AIChE

EQUIPMENT TESTING PROCEDURE

PARTICLE SIZE CLASSIFIERS

A Guide to Performance Evaluation

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AIChE Equipment Testing Procedure

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Prepared by the
Equipment Testing Procedures Committee

ABSTRACT

A procedure for testing and evaluating particle classifiers is presented. The results are to be expressed as a classifier size selectivity function. The size selectivity function is primarily a property of the classifier and its operating conditions, since it tends to eliminate the effect of the feed size distribution. Selectivity can then be combined with the feed size distribution to calculate other measures of performance such as yield and recovery.

The procedure includes methodologies for sampling and measurement of particle streams and summarizes methods of particle size analysis. Operating variables to be considered and measured are listed. Although the procedure is intended specifically for particle classification equipment as distinguished from particle collection equipment, many of the items discussed are also relevant to collection equipment.

Since the procedure is intended to apply to any type of particle classifier, the engineer using this procedure must prepare his own specific set of instructions, following the principles set forth herein.

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A.I.Ch.E. TESTING PROCEDURE FOR PARTICLE SIZE CLASSIFIERS

100.0 PURPOSE AND SCOPE

101.0 *Purpose*

The primary *purpose* of this procedure is to provide methodology for conducting and interpreting performance evaluation tests on particle classification equipment. Emphasis herein is directed toward the equipment user in assessing performance relative to his own application. An important objective is to adopt terminology an nomenclature consistent with the two major classifier application industries, *viz*. the mining and chemical process industries.

102.0 *Scope*

102.1 It is intended that the *scope* of this procedure be limited to classification by size or shape, not including separation by type of material or composition. Included would be the following general types of classifier equipment:

- Using gas flow as in air separators and cyclones
- Using liquid flow as in hydrocyclones and screws
- Using solid flow as in screens

The major technical areas addressed herein are particle sampling, measurement and evaluation methodology.

102.2 This procedure is intended to be applied to particle size classification equipment as distinguished from particle collection equipment. The purpose of particle size classification is to separate particles by size; a collection system is designed to collect or recover as much particulate matter as possible from a gas or liquid stream irrespective of size. However, many of the items discussed (especially sampling, particle size analysis and performance criteria) are also applicable to collection systems.

102.3 This procedure will be useful to the engineer who intends to test and evaluate the performance of classifiers. Moreover, in providing a standard methodology and terminology, it should encourage the uniform and routine publication of usable performance data by equipment manufacturers to aid equipment selection.

200.0 DEFINITIONS AND DESCRIPTIONS OF TERMS

201.0 *Classification*

201.1 *Classification* is the process whereby a collection of particles is separated into two or more portions differing in some physical or chemical property.

201.2 *Size Classification* is a classification process in which the collection of particles is split into fractions comprising particles of different size ranges. For example, in a single-stage classification, particles below a stated size are separated from the feed stream to produce a fine stream containing most of the fine particles. The amount separated usually represents a major portion of the feed stream.

201.3 *Dedusting*, as contrasted with size classification, is a term used to descibe the process of removing "dust producing" fine particles below a stated size from a feed stream in order to produce a coarse stream essentially free of particles smaller than the stated size. Usually the amount to be removed represents a minor portion of the feed material.

201.4 *Fraction* is the term applied to each portion of a collection of particles resulting from a classification process. A fraction can be measured in terms such as mass, volume, number or surface area. Although a size classification process can yield a large number of fractions, such a process can be considered as a number of separations into a *coarse* and a *fine* fraction, each at a different separation size. In that case, however, it must be remembered that the feed material to each successive separation will be different in composition from that to the previous separation. In the subsequent discussion, it will be assumed that a single classification of a given *feed* material will be taking place to yield a single *coarse* and a single *fine* fraction.

202.0 *Particle Size*

202.1 *Particle size* is intended to describe a particle in terms of a characteristic linear dimension, such as diameter for spherical particles. It should be noted that in the USA it has been customary (although not universally so) to express size in terms of a diameter. Failure to specify radius or diameter has been a source of confusion.

202.2 With spherical particles, regularly-shaped particles, and complex but similarly shaped particles, it is theoretically possible to make a separation on the basis of some linear dimension. Irregular particles, however, are of non-similar shape, and it is not possible to define a demarcation in terms of any specific linear dimension alone. Instead, size must be defined in terms of some other size-related property such as, area, or volume, or in terms of a statistically defined dimension.

202.3 In some cases it has been customary (and theoretically rigorous) to specify the size of the particle as

the size of an equivalent sphere. The significance of "equivalence" must then be remembered since the "equivalent size" can be different depending on the size-related property employed. Often a size separation is made on the basis of a process that is predominantly determined by size but is also influenced by other properties of the particle. For example, a separation can be made on the basis of settling velocity in a fluid, which is dependent on the particle size, shape, and density. In those cases, it has also been customary to specify size by the size of a sphere having the equivalent overall behavior in that kind of process. Such an equivalent size is a rigorously correct representation of size if the other properties of the particle are constant. However, if the other properties also vary among the particles of different size, this equivalent size is no longer representative of the size effect alone, but of the overall effect of all the relevant properties in terms of the specific process employed. Thus, in the general case, an equivalent size is a representation of size in terms of some specific phenomenon. It is only when all particulate properties influencing the phenomenon, other than size, are constant, that an equivalent size can be taken as a direct measure of particle size alone.

203.0 *Particle Size Distribution*

203.1 *Particle size distribution* is a representation of the relative amounts of material as a function of size. There can be various distributions depending on the property used as a basis for designating "amount." The common bases for designating "amount" are: (1) number of particles; (2) total particulate area; and (3) mass or volume of particles. Actually any number of bases could be used, including chemical or optical properties.

203.2 Size distributions may be given on either: (1) a frequency basis or (2) a cumulative basis. A *frequency distribution* reports the fractional amount (on some specific basis) of the total particles that lies in an incremental size range as a function of size, where the incremental size range is chosen on some systematic basis. There can be an infinite number of ways of presenting a frequency distribution depending on the system for choosing incremental size. A *cumulative distribution* gives the total fractional amount (on some specific basis) of particles that exists above or below a specific size. The cumulative distribution is essentially the integral of the corresponding frequency distribution. For a given basis of measurement and size discriminatory property, however, there is theoretically only one cumulative distribution regardless of the manner of depicting the frequency distribution.

204.0 *Particle Size Analysis*

204.1 *Particle size analysis* is the technique used to obtain a particle size distribution. There are two broad categories of size analyses: (1) those in which individual particles are measured and counted; and (2) those in which the material is separated into size fractions, the quantity of each then being measured.

204.2 Every size analysis involves two basic considerations: (1) the mechanism used to *discriminate* between particles of different size in either counting particles or in preparing fractions; and (2) the basis used for measuring *the magnitude* of the fractions obtained. Those categories of size analysis in which individual particles are counted are all effectively on a count basis, although the discriminating mechanism can be different for different methods of counting. In any case, the discriminating mechanism determines the significance of the equivalent size in which the distribution is reported. A full discussion of discriminatory mechanism, quantity measurement bases, representation of size, and methods for converting from one basis to another are given in Reference 804.6.

205.0 *Classification Criteria*

205.1 *Classification criteria* are those items used to specify the conditions at which a separation is made and to measure the effectiveness of the separation.

205.2 *Feed* is the total amount of particulate material fed to a classifier to be separated into one or more fractions according to some specified characteristic of the particulates.

205.3 *Product* is the fraction (or fractions) that supposedly contain the material having the desired specified characteristics.

205.4 *Yield* is the total amount of material in the product. All of the yield does not necessarily represent material of the desired characteristics. It may be expressed as a fraction or percentage of the feed (See Section 602.1).

205.5 *Recovery* is the amount of material of the desired characteristics that is present in the yield. It is usually expressed as a fraction or percentage of the total amount of material of the desired characteristics present in the feed. For the perfect or ideal separation, amount of yield and amount of recovery are equal; however, for such an ideal separation when expressed as a fraction or percentage of the amount of material in the feed, the recovery is 100 percent of the material of the desired characteristic in the feed, while the yield will depend on the amount of desired material originally present in the feed. (See Section 602.1).

205.6 *Partition function* is the term applied to the measure of classification performance. In a size classification process, each particle size in the feed distribution has a certain probability of entering the coarse fraction. For example, smaller particles have a lower probability of entering the coarse fraction than larger particles. The curve representing this process is called

a *size selectivity* function*, and expreses the probability of finding a particle of a stated size in the coarse fraction (See Section 601.2).

205.7 In order to obtain the intrinsic performance capability of a classifier, which we may term "intrinsic" size selectivity, it is necessary to operate with a completely dispersed collection of particles at low capacity. Since in practice we have no assurance of complete dispersion, size selectivity should be regarded as a way of presenting classifier performance in a given application which incorporates the effects of material, capacity, and intrinsic classifier properties.

205.8 *Cut size* is the name applied to the equivalent size at which a classification is being made. For a perfect separation, this size is determined unequivocally. For a less than perfect separation, however, a further definition is needed, and this leads to a large number of possibilities. A common definition of cut size, referred to as *equiprobable cut size*, is that feed particle size having equal probability of entering either coarse or fine fraction. (See Section 601.5.1).

205.9 *Sharpness* is the term applied to the effectiveness of a given classification. There are a large variety of ways in which sharpness can be expressed. For a less than perfect separation, the method of specifying sharpness and the method of defining cut size may be interrelated. Sharpness is related to the shape of the size selectivity curve. (See Section 601.5.2).

206.0 *Dispersion*

206.1 *Dispersion* is the act of distributing the particles in a medium so that the particles exist as separate entities not adhering to each other. *Degree of dispersion* is the extent to which the dispersion process is effective. Particles which are not dispersed are said to be *flocculated*, *agglomerated*, or *aggregated*. These terms have been used interchangeably since there exists no generally accepted standard for distinguishing between them. The following definitions are offered to provide a precise and distinguishing meaning for each of these terms.

206.2 In a *floc*, the particles in an assemblage are loosely bonded (as by Van der Waals forces or free electrostatic charges).

206.3 In an *agglomerate*, some form of chemical bond is present between adjacent particles (such as by local reaction or solubility, as the result of moisture absorption). The adhesive force between particles in an agglomerate are orders of magnitude or more greater than in a floc. When a collection of particles consisting of flocs becomes bonded to form agglomerates, it is often said to be *caked*.

206.4 The term *aggregate* should be reserved for a collection of particles of differing composition.

*Note: Other terms that appear in the technical literature having identical meaning to size selectivity include grade efficiency, fractional efficiency and particle size efficiency.

300.0 **TEST PLANNING**

301.0 *Objective of Testing Classifiers*

The objective of a test program is to establish the effectiveness of a classifier. The following lists the possible objectives of such a test program:

301.1 Tests can be performed on existing installed classifiers to check their operating performance.

301.2 Size selectivity data from tests can be published to aid users to select equipment, and to further equipment development.

301.3 Tests can be performed on laboratory classifiers to obtain data necessary for scaleup, and to estimate capital and operating costs for commercial-sized plants.

301.4 Sample products can be obtained with a selected range of particle size distribution, and these can be used to evaluate product quality and performance in some application.

302.0 *Testing Instructions*

302.1 General instructions are dealt with in this section. For specific instructions, see Section 500.0. Since this procedure is intended to apply to any type of particle size classifier, its instructions cannot be specific to any one type. Therefore, the engineer using this procedure must prepare his own specific instructions, following the principles set forth herein. A summary of factors these instructions should consider is given below.

302.2 *General Factors to be Considered*

302.1 Objectives of the test for a specific application

302.2.2 Variables of classifier operation to be measured, and those to be varied

302.2.3 Method of presenting results of tests

302.3 *Specific Factors to be Considered*

302.3.1 Method of feeding a uniform particulate stream to the classifier

302.3.2 Duration of each test period

302.3.3 Method of sampling feed and fraction streams

302.3.4 Method of measuring both particle flow rate and fluid flow rate of feed and fraction streams

302.3.5 Method of subdividing samples for analysis

302.3.6 Method of particle size analysis to be used

302.3.7 Safety precautions

303.0 *Factors and Conditions to be Recorded*

303.1 Since a classifier will make products over a wide

range of operating conditions, a program to completely test its performance should measure the effect of operating variables on product particle size and yield over the full range of operating variables available to the classifier under test. A summary of the type of information that will be required in the general case is presented below. All this information will not necessarily be applicable for all types of classifiers.

303.2 *Equipment Description*

303.2.1 General dimensional details

303.2.2 Mechanical setting of variable items, (such as vanes, fingers, baffles, etc.)

303.2.3 Auxiliary equipment (feeders, conveyors, drives, etc.)

303.2.4 Materials of construction

303.3 *Operating Conditions*

303.3.1 Mechanical

- Speed of rotation
- Power consumptions of drives
- Vibration frequency and amplitude

303.3.2 Fluid

- Flow rates, including primary stream, secondary stream, recycle streams
- Condition (temperature, pressure, humidity)
- Pressure drops and power consumption
- Additives used (dispersion agents)

303.3.3 Particulate

- Feed rates, magnitude and degree of uniformity
- Dispersion methods
- Material balance (coarse fraction, fine fraction, recycle, losses)
- Condition (temperature, moisture content)
- Contamination of product stream
- Physical properties of feed and fractions (size distributions, specific gravity, etc.)

303.4 *Operating Problems*

303.4.1 Health and safety related (toxicity, explosive, ignition, static charge)

303.4.2 Product quality (grinding, contamination)

303.4.3 Maintenance

- Mechanical
- Corrosion
- Wear
- Plugging

303.5 *Analytical Procedures*

303.5.1 Sampling

303.5.2 Rate measurement

303.5.3 Particle size measurement

304.0 *Safety*

304.1 Before embarking on a test program, personal safety requirements should be considered. Feed characteristics to be considered are toxicity, explosiveness, minimum ignition energy, and static charge generation. After analyzing safety hazards, protective measures can be provided such as: respiratory or other personnel protective equipment, equipment grounding and bonding, protection from tramp metal, inert gas blanketing, or exhaust ventilation.

304.2 For information on prevention of dust explosions, consult for example, Reference 804.9, Section 8, pages 9-10. One should be aware that aerosols of any combustible material, such as starch, sugar, or powdered metals, can be explosive.

304.3 The test procedure should conform to the latest requirements of all applicable safety standards. These include, but are not limited to plant, industry, local, state, and Federal regulations. The plant management (or the equivalent if the test is not run in a plant) and the classifier manufacturer should be requested to furnish in writing specific details, which should become a permanent part of the test record. It is recommended, further, that all testing be conducted by, or under the supervision of, personnel fully experienced in plant and equipment operating procedures.

400.0 INSTRUMENTS AND METHODS OF MEASUREMENT

401.0 *Introduction*

401.1 The two most important measurement methods used in evaluating the performance of classifier equipment are *particle sampling and size analysis*. Particle sampling is an important aspect since particle segregation can lead to biased information. Particle segregation means that particles with different properties are located in different positions. For example, when particulate material which is prone to segregate is poured into a pile, the larger particles tend to roll farther than the finer ones. Therefore, the use of a scoop or a thief probe in this pile will give different results, depending on where the sample is taken. Even riffling methods that subdivide the sample into supposedly equivalent portions, such as coning and quartering or the multi-chute riffle, can only partially overcome the variations in composition caused by segregation.

401.2 A size analysis of classified materials may be desired for either of two purposes: (1) to establish the intrinsic classification effectiveness of a given classifier; (2) to establish the effectiveness of classification for a specific application.

401.2.1 For *evaluating intrinsic classifier performance*, it is desirable to use a method of size analysis that depends on the same mechanism of separation as the classifier being evaluated. If a different mechanism is used, it is likely, except for some ideal cases (e.g., spherical particles of known properties), that the apparent measured effectiveness of the classifier will be poorer than

its true intrinsic capability. This is because the measurement will introduce an apparent size overlap that reflects differences between the method of size analysis and the classifier separation mechanism used in addition to any intrinsic size overlap that results from the classification process alone.

401.2.2 For *evaluating classification effectiveness for a specific application*, it is desirable to use a size analysis method that employs a separation mechanism similar to that of the particular mechanism involved in the process for which the product is to be used, regardless of the principle employed by the classifier. Thus, any significant mechanistic differences between the classifier and the application will show up as a poorer apparent classification than would otherwise be possible. This, however, is a realistic measure of the results being achieved for the application desired.

401.3 For reasons of economics, practicality, convenience, or specification, it is often not feasible to use the most desirable or realistic size analysis technique. If the most desirable size analysis technique for the purpose cannot be used, an intrinsic discrepancy in apparent effectiveness of classification is introduced by the size analysis itself and must be recognized as such. In the present state-of-the-art, the specific mechanistic role of particle size in most applications is not understood adequately to permit quantitative assessment of the types of size analysis discrepancies discussed above except for obvious extreme cases.

402.0 *Particulate Sampling*

402.1 The most effective method of obtaining a representative sample depends on passing the entire stream through a device which will cut portions from the stream at succesive time intervals. Using this method, a segregation occurring across the stream has no effect on the sampling. Further, any variation in composition of the stream with time will be averaged and represented in the sample in an unbiased way, provided that the frequency of cuts is statistically sufficient. The following methods of sampling are based on these principles. (See also References 804.1, 804.2, 804.3, and 804.5).

402.2 *Sampling Particles from Conveyors or Feeders*

402.2.1 Frequently the feed stream to a classifier is fed from a hopper through a conveyor, and is already in the form of a stream of solid particles. It is only necessary to insert an appropriate sample cutter at a convenient point where the whole stream can be cut, for example the discharge of the feeder into an intake chute, or a transfer point between conveyors. Feed systems should be designed to provide a sampling position.

402.2.2 Two types of commercially available sample cutters are shown in Figure 802.1 (Reference 804.9, Section 21, pages 36-39). In Figure 802.1a, the cutter is a box with a discharge chute. The top of the box has a rectangular opening. On signal from a timer, a motor draws the cutter across the sample stream. The cutter speed must be uniform to assure that all portions of the stream cross-section are sampled at the same rate. The cutter opening must be large compared to the size of particles to be sampled, so that edge effects do not bias the sampling of the largest particles.

402.2.3 Figures 802.1b and 802.1c show rotary samplers or rifflers operating on a similar principle. These devices contain a cutter with rectangular cross-section, mounted on a box that rotates around an axis. The feed stream passes through a vertical chute and is intercepted periodically as the cutter rotates into the feed stream at a uniform speed. These rifflers are designed to extract a sample amounting to either 5 or 10 percent of the feed stream. Further reduction of the sample is done by passing it through subsequent smaller stages of the same type of riffler.

402.3 *Sampling Bulk Power*

In some cases the particulate material is in a pile or a container. Feed sampling can best be done by passing the feed materials through a conveyor or feeder and sampling by use of the types of cutter samplers described above. Preferably, this will be done while feeding the material to the classifier during the test since any variation in composition while feeding during the test will be reflected in both inlet and outlet samples and thus compensated for. If the material tends to segregate, it is more difficult to provide a uniform, nonvarying feed stream than it is to adequately sample the stream.

402.4 *Sample Reduction*

402.4.1 Depending on the scale of operation of the system being tested, the samples may range in size from a few grams to many kg. The larger samples must be further reduced to provide representative samples of the *quantity needed for size analysis*. This can best be done using the principles discussed above. The rotary riffler shown in Figure 802.1b can reduce a large sample. It is only necessary to feed the material to the riffler at a reasonably constant rate. This can be done by placing it in the hopper of a table or belt feeder. If the material is sufficiently free-flowing, a feed funnel can be used.

402.4.2 Once the sample is reduced to a few kg, it can be further subdivided on a laboratory rotary riffler. Figure 802.2 shows the operating principle of a spinning riffler which divides the sample into as many portions as there are receiving containers. Further subdivision is

achieved by repeat riffling. If there are 10 receiving containers, three passes will reduce the sample size to 1/1000 of the initial sample.

402.4.3 The multi-chute sampling riffler commonly seen in particle laboratories is less effective than the spinning riffler. It only achieves a 1:2 reduction on each pass, and it cuts the sample by location rather than by time. If the sampler has a sufficient number of chutes, it can give a representative sample; but, the commercially available units do not have a sufficient number of chutes. The use of a spinning riffler is recommended rather than a chute sampler. (See Reference 804.5).

402.5 *Sampling Particles from Slurries*

A number of industrial processes require classification of particles in slurry form, particularly in the ore processing and cement industries. Examples of such classifiers are hydrocyclones, wet screens, and settlers. The method of sampling a slurry stream is the same as that used for sampling a powder stream, using rifflers that cut across the stream repeatedly. By these means, one can sample streams of high volume, up to approximately a ton/min (20 kg/sec) or more. Unfortunately, it is frequently the case that the plant was not designed with sampling in mind; e.g. the slurry stream can be pumped through large-diameter pipe with no transfer points where the whole stream can be sampled. It may be necessary to cut out a section of pipe and insert a riffler of the type shown in Figure 802.1c. The feed chute of the riffler then becomes a section of the slurry pipe. Sometimes the slurry stream is accessible at a transfer point, such as where it flows out of a ball mill.

402.6 *Sampling Particles from a Gas Stream*

402.6.1 In many industrial applications, the particles to be classified are suspended in an air or gas stream. Where the feed and fractions are in bulk form, the methods for bulk powder sampling given in Section 402.3 can be used. More often, the feed and at least one fraction stream are associated with some other operation, such as a closed-circuit grinding mill. In this case, it is necessary to extract representative samples from the gas streams.

402.6.2 If the scale of operation is small (less than 700 ft^3/ min or 1/3 m^3/sec), a small bag filter could be used to avoid the sampling problem. Most industrial operations are larger than this so that it is not practical to divert the whole gas stream into the sampler. Then the only practical method is to sample by means of a probe. In this case, best efforts must be made to minimize nonrepresentative sampling due to particle segregation within the gas stream.

402.6.3 Particle terminal settling velocity and concentration are variables that determine the extent of segregation that may occur. The terminal settling velocity of particles is a function of their size and density. If the terminal settling velocity is small compared to the turbulent component of velocity in the duct, then segregation due to settling will be minimized.

402.6.4 If the particle concentration in the gas stream is high, less segregation will occur because the more frequent interparticle contacts reduce the tendency of particles of different mass to flow past each other. However, the limiting concentration for this effect has not been determined.

402.6.5 For coarser particles, segregation due to settling in the duct may be a problem. Ducts should be designed so that velocities are well above conveying velocities (typically over 50 ft/sec or 15 m/sec, but dependent on size and density of the particles) in order to minimize gravitational segregation.

402.6.6 Size segregation can also occur at the entrance to a sampling probe if the flow velocity in the probe is not isokinetic with the flow in the duct, due to inertial differences between small and large particles. Isokinetic sampling is important if particles coarser than 5 μm diameter are present in the stream and especially if the particle concentration is dilute. Isokinetic sampling is achieved by adjusting the flow velocity in the probe entrance equal to that in the duct. This is a difficult task, and it is preferable to use one of the other methods of sampling discussed above. Sampling segregation can be minimized by using large sampling probes with correspondingly high sampling rates

403.0 *Size Analysis Methods*

403.1 In general, any method of size analysis could be employed subject to the limitations discussed above. There are literaly thousands of size analysis methods that have been proposed or used, differing widely in their degree of sophistication, cost, convenience, and availability. For classification processes or applications, the *mass* distribution is usually of prime interest; in some cases, merely the mass oversize or undersize is important. For this reason, methods giving a mass distribution directly are to be preferred over those that give a count distribution because of the inherent errors in converting count distribution into mass distribution at the coarse end. It should also be noted that the more uniform the size of a fraction, the less is the potential error in such a conversion. The following describes some of the methods that have been used in classification processes with a commentary on their applicability or limitations. For more detailed discussions of size analysis methods, see References 804.6 and 804.9 (Section 8, pages 3-8).

403.2 *Mechanical Sizing*

The most common method of mechanical sizing is screening through sieves which contain relatively uniform openings resulting from a plain square mesh of uniform wires. The sieve size is normally specified as mesh number, which refers to the number of openings per linear inch (number of openings per unit of area in some European standards). Each mesh corresponds to a specific aperture since the wire size corresponding to each sieve mesh is also set by specific standards. The standard sieve scale in the USA is the U.S. Sieve Scale, although the Tyler Sieve Scale is still used. These standard mesh number scales are limited to sieves having apertures greater than 25 μm. Electrochemically engraved square-mesh sieves down to 5 μm aperture are available. Because of particle adhesion problems, the utility of sieves finer than 100 μm is questionable for a dry powder system, and special procedures are needed even with wet sieving. Because of their simplicity, screens have been widely used for sizing in the range above 25 μm. A standardized technique must be used since the sizing results can depend on the mode of screen vibration, duration of sieving, and degree of loading of the screen as well as on the screen aperture.

403.3 *Air Sedimentation or Elutriation*

403.3.1 The rate at which particles settle in air under the influence of either a gravitational or centrifugal field is a function of particle size, shape, and density. If the density and statistical shape is reasonably uniform for all particles, this offers a means for measuring particle size. Secondary flow patterns can result in perturbation of results in some devices.

403.3.2 A common device for such an analysis is the *Roller analyzer* in which a powder is dispersed by subjecting it to an air blast; the particles being carried up into a vertical column in which those particles above a certain size settle out and are returned to the air blast. The *Micromerigraph* is a similar unit in which a powder is dispersed at the top of a still air column by means of a momentary air blast. The weight of sediment at the bottom is then recorded electronically as a function of time. The *Bahco* is a centrifugal air elutriator in which powder is introduced into an inwardly flowing air stream in a rotor; the coarse particles moving outwards against the airflow because of the centrifugal field generated by the rotor. All three of these devices are essentially limited to size measurements in the range greater than approximately 5 μm because of intrinsic problems with dust dispersion, dust adhesion to walls, or length of time required for separation.

403.4 *Liquid Sedimentation or Elutriation*

403.4.1 Liquid sedimentation or elutriation can be used for size analysis in a manner comparable to air sedimentation and elutriation. However, liquid methods are largely of the sedimentation type because of special problems of secondary flow patterns posed by elutriation in liquids. Such systems require that the particles be essentially insoluble in the liquid used. However, dispersion of particles is more readily achieved than in air systems by the addition of small amounts of dispersion agents. Dispersion is especially important with particles finer than 10 μm diameter; otherwise, the measured size will represent flocs. Dispersion can be achieved by adding chemicals to adjust the zeta potential to 30 mv or more and then agitating (as with a sonic probe). (Reference 804.12). Specific gravity differences between particles also assume somewhat greater importance in liquids. Magnetic powders or ores (such as magnetite) need to be magnetically deflocculated (depolarized) by alternating current fields before proceeding with sample preparation.

403.4.2 The *Andreasen* pipette method is a sedimentation technique in which a quiescent suspension of particles is sampled at a given level by means of a pipette. The size distribution is obtained from data of particulate concentration as a function of time. The sampling and analysis by this method is relatively time consuming, and the method is limited to the size range over 0.5 μm diameter.

403.4.3 The *MSA-Whitby* device suspends particles in a liquid that is miscible with and capable of floating on the sedimentation liquid. The volume of particles collected in the bottom of a tube is measured as a function of time. The sedimentation is caried out in a gravitational field for analysis of particles larger than 15 μm and in a centrifuge for finer particles. The method is simple and relatively fast, but has problems with selection of liquids, dispersion, and measurement of sediment.

403.4.4 The *Joyce-Loebel Centrifuge* subjects the particles to sedimentation in a liquid under the action of a centrifugal field and is applicable for particles down to about 0.1 μm.

403.4.5 The *Sedigraph* measures sedimentation rates of particles in suspension by means of a moving, finely collimated x-ray beam and automatically presents data as a cumulative particle size distribution. The applicable particle size range for this instrument is 0.1 μm to 100 μm.

403.5 *Particle Counting*

403.5.1 In particle counting, individual particles are sized and counted. This gives a count distribution from which a mass distribution can be calculated. These techniques all suffer from a precision problem if a mass distribution is desired because of the important contribution of

mass by a few large particles that may not be adequately sampled or are missed in the count. There is also a lower particle size limit below which particles cannot be detected.

403.5.2 The most common method in this class is the measuring and counting of particles dispersed on a *microscope slide*, either directly under the microscope or from calibrated photomicrographs. Obtaining a detailed size distribution by this technique is laborious. Under ideal conditions, automatic counting techniques can be employed; but, these involve comparatively expensive scanning equipment. However, the qualitative assessment of fractionated samples under the microscope, with visual "guesstimates" of mean sizes and size ranges is highly recommended prior to making size analyses by other methods. For many practical purposes such a semi-quantitative microscopic assessment may be all that is needed.

403.5.3 *The electrical resistivity counter (e.g. the Coulter Counter)* is a device wherein particles in a very dilute liquid suspension are counted and sized individually by the magnitude of an electrical voltage pulse, resulting from the passage of individual particles through an orifice. It is claimed that the pulse is proportional to the particle volume independent of the particle conductivity. This method requires a conductive liquid in which the particle is essentially insoluble and is limited to particles larger than about 0.7 μm.

403.5.4 *Optical counters* (such as the *Hiac, Royco,* and *Climet*) count and size dilute suspensions of particles (in gas or liquid) by the magnitude of a light signal as the particles pass through a light beam. Particle size can be calculated from the magnitude of the optical pulse by Mie theory, which requires some knowledge of refractive index and assumes spherical particles. However, particle size is frequently obtained by calibration against particles of known size. In practice, the method is limited to particles larger than 0.3 μm diameter for gas suspensions and larger than 1.0 μm for liquid suspensions because of background scatter by the fluid medium. Sampling problems probably set an upper limit for the method of 10 μm for the case of gas suspensions. The *Microtrac* is an instrument that measures Fraunhofer diffraction as particles pass through a laser beam. A microprocessor converts the intensities directly to a size distribution in the range from 2 μm to 125 μm diameter.

403.6 *Surface Area Measurement*

403.6.1 Although a surface area measurement (such as specific surface) does not give a size distribution, it is an integrated function of size distribution, which is in itself of great interest in many applications (such as grinding, pelletizing, catalysis, and chemical reaction or combustion.)

403.6.2 One conventional method of measuring surface area is the *BET* (Brunauer-Emmett-Teller) method or flow modification thereof. It involves a measurement of the amount of a gas, presumed to be a monomolecular film, that is adsorbed on the surface of a collection of particles. This provides a measure of the specific surface (sq. m/g) of the powder, which can be converted to an equivalent spherical size. (See Section 603.2). The BET method is relatively time consuming and involves relatively sophisticated equipment.

403.6.3 Both the *Blaine* and the *Fisher Sub-Sieve Sizer* measure the air permeability of a powder. This measurement is converted to an equivalent specific surface or size by semi-empirical methods, assuming analogy of flow through a powder to flow through a capillary tube. Both units are capable of giving a simple and fast measurement.

403.6.4 The Blaine involves rather simple equipment, but is drastically limited in application because it is operated at a fixed porosity. The Fisher is more widely applicable and can be used for effective particle sizes in the range of 0.02 to 200 μm provided corrections (not specified by the maufacturer) are applied for molecular slip flow in the fine particle size range (less than 5 μm) and for supporting medium resistance for particles larger than 40 μm.

403.6.5 It should be noted that BET measures *total* surface area, including internal surface associated with fissures in the particle and any surface roughness. For this reason, the equivalent diameter of the BET method is likely to be smaller than that obtained by permeability methods.

500.0 TEST PROCEDURE

501.0 *Introduction*

Once the objectives of the test have been determined, as discussed in Section 300.0, then the specific test procedure can be decided upon. A test procedure includes the following steps.

502.0 *Method of Feeding*

502.1 Fluctuation in feed conditions can be an important source of error in measuring classifier performance. The reason is that the particles reside in the classifier for a finite time so that the product samples at one instant of time may represent a shift in feed particle

size distribution from a previous instant.

502.2 It is important that the feed rate to a classifier be maintained constant. Feeders which limit feed rate variation to ±5 percent are recommended. Reference 804.9, Section 7, page 4, describes various feeders available for dry solids.

502.3 Slurries may be constituted from dry powder streams mixed with liquid streams. In this way, the flow rate of each stream can be measured separately. In feeding a slurry from a mixing tank, one should check the uniformity of concentration and particle size delivered over time.

503.0 *Duration of Test Period*

Each sampling should be carried out over a sufficient time to assure that fluctuations in solid and fluid flow rates, etc. are averaged out. Steady operation should be maintained for a long enough period before sampling begins to assure that a steady state has been reached. This will usually require a sampling period corresponding to at least five times the residence time of the particles in the system.

504.0 *Method of Measuring Flow Rates*

504.1 It is generally necessary to measure both solid and fluid flow rates or to measure that of the suspension and its solids concentration.

504.2 Quantities of dry feed material can be determined by measuring the weight passing over a belt, the reduction of weight in a feed hopper, or by the increase of weight in a product hopper. Samples can be collected over a period of time and weighed; but, this may be impractical if the flow rate is large.

504.3 If the stream is a *slurry*, its flow rate can be measured by a flow meter; but, potential of plugging must be considered. (Reference 804.9, Section 5, page 17). The proportion of solids and liquid can then be determined by taking a sample and measuring its density, or evaporating it to dryness and weighing the solids remaining. There are also various nuclear gages used to measure the mass flow of slurries or of dry solids as they pass by at a known velocity.

504.4 If the particles are suspended in a *gas stream*, similar methods can be used to measure particle and fluid flow rates. In this case, particle concentration can be measured by methods discussed in Section 402.6 Gas flow rates are measured by pitot tubes, orifice meters, or other methods described in Reference 804.9, Section 5, pages 7-17.

504.5 In setting up a test, provision should be made to measure flow rates of feed and both fraction streams. A reconstituted feed stream can then be calculated based on the measured fraction streams. Comparison with the measured feed stream will allow a check of error by material balance. In cases where one stream is inaccessible, it can be deduced from the other two; but, this practice is not recommended because it gives no indication of error.

505.0 *Method of Sampling and Subdividing Samples for Analysis*

One of the greatest sources of error in measuring the performance of particulate systems is that of obtaining representative samples. Whenever particles of various sizes, shapes and densities are handled, vibrated, or conveyed, segregation by size, shape or density can ocur. The purpose of sampling procedures is to acquire a representative sample for size analysis or composition analysis. Acceptable sampling techniques are designed to minimize the effects of segregation. Preferred methods are described in Section 402.4. These methods are based on devices that will cut portions from the whole stream at successive time intervals, thus avoiding segregation by position, and averaging variations over time.

506.0 *Method of Particle Size Analysis*

Methods of particle size analysis are described in Section 403.0. No one method can be recommended in general. Principles to be applied in selecting the method are discussed in Section 401.2. Many of the leading methods are described, with additional references given.

507.0 *Test Data to be Recorded*

The recorded classifier test data should be complete enough to permit test duplication and to assure accurate scaleup and related cost estimates. A summary of items to be considered is given in Section 303.0. Data sheets should be prepared beforehand to assure that all necesary measurements are recorded.

508.0 *Observations on Equipment Operability*

508.1 The operability of the classifier may have a dominant effect on operating cost. The following examples of special items should be observed in any test program:

- Evidence of classifier corrosion or wear
- Unusual motor load fluctuation and its cause
- Tendency for plugging in the feed inlet or fine fraction outlet
- Time required for complete cleanout when a different product is to be produced
- Convenience of changing particle cut size
- Product contamination

508.2 Some low melting or waxy materials tend to smear on internal surfaces and in time may plug internal classifier parts. The condition may not be apparent in a short test, but careful post-test inspection of internal parts should reveal if a long term test run is warranted.

600.0 COMPUTATION OF RESULTS

601.0 *Intrinsic Classifier Performance*

601.1 *Parameters To Be Considered*

Basically, three parameters should be considered when evaluating the performance of a given classifier: ***Cut size, sharpness*** of cut (since these affect the product particle size distribution), and processing *capacity*. Cut size is essential because it represents the particle size at which classification actually takes place, while sharpness represents how effectively it is done. Capacity is important because it directly relates to finished-product cost. With most conventional classifier designs, sharp separations at smaller cut sizes are achieved only at the expense of reduced capacity. The significance of these parameters will be discussed more fully in Section 700.0.

601.2 *Size Selectivity*

Size selectivity is the most complete method of expressing classifier performance under a given set of operating conditions. Cut size and sharpness can be calculated from size selectivity data. Size selectivity, expressed as a fraction, is defined by (see Section 205.6):

$$\eta_D = \frac{\text{quantity of size D entering coarse fraction}}{\text{quantity of size D in feed}}$$

where η_D is classifier selectivity and D is particle size. The equivalent mathematical expression is, on a *mass* basis:

$$\eta_D = \frac{w_c d\phi_c}{w_o d\phi_o} = \frac{w_c d\phi_c}{w_c d\phi_c + w_f d\phi_f} \qquad (6.1)$$

where ϕ_c is the cumulative percent by mass of coarse fraction less than particle size D, ϕ_f is the cumulative percent by mass of fine fraction less than particle size D, ϕ_o is the cumulative percent by mass of feed less than particle size D, w_c is the coarse fraction mass flow rate, w_f is the fine fraction mass flow rate and w_o the feed mass flow rate.

601.3 *Mass Balance Considerations*

It should be noted in Equation (6.1) that the masses of feed and both fractions balance. It is generally preferable to calculate the feed size distribution from measured size distributions of both coarse and fine fractions than to measure the feed and one of the fractions and calculate the other fraction. If all three are measured, it is best to use the feed size analysis only for assessment of measurement error by material balance. These recommendations follow from (1) the fact that size analyses are subject to less error the more uniform the fraction and (2) the possibility of loss or grinding in the classification process. The cumulative feed size distribution, ϕ_o, is calculated from cumulative coarse and fine fraction size distributions, ϕ_c and ϕ_f as follows:

$$\phi_o = (w_c/w_o)\,\phi_c + (w_f/w_o)\,\phi_f \qquad (6.2)$$

601.4 *Size Selectivity Calculation*

601.4.1 For purposes of calculating size selectivity from cumulative particle size distribution data, Equation (6.1) can be expressed in incremental form as follows:

$$\eta_{D_i} = \frac{w_c \Delta\phi_{ci}}{w_c \Delta\phi_{ci} + w_f \Delta\phi_{fi}} \qquad (6.3)$$

where, as defined in Figure 802.3, $\Delta\phi_{ci}$ and $\Delta\phi_{fi}$ are the cumulative size distribution intervals of coarse and fine fractions associated with size interval ΔD_i, respectively. An interval representative size, D_i, is arbitrarily taken as the midpoint of ΔD_i.

601.4.2 The precision attainable in the use of Equation (6.3) is dependent on how narrow ΔD_i is chosen. It is not necessary to select a constant value of ΔD_i in calculating size selectivity. A good rule to follow is that ΔD_i should be less than 20% of D_i. While ΔD_i should be taken as small as possible to give a mathematically correct measure of η_{D_i}, it is rarely necessary to have ΔD_i as small as 10% of D_i.

601.4.3 ***A sample calculation*** of size selectivity from cumulative particle size distribution data using Equation (6.3) is given in Section 803.0. This is based on the data given in Figure 802.3 for a centrifugal air classifier operating such that w_c = 0.46 ton/hr (0.12 kg/sec) and w_f = 0.54 ton/hr (0.14 kg/sec). The size selectivity curve thus obtained is shown in Figure 802.4. This method lends itself to rapid, routine calculation using computer techniques. Graphical methods can also be used for direct calculation of size selectivity from cumulative particle size distribution data (Reference 804.4).

601.5 *Performance Parameters Derived From Size Selectivity*

601.5.1 Figure 802.4 exemplifies a calculated size selectivity curve or function. If the separation were ideal, this would consist of a straight vertical line at the *equiprobable cut size* $D_{50\%}$. This means that all particles in the feed larger than $D_{50\%}$ enter the coarse fraction, and all particles smaller than $D_{50\%}$ enter the fine fraction. For an actual classification, the curve varies from vertical by an amount, indicating the extent to which particles of each size are misplaced. From the definition of equiprobable cut size, $D_{50\%}$ corresponds to the 50% value on the

size selectivity curve.

601.5.2 The shape of the selectivity curve at $D_{50\%}$ indicates the spread of misplaced material or *sharpness of cut*. There are many ways in which sharpness can be expressed. One index related to the selectivity curve shape that has been widely used is the ratio:

$$\beta = D_{25\%}/D_{75\%} \qquad (6.4)$$

where β is the sharpness index, $D_{75\%}$ the particle size corresponding to the 75% classifier selectivity value and $D_{25\%}$ the particle size corresponding to the 25% value. For perfect classification, β has a value of unity; the smaller β, the poorer the sharpness of classification.

602.0 *Overall Classification Performance*

602.1 While size selectivity is a complete measure of particle size classifier performance, the user is often faced with taking short cut methods for expressing classification performance on a specific feed material. A practical measurement of overall classification performance for a given application can be obtained by calculating recovery and yield. *Recovery* is the relative amount of material in the feed of the desired size (either coarser or finer than a given size D) that is recovered in the product. Recovery expressed as a fraction of the feed can be calculated from cumulative particle size distribution data as follows.

When the *fine* fraction is the product:

$$R_{D_f} = w_f\phi_f/w_o\phi_o \qquad (6.5)$$

When the *coarse* fraction is the product:

$$R_{D_c} = \left[\frac{w_c(1-\phi_c)}{w_o(1-\phi_o)}\right] \qquad (6.6)$$

Yield is a measure of product obtained irrespective of quality and is calculated as a fraction of feed by:

Fine yield

$$Y_f = w_f/w_o = 1\text{-}Y_c \qquad (6.7)$$

Coarse yield

$$Y_c = w_c/w_o = 1\text{-}Y_f \qquad (6.8)$$

For cases in which w_c and w_f cannot be measured, yield can be estimated from size distributions if mass balance is assumed:

$$Y_c = \frac{\phi_f - \phi_o}{\phi_f - \phi_c} \text{ and } Y_f = \frac{\phi_o - \phi_c}{\phi_f - \phi_c} \qquad (6.9)$$

602.2 The particle size at which recovery is evaluated is determined by the application. For example, if the desired product in Figure 802.3 is the fine fraction below a particle size of 70 μm, the recovery based on the calculated feed size distribution would be:

$$R_{70\mu m} = (0.54 \text{ ton/hr})(93\%)/(1.00 \text{ ton/hr})(64.7\%) = 0.78$$

This means that only 78% of the desired feed material shows up in the fine fraction. The fines yield in this example is simply 0.54 (or 54%).

602.3 Although simple to calculate and useful if properly interpreted, both yield and recovery are related to a given application, and are *not* unique measures of classifier performance.

603.0 *Other Measures of Classification Performance*

603.1 *Classifier "Efficiency"*

While the classifier selectivity curve gives an assessment of classifier performance, the user is commonly concerned with classification performance on a specific feed material. Consequently, various single-number measures of classification have come into use. Often referred to as classifier "efficiencies," these have been extensively reviewed in References 804.10 and 804.11. In most cases, such measures tend to be geared to a particular application. Moreover, it can be shown that all single-number efficiencies are dependent on the following factors:

- classifier size selectivity
- feed material particle size distribution
- particle size at which performance is evaluated

It is for this reason that the preferred procedure for reporting performance is in terms of the classifier selectivity function, rather than in terms of a single-number parameter alone. If the user must use a short cut method for measuring overall classification result, the more generally applicable recovery calculation given in Section 602.0 is recommended. While recovery is dependent on size selectivity and feed powder particle size distribution, it does have an obvious physical significance and gives a direct measure of classification for a given material in the general case. Thus, when properly interpreted, recovery gives information that is not directly apparent from the selectivity curve.

603.2 *Specific Surface Method*

603.2.1 The specific surface average size*, D_s, of either the coarse or fine fractions can be used as a measure of classification effectiveness. For a given fractional separation of a material, there is a given specific surface size for each fraction that corresponds to a perfect classification. As classification becomes poorer, the actual specific surface size of the coarse and fine fractions approach each other and that of the feed. The specific surface size of the feed

*Note: This size, D_s, is often called Sauter diameter and designated as D_{32} (Reference 804.8).

material and the coarse and fine fractions are related by a material balance and, for this case where the specific gravity of all fractions is the same, is given by:

$$D_{so} = \frac{1}{(Y_f/D_{sf}) + (Y_c/D_{sc})} \qquad (6.10)$$

where, D_{so} = particle diameter of the feed having same specific surface as the feed as a whole, D_{sc} = particle diameter of the coarse fraction having same specific surface as the coarse fraction as a whole and D_{sf} = particle diameter of the fine fraction having the same specific surface as the fine fraction as a whole.

603.2.2 The ratio D_{sc}/D_{sf} becomes an exceptionally sensitive measure of effectiveness of classification for a given feed material. This ratio will, however, be a function of the size distribution of the feed material and will not be an intrinsic property of the classifier. The specific surface average size, D_S, is obtainable from the measured specific surface by:

$$D_S = 6/\rho S \qquad (6.11)$$

where, ρ= true particle density and S= specific surface of the powder on a mass basis (m^2/kg).

700.0 INTERPRETATION OF RESULTS

701.0 *Introduction*

For a given classifier and feed material, sharpness of separation is determined by the particle feed rate; whereas, the nominal size of the product is determined by the cut size for which the operating conditions of the classifier are set. If the product can tolerate more of the undesired fraction and still be within desired quality specifications, yield can be increased by changing operating conditions so as to give a different cut size (larger if the fine fraction is the desired product; smaller if the coarse fraction represents the desired product). In a dedusting operation, it is expedient to operate at as large a cut size as possible without removing a significant amount of material from the coarse fraction.

702.0 *Operating Conditions*

702.1 The maximum sharpness, limited by the intrinsic characteristics of the classifier, will be achieved at very low particle feed rates. As feed rate is increased, without changing other operating conditions (such as fluid flow rates, rotor speeds, or vane settings), production rate will increase; but, sharpness of separation will become poorer. This is the result of poorer dispersion of the particles either as the result of poorer initial dispersion or because of the greater probability of interaction (or flocculation) between particles at the higher particle concentration. The smaller the particles, the more important and difficult will be the question of dispersion. The particles will consequently behave like somewhat coarser particles, and it may be necessary to change operating conditions to a somewhat larger cut size to maintain a given desired size separation.

702.2 For gas suspensions, there is no known means for stabilizing dispersions analogous to that achievable in liquid suspensions by the use of dispersing agents. While additives to powders can improve dispersability, they act by reducting adhesive forces between particles, but do not cause dispersion by themselves nor do they stabilize the dispersion.

702.3 With the particle loadings employed in air classification (under 2/3 lb/ft^3 or approximately 10 kg/m^3), drag forces on individual particles are essentially the same as those that would be exerted on the particles in infinite space (so-called "free settling"). For very high volumetric solid concentrations (over 2/3 lb/ft^3 or approximately 10 kg/m^3) such as might be encountered in some liquid suspensions, drag forces on individual particles are larger than they would be for particles in infinite space due to the proximity of other particles (so-called "hindered settling"). Thus, to maintain the same nominal size in each fraction as solids loading is increased with concentrated suspensions of solids in liquids, it may be necessary to change operating conditions to correspond to either a smaller or larger cut size, depending, respectively, on whether the dispersion is stabilized or whether flocculation is controlling.

703.0 *Size Selectivity Curves*

703.1 Figures 802.5 depicts the various types of size selectivity curves that are possible or may be obtained. The subsequent paragraphs will discuss the source or significance of each type. In Figure 802.5, the same cut size, $D_{50\%}$, has arbitrarily been chosen for all curves. It is also assumed in Figure 802.5 that the size selectivity curves are derived from size analyses that have correctly measured the discrete particle diameters in the pertinent fractions. If particle flocculation complicates the size analyses, a wide variety of erratic meaningless results could be obtained.

703.2 Curve a-a′ is representative of a perfect separation. Curve b-b′ is representative of the intrinsic capability of a given classifier and is the best that can be achieved with that classifier at low particle loadings.

703.3 Curves b-c′, c-b′, c-c′, d-b′, and d-c′ are representative of the apparent size selectivity results that may actually be obtained as the result of additional complications introduced by the mode of classifier operation or particle interaction. Deviations from a curve like b-b′, which passes through 0% at the finest

particle size end and 100% at the coarse end, may be due to one of the following:

- mechanical loss of material during the classification process.
- grinding of material during classification
- recycle streams within the classifier
- bypass resulting from splitting main fluid carrier stream
- failure to disperse or flocculation of particles during classification

703.4 If the size analysis of the feed calculated from the size analyses of the coarse and fine fractions agreed with the actual size analysis of the feed, the same size selectivity curve will be obtained regardless of which combination of fractions is used in the calculation of the size selectivity curve. If the calculated feed analysis does not agree with the measured feed, a different size selectivity curve will be obtained depending on which combination of size analyses is used to calculate the size selectivity curve. Curve c′ could reflect the effects of grinding. This could be confirmed if the feed analysis calculated from the analyses of the fine and coarse fraction is finer than that measured for the feed.

703.5 The fishhook curve d is indicative of a failure to adequately disperse the feed material. The leveling off shown by curve c may be due to either contamination of the fine fraction by recycle streams or to failure to disperse the feed. In general, material balances on both an overall mass and on a particle size basis should reveal which phenomena (material loss, recycling, grinding, or maldispersion) are responsible for deviations from a curve of the shape of b-b′ in any specific case.

703.6 In the case of curve c-c′, a *corrected* curve could be calculated to yield one of the form of b-b′ from the following relationship (Reference 804.7):

$$\eta c_{D_i} = (\eta_{D_i} - \Delta\eta_c) / (1 - \Delta\eta_c - \Delta\eta_{c'}) \quad 7.1$$

where η_{D_i} is the measure size selectivity value and ηc_{D_i} is the corrected value; $\Delta\eta_c$ and $\Delta\eta_{c'}$ being the size selectivity increments at the fine and coarse ends, respectively, as illustrated in Figure 802.5. This relationship simply imposes the proper boundary values on the data. While this corrected curve is of interest for purposes of modeling classifier performance, the true correction could be considerably more involved depending on the reasons for the deviations in the measured values.

800.0 APPENDIX

801.0 NOTATION

D = Particle size
D_i = Midpoint of size interval ΔD_i
ΔD_i = Particle size interval
D_s, D_{32} = Sauter diameter, particle diameter having same specific surface as the sample as a whole
D_{sc} = Particle diameter of coarse fraction having same specific surface as the coarse fraction as a whole
D_{sf} = Particle diameter of fine fraction have same specific surface as the fine fraction as a whole
D_{so} = Particle diameter of feed having same specific surface as the feed as a whole
$D_{25\%}$ = Particle size corresponding to the 25% size selectivity value
$D_{50\%}$ = Equiprobable cut size=particle size corresponding to the 50% size selectivity value
$D_{75\%}$ = Particle size corresponding to the 75% size selectivity value
R_{Dc} = Coarse fraction recovery amount of desired coarse material expressed as fraction of feed
R_{Df} = Fine fraction recovery, amount of desired fine material expressed as fraction of feed
S = Specific surface of a powder on a mass basis
w_c = Coarse fraction mass flow rate
w_f = Fine fraction mass flow rate
w_o = Feed mass flow rate
Y_c = Coarse fraction yeild, expressed as fraction of feed
Y_f = Fine fraction yield, expressed as fraction of feed
β = Sharpness index = $D_{25\%}/D_{75\%}$
η_D η_{D_i} = Size Selectivity
ηc_{D_i} = "Corrected" classifier size selectivity
ρ = True particle density
ϕ_c = Cumulative % by mass of coarse fraction less than particle size D
ϕf = Cumulative % by mass of fine fraction less than particle size D
ϕ_o = Cumulative % by mass of feed less than particle size D
$\Delta\phi_{ci}$ = Cumulative size distribution interval of coarse fraction associated with size interval Δ_{D_i}
$\Delta\phi_{fi}$ = Cumulative size distribution interval of fine fraction associated with size interval Δ_{D_i}