Designation: D7743 – 12

Standard Test Method for Measuring the Minimum Fluidization Velocities of Free Flowing Powders[1]

This standard is issued under the fixed designation D7743; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method describes the apparatus and procedure needed for determining the minimum fluidization velocity of Geldart Group A powders and the minimum fluidization or complete fluidization velocity of Geldart Group B powders.

1.1.1 This test method is for powders that are readily or easily fluidizable and fall into the category of Group A and B of the "Geldart" classification. The fluidization of Geldart Group C powders will be addressed in another standard. This test method could apply to Geldart Group D particles but the focus of this document is towards Group and A and B materials.

1.1.2 Geldart classification of powders is often defined by comparing the Sauter mean particle size with the difference between the particle density and the density of the fluidizing gas, as illustrated in Fig. 1(**1**).[2]

1.1.2.1 Group A powders are easily fluidized but there is a difference between the gas velocity where the bed is initially fluidized and the velocity where bubbles are first observed. For Group A powders, bed expansion can be considerable before any bubbles are observed. Group B powders are also easily fluidized; but there is no difference between the velocity where the bed is fluidized and the velocity at the onset of bubbling. The minimum gas velocity, where all of the particles are fully supported by the gas for Group B powders, is often referred to as the "complete fluidization velocity" instead of minimum fluidization velocity. Group C powders are cohesive and can be difficult to fluidize.

1.1.2.2 Group A powders can be distinguished from Group B powders by the response to deaeration. Group A powders deaerate relatively slowly whereas Group B powders deaerate almost instantaneously in fluidized beds.

1.1.2.3 Group A Powders that lie near or on the Group A/C boundary may be tested by this method. However, if the powders do not fluidize freely, test results should be considered invalid.

1.1.2.4 Temperature, moisture (water) content, particle size distribution, particle shape and sometimes other variables influence the Geldart classification of a powder. Deaeration testing specified in 1.1.2.2 is a more definitive test than simply using particle size and density differences as described in 1.1.2.

NOTE 1—A Standard Practice for deaeration testing is under development.

1.2 This test method should be performed in a laboratory under controlled conditions of temperature and humidity.

1.3 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.3.1 The procedures used to specify how data are collected/recorded or calculated, in this standard are regarded as the industry standard. In addition they are representative of the significant digits that generally should be retained. The procedures used do not consider material variations, the purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analysis methods for engineering design.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.24 on Characterization and Handling of Powders and Bulk Solids.

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[2] The boldface numbers in parentheses refer to a list of references at the end of this standard.

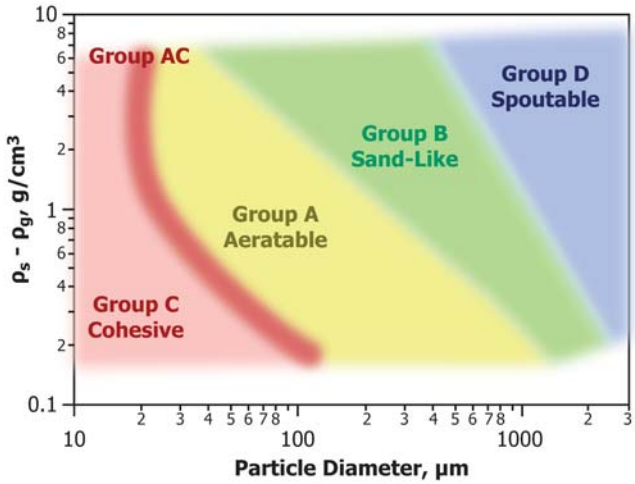

FIG. 1 Geldart Classification of Particles

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D3195 Practice for Rotameter Calibration

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 *Definitions:*

3.1.1 For common definitions of technical terms in this standard, refer to Terminology D653.

3.1.2 *complete fluidization velocity, U_{cf}, n—in powders and bulk solids*, the superficial gas velocity at which all particles in the bed are fully suspended by the gas.

3.1.3 *fluidized bed, n—in powders and bulk solids*, a bed of particulate matter fully suspended by a gas or liquid (liquid suspensions are not covered in this method).

3.1.4 *minimum bubbling velocity, U_{mb}, n—in powders and bulk solids*, the superficial gas velocity at which gas bubbles are first observed in a bed of powder.

3.1.5 *minimum fluidization velocity, U_{mf}, n—in powders and bulk solids*, the superficial gas velocity at which the bed is initially suspended by the fluid (or liquid).

NOTE 2—At minimum fluidization, the pressure drop or differential pressure across the bed becomes relatively constant with additional gas velocity. The pressure drop at minimum fluidization corresponds to the mass of the bed times the gravitational constant divided by the bed cross sectional area.

3.1.6 *superficial gas velocity, n—in powders and bulk solids*, the calculated gas velocity if no particles were present, i.e., the gas volumetric flow rate divided by the cross sectional area with respect to the bed diameter.

3.1.7 *Sauter mean particle size, n—in powders and bulk solids*, the diameter of a sphere that has the same volume to surface area ratio as the particles being measured.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *differential pressure, n*—the static pressure at one location referenced to the static pressure at another location separated by a known distance.

3.2.2 *particle density, n*—the density of a particle including internal voids and pores.

3.2.3 *pressure drop, n*—the same as differential pressure for this application.

4. Summary of Test Method

4.1 Fluidize the specimen to eliminate any internal stresses that may have developed during filling, then terminate the fluidizing gas and allow the bed to deaerate naturally.

4.2 Incrementally increase the gas flow rate and record values of pressure drop as a function of gas flow rate.

4.3 Once the specimen is fully fluidized, incrementally decrease the gas flow rate and record values of pressure drop.

NOTE 3—The final asymptotic pressure drop at full bed suspension corresponds to the bed density or bulk density times the bed height and the acceleration of gravity.

5. Significance and Use

5.1 The data from this test can be used to determine the superficial gas velocity required to suspend a bed of powder in the fluidized state and the resulting pressure drop.

NOTE 4—The quality of the results produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself ensure reliable results. Reliable results depend on many factors: Practice D3740 provides a means of evaluating some of those factors.

Practice D3740 was developed for agencies engaged in the testing or inspection or both of soil and rock. As such it is not totally applicable to agencies performing this standard. However, users of this standard should recognize that the framework of Practice D3740 is appropriate for evaluating the quality of an agency performing this standard. Currently there is no known qualifying national authority that inspects agencies that perform this standard.

6. Apparatus

6.1 The test unit is shown schematically in Fig. 2.

NOTE 5—The fluidization chamber consists of a plenum, a bed of powder and a freeboard. A plenum consists of an expansion chamber for incoming gas and a porous media for gas distribution. The bed of powder is contained within a right circular cylinder. Any cylinder shape can theoretically be used, but the gas needs to be uniformly distributed. Since this is most easily accomplished using a right circular cylinder, this test method is limited to this apparatus. The freeboard is used to disengage entrained or elutriated particles (or at least provide an opportunity for them to disengage). The outlet port in the freeboard region should be equipped with filtering media to prevent the loss of powder to the environment.

6.2 Select porous media based on anticipated bed height and powder properties.

6.2.1 Select the pore size of the porous media to be small enough to prevent particle weepage into pores of the porous media.

NOTE 6—Porous media such as glass or quartz frits or sintered metal discs are commonly used. The pore size does not have to be smaller than the smallest size of the test specimen.

6.2.2 Seal the porous media to the plenum and fluidized bed chamber to ensure gas does not bypass the porous media.

NOTE 7—Typically, this can be done with adhesives or by welding.

6.3 Ensure that the inside diameter of the cylinder is at least 150 mm, preferably 200 mm or larger.

NOTE 8—Smaller columns can be used, but the column diameter needs to be noted in the report. Inner diameters of less than 150 mm may have results affected by wall friction.

6.3.1 Construct the cylinder of any material suitable for the environment in which the experiment is to be conducted.

NOTE 9—Typically, lab-scale units are constructed of Plexiglas™, acrylic or glass. Many of these materials are relatively brittle, so pressure relief devices need to be considered.

6.4 Ensure that the freeboard height is at least the same as the bed height when fully fluidized.

6.4.1 Ensure that the freeboard inside diameter is the same or larger than the inside diameter of the bed.

NOTE 10—In some instances, a freeboard region of greater diameter than the bed can be used to lower the superficial gas velocity to reduce the particle entrainment rate. The expanded freeboard region needs to be sufficiently above the bed such that an expanded bed does not move into this expanded freeboard region. For typical minimum fluidization testing, an expanded freeboard is not needed.

6.4.2 Choose for the filtering media for the outlet port in the freeboard region a fibrous cartridge, cellulose thimble, sintered metal filter, etc.

NOTE 11—Cyclone(s) can also be used if sized correctly.

6.4.3 Consider a pressure relief device in the freeboard assembly.

NOTE 12—Pressure relief can be done with pressure frangible, pressure relief disk, pressure relief valve or static fluid column, depending on the pressure drop across the filter media (pressure in the freeboard with respect to the ambient pressure).

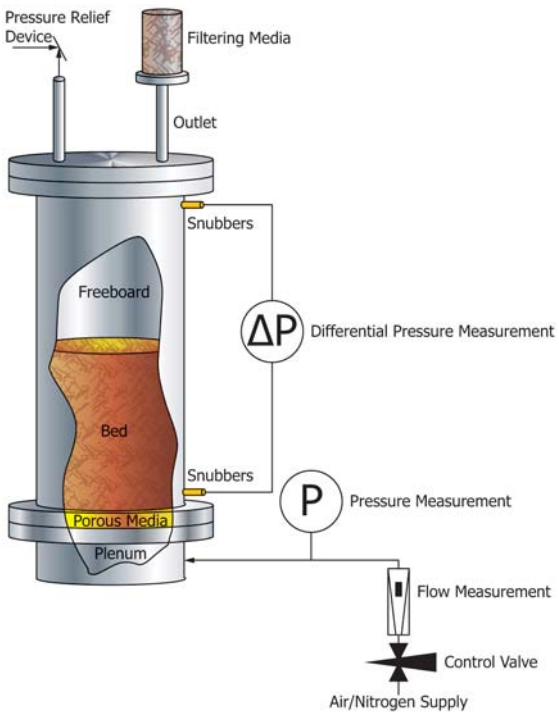

FIG. 2 Schematic of Test Apparatus for Measuring the Minimum or Complete Fluidization Velocity of Geldart Groups A and B Powders

6.5 Select appropriate flow control and measuring devices.

6.5.1 Regulate the flow rate of the gas upstream from the plenum by either a rotameter or a mass flow controller.

6.5.2 Ensure that the rate of gas flowing into the material, Q, can be measured to a precision of ± 3 % of full scale.

NOTE 13—An example of a device is an electronic mass flow meter such as thermal mass flow or Coriolis mass flow meter.

6.5.3 Ensure that the flow measuring device is sized such that flow rates needed for minimum or complete fluidization do not exceed 90 % of the device's maximum capability.

NOTE 14—Minimum fluidization and minimum bubbling velocities can be estimated using available correlations in the literature such as Wen and Yu (**2**) for minimum fluidization velocity and Abrahamsen and Geldart (**3**)for minimum bubbling velocity.

6.5.4 Install a pressure measuring device on the compressed gas supply between the plenum and gas flow measuring device.

6.5.5 Choose a pressure gauge or transducer that is rated with respect to the maximum pressure rating on the compressed gas supply or the pressure regulator (if a regulator is being used).

NOTE 15—The gauge or transducer is used in conjunction with flow measurement instrument to establish the flow at recorded temperature and pressure.

6.5.6 Install a differential pressure measuring device to measure the pressure drop across the fluidized bed.

6.5.6.1 Use a fast response, low volume differential pressure transducer or manometer.

6.5.6.2 Connect the device to two ports in the fluidizing chamber, one port in the lower part of the bed of powder just above the distributor (at 10 but no more than 50 mm), and the other port located high in the freeboard region.

6.5.6.3 Use snubbers (fittings equipped with sintered metal filters) on each port to prevent the backfilling of powder into the differential pressure lines.

6.5.6.4 Ensure that one of the two snubbers will be in the bed when the specimen is added.

6.6 Ensure that the correct fluidizing gas is available. See 7.1.

6.6.1 Ensure that the compressed gas supply is pulsation free, has sufficient volumetric capacity at all anticipated flow rates, is dry and oil free, and is capable of at least 200 ± 5 kPa absolute pressure.

7. Hazards

7.1 **Warning—**Some powders may have a tendency to explode, catch fire, are toxic or are hazardous when used with the fluidization gas.

7.1.1 Dust explosions can occur when some powders are airborne in an oxidizing environment with an ignition source. Materials such as flour, coal, cellulose material, sugar, etc. have caused devastating dust explosions.

7.1.2 Pyrophoric material such as many reduced metals and nitrated organic materials, can cause fire and explosions when exposed to an oxidizing environment. An ignition source is not needed.

7.1.2.1 Fluidizing pyrophoric material with air could be a safety risk.

7.1.2.2 Fluidizing pyrophoric material with nitrogen and then exposing the bed to air could be a safety risk.

7.1.3 Fluidizing oxidized material that has been reduced in nitrogen (or any other reducing gas such as hydrogen, carbon monoxide, etc.) and subsequent exposure to air could be a safety risk.

7.2 Toxic material should be handled in accordance with MSDS specifications and local safety and environmental regulations. Personal protective equipment needs should be evaluated for each test.

7.3 Over-pressurization of the test apparatus should be safeguarded by limiting the air/nitrogen supply or the release limit of the pressure relief device or both. Materials such as acrylic and glass are brittle and can fail catastrophically when over-pressurized.

7.4 All electronic equipment should be properly grounded or doubly insulated in compliance with local electrical codes.

7.5 The above noted hazards are not all inclusive. All potential hazards should be evaluated before each test.

8. Preparation of Apparatus

8.1 Ensure the test rig is clean and dry to limit any cross contamination of the test specimen and to allow the porous media to work satisfactorily.

8.1.1 Ensure that the porous media is not blinded with powders such that poor gas distribution results.

NOTE 16—Porous media can be checked against a reference gas velocity via pressure drop.

8.2 Calibrate rotameters or flow meters or both before the test using Practice D3195.

8.3 Calibrate pressure transducers or gauges before the test in accordance with manufacturer's standards.

9. Sample

9.1 Ensure that the powder sample is free flowing and not hindered by cohesive forces (such as electrostatics).

9.2 Ensure that the sample is representative of the bulk powder to be tested, and that sufficient volume is available for testing.

9.3 Ensure that the sample meets the criteria of a Geldart Group A or B powder. See 1.1.

10. Procedure

10.1 With the fluidization chamber empty, measure the pressure drop across the distributor plate at three superficial gas velocities.

10.1.1 Generate a pressure versus superficial gas velocity curve making sure that the expected minimum fluidization velocity is between the upper and lower superficial gas velocities tested with the fluidization chamber empty.

10.2 Introduce a test specimen into the fluidization chamber. This specimen is to be sufficient in size such that:

10.2.1 The bed height is such that the pressure drop is at least 10 % of the maximum measuring capabilities of the pressure instrument or at least 150 mm, whichever is greater.

10.2.1.1 Calculate the minimum required bed height from the expression:

$$h_{\min} = \frac{0.1\Delta P_{instrument}}{\rho_{bulk}} \frac{g_c}{g} = \frac{0.1\Delta P_{instrument}}{(1 - \epsilon_{mf})(\rho_p - \rho_f)} \frac{g_c}{g} \quad (1)$$

where:

h_{min} = the minimum bed height, m (and greater than 0.15 m),
$\Delta P_{instrument}$ = the maximum range of the pressure measuring instrument in Pascals,
g = the acceleration of gravity at 9.8 m/sec^2,
g_c = the gravity conversion factor at 1 kg-m/(N-sec^2),
ρ_p = the particle density in kg/m^3,
ρ_f = the fluid density in kg/m^3,
ρ_{bulk} = the bulk density in kg/m^3, and
ε_{mf} = the bed volume voidage fraction at minimum fluidization.

10.2.2 The bed height is limited such that the pressure drop across the porous media is at least ⅓ of the pressure drop across the bed at minimum fluidization, preferably equal to the pressure drop across the bed.

10.2.3 The bed height is limited to allow sufficient bed expansion when gas is added.

10.3 Reinstall the filtering media on the top of the fluidizing chamber.

10.4 Fluidize the specimen to eliminate any internal stresses that may have developed during filling.

10.4.1 Slowly open the valve to allow the fluidizing gas to enter the chamber up through the plenum and porous media.

10.4.2 Slowly increase the gas flow rate being careful to minimize channeling, or separation of the bed leaving a void.

NOTE 17—The characteristics of the material will determine the rate at which the flow rate can be increased.

10.5 Once fully fluidized, terminate the fluidizing gas and allow the bed to deaerate naturally.

NOTE 18—Geldart Group A powders require several seconds to minutes to deaerate depending on the depth of the bed.

10.6 Incrementally increase the gas flow to the bed using at least 10 increments from zero to maximum gas flow.

10.6.1 With each incremental gas flow increase, allow sufficient time to ensure the resulting pressure drop measurements are relatively constant. If the pressure drop fluctuates periodically, record enough measurements to achieve a statistically significant mean value.

10.6.2 Should the specimen start to rise creating a void in the fluidization chamber, there are three courses of action: continue to increase the flow of the fluidizing gas until the material collapses, run the test with a larger diameter cylinder, or start over.

10.6.3 Continue to increase the gas flow rate until the differential pressure becomes independent of gas flow rate.

NOTE 19—For some materials such as cohesive powders or materials with particle sizes larger than 600 μm or both, this condition may not occur within the range of flow rates used in this test method. If this occurs the test is invalid.

10.7 Once at bubbling fluidized bed conditions, ramp down the gas flow rate using at least 10 discrete increments until the flow is zero.

10.8 Run the fluidizing tests a minimum of three times for repeatability.

11. Calculation or Interpretation of Results

11.1 For each gas flow rate calculate superficial gas velocity:

$$u_o = \frac{Q}{A} \quad (2)$$

where:

u_o = the superficial gas velocity in m/sec,
Q = the gas volumetric flow rate in m^3/sec, and
A = the fluidizing chamber's cylinder section cross sectional area in m^2.

11.2 Generate two curves from the experimental procedure in Section 9: pressure drop vs. increasing gas velocity and pressure vs. decreasing velocity.

NOTE 20—Wall effects, yield stress, and cohesive forces can distort the increasing velocity curve on occasion. The decreasing velocity curve tends to be less prone to external effects for determining the minimum fluidization velocity.

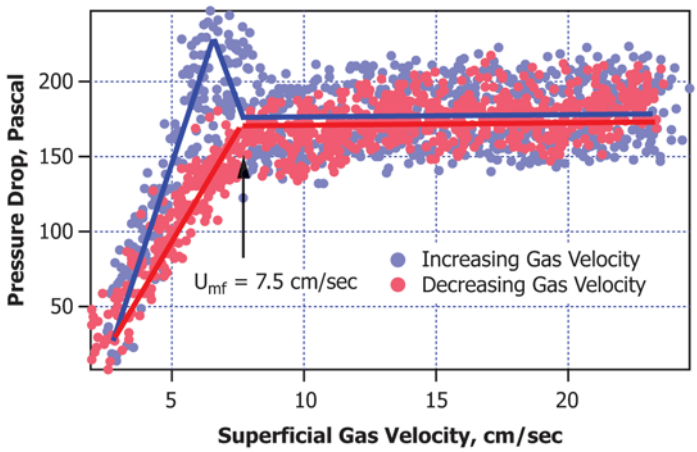

FIG. 3 Pressure Drop with Increasing and Decreasing Superficial Gas Velocity for a Typical Geldart Group A Material

NOTE 21—These two curves should compliment each other in terms discerning the minimum fluidization velocity or complete fluidization velocity, as shown in Figs. 3 and 4.

11.3 For Geldart Group A powders, use either the pressure drop vs. increasing gas velocity curve or pressure drop vs. decreasing gas velocity curve.

NOTE 22—The pressure drop vs. decreasing gas velocity curve is preferred (see Note 20).

11.3.1 With the pressure drop vs. increasing gas velocity curve, determine the minimum fluidization velocity by the intersection of the increasing pressure drop line with the constant differential pressure line, which is indicative of bubbling fluidization. See Fig. 3.

11.3.2 With the pressure drop vs. decreasing gas velocity curve, determine the minimum fluidization velocity by the intersection of the constant differential pressure line, which is indicative of bubbling fluidization, with the decreasing differential pressure line, which is indicative of flow through a packed bed. See Fig. 3.

11.4 For Geldart Group B powders, use only the pressure drop vs. decreasing gas velocity curve.

11.4.1 Determine the complete fluidization velocity, which is the minimum superficial gas velocity at which constant differential pressure drop across the bed is achieved. See Fig. 4.

11.5 If a less than optimal minimum fluidization or complete fluidization velocity curve develops, such as shown in Fig. 5, do not use such a curve to discern the minimum fluidization or the complete fluidization velocity.

NOTE 23—This sometimes is the result of cohesive forces or particle shapes or both that cause channeling.

11.6 Verify the accuracy of the minimum fluidization or the complete fluidization velocity value by comparing the value of the pressure drop at the constant pressure drop part of the curve with the expected pressure based on the mass of solids in the bed.

$$\Delta P = \frac{W_s \frac{g}{g_c}}{A} \quad (3)$$

where:

ΔP = the pressure drop across a fully suspended bed,
W_s = the mass of the powder specimen in the fluidizing chamber,
A = the cross sectional area of the fluidizing chamber in the location of the fluidized bed,
g = the gravitational constant, and
g_c = the force-mass conversion factor.

12. Report: Test Data Sheet

12.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below is covered in 1.3.

12.2 Record as a minimum the following general information (data):

12.2.1 Requesting agency or client.
12.2.2 Technician.
12.2.3 Identifying number for job or project.
12.2.4 Date test was run.

12.3 Record the following information concerning the apparatus:

12.3.1 Inside diameter of fluidizing chamber.
12.3.2 Height of fluidizing chamber.
12.3.3 Description of porous media, including its pressure drop characteristics if known.
12.3.4 Make and model of rotameter or mass flow meter.
12.3.5 Make and model of pressure gauge or transmitter for differential pressure measurements.
12.3.6 Chemical name of fluidizing gas.
12.3.7 Temperature of fluidizing gas.
12.3.8 Humidity of fluidizing gas.
12.3.9 Room temperature and pressure.
12.3.10 Gas source pressure.

12.4 Record, as a minimum, the following test specimen data:

12.4.1 Generic name of sample.
12.4.2 Sample identification number.
12.4.3 Chemical name of sample, if known.
12.4.4 Hazard awareness labeling.

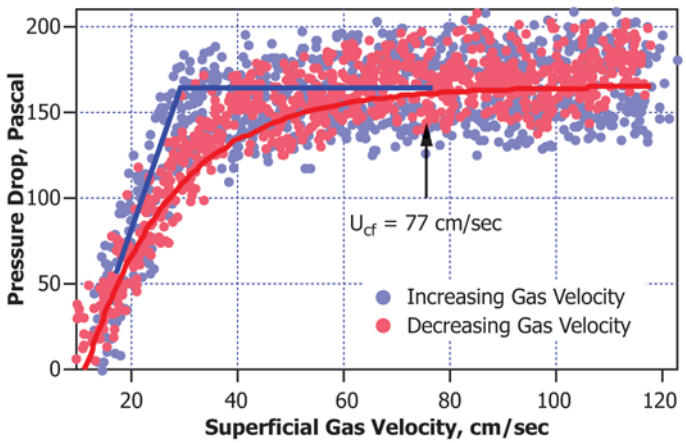

FIG. 4 Pressure Drop with Increasing and Decreasing Superficial Gas Velocity for a Typical Geldart Group B Material

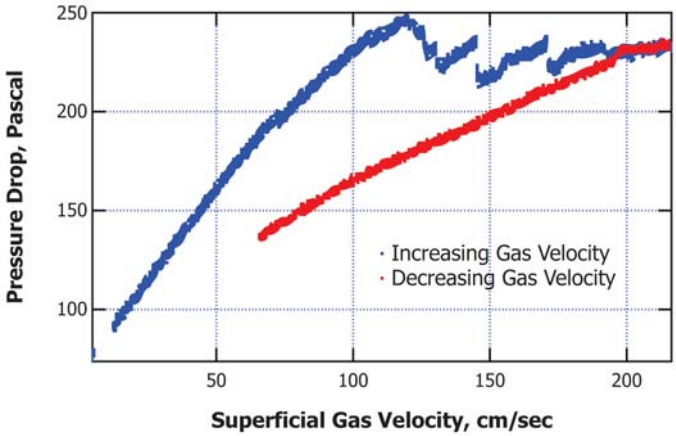

FIG. 5 U_{mf} Curve Indicative of Gas Channeling Due to Cohesive Forces

12.4.5 Specimen moisture (water) content. Record value to nearest 0.1 %. Indicate method used to determine moisture if not Test Method D2216.

12.4.6 Specimen temperature. Record value to nearest 1°C.

12.4.7 Specimen particle size expressed as median particle size or $d_{p,50}$, or preferably as Sauter mean diameter or more preferably as the distribution of particle sizes.

12.4.8 Particle Density (Specific Gravity).

12.5 Record as a minimum the following test data:

12.5.1 The pressure drop across the distributor with respect to at least three superficial gas velocities for an empty chamber.

12.5.2 Height of the specimen in the fluidizing chamber at rest.

12.5.3 Mass of specimen added to the fluidizing chamber.

12.5.4 Values of superficial gas velocity (or gas flow rate) and associated differential pressure at stable pressure response, including plot of data.

12.5.5 Fluidizing chamber pressure in freeboard (although atmospheric pressure is typically used).

13. Precision and Bias

13.1 *Precision*—Test data on precision is not presented due to the nature of the powder and other bulk solids tested by this standard. It is either not feasible or too costly at this time to have ten or more laboratories participate in a round-robin testing program. In addition, it is either not feasible or too costly to produce multiple specimens that have uniform physical properties. Any variation observed in the data is just as likely to be due to specimen variation as to operator or laboratory testing variation.

13.1.1 Subcommittee D18.24 is seeking any data from the users of this standard that might be used to make a limited statement on precision.

13.2 *Bias*—There is no accepted reference value for this standard; therefore, bias cannot be determined.

14. Keywords

14.1 complete fluidization; fluidization; Geldart Group A; Geldart Group B; minimum bubbling velocity; minimum fluidization velocity

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(3) Abrahamsen, A. R., and Geldart, D., "Behavior of Gas-Fluidized Beds of Fine Powders. Pt. 1. Homogeneous Expansion," *Powder Technology*, 26, 1980, 47.