutes. Remove from the heat and wash down the cover glass and walls of the beaker with hot water.
4. Using a vacuum, filter through a Buchner funnel containing a fine grade of filter paper. Catch the filtrate in a clean, properly trapped vacuum flask. Wash the beaker and the funnel well with hot water from wash bottle. Discard residue. See Note 1.
5. Transfer filtrate to a 400 ml beaker. Add 3 ml of concentrated Hydrochloric Acid. Increase the volume to approximately 250 ml with water and bring to a gentle boil.
6. Remove from the heat and, while stirring vigorously, slowly add 10 ml of Barium Chloride Solution. Allow Beaker to set for at least two

hours, with periodic stirring, at a temperature of 50–70 C.

7. Filter through a fine grade of filter paper or through a pre-ignited weighed Gooch crucible. Police the beaker well as the Barium Sulfate precipitate tends to adhere to the walls and bottom of the beaker. Wash well with hot water, but not with excessive amounts if quantity of precipitate is small.

8. Dry and ignite the Gooch crucible over a Bunsen burner or in a muffle furnace for one-half hour. If a filter paper is used, the paper should be charred carefully and ignited with free access of air. Cool in a desiccator and weigh. Record weight of Gooch crucible (or pre-ignited standard crucible if filter paper is used) before filtration as W_2. Record weight after filtration and ignition as W_3.

Calculations:

1. Calculate the Water Soluble Sulfate Content to the nearest 0.1 per cent as follows:

Water Soluble Sulfate Content as

$$H_2SO_4\text{, in \%} = 42 \times \frac{W_P}{W_S}\text{, where}$$

$W_P = W_3 - W_2$ = weight of Barium Sulfate precipitate, in grams.

$W_s = W_1$ = weight of sample, in grams.

Notes:

1. This method can be combined with that for the determination of Water Soluble Content. In Step 4 of the Procedure use a pre-dried, weighed Gooch crucible containing an asbestos mat. Then, using this crucible, proceed with Step 5 of the Procedure for the determination of the Water Soluble Content.

2. All water used in this method shall be either distilled or demineralized.

4.10 – METHOD FOR THE DETERMINATION OF BULK DENSITY

Reference:

1. ASTM Designation B 329-58T, "Tentative Method of Test for Apparent Density of Refractory Metals and Compounds by the Scott Volumeter."

Apparatus:

1. Scott Volumeter, constructed in accordance with Ref. 1. See Fig. 13.

2. Balance, having a capacity of at least 100 grams and a sensitivity of 0.1 grams.

3. Spatula, flat, with a ½ inch wide blade.

4. Graduated Cylinder, 25 to 50 ml capacity.

Procedure:

1. Assemble the test apparatus as shown in Fig. 13.

2. Measure out a portion of the sample approximately 20 to 25 ml in volume. Pour this test specimen carefully into the funnel and permit the material to run into the density cup only until it completely fills and overflows the periphery of the cup. Then rotate the funnel and baffle box approximately 90 degrees in a horizontal plane to obtain access to the top of the density cup.

3. Remove the excess material by passing a spatula blade parallel to, and in contact with, the top of the cup. Move the spatula smoothly along a diagonal of the cup and back again until all excess sample has been removed. Where there is insufficient sample left for the first reverse pass to smooth out the surface completely, the material on the spatula should be gently replaced on top of the cup first. It is important that the spatula be kept level at all times to prevent packing or pulling out of the sample.

4. After the leveling operation, tap the side of the density cup lightly to settle the sample to avoid spilling in transfer. Transfer the sample to the balance and weigh to the nearest 0.1 grams. Record weight as W_s.

Calculations:

1. Calculate the Bulk Density to the nearest lb/ft^3 as follows:

Bulk Density, in pounds per cubic foot = $W_s \times 3.81$, where

W_s = weight in grams of 1 cubic inch of uncompacted sample.

Notes:

1. The dust sample should be predried for one hour in a drying oven at a temperature of 105–110 C. Cool sample in desiccator to room temperature prior to performing the above test procedure.

4.11 – METHOD FOR THE DETERMINATION OF SPECIFIC SURFACE

Reference:

1. ASTM Designation C 204-55, "Standard Method of Test for Fineness of Portland Cement by Air Permeability Apparatus."

Apparatus and Reagents:

1. Blaine Air Permeability Apparatus, constructed in accordance with Ref. 1. See Fig. 12.
2. Manometer Fluid. A nonvolatile, nonhygroscopic liquid of low viscosity and density, such as dibutylphthalate or a light grade of mineral oil.
3. Filter Paper, such as Whatman No. 40, corresponding to Type 1, Grade B, as prescribed in Federal Specifications for Paper; Filtering (UU-P-236)
4. Filter Paper Disk Cutter. See Note 1.
5. Timer, readable to ½ second.
6. Chemical Balance.
7. Mercury, approximately 150 grams.
8. Tared Beaker and Watch Glass for mercury and sample.
9. Flat Glass, for leveling mercury, such as microscopic slide.
10. Rubber Cell Holder. See Note 2.
11. Petri Dish, approximately 100 mm diameter.
12. Stopcock Grease.

Procedure: Determination of specific surface and/or density –

1. Determine specific gravity of sample using "Method for the Determination of Specific Gravity," described in this Code. Record the value obtained as ρ_s. See Note 3.

Procedure: Determination of sample porosity in cell –

1. Cut two filter disks and place in bottom of cell on perforated brass disk. They must lie flat and be free from wrinkles.
2. Insert cell in rubber cell holder and place within the Petri dish. Fill cell to overflowing with mercury. With watch glass, level the mercury, using a cutting motion across top of cell. Do not tip cell. Catch excess mercury in Petri dish.
3. Transfer mercury from cell to tared beaker and weigh. Record weight to nearest 0.01 grams as W_1.
4. Remove top filter disk. Select trial amount of sample weighed to nearest 0.01 grams. Select weight as 0.1 to 0.2 grams less than the numerical value of the specific gravity. Put sample, carefully fluffed, into cell. Record sample weight as W_s.
5. Replace top filter disk and insert plunger. Turn plunger into cell until shoulder of plunger is flush with top of cell.
6. Remove plunger, insert cell in rubber cell holder within Petri dish, and carefully fill space in cell above sample to overflowing with mercury.
7. Level as before and transfer mercury in cell to the tared beaker. Weigh mercury to nearest 0.01 grams and record weight as W_2.

Calculations: Determination of sample porosity in cell –

1. Select density of mercury from Table 1 in the Appendix according to the ambient temperature. Record density in grams/cm³, as ρ_m.
2. Calculate the volume occupied by the sample to the nearest 0.01 cm³ as follows:

   $$\text{Sample Volume} = (W_1 - W_2)/\rho_m = V_s$$

3. Calculate porosity of sample in cell to the nearest 0.001 as follows:

   $$\text{Porosity} = 1 - W_s/V_s\,\rho_s = e$$

4. The desired porosity is 0.505 ± 0.005. The firmness of the bed, however, is the critical factor. Variations in the physical characteristics of the dust sample may make it dif-

ficult to achieve a firm bed with the desired porosity. Make several attempts to create a firm bed by adjusting the sample weight. Do not, however, use excessive pressure in attempting to achieve the desired porosity or make use of a loose bed even if its porosity is between 0.500 and 0.510.

5. Retain sample of desired porosity in cell for determination of specific surface. Use the values of W_s and e obtained for this sample in future calculations.

Procedure: Determination of Specific Surface –

1. Place cell containing sample of desired porosity, e, in cup of manometer, sealing joint with stopcock grease.
2. With stopcock open, draw manometer fluid to top graduation. Close stopcock. Time the interval required for level of fluid to drop from the second to the third graduation when the stopcock is opened. Record time to the nearest 0.5 second as T.
3. Repeat Step 2 until time intervals are constant to within 0.5 seconds. Use the final value of T in the following calculations:

Calculations: Determination of Specific Surface –

1. Calculate the Specific Surface, in cm²/gram, as follows:

$$\text{Specific Surface} = \frac{k\sqrt{e^3}\sqrt{T}}{\rho_s(1-e)\sqrt{\eta}}, \text{ where}$$

k = calibration constant for apparatus. See Note 5.

$\sqrt{e^3}$ = value taken from Table 2 in the Appendix for the appropriate value of e.

$\sqrt{T}$ = value taken from Table 3 in the Appendix for the appropriate value of T.

$\sqrt{\eta}$ = value taken from Table 1 in the Appendix for viscosity of air at the room temperature.

Notes:

1. A cork borer, or similar device, shall be used to cut filter paper disks of the proper size to fit smoothly in the bottom of the sample cell.
2. A large rubber stopper, drilled to receive the base of the sample cell, should be used to hold the cell upright in the Petri dish.
3. The term ρ_s is by definition the specific gravity of the dust sample. However, this numerical value shall be used for calculation purposes in this test method as a density value having units of grams/cm³.
4. The dust sample should be predried for one hour in a drying oven at a temperature of 105–110 C. Cool sample in desiccator to room temperature prior to performing the above test procedures.
5. Blaine Air Permeability Apparatus must be calibrated on National Bureau of Standards standard sample No. 114. This shall be done by performing the procedures described above, using the standard sample. Using the value of specific surface assigned to the standard sample, solve the above equations for the calibration constant, k. Use this value of k in succeeding calculations when determining the Specific Surface of dust samples.

SECTION 5, APPENDIX

5.01 Note: The term "weight" is used in this Code in accordance with the general practice although the term "mass" would be technically correct. "Weight" is by definition a force of gravitational attraction which changes with location and altitude. "Mass" is a property of matter independent of the force of gravitational attraction.

5.02 Description of Centrifugal Classifier. A Centrifugal Classifier shall be used for the determination of Terminal Velocity Distribution. The instrument is a combination air centrifuge-elutriator consisting of a rotor assembly driven by a totally enclosed electrical motor. The rotor is enclosed in a housing which also supports the sample feed mechanism. A typical instrument of this type is shown in Fig. 1. The motor operates at 3500 rpm creating precisely controlled air velocities within the air spiral and sifting chamber of the centrifuge. The unit employs the following operating principle:

5.03 The sample is introduced into a spiral shaped air current flowing toward the center. The spiral current of air has suitable values of tangential and radial velocities so that a certain part of the sample is accelerated by the centrifugal force toward the periphery of the whirl, the other part of the sample being carried by the air current toward the center of the whirl by means of friction between the air and the dust particle. The size, shape, and weight of the particles determines which direction they will take in the air current. By varying the air flow, it is possible to change the terminal velocity limit of division and thus the material can be divided into a number of fractions with limited terminal velocity ranges.

5.04 By referring to Fig. 2, the operation can be followed in greater detail. The sample passes from the feed hopper (5) down the funnel and enters the feed hole (12) in the upper rotor assembly along with an extremely small quantity of air moving at high velocity. In the small rotary duct (11) the air velocity is rapidly reduced as the radius increases and the conveyance of the material is taken over by centrifugal force. During the passage through the narrow duct (11), where the rotation of the air is high owing to the friction against the walls, the particles are also given a preliminary velocity in the direction of rotation of the air in the sifting chamber (19), to which the sample is introduced through the slot (8).

5.05 The spiral of air operating in the sifting chamber (19) is created by the vanes (22) of the fan wheel in the upper rotary assembly. These vanes draw air between the grading member (16) and the lower rotor assembly casting (1). As the fan runs at a constant speed, the position of the grading member as set by the horseshoe shaped throttle spacing piece (14) produces a predetermined flow of air which is easily altered by the exchange of throttles.

5.06 After entering the annular opening the air passes through a bank of closely spaced disks (18) which impart the necessary symmetrical rotation to the air by the friction against the disks. The air then passes in a spiral through the sifting chamber and is driven out through the vaned fan wheel. The design is such that a homogeneous gyratory field is established in the sifting chamber with streamlines having the same inclination towards the radius and the same velocity at every point of an arbitrary circle within the sifting chamber.

5.07 The sample enters the sifting chamber symmetrically from the duct mentioned above and is divided into two fractions. The lighter fraction is borne by the spiral air out through the fan to stop ring where most of it is deposited due to the strong centrifugal force and the relatively low radial air velocity at this point. The heavier fraction is carried by centrifugal force out against the rotating wall of the catch basin (20) where it forms a drift uniformly distributed around the entire periphery.

5.08 As all the surfaces have approximately the velocity of the air, the treatment of the material is gentle so that it is not worn during its repeated passages through the apparatus.

5.09 The method of introducing the sample into the air stream insures good deagglomeration and dispersion without fracture. The feed hopper is shaken by the vibrator (3), the amplitude of the vibration being controlled by a rheostat. The sample passes slowly under the adjustable slide (4) where the revolving brush (6) aids in passing the sample into the feed tube (7). The sample then passes into the rotary duct (11) through the feed hole (12). Nitrogen gas, under low pressure, is admitted to the brush chamber through the small tube shown at the right to assist in transporting the sample. The amplitude of the vibration, the position of the adjustable slide, the position of the revolving brush, and the nitrogen flow rate are so adjusted as to insure uniform sample flowrate with good deagglomeration.

5.10 Various models of this instrument are available, each incorporating various modifications of the feed mechanism and housing. However, the operating principles remain the same. Dimensional differences between various models will produce different ranges of air velocity and centrifugal force at the point where the sample enters the sifting chamber from the feed slot. The actual values of these parameters are not critical as long as the terminal velocity cut-points available with the throttles supplied provide an adequate number of test points to permit the plotting of a smooth terminal velocity distribution curve over the range of 0.1 to 100 inches per minute.

5.11 Installation and Calibration of Centrifugal Classifier.

Installation:

The Centrifugal Classifier should be assembled in accordance with the manufacturer's instructions and installed on a firm table or bench away from ovens, heaters, or direct drafts. The instrument should be located in a room having a dust-free atmosphere with a temperature range of 65–75 F and relative humidity of less than 50 per cent.

Calibration:

The Centrifugal Classifier should be operated in accordance with the manufacturer's instructions and the "Method for the Determination of Terminal Velocity Distribution" during the calibration procedure except for the following modifications and supplementary steps.

1. Determine the weight of one of the three samples in the Standard Sample Set to the nearest 0.01 grams. The samples have been screened and dried during preparation so that these steps are to be omitted during the calibration operation.

2. Using the first throttle, feed the entire sample through the centrifugal Classifier. Weigh the collected fraction of the sample (the fraction larger than the throttle cut-point). Calculate the weight per cent of the sample smaller than the cut-point value. Using a data sheet similar to that shown in Fig. 4, enter this value, to the nearest 0.1 per cent, opposite the appropriate throttle number in the column labelled Test No. 1.

3. Using the second throttle, feed the entire collected fraction from the previous run through the classifier. Weigh the collected fraction of the sample. Calculate the total weight per cent of the original sample smaller than this cut-point. Enter this value opposite the appropriate throttle number in the same column.

4. Repeat as above, using successively all the throttles. Enter the cumulative weight per cents smaller than the indicated throttle cut-points in the Test No. 1 column.

5. Repeat the above procedure using the second sample of the set. Enter the test data in the column labelled Test No. 2.

6. Repeat the above procedure using the third sample of the set. Enter test data in the column labelled Test No. 3.

7. Average the data in the three columns to the nearest 0.1 per cent for each of the throttles and enter the averages in the column labelled Test Avg.

8. Plot the terminal velocity data enclosed with the Standard Samples as shown in the example in Fig. 5.

9. On the graph draw a vertical line up to the terminal velocity distribution curve from the appropriate weight per cent for the first throttle. From the intersection of this line and the curve, draw a horizontal line to the terminal velocity scale on the left. Indicate the throttle designation in the margin opposite this horizontal line.

10. Repeat the above steps for each of the other throttles. The terminal velocity values intercepted by the horizontal lines are the calibration points for the respective throttle numbers. Enter these values to three significant figures in the Term. Vel. column on the data sheet.

11. The terminal velocity cut-point for the throttles, thus obtained, shall be used in the determination of the Terminal Velocity Distribution of

dust samples in accordance with the test method described in this Code.

5.12 Standard Samples For Calibration of Centrifugal Classifier.

The distribution of standard samples is limited. In order to obtain a sample set, the following qualifications must be met:

(1) User possesses a centrifugal classifier of the type specified in this Code,

(2) Standard samples are to be used in conjunction with the elevation of air pollution control equipment, and

(3) No more than one set of samples is acquired per year unless a major repair has been made on the centrifugal classifier.

Address all requests for standard samples to Chairman, Power Test Code Committee No. 28, c/o The American Society of Mechanical Engineers, 345 East 47th Street, New York, N.Y. 10017, along with $5.00, to cover handling and mailing expenses.

5.13 Relationship Between Terminal Velocity and Particle Diameter. Terminal Velocity Distribution, defined elsewhere in this Code, is a property of dust that has a major effect on the performance of many types of dust separating apparatus, in particular, those which utilize inertial or centrifugal forces to separate the dust from the gas stream. For this type of equipment, the particle Terminal Velocity is a more significant parameter than the actual particle dimensions because it includes the effect of particle shape and specific gravity for each particle. This is especially important for heterogeneous dusts that are composed of particles of varying shape and specific gravity. For example, a portion of dust may consist of hollow particles with an effective specific gravity considerably lower than the average value as determined by analysis of the bulk sample. From microscopic measurement of the particle dimensions, combined with the average specific gravity value, one might conclude that a given piece of dust separating apparatus would collect these particles, whereas in fact, these particles would have a much lower Terminal Velocity than calculated and would escape separation.

5.14 However, since dust "size distributions" are commonly given in terms of particle size rather than Terminal Velocity, Fig. 6 is included in this Code as a means of converting Terminal Velocity values to equivalent solid spherical particle diameters, for a given specific gravity. Whenever this conversion is used, the resulting particle diameter should be clearly labeled as an "Equivalent Solid Spherical Particle Diameter based on Stokes' Law and a specific gravity of - - - ."

5.15 This interrelation of particle dimensions, shape, and specific gravity is the basic reason why "particle size" analyses determined by different methods can seldom be correlated although each method may give consistent and reproducible values of the particular dust property which is measured.

Notes:

If it is desired to use the Stokes' Law formula given on Fig. 6, it may be more convenient to use the following units with a conversion factor rather than the basic cgs system of units.

$$V = \frac{KD^2(\rho_1 - \rho_2)}{\eta} \times 10^{-6}$$

where:

V = terminal velocity, in in./min.

D = particle diameter, in microns

ρ_1 = specific gravity of particle relative to water at 4 C.

ρ_2 = specific gravity of fluid relative to water at 4 C.

η = viscosity of fluid, in poises

K = 12.93 = conversion factor for units used.

Table 1

Density of Mercury (ρ_m), Viscosity of Air (η) and $\sqrt{\eta}$ at Given Temperatures

Room Temp. (°C)	Density of Mercury, ρ_m (gms/cm ^{3})	Viscosity of Air, η (poises)	$\sqrt{\eta}$
16	13.56	0.0001788	0.01337
18	13.55	0.0001798	0.01341
20	13.55	0.0001808	0.01344
22	13.54	0.0001818	0.01348
24	13.54	0.0001828	0.01352
26	13.53	0.0001837	0.01355
28	13.53	0.0001847	0.01359
30	13.52	0.0001857	0.01362
32	13.52	0.0001867	0.01366
34	13.5	0.0001876	0.01369

Table 2

Values for Porosity of Bed

Porosity of Bed, (e)	$\sqrt{e^3}$
0.490	0.343
0.491	0.344
0.492	0.345
0.493	0.346
0.494	0.347
0.495	0.348
0.496	0.349
0.497	0.350
0.498	0.351
0.499	0.352
0.500	0.354
0.501	0.355
0.502	0.356
0.503	0.347
0.504	0.358
0.505	0.359
0.506	0.360
0.507	0.361
0.508	0.362
0.509	0.363
0.510	0.364

Table 3. Determination of Specific Surface – Time of Air Flow

T = time of air flow in seconds

$\sqrt{T}$ = factor for use in equations

T	$\sqrt{T}$	T	$\sqrt{T}$	T	$\sqrt{T}$	T	$\sqrt{T}$	T	$\sqrt{T}$	T	$\sqrt{T}$
26	5.10	51	7.14	76	8.72	101	10.05	151	12.29	201	14.18
26½	5.15	51½	7.18	76½	8.75	102	10.10	152	12.33	202	14.21
27	5.20	52	7.21	77	8.77	103	10.15	153	12.37	203	14.25
27½	5.25	52½	7.24	77½	8.80	104	10.20	154	12.41	204	14.28
28	5.29	53	7.28	78	8.83	105	10.25	155	12.45	205	14.32
28½	5.34	53½	7.31	78½	8.86	106	10.30	156	12.49	206	14.35
29	5.39	54	7.35	79	8.89	107	10.34	157	12.53	207	14.39
29½	5.44	54½	7.38	79½	8.92	108	10.39	158	12.57	208	14.42
30	5.48	55	7.42	80	8.94	109	10.44	159	12.61	209	14.46
30½	5.52	55½	7.45	80½	8.97	110	10.49	160	12.65	210	14.49
31	5.57	56	7.48	81	9.00	111	10.54	161	12.69	211	14.53
31½	5.61	56½	7.51	81½	9.03	112	10.58	162	12.73	212	14.56
32	5.66	57	7.55	82	9.06	113	10.63	163	12.77	213	14.59
32½	5.70	57½	7.58	82½	9.09	114	10.68	164	12.81	214	14.63
33	5.74	58	7.62	83	9.11	115	10.72	165	12.85	215	14.66
33½	5.79	58½	7.65	83½	9.14	116	10.77	166	12.88	216	14.70
34	5.83	59	7.68	84	9.17	117	10.82	167	12.92	217	14.73
34½	5.87	59½	7.71	84½	9.20	118	10.86	168	12.96	218	14.76
35	5.92	60	7.75	85	9.22	119	10.91	169	13.00	219	14.80
35½	5.96	60½	7.78	85½	9.25	120	10.95	170	13.04	220	14.83
36	6.00	61	7.81	86	9.27	121	11.00	171	13.08	222	14.90
36½	6.04	61½	7.84	86½	9.30	122	11.05	172	13.11	224	14.97
37	6.08	62	7.87	87	9.33	123	11.09	173	13.15	226	15.03
37½	6.12	62½	7.90	87½	9.36	124	11.14	174	13.19	228	15.10
38	6.16	63	7.94	88	9.38	125	11.18	175	13.23	230	15.17
38½	6.20	63½	7.96	88½	9.41	126	11.22	176	13.27	232	15.23
39	6.24	64	8.00	89	9.43	127	11.27	177	13.30	234	15.30
39½	6.28	64½	8.03	89½	9.46	128	11.31	178	13.34	236	15.36
40	6.32	65	8.06	90	9.49	129	11.36	179	13.38	238	15.43
40½	6.36	65½	8.09	90½	9.51	130	11.40	180	13.42	240	15.49
41	6.40	66	8.12	91	9.54	131	11.45	181	13.45	242	15.56
41½	6.44	66½	8.16	91½	9.57	132	11.49	182	13.49	244	15.62
42	6.48	67	8.19	92	9.59	133	11.53	183	13.53	246	15.68
42½	6.52	67½	8.22	92½	9.62	134	11.58	184	13.56	248	15.75
43	6.56	68	8.25	93	9.64	135	11.62	185	13.60	250	15.81
43½	6.60	68½	8.28	93½	9.67	136	11.66	186	13.64	252	15.87
44	6.63	69	8.31	94	9.70	137	11.70	187	13.67	254	15.94
44½	6.67	69½	8.34	94½	9.73	138	11.75	188	13.71	256	16.00
45	6.71	70	8.37	95	9.75	139	11.79	189	13.75	258	16.06
45½	6.74	70½	8.40	95½	9.78	140	11.83	190	13.78	260	16.12
46	6.78	71	8.43	96	9.80	141	11.87	191	13.82	262	16.19
46½	6.82	71½	8.46	96½	9.83	142	11.92	192	13.86	264	16.25
47	6.86	72	8.49	97	9.85	143	11.96	193	13.89	266	16.31
47½	6.89	72½	8.52	97½	9.88	144	12.00	194	13.93	268	16.37
48	6.93	73	8.54	98	9.90	145	12.04	195	13.96	270	16.43
48½	6.96	73½	8.57	98½	9.93	146	12.08	196	14.00	272	16.49
49	7.00	74	8.60	99	9.95	147	12.12	197	14.04	274	16.55
49½	7.04	74½	8.63	99½	9.98	148	12.17	198	14.07	276	16.61
50	7.07	75	8.66	100	10.00	149	12.21	199	14.11	278	16.67
50½	7.10	75½	8.68	100½	10.03	150	12.25	200	14.14	280	16.73

Table 4. Specifications for U.S. Standard Sieves, Fine Series

NOMINAL DIMENSIONS, PERMISSIBLE VARIATIONS, AND LIMITS FOR WOVEN WIRE CLOTH OF STANDARD SIEVES.

(U.S.Standard Series (4th Root of 2 Ratio))

Sieve Designation		Sieve Opening		Permissible Variations in Average Opening, per cent	Permissible Variation for not more than 5 per cent of Openings, per cent	Permissible Maximum Variation in Individual Openings, per cent	Nominal Wire Diameter[b]	
Standard	Alternate	mm	in. (approximate equivalents)				mm	in. (approximate equivalents)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
*5.66 mm...	No. 3½....	5.66	0.223	±3	+5	+10	1.68	0.0661
4.76 mm...	No. 4......	4.76	0.187	±3	+5	+10	1.54	0.0606
*4.00 mm...	No. 5......	4.00	0.157	±3	+5	+10	1.37	0.0539
3.36 mm...	No. 6......	3.36	0.132	±3	+5	+10	1.23	0.0484
*2.83 mm...	No. 7......	2.83	0.111	±3	+5	+10	1.10	0.0430
2.38 mm...	No. 8......	2.38	0.0937	±3	+5	+10	1.00	0.0394
*2.00 mm...	No. 10.....	2.00	0.0787	±3	+5	+10	0.900	0.0354
1.68 mm...	No. 12.....	1.68	0.0661	±3	+5	+10	0.810	0.0319
*1.41 mm...	No. 14.....	1.41	0.0555	±3	+5	+10	0.725	0.0285
1.19 mm...	No. 16.....	1.19	0.0469	±3	+5	+10	0.650	0.0256
*1.00 mm...	No. 18.....	1.00	0.0394	±5	+7½	+15	0.580	0.0228
841 μ........	No. 20.....	0.841	0.0331	±5	+7½	+15	0.510	0.0201
*707 μ........	No. 25.....	0.707	0.0278	±5	+7½	+15	0.450	0.0177
595 μ........	No. 30.....	0.595	0.0234	±5	+7½	+15	0.390	0.0154
*500 μ........	No. 35.....	0.500	0.0197	±5	+7½	+15	0.340	0.0134
420 μ........	No. 40.....	0.420	0.0165	±5	+12½	+25	0.290	0.0114
*354 μ........	No. 45.....	0.354	0.0139	±5	+12½	+25	0.247	0.0097
297 μ........	No. 50.....	0.297	0.0117	±5	+12½	+25	0.215	0.0085
*250 μ........	No. 60.....	0.250	0.0098	±5	+12½	+25	0.180	0.0071
210 μ........	No. 70.....	0.210	0.0083	±5	+12½	+25	0.152	0.0060
*177 μ........	No. 80.....	0.177	0.0070	±6	+20	+40	0.131	0.0052
149 μ........	No. 100....	0.149	0.0059	±6	+20	+40	0.110	0.0043
*125 μ........	No. 120....	0.125	0.0049	±6	+20	+40	0.091	0.0036
105 μ........	No. 140....	0.105	0.0041	±6	+20	+40	0.076	0.0030
*88 μ........	No. 170....	0.088	0.0035	±6	+20	+40	0.064	0.0025
74 μ........	No. 200....	0.074	0.0029	±7	+30	+60	0.053	0.0021
*63 μ........	No. 230....	0.063	0.0025	±7	+30	+60	0.044	0.0017
53 μ........	No. 270....	0.053	0.0021	±7	+30	+60	0.037	0.0015
*44 μ........	No. 325....	0.044	0.0017	±7	+30	+60	0.030	0.0012
37 μ........	No. 400....	0.037	0.0015	±7	+30	+60	0.025	0.0010

*These sieves correspond to those proposed as an International (ISO) Standard. It is recommended that wherever possible these sieves be included in all sieve analysis data or reports intended for international publication.

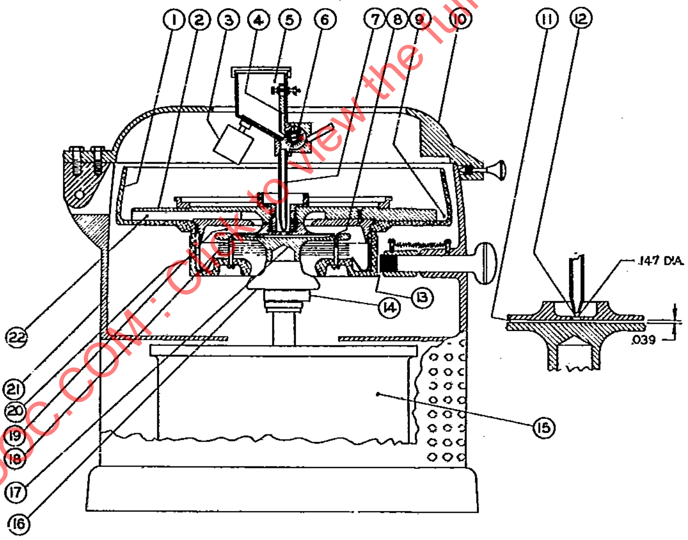
[a] These sieves are not in the fourth root of 2 Series, but they have been included because they are in common usage.

[b] The average diameter of the warp and of the shoot wires, taken separately, of the colth of any sieve shall not deviate from the nominal values by more than the following:

Sieves coarser than 590 μ................................	5 per cent
Sieves 590 μ to 125 μ................................	10 per cent
Sieves finer than 125 μ................................	15 per cent

NOTE – All measurements of openings and wire diameters shall be made on the completed sieve.

FIG. 1 CENTRIFUGAL CLASSIFIER

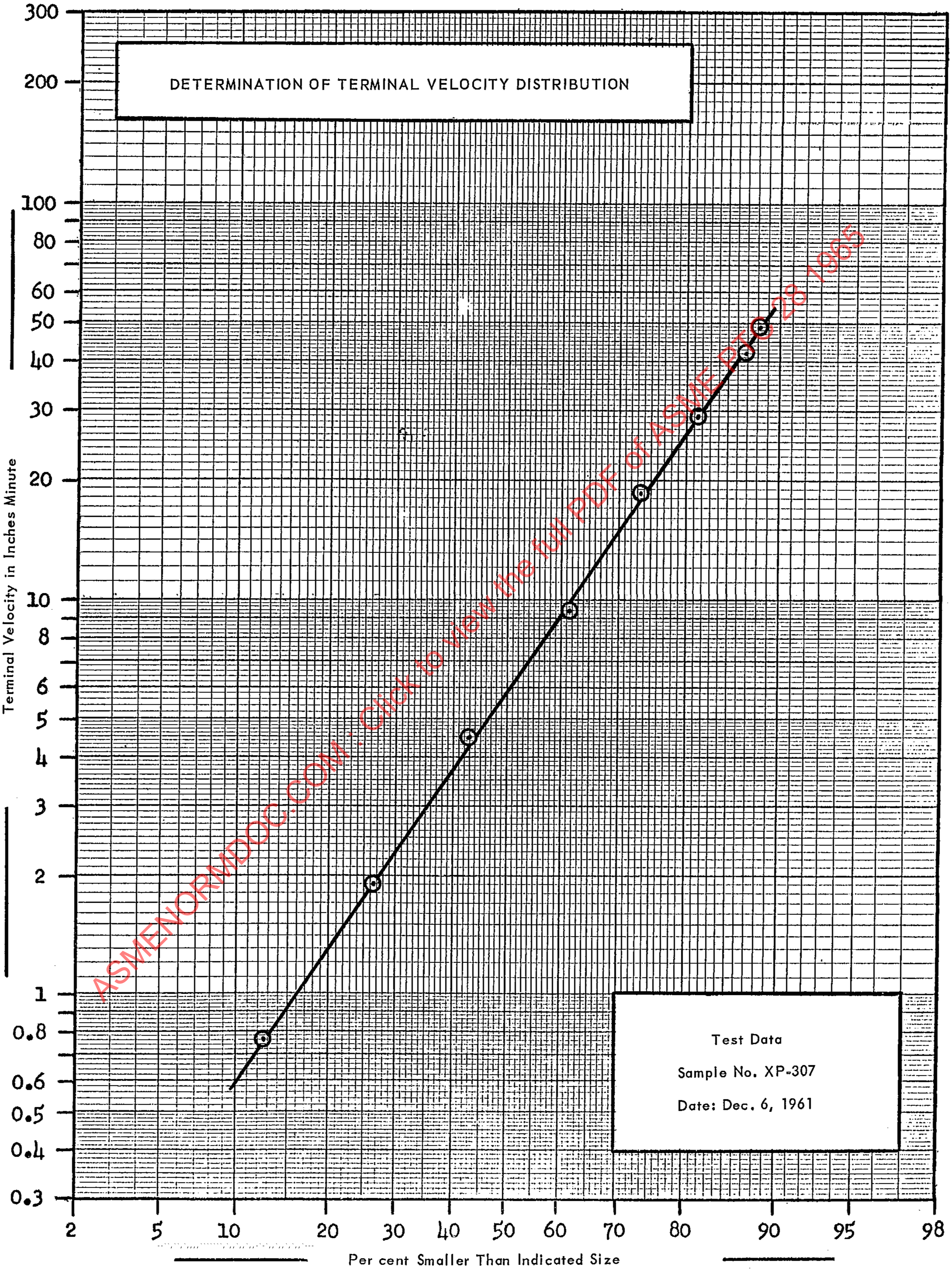


1. ROTOR CASTING
2. FAN
3. VIBRATOR
4. ADJUSTABLE SLIDE
5. FEED HOPPER
6. REVOLVING BRUSH
7. FEED TUBE
8. FEED SLOT
9. FAN WHEEL OUTLET
10. COVER
11. ROTARY DUCT
12. FEED HOLE
13. BRAKE
14. THROTTLE SPACER
15. MOTOR-3520 RPM
16. GRADING MEMBER
17. THREADED SPINDLE
18. SYMMETRICAL DISC
19. SIFTING CHAMBER
20. CATCH BASIN
21. HOUSING
22. RADIAL VANES

FIG. 2 CROSS SECTION OF CENTRIFUGAL CLASSIFIER

TEST REPORT

FIG. 3



THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

Power Test Code 28

TEST RESULTS

Test: Calibration of Bahco Centrifugal Classifier

Sample: Standard Sample Set No. 976

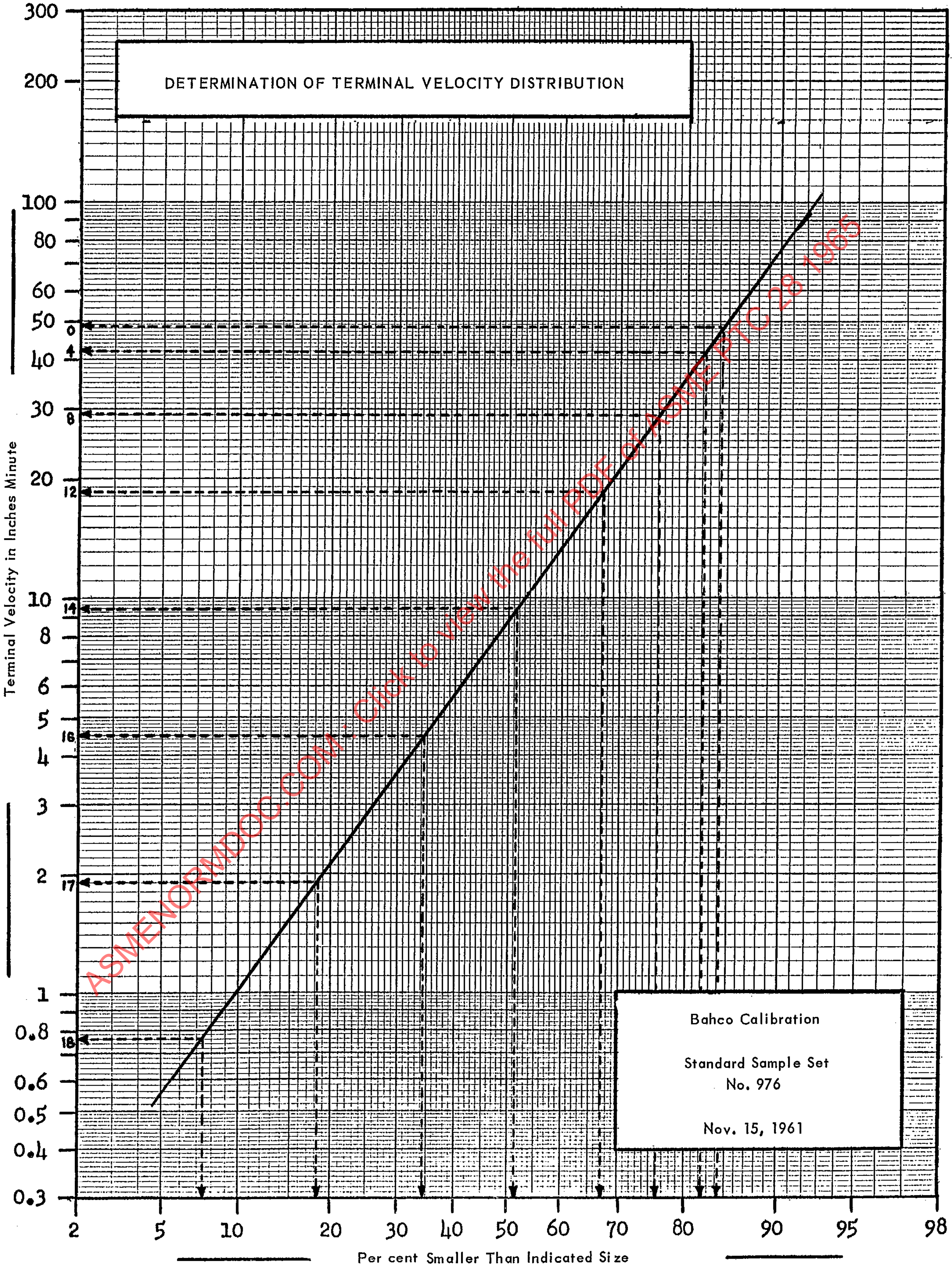
Date: Nov. 15, 1961

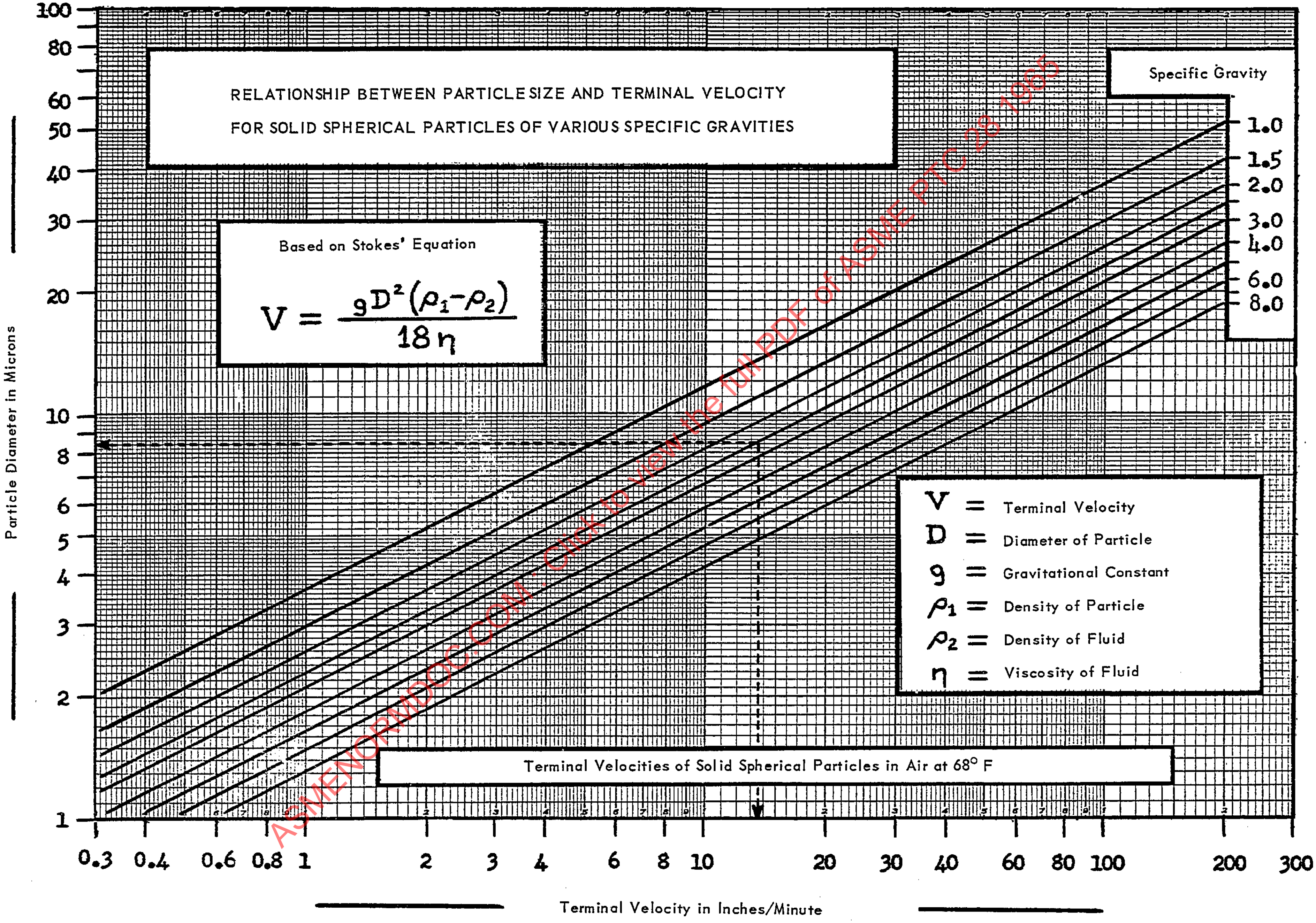
		Percent Smaller Than Indicated Size			
Throttle No.	**Term. Vel. Inches/Min.**	**Test No. 1.**	**Test No. 2.**	**Test No. 3.**	**Test Avg.**
18	0.76	7.7	7.3	7.2	7.4
17	1.90	18.1	18.3	18.5	18.3
16	4.60	34.0	34.6	34.6	34.4
14	9.40	51.5	51.6	51.1	51.4
12	18.5	67.6	66.9	67.1	67.2
8	29.0	75.8	75.7	76.5	76.0
4	42.0	82.3	82.7	81.9	82.3
0	49.0	84.6	84.1	84.2	84.3

FIG. 4

TEST REPORT

FIG. 5





Based on Stokes' Equation

$$V = \frac{g D^2 (\rho_1 - \rho_2)}{18 \eta}$$

V = Terminal Velocity

D = Diameter of Particle

g = Gravitational Constant

ρ_1 = Density of Particle

ρ_2 = Density of Fluid

η = Viscosity of Fluid

FIG. 6