Glossary of Terms in

Powder and Bulk Technology

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The British Materials Handling Board

Foreward.

Bulk solids play a vital role in human society, permeating almost all industrial activities and dominating many. Bulk technology embraces many disciplines, yet does not fall within the domain of a specific professional activity such as mechanical or chemical engineering. It has emerged comparatively recently as a coherent subject with tools for quantifying flow related properties and the behaviour of solids in handling and process plant. The lack of recognition of the subject as an established format with monumental industrial implications has impeded education in the subject. Minuscule coverage is offered within most university syllabuses. This situation is reinforced by the acceptance of empirical maturity in some industries and the paucity of quality textbooks available to address its enormous scope and range of application. Industrial performance therefore suffers.

The **British Materials Handling Board** perceived the need for a Glossary of Terms in Particle Technology as an introductory tool for non-specialists, newcomers and students in this subject. Co-incidentally, a draft of a Glossary of Terms in Particulate Solids was in compilation. This concept originated as a project of the Working Part for the Mechanics of Particulate Solids, in support of a web site initiative of the European Federation of Chemical Engineers. The Working Party decided to confine the glossary on the EFCE web site to terms relating to bulk storage, flow of loose solids and relevant powder testing. Lyn Bates*, the UK industrial representative to the WPMPS leading this Glossary task force, decided to extend this work to cover broader aspects of particle and bulk technology and the BMHB arranged to publish this document as a contribution to the dissemination of information in this important field of industrial activity.

The value of the Glossary is seen as being particularly useful to newcomers to this broad subject. Explanations are provided for key terms in the various sections that merit a deeper appreciation than a strict basic definition. Suggestions are also included for preferred terms that eliminate ambiguity or misinterpretation. A universality of expressions for use in technical documents and publications is also an implicit aim. It is inevitable that within the wide range of terms included will be some that merit a more comprehensive or different description, and undoubtedly there are a formidable number of exclusions that would enhance the list. The publishers are not responsibility for any errors, omissions or statements made in this publication. The information is presented for information only and is not intended for action without independent substantiating investigation on the part of a potential user. The definitions are presented by the author as collated from wide sources and not necessarily endorsed by the British Materials Handling Board or its publishers.

The work is dedicated to C.K.Andrews, who lit the path of professionalism for the author.

Other books by Lyn Bates include: – '*User guide to Segregation*', published by BMHB and '*Guide to the Design, Selection and Application of Screw Feeders*' published by the I.Mech.E.

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The terms are broken down into the sections listed to aid the review of specific fields of interest.
Descriptions of the relevant sections are followed by an alphabetic list of the terms

Note:- Words shown in Italics in the definitions are defined elsewhere in the glossary.

Some text is included that is not part of the definition but added to aid understanding.

Section 1 – Introduction

1.1 Bulk solids in industry

Approximately half of all materials that are used and consumed by society are solid materials that are handled and processed in a loose particulate form. During their passage from source to ultimate use most are stored and handled many times. They are subjected to a wide range of ambient and operational conditions and almost invariably incur significant changes in their physical nature during their route. The particles of composition of these materials span an enormous scale of physical and chemical properties, many bearing the same title existing in radically different conditions because of variations and changes that occur during their lifetime, due either to the natural unstableness of the product or changes induced during handling and processing. Bulk solids are also mixed, blended and treated in ways that change the way in which the bulk behaves. The influences of scale and time also bear on behavioural aspects.

The make-up of any bulk material comprises of at least two phases, the essential mass of the solid component and that of the fluid, most usually air, that occupies the void space between the particles. Where moisture or another liquor is present there are three phases, two of which tend to vary in quantity. Considering that the subject of particle size alone is difficult to define and that particle size distribution has a considerable influence on the behavioural nature of a bulk material, it is not surprising that the rheological behaviour of particulate solids is the most complex of all material masses. In respect to deformation characteristics of a bulk material under stress, loose solids can be classed with gases, liquids and mass solids as a fourth state of matter.

The subject is both exceptionally comprehensive and diffuse at the same time, as no individual can possibly encounter all the conditions and circumstances what fall within the field. The scientific disciplines involved include organic and physical chemistry, mechanical engineering, soil mechanics, physics, electrostatics, solid and fluid mechanics and many topics relating to health and safety, economics and numerous other concerns. Education in the subject is seriously handicapped by it being an emerging technology in a mature field of application and falling between the many schools of scientific interest.

1.2 Rand Reports on the performance of plants that handle bulk solids

Two detailed surveys were conducted at different times to compare the commissioning and operating performance of substantial industrial plants that were constructed to carry out a various types of production processes. The conclusions clearly showed that the results on plants that involved the handling of bulk solids incurred far more difficulties at the commissioning stage and seldom attained the level of efficiency that was regularly secured with equipment that handled liquids and gasses. In most cases, plants that handled particulate materials took far longer to bring into production and ran further over budget than those dealing with fluids, and that they rarely achieved their full design rating of output. Another finding of some significance was that, despite the considerable advances made in the technology, plants that were built in the 1980's did not measurable show improvements in these respects over plants built in the 1960's. See Appendix.1

There is much evidence that, with a few notable exceptions, this situation still persists.

1.3 General Terms.

accuracy	The closeness of the agreement between the result of a measurement and the true value.
aerosol	A *dispersion* of fine *particles* (solids or liquids) suspended in a gas.
adsorbed water	water attracted to the particle surface by physiochemical forces, having properties that may differ from the pore water at the same temperature and pressure due to the altered molecular arrangement. Adsorbed water does not include water that is chemical combined within the particles.
aeration	The action of injecting gas, usually air, to a *bulk material* to weaken the *particulate structure* by *dilatation*. The process induces the material to adopt a fluid or highly agitated state. (See *quiescent* and *boiling bed)*
anistropic	Not of the same composition, structure or condition in all axial directions.
attrition	Unwanted reduction in particle size caused by the collision of *particles* with other *particles* or with a surface, resulting in abrasion, causing fines, or fracture that creates 'mother' and 'daughter' particles.
barrel section	The upper, parallel section of a circular storage hopper. See *body section.*
bed	An assembly of particles in a contained state.
biaxial compression	Compression of a bulk mass by the application of normal stresses in two directions at right angles to each other
biaxial state of stress	State of stress in which one of the three principal stresses is zero
big bag	See *FIBC*
bin	A bulk storage container, usually of small or medium size. Synonymous with *hopper* and, to a limited extent, with *silo.* May be mobile or transportable, See *IBC*
binder	An additive that coheres a loosely assembled particulate mass.
Bingham plastic	A form of deformation that exhibits Newtonian behaviour once a threshold shear stress is exceeded.
body force	A force, such as gravity, magnetic force or inertia, whose effect is distributed throughout a material body by direct action on each elementary part of the body independent of others.
body section	The upper, parallel part, of largest cross section, of a storage container.

bunker	Generic term for a fixed container for bulk storage. Typically of shallow construction with a large, open top. See *hopper, bin.*
capillarity	A phenomenon associated with surface tension and angle of contact that leads to the migration of fluids through narrow channels, as the interstitial voids of closely packed particulate beds.
cavitation	The formation of a cavity
clean room	A room with control of *particulate* contamination to a defined level.
C/M/R substances	Materials classified as category 1 or 2 carcinogens, mutagens or toxic to reproduction. (Related to points 29, 30 and 31 pf Annex 1 of Directive 76/769/EEC. (A Consolidated, 100 page, list of materials is given).
coagulant	An agent causing *coagulation.*
colloid	A state of matter comprising a system with two or more *phases*, in which one *phase* exists as discrete *particles* of the order of 100 to 100,000 nanometers densely *permeating* a continuous *phase*. Physical characteristics related to the enormous *surface area* of the bulk tend to dominate the behaviour of such materials
compression index	The slope of the linear portion of the pressure-void ratio curve on a semi-log plot.
compressive stress	A normal stress that tends to shorten the body to which it is applied, in the direction in which it acts. In solids, the effect is termed *compaction.*
consolidation	The reduction in volume of a bulk particulate mass resulting from the effect of gravity over time, or of a compacting stress. It is useful to consider *consolidation* as a state, rather than a process of volume reduction, which is better distinguished by the term '*compaction'*.
creep	A slow, plastic deformation under *stress* lower than the *failure stress*.
critical density	The unit weight of a unit volume of a granular material that will deform in a specific state of *stress* without change of volume. Below this value of *density* the bulk will gain strength when subjected to deformation, i.e. it is *under-consolidated,* and above which it will loose strength when deformed, an *over-consolidated* condition. C*ritical density* reflects the condition of a material in instantaneous equilibrium during gravity flow.
deliquescent	The ability to absorb moisture from the atmosphere, to the extent that the product dissolves in the absorbed fluid.
dilatant suspension	A material that increases in shear strength with the rate of shear.

dilatation — A conditions of expanded *particulate* structure that may be brought about by such as agitation, *aeration* or *shear.* The opposite of *compaction.*

disintergrant — Materials incorporated within *compacts* of dry *powders* or *granules* to promote separation to the primary *particles*, on addition to a liquid.

elastic limit — Point on the *stress-strain* curve beyond which deformation will not fully recover on the removal of *stress.*

elastic state of equilibrium — State of *stress* within a stressed mass when the internal resistance to permanent deformation is not fully mobilised.

elastic strain energy — Potential energy stored within a strained solid equal to the work done in deforming the solid from its unstrained condition, less any energy dissipated by inelastic deformation.

elasto-plastic — A deformation that will partially recover on relaxation of the applied *stress*

emulsion — A dispersion of immiscible liquids.

entrainment pattern — The *flow* velocity contours that are generated over the cross section of the interface from a *hopper* outlet by a feeder used to discharge the container.

equivalent surface level — The level that the contents of a *hopper* would reach if the material were evenly spread across the surface.

failure — A state of dis-equilibrium brought about by stresses exceeding the elastic limit of deformation of a *powder compact*. (See *shear failure, yield*).

failure criterion — Specification of the mechanical conditions under which a *bulk solid* will fail to support the applied *stress.*

feeder — A device used to discharge a *bulk* storage container in a controlled manner. Typical equipment for this purpose are screw feeders, belt conveyors, scraper type conveyors, vibratory feeders, table feeders, rotary valves and disc type feeders.

FIBC — A Flexible Intermediate Bulk Container, See *IBC.*

filter porosity — The ratio (or percentage) of the *void* volume within the filter material to the total volume of the filter material.

flocc, floc; flocculate — An assemblage of *particles* which, having been initially dispersed, have become loosely coherent.

fluid — A liquid or gas.

fractions	Portions of the mass that fall into a certain defined category, usually a *particle size* range.
fume	Cloud of airborne *particles*, generally visible, that arise from condensing vapours from either a chemical or physical reactions
Gausian distribution	(See *normal distribution*)
health hazard ranking	For substances within EU classification as a dangerous substance are ranked in five groups of acute health hazard with respect to corrosive/irritation and organ toxicity. These classes are ranked 1 – 5 (with 0 for unidentified products).
Class 0	No data available relevant to human heath hazard
Class 1	Very high risk. (e.g. very acute toxicity).
Class 2	High risk. (e.g. acute toxicity).
Class 3	Moderate risk, (e.g. mild toxicity).
Class 4	Low risk, (e.g. low toxicity).
Class 5	No reasonable concern with regard to health hazard effects

Five sub-chronic/chronic health hazards relating to allergy, neurotoxicity, carcinogenicicity, genotoxicity and rproductive toxicity are, ranked A – E, as below

Class 0	No relevant data available
Class A	Severe effects from low exposure
Class B	Severe effects after medium exposure, or mild effects with low exposure
Class C	Severe effect only from extensive exposure, or to limited cases
Class D	Effects limited or applies to isolated cases.
Class E	No reason for concern with regard to heath effects.
HEPA filter	Acronym for High Efficiency Particulate Air filter, for *particles* in air, having a specified minimum collection efficiency to the *D O P test.*
heterogeneous material	Material in which a *spot sample* will have a significantly different value of the characteristics under consideration from the mean value of that characteristic of the *bulk material.*
homogeneous	Material in which a spot sample will have the same value of the

material characteristic under consideration as the mean value of that characteristics for the *bulk material.*

homogeneous suspension — A *suspension* in which the *particles* are uniformly distributed in a liquid.

homogenisation
1. (Relating to a fluid based product). *Mixing* using a high *shear* rate.
2. (Relating to a particulate solid). Re-ordering the *particle* distribution of a *heterogeneous* material to the condition of a *homogeneous* material.

hopper
1. Generic term for a bulk storage container.
2. The converging section of a bulk storage container.

(The ambiguity of this term demands that, for appropriate clarity, the meaning is clarified within the context in which it is used).

hopper half angle — The inclination of the wall of a symmetrical *hopper* from the vertical axis.

hopper section — The converging section of a bulk storage container leading to the outlet.

(of bulk storage container) See *hopper.*

Hvorslev surface — The envelope of a family of *yield loci* on a three dimensional axis of *shear stress*, *normal stress* and *bulk density*. The boundary conditions are: -

- The line of *tensile strength* on the axis of *density.*
- The *critical state line*, being the limiting *shear strength* of a bulk mass against its *density*.
- The envelope of the *yield loci* at each condition of *bulk density.*
- The *bulk density* condition at zero shear strength. (Maximum density for fluidity).
- The *bulk density* condition of maximum *consolidation*.

hygroscopic — Possessing the tendency to absorb moisture from the atmosphere. In the case of particulate solids this leads to many potential flow problems as the effect of moisture changes the bulk strength and slip characteristics of the bulk, sometimes dramatically with only a small change of water content.
Equilibrium atmospheric moisture conditions depend upon the ambient temperature, pressure and relative humidity.

Changes in ambient conditions can cause moisture content variations according to the boundary surface contact conditions of the bulk mass. Moisture migration and condensation conditions can give rise to massive imbalances in moisture distribution, leading to *caking* or *surface adhesion* problems. (See *moisture content*).

hysteresis	Incomplete recovery of shape on the relaxation of stress. i.e. A partial elastic recovery inhibited by a degree of permanent deformation.
IBC	Intermediate bulk container.
intensity of variation	The degree to which a variation of a physical property deviates from defined bounds, the average value of a batch or from adjacent product, whichever is significant. (See *Scale of scrutiny* and *Scale of variation*).
interstice	The space between *particles* in a mass. (See preferred term *void*).
interstitial	Occurring in the space between the particles of composition.
isotropic	Pertaining to axial directional differences. This applies to individual particles, their structure in a bulk arrangement of *particles*, to *stresses* and to *strains*. A sphere is isotropic, whereas elongated *particles* and *flakes* are not. Fluids are, whilst wood, by virtue of its grain, is not. *Strain*, *Shear* and *uniaxial compaction* are essentially *anistotropic* (non-isotropic) processes that produce *anistropic* states in *the bulk material*. The feature is relevant to both the preparation and loading of a sample of bulk material for testing, as the failure conditions depend upon how the bulk will *shear*. This in turn depends on the orientation of the constituents of the *particulate structure* in relation to the direction of stresses that produced the specific *state* of the bulk and the direction of stresses applied to cause the bulk to *fail*. The isotropy of a *particulate structure* is essentially disturbed when shear takes place.
Jenike, Andrew	See Appendix II. (Recommended reading).
laminar flow	Flow in which the head loss is proportional to the first power of the velocity. It is characterised by the lack of turbulence.
latex particles	*Particles* of natural latex or other polymer; usually spherical and of a narrow size range; often used for *calibration* purposes.
liquefaction	The process whereby a powder bed is transformed from a solid state to a liquid state, usually as a result of the restructuring of particles in a fully saturated bed to a higher packing density arrangement or the introduction of excess fluid. Additional fluid separates the particles, whereas closer particle packing allows the pore pressure of the incompressible fluid to support the applied stresses. Either change relaxes the particle-to particle contact pressure and resulting in a much greater freedom for the particles to shear with little resistance. Fluidisation is an equivalent process with a gas, instead of a liquid, providing the void pressure to reduce the contact pressure between particles.
Log-normal	A distribution which results in a straight line when a cumulatively

distribution	quantity on a probability axis is plotted against *particle size* on a logarithmic axis.
measuring range	The range over which an instrument as set-up can give results within a specified uncertainty. (Note: – Some instruments have many measuring ranges).
micrometre (μm)	One millionth part (10^{-6}) of a metre.
micron	(See *micrometre*)
monolith	A block of material; a very large *particle*.
nanometre (nm)	One thousand millionth part (10^{-9}) of a metre.
nano technology	The study of particles in the size region of one nanometre or less. (This is an area of intense interest because of some useful physical characteristics of ultra fine particles, such as their large surface area in relation to mass).
normal distribution	A distribution which results in a straight line when cumulative quantity on a probability axis is plotted against *particle size* on a linear axis.
normal stress	The stress acting at 90 degrees to the considered plane. (usually that of *shear failure*).
particle	A discrete piece of matter.
particle adhesion	The tendency for neighbouring *particles* to hold together by attraction forces, such as *surface tension*, *Van der Waal forces* at the molecular level, surface sintering, thermal fusion or by electrostatic forces.
particle, effective	A *particle* as perceived by a measuring technique that discriminates between the constituent elements of a *powde*r.
particle, primary	The basic *particle* within a *agglomerate* or *flocculate.*
particulate	Consisting of *particles.*
particulate bed	A *particulate solid* occupying a given space.
particulate solid	A crowd of particles, the number of particles being sufficient for the statistical mean of any property to be independent of the number of particles present. The mass assumes a behaviour due to their interaction such that the assembly may be considered as a continuum. Particulate solids may be called bulk solids, granular solids or powders although, in certain contexts, these terms have different meanings from one another.
particulate structure	The manner of composition of touching *particles* in a *bed*.

period of scrutiny — The time interval over which variations of a given property are significant. A typical example is for defining the time interval over which a weighed sample should be collected to determine the relevant accuracy of a Loss-in-weight feeder output. Typically, for this duty, the period is of the order of 60 seconds. Whereas feedback control can ensure that the average feed rate is relatively accurate, there are circumstances, such as metering the feed into a high-speed mill where the residence time is very short, that place a high premium on the very short-term feed evenness, rather than the precise accuracy, in relation to the mill power demands and consistency of the product produced.

phase — A physical state that constitutes all or part of a material mass, such as a liquid, gas or solid. Particulate solids comprise a minimum of two phases, the solid and the medium occupying the voids. There are three phases if a loose fluid is present in addition to a gas in the void space.

points of co-ordination — The points of contact between *particles* in a *particulate bed*.

Poison's ratio — The ratio between linear strain changes perpendicular to, and in the direction of, a given *uniaxial stress* change.

porosity, filter — (See *filter porosity)*.

powder — A *bulk solid* consisting of *particles* less than 1 mm.

primary consolidation — The reduction of volume that occurs in a dilated powder due to the escape of excess gas from the voids.

relative humidity — The proportion of moisture that can be held in air as a vapour compared with the maximum vapour holding capacity at the given temperature.

Reynolds number — The dimensionless number which defines the flow pattern of a fluid surrounding a particle, where $R_e = v.d.\ \rho / \eta$

R_e is the Reynolds number
v is the relative velocity
d is the diameter of spherical particles
ρ *is the density of fluid*
η = viscosity

All values being in the same system of units.

rheology — The subject of deformation and flow.

rheopectic — The behaviour of materials that set or increase in viscosity when shaken or tapped.

risk phrases — Legends used in the Countries of the EU to denote category of risk related to dangerous substances and preparations. See *Attributes.*

Rosin-Rammler distibution — A mathematical function to describe *particle* size distribution (The expression was originally developed for broken coal).

safety — See *attributes, risk phases, MSDS, CMR substances,* and Directives 99/45/EC, 67/548/EEC (in Appendix of standards)

scale of scrutiny — The amount, volume or mass, that is sufficient to ensure that specific determined qualities of interest in a bulk material sample will satisfy the requirement for purpose. A common use is to define the size of a mixture sample that must be taken, to ensure that the ratio of constituents falls within acceptable bounds for the application. In the case of a mix prepared for making pharmaceutical tablets, this should be no more than that required for an individual tablet to confirm that the amount of active ingredient per dose is within prescribed bounds.

A larger sample may be appropriate for a detergent for use in domestic appliances and a different again scale for a solid fuel supply to a power station, where the average calorific value on a large scale is of interest. Some circumstances demand that more than one *scale of scrutiny* be considered, for each of which different levels of tolerances can apply. (See *Scale of variation*, i*ntensity of variation, period of scrutiny*).
An analogy may be considered with colour differences in a fabric or sheet, where a small, intense spot is obvious, but a small shade difference at that scale would be un-noticed. However, a similar fine shade difference on a much large scale would be immediately apparent and un-acceptable.

scale of variation — The size of region over which a significant variation of an interesting physical property is detected. This may be from defined bounds or from the average in the *universal sample*. (See *scale of scrutiny* and *Intensity of variation)*. Note that this term relates to the scale of causal occurrence of a variation, whereas the *scale of scrutiny* applies to the scale of significance relevant to an application, as with the suitability of the material to subsequent processing or for its ultimate use.

shear failure — The permanent disturbance of a *particulate* structure by the application of a shear stress. Interest may focus on incipient failure and/or sustained failure.

silo — A *bulk* storage container, usually of large volumetric capacity and tending to have a slender, cylindrical body section with a conical *hopper section*. May be built in banks and constructed of metal or concrete. Broadly synonymous with *hopper* and, to a limited extent, with *bin* and *bunker*

solid — A state of matter in which the constituent molecules or ions possess no translational motion, but can only vibrate about fixed mean positions.

A solid has definite shape and offers resistant to changes in shape and/or volume.

spot sample — A sample taken at random from a bulk mass.

state, (of a bulk material) — The condition of dilatation of a bulk material, as characterised by the packing arrangement of the constituent particles.
Material state is normally quantified by its condition of *density*, although strictly, this does not take account of any *anisotropy* in the system.

Stokes-Einstein equation — The equation relating the pace of *Brownian motion* to the diameter of the *particle* in motion, expressed as: -

$$D = kT/3\pi.\eta.\ d$$

where:
D is the *diffusion coefficient* of the *particle*.
K is the Boltzmann's constant.
T is the temperature.
η is the viscosity of the surrounding fluid
d is the *particle* diameter (*diffusion diameter*).

and where D is determined in *photo correlation spectroscopy* using the equation: -

$$k = 4\ \pi.n.\ \sin(\theta/2) / \lambda$$

where
n is the refractive index of the suspending field
.
θ is the scattering angle
λ is the wavelength of incident light.

Stoke's law — The equation which determines the *free falling velocity*, v, (*terminal velocity*), attained by a *particle* in *viscous flow* conditions and allows a calculation to be made of the particle size.

$$v = d^2.g\ (\partial_s - \partial_f) / 18\ \eta \quad \text{in SI Units,}$$

Where: -
v is the free-falling velocity.
d is the *Stoke's diameter* of particle.
g is the gravitational acceleration.
∂_s is the density of *particle*.
∂_f is the density of *fluid.*
η is the viscosity..

strain ellipsoid — Representation of *strain* in the form of an ellipsoid into which a sphere of unit radius deforms and whose axis are the principal axis of *strain*.

stress — The value of an applied force divided by the area of its application.

stress ellipsoid — The representation of the state of *stress* in the form of an ellipsoid whose semi-axes are proportional to the magnitude of the *principal stresses* and lie in the principal directions. The coordinates of a point, P, on this ellipse are proportional to the magnitudes of the respective components of the *stress* along the planes normal to the direction, OP, where O is the centre of the ellipsoid.

stress history — The sequence of *stress* conditions that have brought a *bulk material* to the *state* in which it now resides.

stress relaxation — The reduction in *stress* due to *creep* or the reduction in confinement during flow. See *Sigma Two relief.*

surfactant — A substance which reduces surface tension.

suspension — A *dispersion* of *particles* in a *fluid*.

tangent modulus — The slope of the tangent to the *stress-strain* curve at a given *stress* value. (generally taken at a stress equal to half the compressive strength).

thixotropic suspension — A condition that requires an initiating stress to commence deformation, but then resistance decreases with increased strain.

turbitity — The light scattering properties of *particles* suspended in a *fluid*.

ullage — The space in the upper part of a bulk storage container that cannot be filled because of the surface contours formed by the repose conditions acting from the point of fill.

unconfined failure — The *failure* of a *particulate bed* that is not supported on a boundary by a confining surface, therefore no normal force or *shear* force is acting on this surface. Such is the situation at the underside of an *arch*.

under-consolidated — A *state* of *consolidation* and applied stress where shearing causes compaction of the *particulate structure* in the shear plane

uniaxial state of stress — State of *stress* in which two of the *principal stresses* are zero.

unloading module — Slope of the tangent to the unloading *stress-strain* curve at a given *stress* value.

van der Waal forces — Molecular attractive forces between closely aligned fine *particles*.

viscous flow — Of *permeability*. A form of *flow* in which adjacent layers of *fluid* do not mix except at the molecular level and when the velocity at the *particle* interface is zero.

void — Space in a *particulate bed* that is not occupied by *particulate* matter. This volume may be occupied by air, water or any other liquid or gas in any combination. If the *void* space is totally occupied by a liquid, the *bed* is said to be ‘fully saturated’.

void pressure	The pressure of the fluid, usually air, in the *interstitial voids* between the *particles* in a *bed.*
void ratio	The ratio of the volume of the *void* space to the volume of the solid particles in a given *particulate* mass. At higher normal loads, with a particular condition of preparation, the *shear strength* will not peak, and continue to increase accompanied by an increase in the *density* of the sample to a different *bulk* condition, where it has a greater *shear strength*. See *underconsolidated.*

Section 2 - Types of Powder

Arizona test (road dust).	A powder of specified size distribution used for calibration, quality control or filter testing.
atomised powder	A *powder* produced by the *dispersion* of molten material sprayed under conditions such that it solidifies as a finely divided *powder*.
ballotini	Solids glass spheres, graded in size ranges.
calcined powder	A *powder* produced or modified by dry heat treatment.
calibration material	A *powder* or *suspension* used to standardise instruments and methods.
carbonyl powder	A metal *powder* produced by thermal decomposition of a metal carbonyl, generally nickel or iron or a combination of the two.
cenospheres	Fine, hollow glass spheres, a fractional component of *fly ash*.
certified reference material	A *reference material* that is accompanied by, or traceable to, a certificate stating the property value(s) concerned, issued by an organisation that is generally accepted as technically competent.
clay	Fine grained soil that exhibits plasticity, (putty-like properties), within a range of water contents and that exhibits considerable strength when dry. (The term has been used to designate the percentage of *particles* finer than 0.002 mm, (even 0.005 mm in some cases), but it is recommended that this definition is not used as, from the engineering standpoint, the properties described in the initial definition above are many time more important).
CRM 116	A standard *powder* (ground limestone) used for the verification of consistency and tester calibration with a *Jenike shear cell*. See *SSCT*. Samples are available from BCE, (Community Bureau of Reference to the European Union, together with certified yield loci for the Jenike test).
crystalline powder	A *powder* produced by the process of crystallisation.
‘C’ test dust	A *powder* of specified size distribution, coarse or fine, for *calibration*, quality control or filter testing. (Air cleaner tests).
diatomatious earth	A siliceous deposit occurring as a whitish powder, consisting essentially of the frustules of diatoms. It is resistant to heat and chemical action, so is used in fireproof cement, insulating materials and as an absorbent in the manufacture of explosives.

dust (of occupational hygiene). A definition given in health and safety manual is: -

‘A p*articulate* material that is, or has been, airborne and would pass through a 75 µm *sieve*’.

This description takes no account of the *particle density* and shape factor. The term may be more appropriately applied to - ‘*Particles* of low *aerodynamic diameter*, that tend to become airborne in low velocity air currents and are slow to settle’.

In general, *particles* above 20 µm are captured in the primary air passages of inhalation and are absorbed, if soluble, or eventually expelled by the system, if insoluble. *Particles* in the general aerodynamic *particle size* range of 7 to 20 µm tend to move through to upper airways of the respiratory tree and have more significant effects in irritation or asthmatic sensitisation. *Particles* of sub 5 µm aerodynamic size tend to pass to the foundations of the respiratory system and cause accumulative damage.

Suspended *particles* less than 200 µm can represent an explosion hazard if a potential ignition source is present and the *particle* concentration is such that a flame front can propagate itself. Settled *dust* carries a serious hazard of causing a secondary explosion when the disturbance of a primary explosion mobilises this dust to an airborne cloud.

Fugitive *dust* is a major source of mess, spillage and product loss, as well as raising health hazards, handling difficulties and quality issues of the product from which it originated.

Typical materials in this category are: -

Carbon black, tobacco smoke, paint pigments, insecticides, milled flour, coal dust and fly ash.

Coarse *particles* can be removed from entrainment by cyclones, intermediate size *dust particles* are generally collected by fabric or sintered sheets and very fine *particles* captured by electrostatic filters.

filter cake A packed *bed* formed by a filtering process and held together by *cohesive strength* if dry and by *surface tension* of residual moisture if the result of filtering from an initially saturated mass.

fly ash Finely divided ash composed of fused silica and glass, collected from electrostatic precipitators of power stations burning pulverised coal.

fumed powder A *powder* recovered from *fume*.

grit (Of occupational hygiene). *Particulate* material which is or has been airborne and which would be retained on a 75 µm *sieve.*

hydrogen reduced powder	*Powder* produced by the hydrogen reduction of a metallic oxide or other compound.
hydrophilic	The property that defines a material as attracting water. Water exhibits an obtuse contact angle with *hydrophilic* materials.
hydrophobic	The property that defines a material as water repellent. Water exhibits an obtuse contact angle with *hydrophobic* materials. This property favours the use of such materials, for example sheets of ultra-high molecular density polyethylene, as contact surfaces for damp and wet bulk products, to minimise the wall cohesive effects of surface tension,
hydrostatic pressure	A state of stress in which all the principal stresses are equal, (there is no shear stress), as in a fluidised powder where the pressure in the voids is due to the head of product and acts in all directions.
milled powder	A *powder* produced by *comminution* in a *mill*.
natural powder	Material occurring naturally as a fine *powder.*
precipitated powder	A *powder* produced by chemical or electrostatic precipitation.
reference material	A material, the relevant properties of which are sufficiently established and consistent for it to be used for the *calibration* of a measuring instrument. (See also *certified reference material, CRM116*)..

Section 3 - Powder properties

absolute powder density — The mass of *powder* per unit of *absolute powder volume.*

absolute powder volume — The volume occupied by the solid content of a *powder,* excluding all *pores* and *voids*.

absorption
1. Penetration of a substance, usually a fluid, into the body of another.
2. The attachment of water molecules to the surface of *particles*

aerated bulk density — (See *density, aerated bulk*)

agglomerate — An accumulated cluster of many *particles* that are rigidly bonded together by inter-particle forces, partial fusion, *sintering* or by growing together, such that they act as a single, larger *particle.*

apparent powder density — The mass of powder per unit of *apparent powder volume.*

apparent powder volume — The total volume occupied by solid matter, including open and closed *pores*.

bed porosity — (See *powder bed porosity*).

blinding — The building up of small *particles* on a screening surface reducing the *aperture size* or closing them completely.

bulk — A mass of *particles*.

coefficient of compressibility — $\alpha_v = (L^2 F^{-1})$. The secant slope, for a given pressure increment, of the pressure-*void ratio* curve. Where *a stress-strain* curve is used, the slope of this curve is equal to $\alpha_v/(1+e)$.

coefficient of consolidation — $\alpha_v\ (L^2 T^{-1})$. A coefficient utilised in the theory of *consolidation*, containing the physical constant of the loose *solid* affecting its volume change. $c_v = k(1+e)/\alpha_v\lambda_w$, where: -

k = coefficient of permeability, LT^{-1}
e = Voids ratio,
α_v = coefficient of compressibility, $(L^2 F^{-1})$.
λ_w = unit weight of water, FL^{-3}

coefficient of friction — μ, The relationship between *normal stress* and the corresponding *shear stress* at which sliding takes place between two surfaces. (Between a loose solid and a contact surface, this behaviour is referred to as *wall friction*). See *static friction* and *dynamic friction.*

coefficient of permeability — The rate of passage of a fluid under *laminar flow* conditions through a unit cross section of a media under a unit pressure drop at standard temperature conditions.

coefficient of uniformity C_u (D), The ratio D_{60}/D_{10}, where D_{60} is the *particle* diameter corresponding to 60 % finer on the cumulative *particle-size* distribution curve, and D_{10} is the *particle* diameter corresponding to 10 % finer on the *cumulative particle-size* distribution curve.

compression ratio The ratio of the *loose poured density* to the *pressed density.*

dynamic friction The frictional resistance to sustained sliding. See *friction*.

friability The tendency of *particles* and *granules* to break down in size during handling and storage under the influence of light physical forces.

gravel Mineral *particles* greater in size than 2000 microns

Hausner ratio The ratio of *tapped density* to *loose poured bulk density*.

hydrodynamic cluster The phenomenon of multiple, closely-grouped, individual *particles* falling through a *fluid* with a higher terminal velocity than that of the individual *particles*. Note that a focused flow stream achieves a higher fall velocity than the *terminal velocity* of an individual particle

major principal stress The largest *principal stress* acting on a *bulk solid.*

minor principal stress The *principal stress* acting on a *bulk solid* at 90 degrees to the *major principal stress.*

oscillating hopper sample divider A method of securing a representative sample by oscillating feed from a *hopper* over two contiguous chutes leading into separate collectors.

parent population The overall *bulk* system from which a *powder* sample is taken.

permeability The ease with which a porous mass e.g. a *powder bed* or *compact*, permits the passage of a *fluid* such as air. This feature has a major influence on the *flow* behaviour of fine *powders*. Changes in volume of the *bulk* essentially are reflected in changes in the *voidage*. This must initially respond to the volume variation by pressure change of the ambient *fluid*. A positive *void* pressure acts to partially support the *particle* mass. This support reduces *particle*-to-*particle* contact pressures and surface interferences that resist *shear*. In extreme circumstances, the *shear strength* of the bulk is negated and a highly dilated mass behaves as a *fluid.* A *void* pressure less than ambient, as generated by the *shear* of a settled *bed*, opposes the expansion of the *bulk* and hence increases its resistance to expansion and *flow*.

powder density, absolute (See *absolute powder density*).

powder density, apparent (See *apparent powder density*).

powder density, bulk (See *bulk density*).

powder density, tapped (See *tapped density*).

powder volume, apparent (See *apparent powder volume*).

pressed density (See *density, pressed*).

principal stress A *stress* acting in a plane that is not subjected to a *shear stress*

principal stress, major See *major principal stress*

principal stress, minor See *minor principal stress*

pyrophoric The property of a *powder* to self combust when exposed to oxygen

ratio, compression (See *compression ratio*).

recovery factor The change in dimension of a non-metallic *compact* on ejection from its die or mould.

representative sample A quantity taken from a larger amount, that fairly reflects the qualities relative to the conditions of interest of the whole.

sampling table A device for taking a small *powder* sample from a large quantity by pouring the material through a series of divided chutes that successively reject 50% of the material flowing.

sand Mineral *particles* in the size range 200 to 2000 microns

sand, fine Mineral *particles* in the size range 20 to 200 microns.

silt Mineral *particles* in the size range 2 to 20 microns. (Mineral *particles* less than 20 microns are usually referred to as 'clay').

sliding friction See *dynamic friction*

static friction The *friction* value developed when resistance to slip is fully mobilised prior to relative movement taking place between the material and the contact surface. Note that *friction* is dependent upon both the nature of the *bulk solid* and its interaction with a specific contact surface. The magnitude of frictional resistance is then a function of the *normal stress* acting between the *bulk* material and the contact surface. See *surface friction*, *co-efficient of friction*, *dynamic friction.*

surface adhesion The result of attractive mechanisms between a *particulate solid* and a contact surface. These will give rise to surface *cohesion* effects according to the frictional nature of the interface. See *adhesion, cohesion.*

surface cohesion The resistance to slip offered by internal forces between a *particulate solid* and a contact surface, separate from any frictional effect due to a normal force acting on the surface. These forces may be generated by such effects as surface tension, in the case of a damp *powder*, electrostatic forces or molecular forces. The effect may be exacerbated by a negative *void* pressure differential with ambient pressure. See *adhesion. Cohesion.*

surface friction — See s*tatic friction, dynamic friction*

tortuosity — A measure of the convoluted path followed by an element of *fluid* passing through the intensities of a packed *powder* bed.

volume, absolute — The volume of the *solid* matter after exclusion of all the spaces (*pores* and *voids*).

volume, apparent powder — (See *apparent powder volume*)

volume, powder — The apparent volume of a *powder* as measured under specific conditions.

Section 4 - Powder Processing.

blending	The placing together of different materials in a prescribed ratio at a *scale of scrutiny* that is significant to the application by way of low energy mechanisms, such as by intermingling gravity *flow* streams or layering onto a moving belt. (See *mixing* and h*omogenising*).
'boiling' fluid bed	A *fluid bed* where the quantity of the fluidising media agitates the mass by passing through the *bed* in large bubbles.
calcining	A process of modifying the properties of a *powder* by subjecting it to a high temperature.
capture zone	The converging region between the rollers of a *roll press* where the *surface friction* on the product causes the material to move towards the nip point without slipping on the roller surfaces.
cementation	The binding together of *particles* by precipitation at their points of contact.
cold pressing	The compaction of a *powder* carried out at room temperature.
comminution	The reduction of *particles* size by intensive fracture.
compact	A form prepared by compressing *powder* in a mould or die.
compact, green	(See *green compact*)
compact, sintered	A *green compact* after *sintering.*
cut	The division point for separating a *flow stream* in which *particles* are preferentially directed to each side of the '*cut*' according to some physical *attribute*.
dilated bed	A bed of powder that is expanded to a dilate condition by a gas pressure in the voids in excess of ambient. (See *settling bed, expanded bed*).
dry inertial collectors	A type of *dust* collector that disengages *particles* from a gas by virtue of exploiting their physical dynamics.
electrostatic precipitators	A *dust* collecting system that imparts an electric charge to *particles* in a *dust* laden stream and subsequently collects them on plates maintained at a high voltage.
expanded bed	A bed of *particulate solids* held in a state of dilatation by the upwards passage of a second phase media such that the *particle*-to-*particle* contact pressure is reduced from that of a *settled bed.* (See *dilated bed*)

fabric filters	A dust collecting system that uses porous fabric as a barrier to collect *dust particles*.
fluid bed	A suspension of *particles* suspended in an upward flow of *fluid* (or downward flow if the *particles* are less dense than the *fluid*).The bed may be *quiescent* or *boiling*, according to the quantity of the fluidising *fluid.*
fluidising	The process of injecting a gas underneath a *bed* of *particulate solids* , to dilate the material in a rising gas stream such that it behaves like a liquid. See *fluid bed.*
granulation	The process of combining *particles* into larger *agglomerates* (granules)
green compact	A formed *compact* intended for *sintering,* or which hardens with time or other treatment.
Haultain infrasizer	A vertical air *elutriator* similar to the *roller elutriator*.
homogenising	The rendering of components that were initially separate or varied in nature throughout the volume of a mass, to a compound of uniform composition at a *scale of scrutiny* that is significant to the application. (See *blending* and *mixing*).
hot pressing	The *compaction* of a powder under heat and pressure, to result in *sintering* of the mass to a strongly bound mass.
minimum fluidising velocity	The minimum gas velocity required to fluidise a *bed* of *powder*. The value depends mainly upon the *particle* size and *effective particle density*.
pegging	The conditions which occurs when *particles* wedge in the apertures of a *sieving* medium.
pellet	An *agglomerate* of *particles* produced by specialised techniques, such as *pressing*.
pre-sintering	A heat treatment carried out at a temperature below a final *sintering* temperature to strengthen a powder *compact.*
pressing	The *compaction* of a *powder* under pressure in a mould or die.
pressing, cold	(See *cold pressing*).
pressing, hot	(See *hot pressing*).
pressing, warm	(See *warm pressing*).
quiescent bed	A bed of *particulates* held in a steady, tranquil state of suspended dilatation by the passage of a second phase media

roller elutriator	A vertical air *elutriator* used for fractionating *powder* in the size range 5 to 300 microns
roll press	A *compacting* device that consolidates *powder* between two contra-rotating rollers under a nip pressure acting on the small gap between the rollers. The rollers may have flat surfaces, to produce flakes, or have mould indentations that form pellets or nodules.
scalping	The separation of a small amount of oversize *lumps* or *particles* from a *bulk* material by *size classification*.
settled bed	A stable *bed* of *particulates* where *particle* to *particle* contact pressure is fully developed and not relieved by internal *void pressure* or the counter-flow of a fluid.
settling bed	A transient condition, where a *bed* of dilated *particles* has an increasing *density* condition and a decreasing *void pressure* as the media in the interstitial volume at a higher pressure than ambient percolates from the *bed*, ultimately to allow *particle*-to-*particle* contact pressures to develop to those of a fully-*settled bed* where the void pressure is ambient.
shrinkage	The reduction in size of a *compact* on drying or *sintering*, expressed as a percentage of the final volume or stated linear dimension.
sintering	The bonding of contiguous *particles* in a mass of *powder* or a *compact* by partial fusion at temperatures below the melting point of the *particles*.
spiral flow classifier	A device for fractionating fine *particles* by moving a *fluid* stream in which the *particles* are suspended through a cylindrical vessel from a tangential inlet to a more centrally located outlet. The extend to which centripetal forces on the particles overcome *fluid drag* is related to the physical characteristics of the individual *particles* and determines the ability of the *particles* to exit at specific radially located outlets of the equipment. The division between outlet positions being terms the 'cut'.
tablet	A small *compact.*
trajectory	The path taken by a *particle* with an initial component of horizontal motion under the influence of gravity and/or prevailing air flow.
warm pressing	The *compaction* of a *powder* under pressure above room temperature and below *sintering* temperature.
wet scrubbers	A dust collecting system that employs a spray system to capture *particles*.

Section 5 - Particle Properties

abrasiveness — The ability of *a particle* to cause wear on a contact surface. This quality is determined by its *hardness* factor and sharpness of the points of contact. The actual degree of wear then depends on power factors of both the contact pressure and the relative velocity of the contact surfaces. Hard, sharp, angular shaped *particles* may be expected to be highly abrasive.

aerodynamic diameter — The diameter in µm, of a unit density sphere that has the same *terminal velocity* in air as the *particle* in question.

apparent particle density — (See *density*, apparent *particle*).

Blain fineness — The fineness of a *particulate material*, expressed as the surface area per unit of mass.

Bond work index — The energy required to reduce the size of unit mass of material from infinity to 100 µm in size.

Brownian motion — The random movement of small *particles* in a disperse phase caused by the bombardment of molecules of the surrounding media.

classification — *Grading* in accordance the *particle size*, shape, *density* or other attribute.

cleavage — The tendency to cleave, or split, along definite parallel, closely spaced, particle planes of least *cohesion.*

coagulation — The change from a *fluid* to a more or less irregular solid state.

coalescence — The joining together of *fluids* originally separated by boundaries.

de-flocculation — The breaking down of *flocculates.*

density, apparent particle — The mass of a *particle* divided by its volume.

density, effective particle — The mass of a *particle* divided by its volume including *open pores* and *closed pores*.

density, immersed particle — The mass of a *particle* per unit volume of suspension *fluid* displaced.

density, true — The mass of a *particle* divided by its volume, excluding *open pores* and *closed pores.*

dispersion — The separation and distribution of one phase in another.

effective particle density — (See *density,* effective *particle*).

electrokinetic potential See *zeta potential*

flocculation The *coalescence* of *particles* into *floccs.*

fouling The building up of *particles* onto surfaces because of the *particles* stronger attraction to the surface than to the *fluid* in which they are dispensed.

free-fall velocity Velocity of fall of a *particle* though a still *fluid* at which the affective weight of the *particle* is balanced by the drag exerted by the *fluid* on the *particle.*

hardness Hardness is characterised, in general, by the resistance of a material to deformation. This property reflects a material's susceptibility to abrasion by other material of contact and its ability to abrade other materials. As such, the value is a measure of its resistance to wear and aggressiveness to cause wear on other materials. When the surface is sufficiently large, absolute hardness is normally measured by determining the resistance to indentation, as in Brinell, Rockwell, Vickers diamond pyramid and scleroscope hardness tests. For *particles* and *powders* hardness, it is generally described in relation to its capacity to scratch or wear other materials, without itself suffering surface *degradation*. Ten materials of different hardness are defined by *Mohr's scale of hardness*, to act as a basis for comparison and interpolation.

immersed particle density (See *density*, immersed *particle*).

Mohr's scale of hardness A scale that gives a comparative order of hardness by expressing it in terms of the ability of one material to scratch another, without itself being affected. A set of reference materials is listed with which others may be compared.
In ascending order of hardness, these are: -

1. Talc
2. Gypsum
3. Calcite
4. Fluoride
5. Apatite
6. Orthoclase
7. Quartz
8. Topaz
9. Corundum
10. Diamond.

It should be noted that some material surfaces are an-isotopic in hardness, the resistance to scratching being 'tougher' in one direction than another.
The ability to mark another surface is dependent upon the intensity of local pressure, therefore a *particle* that has sharp corners will concentrate any given contact force on a smaller area.

Ostwald ripening The growth of some *particles* in a *suspension* at the expense of others as a result of dissolution and re-crystallisation.

particle density (See *density, apparent density*, or *density, effective particle*).

particle density, true	(See *density, true*).
sedimentation	The settling of *particles* in a still fluid, resulting in grading by mass.
settling velocity	The distance per unit time that a *particle* falls in a still *fluid*. *Stokes' law* has been developed, at low *Reynolds number*, to relate *settling velocity* to *particle* size.
temperature	Generally, most materials are handled in ambient temperature conditions. In sensitive cases, the physical properties of the *bulk* material may be affected at high ambient temperatures, and almost certainly so at elevated temperatures. High temperature also affects the gas in the *voids*, almost invariably to increase the gas viscosity and thereby significantly influence the effects of *bulk* volume changes. See *porosity.* Hot, fine *powders* from driers and kilns are considerably more prone to sustained aeration and fluidity than the same material at normal ambient temperature. This is because of the increased resistance to loss of excess air from the *voids* by virtue of the reduced *permeability* of the mass to the higher viscosity gas. Changes of temperature also cause secondary effects of moisture holding capacity of the gas, condensation migration and 'thermal ratcheting', a process of repeated change of volume due to fluctuating thermal variations, as between day and night conditions, that alternately contract a *bulk* volume in a silo to cause settlement, and then expand to *stress* the container walls.
terminal velocity	1 - See *free-falling velocity*. 2. - See *terminal gas velocity*
velocity, free falling	See *free-falling velocity*.
viscous drag	The resistance to movement of a *particle* through a *fluid*.
zeta potential	The potential difference between the surface of a solids *particle* immersed in water or a conducting liquid and the fully dissociated ionic concentration in the body of the liquid. It can be determined using the Smoluchowski equation: $\zeta = 4\pi.\eta.U/E_{oo}$ Where ζ is the zeta potential η is the viscosity of the liquid U is the velocity of a particle under an applied electric field E_{oo}.

Section 6 - Particle Size

apparent particle volume	The total volume of the *particle*, excluding *open pores*, but including *closed pores.*
boulder	A rock fragment, usually rounded by weathering or abrasion, normally larger than 300 mm.
chip	crushed, angular rock fragment smaller than a few centimetres.
classified grading (of lump size)	These are *bulk* materials for which the ratio between the sizes of the biggest and the smallest lump is less than or equal to 2.5. (This includes material of a single dimension). A classified material is adequately defined by the values of d_{max} and d_{min}.
cumulative oversize distribution plot	A plot obtained by recording the amount of the oversized *particles* (y axis) against *particle* size (x axis) for several different size levels.
cumulative undersize distribution plot	A plot obtained by recording the amount of the undersize *particles* (y axis) against *particle* size (x axis) for several different size levels.
D_{10}	The diameter of a *particle* at which 10 % by weight (dry) of the constituent *particles* of a sample are finer.
D_{60}	The diameter of a *particle* at which 60 % by weight (dry) of the constituent *particles* of a sample are finer.
density distribution	Of size distribution. (See *frequency distribution plot*).
diameter, diffusion	The diameter of a *particle* calculated from photon correlation spectroscopy, using the *Stokes-Einstein equation.*
diameter, equivalent diffraction	The diameter calculated from light *diffraction* observations.
diameter, equivalent free-falling	The diameter of a sphere which has the same *free-falling velocity* in a given *fluid* as the *particle* when determined under similar conditions.
diameter, equivalent perimeter	The diameter of a circle with a perimeter equal to that of the *particle* .
diameter, equivalent sphere	The diameter of a sphere which behaves like the observed *particle* relative to or deduced from a chosen property.

diameter, equivalent surface	The diameter of a sphere which has the same effective surface as the *particle* when determined under similar conditions.
diameter, equivalent volume	The diameter of a sphere which has the same effective volume as the *particle* when determined under similar conditions.
diameter, Ferrets	The distance between two parallel tangents on opposite sides of the image of a *particle.*
diameter Martins	The length of a line which bisects the *particle* image.
diameter, maximum chord.	Maximum length of a line limited by the *particle* contour .
diameter, mean	Several mean diameters can be presented of *particle size* distribution data. To understand them, consider an experimental study (for example, by microscopy) where the population of *particles* is counted within several finite size classes. It is found that there are η_i *particles* within any size interval (i), which has an arithmetic mean diameter of d_i. The full size distribution is obtained by accumulating data over several size intervals, becoming more accurate if the intervals are small, so that di becomes a better estimate of the real average particle size within the interval.
e.g diameter mean	Let any mean, m_q, be represented by $m_q = \sum n_i (d_i)^q / \sum n_i$

The more commonly used mean diameters of the size distributions are:

Systematic code	Nomenclature	Calculated from
D_1,0	Number mean diameter	m_1
D_2,0	Surface mean diameter	m_2
$D_{3,0}$	Volume* mean diameter	m_3
$D_{2,1}$	Diameter-weighted mean diameter	m_2/ m_1
$D_{3,2}$	Surface-weighted mean diameter	m_3 m_2
$D_{4,3}$	Volume*-weighted mean diameter	m_4 m_3

*Note . Mass means are equal to volume means if all of the particles have the same *density*.

diameter , median	The middle of a number of observations of diameters.
diameter, modal	The most commonly occurring *particle* diameter.

diameter, projected area	The diameter of a circle which has the same area of projection as the projected area of the *particle*.
diameter, sieving	The diameter of the aperture of the mesh of the *sieve* which just allows the passage of the *particle*.
diameter, specific surface	The diameter of a sphere having the same surface area as the *particle*.
diameter, specific volume	The diameter of a sphere having the same volume as the *particle*.
diameter, Stokes'	The diameter of a sphere with the same *settling velocity* as the *particle,* calculated according to *Stokes' law*. This is of the form: -

$d = [\, 18\, \eta . H / (\partial_s - \partial_f)\, g.t \,]^{1/2}$ where: – d = diameter of sphere

η = viscosity coefficient of the fluid
H = distance moved by the sphere in the time interval - t
g = acceleration due to gravity
H/t = falling velocity = v
∂_s = density of the particle
∂_f = density of the fluid

differential distribution plot (See *frequency distribution plot*).

diffusion diameter	(See diameter, diffusion).
dispersity	(See *monodisperse system* and *polydisperse system*).
distribution, mass	(See *mass distribution*).
distribution, number	(See *number distribution*).
distribution, particle size	(See *particle size distribution*).
distribution, volume	(See *volume distribution*).
dynamic range	The ratio of the sizes of the largest and smallest *particles*.
envelope volume	The external volume of a *particle*, *powder*, or *monolith* such as would be obtained by tightly shrinking a film to contain it.
equivalent free-falling diameter	(See *diameter, equivalent free-falling*)
equivalent settling	(See diameter, equivalent settling).

diameter

equivalent surface diameter	(See diameter, equivalent surface)
equivalent volume diameter	(See diameter, equivalent volume)
Feret's diameter	(See *diameter, Ferret's*)
fines	*Particles* that are smaller than a given size.
Fisher number	An indication of average *particle size* as given by a *Fisher sub-sieve sizer.*
free-falling diameter, equivalent	(See diameter, *equivalent free-falling*)
frequency distribution plot	A plot exhibiting a series of observations of values as a function of the frequency of occurrence.
grading	Separation of a *powder* into *particles size fractions*. See *classified* and *non-classified materials*
heterodisperse system	A *bulk powder* or *suspension* containing *particles* with a range of sizes.
length	The longest *Feret's diameter* of a *particle.*
lump size (grading)	The size of the lump is denoted by the longest edge, d, of the cuboid in which it can be contained. Materials are distinguished as *classified* or *non-classified.* Note – Whatever the grading might be, an indication should be made as to whether is can be considered as a regular average. If the grading differed over a period of time, the limits of probable variations and their duration shall be defined, especially if repeated periods are anticipated where concentrations of big lumps will occur. The size of a piece is the minimum rectangular parallel box in which it can be contained of length, l, (the longest dimension), thickness (the smallest dimension) t, and width, w.
lump form, (shape)	See *particle shape.* Section 7.
Martin's diameter	(See *diameter, Martin's*).
mass diameter	The distribution by mass of *particles* as a function of their size.
mean particle size	Dimension of a hypothetical *particle* such that, if the total mass of the *particulate* system was wholly composed of such identical *particles,* they would all have that dimension.

median diameter	(See *diameter, median*).
modal diameter	(See *diameter, modal*).
monodisperse system	A *dispersion* having *particles* all of effectively the same size.
non-classified grade (of lump size)	These are materials for which the ratio between the size of the largest and smallest lump is greater than 2.5. These materials normally require a complete grading analysis, made by section in which the extreme ratios of the lump size should not exceed 2.5. The grading should at least indicate the proportion, (by mass), of the lumps between 0.8 d_{max} and d_{max}, d_{max} being the size of the biggest lump which can be found in the material.
number distribution	The distribution by number of *particles* as a function of their size.
oversize	The fraction of a *powder* composed of *particles* which are larger than a specified size, e.g. the fraction of the test portion retained on a *sieve*.
perimeter diameter, equivalent	(See *diameter, equivalent perimeter*).
particle size distribution	A description of the size and frequency of *particles* in a population.
particle size, mean	(See *mean particle size*).
particle volume, apparent	(See *apparent particle volume*).
polydisperse system	A dispersion having *particles* of significantly different sizes.
projected area diameter	(See *diameter, projected area*).
range, dynamic	(See *dynamic range*).
sedimentation analysis techniques	*Particle size* characterisation based upon *Stoke's diameter* studies.
sedimentation diameter, equivalent	(See *diameter, equivalent free-falling*).
sieve size of a particle	The smallest sieve aperture through which a *particle* will pass if presented in the most favourable attitude.
size distribution, particle	(See *particle size distribution*).

size fraction — The portion composed of *particles* between two given size limits, expressed in terms of mass, volume, surface area or numerical frequency.

size, mean particle — (See *mean particle size*).

Stokes' diameter — (See *diameter, Stokes'*)

undersize — The portion of a *powder* composed of *particles* which are smaller than a chosen size. e.g. the fraction of the test portion passing through the *sieve*.

volume, apparent particle — (See *particle volume, apparent*)

volume, distribution — The distribution by volume of *particles* as a function of their size.

volume, equivalent diameter, (See *diameter, equivalent volume*).

Section 7 - Particle shape

acicular	Long, thin shape, like a stiff thread or needle.
angular	Sharp edged, or having approximately polyhedral or irregular shape.
aspect ratio	The ratio of the longest *Feret's diameter* of a *particle* to the largest width measured at right angles.
cavity	A natural opening in the body of the *particle* that may be small or large.
convex perimeter	(Of *image analysis*.) The shortest perimeter that will circumscribe the object. (Like the length of a piece of string tied around the object).
crystal	A *particulate* body, generally solid, whose atoms are arranged in a definite pattern, the outer faces being an expression of the regular structure of the atomic composition. Usually formed from a solution.
crystalline	Having geometric or multi-faceted, regular shape characteristic of the substance, as grown from a crystal, such as granular sugar and salt.
cylindrical	Shaped like a cylinder. Extruded plastic pellets typically take this form.
dendritic	Having a branched crystalline shape with the branches extending in a tributary manner from the faces of the body.
fibrous	Threadlike, either regular formed or not, with a flexible structure.
flake	A thin, broad *particle*. May be flat or of convoluted form.
flakiness ratio	The ratio of the breadth of a *particle* to its thickness.
flaky	Consisting of *flakes*, usually of irregular form. (See *lamellar*).
globular	Of rounded composition, such as a coastal pebble.
granular	A large *particle* with approximately equal dimensions, but of irregular shape with the surface characterised by angular points or irregularities.
Hausner shape factor	The ratio of the two sides of a rectangle constructed with minimum area to contain the profile of a *particle* viewed at right angles to its position of maximum stability, inscribed within the minimum circle required to contain the *particle* boundaries.
Heywood elongation ratio	The ratio length/breadth of the *Heywood shape factor.*
Heywood flakiness ratio	The ratio breadth/thickness of the *Heywood shape factor*.

Heywood shape factor — A method of defining *particle* dimensions based upon the ‘thickness’ defined as the minimum distance at which two parallel plates can contain the particle. The ‘breadth’ being the minimum distance at which two parallel plates set at 90 degrees to those defining the ‘thickness’ can contain that plane of the particle. ‘Length’ being the minimum distance required for two parallel plates set at 90 degrees to those capturing the thickness to contain the largest dimension across the particle in that plane.

irregular — Having different measurements in the three dimensions.

isometric — Having the same measurement in three dimensions.

lamellar — Plate like, usually of flat, regular form in contrast to *flakes*, which as usually of irregular profile and/or surface flatness

modular — Having a rounded *irregular* shape.

needle-like — Long, thin rigid, straight and pointed shaped *particles*

nodule — A large rounded *particle*.

out-of-round — A flattened sphere or oblate spheroid.

rod-like — Straight, smooth, extended length *particles*

rugosity — A measure of the degree of wrinkling on a surface of a *particle.*

shape coefficient, dynamic — The ratio of the resistance to motion of a given *particle* in a *fluid* to that of a spherical *particle* of the same volume.

shape elongation factor — The ratio of the length of a rectangle, with two sides parallel to the longest dimension of a *particle,* to its width.

shape sphericity factor —

1. A means to express the deviation from spherical uniformity of the *particle*. One such is the *sphericity factor.*
2. The name is also given to the factor correlating different values of a *particle* parameter that is secured by different methods; such as the ratio of the *mean diameter* of a *particle* as separately determined by microscope and *sedimentation analysis*.

spherical — Ball or globe shaped, of perfect symmetry.

sphericity factor, — The ratio of the surface area of the *particle* to that of a sphere that has the same volume as the *particle*.

spheroid — Of basically *globular* or spherical shape.

Section 8 - Pore Size and Shape

closed pore	A cavity with no access to an external surface.
'ink bottle' pore	(See *pore, 'ink bottle'*).
lattice structure	A framework of pores in thin shell (as with a spray dried product)
macropore	A *pore* with a width greater than approximately 50 nm.
mesopore	A *pore* with a width between approximately 2 nm and 50 nm.
micropore	A *pore* with width less than approximately 2 nm.
multi-pore	A *particle* with multiple, discrete cavities – closed or open
open pore	A cavity or channel with access to an external surface.
pore	A cavity in a *particle*.
pore, closed	(See *closed pore*).
pore, 'ink bottle'	A narrow-necked *open pore*.
pore, macro	(See *macropore*).
pore, meso	(See *mesopore*).
pore, micro	(See *micropor*e).
pore, multi	(See *multi-pore*).
pore, open	(See *open pore*).
pore size distribution	The distribution of *pore* width in a *porous* body, as determined by a specific method.
pore volume	The volume of open *pores*, measured by a specific method
porosity (of particle)	The ratio of the volume of any *open pores* and *voids* to the *envelope volume*.

Section 9 - Particle Surface Area

adsorbate — A substance in the absorbed state.

adsorbent — A substance on whose surface *adsorption* of another substance take place.

adsorption — The taking up of a substance, usually gas or liquid, on the surface of another

adsorption hysteresis — The phenomenon which occurs when the amount of substance desorbed is not the same as the amount absorbed.

adsorption isotherm — The relation, at constant temperature, between the amount of substance adsorbed and he equilibrium pressure of the *adsorptive*.

adsorption surface area — See *surface area, adsorption*.

adsorptive — The surface to be adsorbed.

area, calculated surface — (See *surface area, calculated*.

area, permeability surface — See *permeability surface area*.

BET surface area — The surface area calculated from the Brunauer, Emmett and Teller theory for the multi-layer *adsorption* of a gas on a solid surface.

calculated surface area — See *surface area, calculated*.

chemisorption — Adsorption in which the *adsorbate* is held on the surface by chemical forces.

dead-space (adsorbate) — The amount of gas required to fill the space around the *adsorbent*.

desorbtion — The giving up of one substance, usually gas or liquid, at the surface of another

effective permeability, mass specific surface — The *effective surface* area divided by the *effective solids density*, as determined by *permeametry*.

effective permeability, volume specific surface — The *effective surface area* divided by the *effective solids volume*, as determined by *permeametry*.

equilibrium adsorption pressure — The pressure of the gas in equilibrium with the *adsorbate*.

isotherm, adsorption — (See *adsorption isotherm*).

Knudsen flow — (See *molecular Knudsen flow*).

Kozeny-Carman equation	Of *permeametry*. An equation used to calculate a surface area of a packed bed from its *permeability*.
molecular cross-sectional area	Of gas adsorption. The average area occupied by an adsorbate molecule in the *monolayer*.
molecular Knudsen flow	The flow of low pressure gas through a *pore* or *interstice,* whose diameter is much smaller than the mean free path of the molecules.
monolayer amount	The number of moles of *adsorbate* that forms a monomolecular layer over the surface of an *adsorbent*.
monolayer capacity	The amount of *adsorbate* needed to cover an *absorbent* surface with a complete monolayer of molecules.
permeability surface area	The surface area of a *powder* calculated from the *permeability* of a powder bed under stated conditions.
pressure, equilibrium adsorption	The pressure of a gas in equilibrium with an *adsorbate*.
pressure, relative	The ratio: - *equilibrium adsorption pressure* to *saturation vapour pressure*.
pressure, vapour	The vapour pressure of the bulk liquefied *adsorptive* at the temperature of the *adsorption*.
slip flow,(of *permeability*).	The enhanced airflow caused by the air velocity at the air/powder interface not being zero, as assumed for *viscous flow*. This feature becomes significant at low pressures or for very fine *powders*, and can affect *permeability* measurements.
specific surface area	The surface area of the *particles* in a unit mass of *powder*, determined under stated conditions.
surface area, adsorption	The surface area of a *powder* calculated from an *adsorption* method.
surface area, calculated	The surface area of a *powder* calculated from its *particle size distribution*.
surface area, permeability	The surface area of a *powder* calculated from the *permeability* of a *powder* bed under stated conditions.
surface area, specific	See *specific surface area*.
vapour pressure	See *pressure vapour*

Section 10 - Particle Test Methods (of Image Analysis)

background	The regions of an image that are not currently considered as *objects*.
binary image	A processed image having two levels of intensity.
blob	An *object*.
Boolian operation	A logical procedure where two binary images are compared, *pixel* by *pixel,* to produce a third binary image.
close	To *dilate,* and then *erode,* objects in a *binary image* to reduce the roughness of their *edges*.
cut	The intervention by an operator, to insert a line of non-object *pixels* in a *binary image* to separate overlapping *objects*.
delineation	An image processing operation which introduces abrupt changes in *grey level* at the boundaries of objects in a *grey level image*. Its main use is to prevent errors in measuring sizes of objects having different *grey levels* in the same image.
detection	(See segmentation).
dilate	To add *pixels* uniformly to the periphery of an object in a *binary image*.
dispersative quotient	The variation or *refractive index* with wavelength.
edge	The boundary between regions of interest and *background* (also see *segmentation*).
edge enhancement	(See *delineation*).
erode	To remove *pixels* uniformly from the periphery of an *object*.
eyepiece graticule	A scale or grid inserted in the eyepiece of a light microscope, for the purpose of measurement.
false colour	(See *pseudo-colour*)
field	The area which can be viewed simultaneously by an imaging device e.g. a camera or microscope.
filling	(See *hole filling*).
frame	The area of an image over which *image analysis* operations are executed.

graticule, eyepiece	(See *eyepiece graticule*).
grey area	A number representing the brightness of a *pixel* in an image.
halo	(Of light microscopy and image analysis). The apparent grey perimeter surrounding a dark abject caused by the finite resolution of the imaging system.
halo error	(Of light microscopy and *image analysis*). The over-sizing of objects due to a *halo* effect.
Helos diffraction pattern analyser	A proprietary *particle size* measuring device based upon laser diffraction.
hole filling	The process of filling gaps left in *objects* within a *binary image*.
iconometrics	The scientific study of *image analysis*.
image analysis	The process of producing numerical or logical results from an image, which can be expressed in non-image terms.
image enhancement	(See *image* processing)
image frame	(See *frame*).
image processing	Operations on an *image* which produces a different *image.*
inversion	The reversal of a binary *image* by the conversion of all the 1's to 0's and the 0's to 1's. Inversion is an example of a *Boolean* operation.
measurement frame	(See *frame*)
micrometer	A fabricated scale used to measure magnification. The micrometer is placed in the object plane of the microscope and compared with a length in the plane.
object	A region in which all the *pixels* in the binary image are connected and which are surrounded by *pixels* of the alternative state. It is sometimes referred to as a *feature* or a *blob.*
open	To *erode,* and then *dilate,* objects in a *binary state*.
picture point	(See pixel).
pixel	The smallest spatially-digitised unit of an *image.*
pseudo-colour	A technique for enhancing *grey level* differences by converting them into different colours and displaying the result on a colour monitor.
relaxation	See *smoothing*

retro-diffusion	The optical diffusion which takes place in the half space containing the pencil of incident light and limited by the plane tangent to the diffusion at the point of incidence of the beam.
'salt and pepper'	The spurious unwanted fluctuations in an electronic signal as shown on a video screen.
scanner	The *image* device for an *image analyser*, usually a video camera or an electron microscope.
segmentation	The process of distinguishing from the *background* those parts of a *grey level image* that are of interest.
shading	The variation in electrical output from a video *scanner* when scanning across areas of identical brightness in different parts of the *image. Shading* can be caused by optical effects and *scanner* deficiencies.
shading corrector	A device which compensates for uneven *scanner* output using an *image* from a blank field, i.e. one with no *particles* present.
skeletonising	The process of successive erosion from the periphery of an *object* unless this would destroy connectivity. The resulting skeleton has no *pixel* in it with more than two intermediate neighbours, unless it is at a junction.
slicing	(See segmentation).
smoothing	The process of digitising an *image* whereby each pixel is considered in turn, and its value modified by reference to its neighbours.
stereology	The study of three dimensional structures from two dimensional sections or projections of them.
thinning	(See skeletonising).
threshold	A grey level value which separates regions of interest from background in a grey level image. (See also *slicing* and *segmentation*).
threshold setting	The voltage level at which a *particle* counter detection circuit is set in order to identify a *particle* of a specific size.
video signal	The analogue signal from a *scanner.*

Section 11 - Particle Test Methods - (others)

analysis sample — (See sample, test portion).

Andreasen pipette — A device to determine *particle size distribution* by *gravitational liquid sedimentation* by taking sample from fixed depths by means of a pipette. BS 3406 Part 2 1980

aperture size — The dimensions of an opening

attrition test — The measurement of *particle fracture* or *abrasion* characteristics

autocorrelation spectroscopy — (See *photo correlation spectroscopy*).

BCIRA dust sampler — British Cast Iron Research Association gravimetric size- selection personal *dust* sampler

BCURA sampling train — An apparatus for sampling dusty gasses in gaseous streams. (British Coal Utilisation Research Association).

BCURA sedimentation — A *sedimentation* column for a cumulative method of grametational *sedimentation size analysis*, (British Coal Utilisation Research Association).

Blain permeameter — An instrument for estimating a *specific surface area* of a *powder*.

Bostock's sedimentation balance — A *sedimentation balance* for determining the *Stoke's diameter* of particles.

Boundbrook photsedimentometer — A commercial *photosedimentometer*.

bridge width — The distance between the nearest edges of two adjacent holes in a *perforated plate*.

bubble point — The differential gas pressure at which, under specified conditions, the first, steady stream of gas bubbles is emitted from a horizontal disc of porous medium when immersed in, or pre-wetted with, a liquid. The *bubble point* is used to estimate the diameter of the largest *pore* present.

buffered line start method — The use of a small *density* gradient between the layer of suspension and the beginning of the column of clear liquid in a *sedimentation balance*.

calibration — The determination of a bias conversion factor of an analytical process, under specified conditions, in order to obtain meaningful results.

calibration factor — A factor used to adjust measurements after *calibration*.

cascade impactor — A device for separating *particles* from a fluid by leading the *fluid* stream through a series of jets.

centrifugal classification — The grading of *particles* by *size, shape* and *density* in a *fluid*, accelerated by centrifugal forces.

centrifugal disc photosedimentometer — A commercial *photosedimentometer* that uses centrifugal force to accelerate the s*edimentation* process.

centrifugal elutriation — The classification of *particles* by their movement relative to a rising *fluid*, accelerated by centrifugal force.

centrifugal sedimentation — The classification of *particles* by their rate of fall in a *fluid*, accelerated by centrifugal force.

cone and quartering — A method of sub-dividing a dry *powder* sample. (See BS 3406: part 1)

contamination classes — Levels of *particulate* contamination according to various standards.
Example 1. Particles in air (clean rooms): BS 5259 Part 4.
Example 2. Particles in hydraulic fluids: BS 5540 Part 4.

Coulter Counter — An *electrical sensing zone method* of determining particle size, named after the inventor. The size of a *particle* is indicated by the change of potential caused by the *particle* flowing through a small cross section of flow channel in dilate suspension in an electrolytic solution.

cyclosizer — A form of inverted cyclone used for the *fractionation* of particles.

diffraction — The deviation of light caused by it interaction with the *edges* of a *particle*.

diffraction pattern — The pattern of varying light intensity resulting from the diffraction of light by *particles*.

direct method of measurement — A method by which the value of a measurement is obtained directly, rather than form estimation of other functionally related quantities.

DOP test — An air filter efficiency test, using an aerosol of dioctylphthalate (of approximately 0.3μm diameter).

dry sieving — (See *Sieving, dry*).

Eagle Pincher photosedimentometer — A commercial *photosedimentometer*.

Eel photosedimentometer — A commercial *photosedimentometer* electrical sensing zone method — The measurement of number and volume of individual *particles* suspended in an electrolytic solution as they pass through a small aperture in an electrical field.

electrophorietic mass transport — The migration of *particles* in a *fluid* caused by an applied electrical filed.

elutriation — Classification of *particles* effected by their upwards movement relative to a rising *fluid*. (A specific particle will achieve a *terminal velocity* in free fall, hence classification is determined by the velocity of gas required to generate a *viscous drag* on the *particle* that is greater than its mass, (i.e. gravitational attraction). Note that the gas velocity to dilate or fluidise a *bed* of *particles*, *fluidisation velocity*, is lower than the *elutriation*, or *terminal velocity* of the constituent particles.

elutriation, centrifugal — (See *centrifugal elutriation*).

end-point, (of test) — The stage in a test when continuation of the procedure fails to alter the result significantly.

Fisher sub-sieve sizer — A device for estimating *particle size* based upon *permeability* measurements

Fox and Parekh permeamenter — A device for estimating surface area by permeability techniques

frame, (of *particle* sizing) — A rigid framework which supports the *sieving medium* and limits the spread of the material being *sieved*.

Fraunhofer diffraction — Measurement of special distribution of laser light scattering patterns from particle assemblies using Fraunhofer diffraction theory.

Gooden and Smith permeameter — An early instrument to estimate *particle size* from the *permeability* of a packed *powder bed* comparing the gas flow rate to a reference bed of sand.

Goring-Kerr photosedimentometer — A commercial *photosedimentometer*.

gravity sedimentation — A method of analysis of *particle size distribution* of a *suspension* by measuring the rate of settling of *particles* under gravity.

Hitatchi scanning photosedimentometer — A commercial *photosedimentometer*.

impaction sampling — The process of selectively removing *particles* from a gas-borne stream by obstructing the flow of gas so that *particles* of higher momentum collect on a solid surface.

impactor — A device to remove *particles* selectively from a gas-borne stream by means of a solid collecting surface.

impact test — The generation of impact forces to determine *particle* fracture or surface wear characteristics.

impinger — A device to remove *particles* selectively from a gas stream into a liquid medium

indirect method of measurement — A method in which the value of a measurement is obtained from estimation of other functionally related quantities.

inversion procedure — A back-calculation method used to obtain a result (e.g. of *particle size distribution* from light diffraction energy pattern).

isokinetic sample — Sample taken at the same velocity as that in the process under test.

ISO scale number — A contamination class level in hydraulic fluids, as specified in International Standards Organisation document ISO 4406. BS 5540 Part 4.

jet impacter — A device for separating *particles* from an *aerosol* by deflecting the *fluid* stream by a surface on which the *particles* are deposited.

Joyce-Loebel centrifuge — A commercial version of an I.C.I. developed disc centrifuge type *Photosedimentometer*.

Kaye disc centifuge — A photosedimentometer that utilises centrifugal force to accelerate Sedimentation. After Brian Kaye.

Knudsen flow permeametry — A method of measuring specific surface by the steady-state diffusion flow of a gas through a uniformly packed *powder* bed.

konimeter — A device in the class of '*impingers*', for measuring the *particle size* distribution of *dusts*.

Lee and Nurse permeameter — An instrument for measuring the *specific surface area* of a *powder* by air *permeability*. The Lee and Nurse equation enables specific surface area to be calculated from the flow rate and pressure drop across the *powder.*

Leschonski pipette equipment — A variant of the *Andreasen* method of sample extractions from *sedimentations* by means of pipettes with graduated positions of extraction holes

levigation — The classification of *particulates* according to their movement through a separating *fluid*. (See also *sedimentation* and *elutriation*).

lid, cover — A cover which fits snugly over a *sieve* to prevent the escape of the material above the mesh,

line start technique — A technique in which a thin layer of a homogeneous *suspension* is floated on the surface of the *sedimentation* liquid.

Lotzch Permeameter — An instrument to measure *permeability* through a packed bed of *powder* using a rotometer to measure the gas flow directly.

manometer — A device for measuring *fluid* pressure.

margin — The region between the outside *edges* of the outside row of holes and the edges of a *perforated plate*.

micromerograph — A commercial *sedimentation balance* where the *particles* sediment through a column of gas from a *line start system,* in which a well defined cloud of *particles* is blown onto the top of a column of gas.

noise — The spurious unwanted fluctuation in an electronic signal.

percentage open area — (1) For *woven wire*, *cloth* and *wire screen*:
The proportion of the total area of the aperture to the total area of the cloth or screen, expressed as a percentage.

(2) For *perforated plate*:
The proportion of the total area of holes to the total area of perforated part of the plate (excluding any non-perforated part), expressed as a percentage.

perforated plate — A *sieving medium,* consisting of a plate with uniformly sized holes in a symmetrical arrangement.

permeameter — An instrument for estimating a surface area by measuring the resistance offered to a flowing *fluid* by a packed bed of *particles*.

photo correlation — A method of estimating *diffusion diameter* from *Brownian motion*.

photosedimentometer — An instrument which combines *sedimentation* with the photoelectrical determination of concentration, for measuring *particle size distribution*. In simple cases, Lambert-Beer law is used to relate the concentration to the transmission levels. (Sometimes referred to as Beer's law). More refined interpretation hypotheses utilise the Mie theory of light scattering, often using wide angle light collectors, such a with fibre optics and scanning systems.

pipette centrifuge — Centrifugal settling in a spinning disc of suspension.

pitch — The distance between corresponding points of two adjacent holes in a *perforated plate*.

plain weave — The *weave* in which every *warp* wire crosses alternately above and below every *weft* wire and vice versa.

plate thickness — The thickness of the plate *sieving* medium after perforation.

porosimeter, The assessment of *porosity* and *pore size distribution* by means of the intrusion of mercury under pressure.

pycnometer A vessel, of accurately defined volume, used for determining the *density* of liquids or *particles*.

quasi-electric light scattering (See photon correlation spectroscopy).

rate method of sieve analysis A procedure of measuring the weight of *powder* retained by a *sieve* at given time intervals and calculating the ultimate residue from the logarithmic decay of the weight .

receiver; pan A pan which fits snugly under a *sieve* to collect fine *particles*.

repeatability The closeness of the agreement between the results of successive measurements of the same sample that are carried out subject to all of the following conditions: -

- The same measuring instrument;
- The same method of measurement;
- The same conditions of use;
- The same observer;
- The same location;
- Repetition over a short period of time.

reproducibility See *repeatability*

resolution A quantitative expression of the ability of a measuring device to distinguish meaningfully between closely adjacent values of the quantity indicated.

riffler A device for dividing a stream of *particles* into representative samples.

riffler, spinning A rotary sample divider that collects a multiple series of consecutive samples from a flow stream as a means to secure a representative sample as a specific proportion of the total amount passing.

Rigden permeameter A device in which the powder bed under test is connected across the two arms of a U-tube manometer when the liquid columns of the manometer are displaced with respect to each other. The rate at which air flows through the *powder bed* is a measure of the *permeability* of the *bed.*

Rose photosedimentometer An early type of *photosedimentometer*.

sample analysis (See *sample*, *test portion*).

sample, gross	Sample obtained or prepared from the *bulk material* under the sampling plan, from which subdivision for testing, reference or storage can be made.
sample, laboratory	The sample delivered to the laboratory.
sample, test	The sample prepared from the laboratory sample from which the test portions are drawn.
sample, test portion	Portion taken from test sample, for use entirely in the observed test.
Sartorius sedimentation balance	A commercial, high-accuracy, *sedimentation balance.*
screen	A *sieve* or *sieving medium* used for separating *particulate* material in a manufacturing process.
sedimentation balance	An instrument used to determine the *Stoke's diameter* distribution of particles.
sedimentation, centrifugal	The grading of mass of suspended *particles* accelerated by centrifugal force.
sedimentation, gravitational	The grading of mass of suspended *particles* accelerated by means of gravitational force.
segregation tester	A device that reflects a *segregation* mechanism and shows its effect.
sensor	That part of an instrument which captures the information relevant to the dimension being measured.
Shimadzu sedimentation balance	A low-sensitivity *sedimentation* balance used for quality control.
sieve mesh number	The number of apertures occurring in the surface of a *sieve* per linear inch. Note 1. - Unless the size of the wire used in forming the *mesh* is specified, the *mesh number* does not specify the aperture size. Note 2. - This term is still recognised in industry, but the preferred designation of *test sieves* is by aperture size. See Appx E of BS 410 1986
sieves, nest of	A set of test *sieves* assembled together.
sieves, test	A frame supporting a sieving medium intended for *particle size analysis*, and conforming to a standard specification.
sieving aids	The addition of foreign bodies to *sieve* surfaces, to promote the motion of particles through the sieve mesh. A process to be used with caution, as the induced mechanism may cause crushing and generate *fines.*

sieving, air jet	A device in which a portion of *powder* in a *sieve* is *fluidised* by air passing upward through it from a rotating slit. At the same time a negative pressure is applied to the bottom of the *sieve* which removes fine *particles* to a collecting device.
sieving, dry	The *sieving* of *powders* without the aid of a liquid.
sieving medium	A network or perforated sheet used for separating *particles* according to their size.
sieving, test	The use of *test sieves* in a prescribed manner to perform separation of *particles* into size classes.
sieving, wet	The *sieving* of *particles* with the aid of a liquid.
sifter	A type of *screening* machine having a rotary motion substantially in the plane of the *screening* surface, used for the screening of *powders*.
sonication	(See ultrasonic agitation).
spatualtion	The gentle working and kneading with a flexible spatula of a *powder* after the addition of a few drops of dispersant.
Spillane	An automated version of the *Blain permeameter*.
spinning riffler	See *riffler, spinning*
test portion	(See *sample, test portion*).
test sample	(See *sample, test*).
test sieve	(See *sieve, test*).
turbidimeter	An instrument which measures *turbidity*, from which *surface area* can be estimated.
ultrasonic agitation	The vibration of *particles* in a *fluid* by means of ultrasonic waves, thereby assisting their dispersion.
ultrasonic attenuation measurements	The change in frequency of an ultrasonic signal when caused by the interaction with *particles*. This can be used to measure *particle size*.
ultrasonic bath	A bath in which pressure waves in the *fluid* are caused by ultrasonic vibrations.
ultrasonic probe	A point source of ultrasonic vibrations.
underflow, of sieving.	(See *fines*). That portion of the feed material that has passed through a screening surface.

undersize control	A *screen* used for the removal of undesirable *fines* from a material.
vibrating screen	A *screen* oscillated by mechanical, electrical or ultrasonic means.
warp	All threads or wires running lengthways of the fabric as woven.
weave	The way in which *warp* and *weft* threads cross each other.
weave, plain	The way in which every *warp* thread crosses alternatively above and below every *weft* thread, and visa versa.
weave, twilled	The way in which every *warp* thread crosses alternatively above and below every second *weft* thread, and visa versa.
wedge wire screen;	A *screening* surface comprising wires of wedge shaped cross section spaced from each other at a fixed dimension. The underflow therefore passes through an aperture of increasing cross section.
weft; shoot	All threads running crosswise of the fabric as woven.
wire diameter	The diameter of the wire in the woven fabric.
wire screen	A *screen* produced by a wire weaving process (or by pressure-welding of two layers of parallel wires set at 90 degrees) to form apertures of nominally uniform size.
woven wire cloth	A *sieving* medium of wires that cross each other to form the apertures.

Section 12 - Bulk Properties and Test Methods

active stress	A *stress* that *a bulk material* generates against a *confining surface* as a result of forces acting within the *bulk*. Note that this has the dynamic capacity to follow a retracting surface. See antonym of *passive stress*.
adhesion	Resistance to separation between two unlike materials under zero applied normal pressure.
aeroflow tester	(See *avalanche tester*).
Ajax tensile tester	A tensile test device that applies a tensile failure load at 90 degrees to the direction to the compacting load
Ajax cohesion tester	A device that measures the *shear strength* attained by a uni-axially loaded sample after the removal of the compacting *stresses*.
angle of effective yield locus	The inclination of the *effective yield locus*, (EYL), as specified by *Jenike.*
angle of internal friction	The angle between the axis of *normal stress* and the tangent to the *Mohr* envelope at a point representing a given *failure stress* condition for the solid material.
angle of obliquity	The angle between the direction of the resultant stress or force acting on a given plane and the normal to that plane.
angle of repose	The natural inclination adopted by an *unconfined surface* formed in a defined manner. Note that the method of formation of the slope and the. rate of deposition can create different curved or flat inclinations. See *poured cone*, *drained cone* and *planar repose surface*. The term is meaningless for *cohesive* products.
angle of wall friction	See *wall friction*
anisotrophy	The feature of not being *isotropic.* This applies in a various ways to *bulk solids*. Therefore rigor is needed to define the *bulk state*. It may be *anisotropic* by virtue of the *particle shape* or *particulate* structure, be subjected to *stress* or *strain* in different planes, or any combination of these. Invariably, the composition of a *loose solid* is not similar in all planes. Strength values must therefore be strictly related to the *stress history*, the current *stresses* and the orientation of the applied *stresses*.
annular attrition cell	A rotating trough device that subjects a sample bed of *particles* to a controlled rate of shear under a selected applied stress.

annular shear cell — A rotary type of *shear cell* originally developed by Walker to offer unlimited strain by the use of an annular trough to contain the *powder bed* that is to be sheared.

ANSI MSDS Format — American National Standards Institute Material Safety Data Sheet. Information to be advised by manufacturers and suppliers to persons who may come in contact with a product.

The American National Standards Institute, 11 West 42nd Street. New York, NY. USA, (ANSI) standard format (Z400.1-1993) was designed to aid the preparation of Material Safety Data Sheets (MSDS)

It has 16 Sections, comprising: -

Section I: Chemical Product and Company Identification

Section II: Composition / Information or Ingredients

Section III: Hazard Identification

Section IV: First Aid Measures

Section V: First Aid Methods

Section VI: Accidental Release Measures

Section VII: Handling and Storage

Section VIII: Exposure Controls / Personal Protection

Section IX: Physical and Chemical Properties

Section X: Stability and Reactivity

Section XI: Toxicological Information

Section XII: Ecological Information

Section XIV: Transportation Information

Section XV: Regulatory Information

Section XVI: Other Information

ASTM Standard D – 612D — USA standard test procedure for the Jenike Shear test. See *SSTT.*

attributes	A number of bulk attributes influence the 'handle-ability' of a *bulk solid*. These properties may affect the behaviour of the material and/or the type of equipment that may be used to handle the product.

attributes marked * are related to the flow property of the bulk material
attributes marked ^ are related to the type/construction of equipment
attributes with Legends are related to operator protection considerations

Legends	A	=	Sensitising
	C	=	Corrosive
	E	=	Explosive
	Fo	=	Flammable
	Fx	=	Extremely Flammable
	H	=	Skin Absorption
	K	=	Carcinogenic
	Lk	=	No Classification required
	N	=	Danger to the Environment
	M	=	Geotoxic
	O	=	Oxidising
	R	=	Causes Birth Defects
	Tx	=	Very Toxic
	Xi	=	Irritant
	Xn	=	Harmful

These attributes may be structured according to the nature of the property and its effect on the specification of the equipment, as follows: -

	Property	Effect	Typical Material
*	Packs under pressure	more difficult to flow	Hydrated lime, pigments
*	Cohesive	forms poor flow mass	flour, fly ash, titanium dioxide
*	Fibrous	interlocks to resist shear gains strength with compaction	hair, wood shavings asbestos
*	Fluidises	difficult to contain	fly ash, talcum powder
*	Fatty	sticks together to resist flow	High fat mixes, waxes
*	Elastic	deforms at contact points to resist flow	ground cork, rubber granules
*	Plastic	deforms at contact points to resist flow	plastics,
*	Chemically active	forms solid mass Must prevent	ground phosphate

*	Melts	can fuse to solid	plastic, ice
*	Sinters	fuses to solid mass	warm plastics,
*	Fuses	forms solid mass, must prevent	raw rubber
*	Cakes	forms solids mass must prevent	salt, sugar, crystals
*	Wet	sticky, may dry to ‘cake’	filter & centrifuge cake
*	Sticky	adhesive to surfaces	damp & fatty products.
*	High friction	resists slip on contact surface	titanium dioxide
^ !	Abrasive	wears plant	sand, aggregate, crystals
^ !	Corrosive	attacks surfaces	salt, acidic chemicals
^	Friable flakes	delicate handling needed	tea, coffee granules,
^	Explosive	must contain, inert, suppress or vent	coal dust, aluminium powder, flour.
^	Flammable	must prevent or protect Equipment	wood shavings
^ !	Dusty	hazard and objectional should contain, collect or suppress	cement, fly ash.
^	Hygroscopic Deliquescent	becomes sticky	sugar, soda ash
!	Noxious	offensive to operatives must contain	sewage sludge, waste
!	Toxic	dangerous to operatives must contain	arsenic powder, active Drugs.
!	Irritant	hazard to operatives must contain	
!	Sensitiser	hazard to operatives must contain	Penicillin intermediates
^	Degradable	cleanability	organic products
^ !	Hot	hazard to operatives,	kilned powder

!	Sharp,	hazard to operatives	Cullet, metal cuttings.
^	Ultra-pure	sanitary	drugs, meat. Fish.

This list is not exhaustive, as indicated below, but illustrates that interactive factors may determine the overall specification of equipment. Fundamental to the performance of plant however, is that the flow behaviour must be reliable and safe, which means that it must be predictable and the potential hazards recognised and accommodated.

Product Risk Hazards are set out in a detailed format by the International Occupational Safety and Health Centre as below: -

Risk Phrases Used in the Countries of EU

(Phrases in parenthesis) are no longer in use.

Nature of Special Risks Attributed to Dangerous Substances and Preparations

R1 Explosive when dry.
R2 Risk of explosion by shock, friction, fire or other sources of ignition.
R3 Extreme risk of explosion by shock, friction, fire or other sources of ignition.
R4 Forms very sensitive explosive metallic compounds.
R5 Heating may cause an explosion.
R6 Explosive with or without contact with air.
R7 May cause fire.
R8 Contact with combustible material may cause fire.
R9 Explosive when mixed with combustible material.
R10 Flammable.
R11 Highly flammable.
R12 Extremely flammable.
(R13 Extremely flammable liquified gas.)
R14 Reacts violently with water.
R15 Contact with water liberates highly flammable gases.
R16 Explosive when mixed with oxidizing substances.
R17 Spontaneously flammable in air.
R18 In use, may form flammable/explosive vapour-air mixture.
R19 May form explosive peroxides.
R20 Harmful by inhalation.
R21 Harmful in contact with skin.
R22 Harmful if swallowed.
R23 Toxic by inhalation.
R24 Toxic in contact with skin.
R25 Toxic if swallowed.
R26 Very toxic by inhalation.

R27 Very toxic in contact with skin.
R28 Very toxic if swallowed.
R29 Contact with water liberates toxic gases.
R30 Can become highly flammable in use.
R31 Contact with acids liberates toxic gas.
R32 Contact with acids liberates very toxic gas.
R33 Danger of cumulative effects.
R34 Causes burns.
R35 Causes severe burns.
R36 Irritating to eyes.
R37 Irritating to respiratory system.
R38 Irritating to skin.
R39 Danger of very serious irreversible effects.
R40 Possible risks of irreversible effects.
R41 Risk of serious damage to eyes.
R42 May cause sensitisation by inhalation.
R43 May cause sensitisation by skin contact.
R44 Risk of explosion if heated under confinement.
R45 May cause cancer.
R46 May cause heritable genetic damage.
(R47 May cause birth defects.)
R48 Danger of serious damage to health by prolonged exposure.
R49 May cause cancer by inhalation.
R50 Very toxic to aquatic organisms.
R51 Toxic to aquatic organisms.
R52 Harmful to aquatic organisms.
R53 May cause long-term adverse effects in the aquatic environment.
R54 Toxic to flora.
R55 Toxic to fauna.
R56 Toxic to soil organisms.
R57 Toxic to bees.
R58 May cause long-term adverse effects in the environment.
R59 Dangerous for the ozone layer.
R60 May impair fertility.
R61 May cause harm to the unborn child.
R62 Possible risk of impaired fertility.
R63 Possible risk of harm to the unborn child.
R64 May cause harm to breastfed babies.

Combination of R-Phrases

R14/15	Reacts violently with water liberating highly flammable gases.
R15/29	Contact with water liberates toxic, highly flammable gas.
R20/21	Harmful by inhalation and in contact with skin.
R20/22	Harmful by inhalation and if swallowed.
R20/21/22	Harmful by inhalation, in contact with skin and if swallowed.
R21/22	Harmful in contact with skin and if swallowed.
R23/24	Toxic by inhalation and in contact with skin.
R23/25	Toxic by inhalation and if swallowed.
R23/24/25	Toxic by inhalation, in contact with skin and if swallowed.
R24/25	Toxic in contact with skin and if swallowed.
R26/27	Very toxic by inhalation and in contact with skin.
R26/28	Very toxic by inhalation and if swallowed.
R26/27/28	Very toxic by inhalation, in contact with skin and if swallowed.
R27/28	Very toxic in contact with skin and if swallowed.
R36/37	Irritating to eyes and respiratory system.
R36/38	Irritating to eyes and skin.
R36/37/38	Irritating to eyes, respiratory system and skin.
R37/38	Irritating to respiratory system and skin.
R39/23	Toxic: danger of very serious irreversible effects through inhalation.
R39/24	Toxic: danger of very serious irreversible effects in contact with skin.
R39/25	Toxic: danger of very serious irreversible effects if swallowed.
R39/23/24	Toxic: danger of very serious irreversible effects through inhalation and in contact with skin.
R39/23/25	Toxic: danger of very serious irreversible effects through inhalation and if swallowed.
R39/24/25	Toxic: danger of very serious irreversible effects in contact with skin and if swallowed.
R39/23/24/25	Toxic: danger of very serious irreversible effects through inhalation, in contact with skin and if swallowed.
R39/26	Very toxic: danger of very serious irreversible effects through inhalation.
R39/27	Very toxic: danger of very serious irreversible effects in contact with skin.
R39/28	Very toxic: danger of very serious irreversible effects if swallowed.
R39/26/27	Very toxic: danger of very serious irreversible effects through inhalation and in contact with skin.
R39/26/28	Very toxic: danger of very serious irreversible effects through inhalation and if swallowed.
R39/27/28	Very toxic: danger of very serious irreversible effects in contact with skin and if swallowed.
R39/26/27/28	Very toxic: danger of very serious irreversible effects through inhalation, in contact with skin and if swallowed.
R40/20	Harmful: possible risk of irreversible effects through inhalation.

R40/21	Harmful: possible risk of irreversible effects in contact with skin.
R40/22	Harmful: possible risk of irreversible effects if swallowed.
R40/20/21	Harmful: possible risk of irreversible effects through inhalation and in contact with skin.
R40/20/22	Harmful: possible risk of irreversible effects through inhalation and if swallowed.
R40/21/22	Harmful: possible risk of irreversible effects in contact with skin and if swallowed.
R40/20/21/22	Harmful: possible risk of irreversible effects through inhalation, in contact with skin and if swallowed.
R42/43	May cause sensitisation by inhalation and skin contact.
R48/20	Harmful: danger of serious damage to health by prolonged exposure through inhalation.
R48/21	Harmful: danger of serious damage to health by prolonged exposure in contact with skin.
R48/22	Harmful: danger of serious damage to health by prolonged exposure if swallowed.
R48/20/21	Harmful: danger of serious damage to health by prolonged exposure through inhalation and in contact with skin.
R48/20/22	Harmful: danger of serious damage to health by prolonged exposure through inhalation and if swallowed.
R48/21/22	Harmful: danger of serious damage to health by prolonged exposure in contact with skin and if swallowed.
R48/20/21/22	Harmful: danger of serious damage to health by prolonged exposure through inhalation, in contact with skin and if swallowed.
R48/23	Toxic: danger of serious damage to health by prolonged exposure through inhalation.
R48/24	Toxic: danger of serious damage to health by prolonged exposure in contact with skin.
R48/25	Toxic: danger of serious damage to health by prolonged exposure if swallowed.
R48/23/24	Toxic: danger of serious damage to health by prolonged exposure through inhalation and in contact with skin.
R48/23/25	Toxic: danger of serious damage to health by prolonged exposure through inhalation and if swallowed.
R48/24/25	Toxic: danger of serious damage to health by prolonged exposure in contact with skin and if swallowed.
R48/23/24/25	Toxic: danger of serious damage to health by prolonged exposure through inhalation, in contact with skin and if swallowed.
R50/53	Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.
R51/53	Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.
R52/53	Harmful to aquatic organisms, may cause long-term adverse effects in the aquatic environment.

Substances identified as posing a specific risk to heath are listed in Directive 76/769/EEC and published as a Consolidated list of C/M/R-Substances. (Classified as category 1 or 2 Carcinogens, Mutagens or Toxic to reproduction). This list runs to 100 A4 pages.

avalanche tester — A test method devised by B. Kaye to relate the *dynamic repose* behaviour of a sample in a cylinder rotating on its horizontal axis to its flow characteristics, by way of chaos theory. The device may be used to characterise the flow behaviour of *powders* or compare their *unconfined shear strength* in dynamic conditions

biaxial shear tester — A powder testing device that controls *shear* in a sample in two planes, to reflect *steady state flow* conditions.

BMHB — The British Materials Handling Board.

An organisation set up by U.K. Government to identify useful areas of research and aid the dissemination of technology in handling. It identified bulk solids handling and processing as major fields in which general industrial practices tends to lag the state of art technology and promoted research projects, industrial Education in the technology and publications.

BMHB Publications include: - This Glossary, and: -

'Bulk Solids Physical Properties Test Guide',
'Guide to the Handling of Dusty Materials in Ports',
'Guide to the Effect of Vibration on Bulk Materials and Plant',
'Guide to Standards Relating to Materials Handling',
'User Guide to Particle Attrition in Mechanical Handling Equipment',
'A Survey of Dust Explosions in the UK.',
'User Guide to Segregation'.
'Guide to the Design, Selection and Application of Screw feeders'
'Code of Practice for the Purchase and Operation of Fabric Filters for Dust Control'.
'Guide to the design of silos'.
'User Guide to Valves use in Solids Handling'
'User guide to I.B.C's'
'User Guide to the control of dust in large scale solids handling applications'
'The Global Status of Bulk Solids Handling'

bulk density — The mass of a quantity of *bulk material* divided by the total volume that it occupies under defined conditions of preparation. See *apparent powder density, loose poured density, tapped density, compacted density.*

Fine *particulate solids* vary in *density* more than *granular* materials due to the variable presence of air in the interstitial *voids* and are more sensitive to applied *stress* because of the much greater number of points of co-ordination that can be disturbed to allow closer *particle* packing under load. Coarse *granular* materials settle readily to a stable density as air can enter or leave the voids easily. Coarse *particles* also support applied stresses with little deformation because the load path through the points of contact are well established. However, such a loose poured assembly of coarse *particles* will tend to reduce in volume under the influence of vibration, as the less stable *particle*-to-*particle* contact points are disturbed and re-orientation takes place as the *particles* re-arrange to attain a denser degree of packing.

Bulk Materials Handling Committee A group formed by the I.Mech.E Process Board to further the spread of technical information in solids handling.

caking tester A test procedure that measures the strength of a *sample* exposed to controlled ambient changes that generate *particle*-to-*particle* bonding.

Carr's compressibility index A measure of the compressibility of a *powder* that is determined by dividing the difference between the measured *tapped density* and *aerated bulk densities,* as determined by specific methods, by the measured *tapped bulk density* as a proportion of 100.

CEMA Conveyor Equipment Manufacturers Association, USA. publications include: -

'Book 350 'Bulk Material Properties'.
'Book 500 'Screw Conveyors',

classification The *flow* behaviour of a *bulk solid* may be classified according to the ease with which the material deforms when in a compacted condition. There are no rigid demarcation boundaries, and other factors such as the *elasticity* of, the bulk material, *wall friction*, stability, *caking* and *segregation* potential will influence the degree of difficulties that impedes *flow*, but for convenience materials may be grouped in five *flow* categories.

A secondary classification may be made according to the significant *attributes* of the *bulk material*. These are features influencing the suitability of the flow route for operations dictated by the handling and process requirements and the sensitivity of the product quality and value to its final condition delivered from the system.

Group 1 These materials are the easiest to store, discharge and convey, having a uniform *particle size*, with consistent, small length to width ratio. Generally are hard, granular shapes that do not degrade easily. These materials exhibit no discernable *adhesive* or *cohesive* properties and maintain consistent physical properties with time and in variable ambient conditions. The *loose solid* will not gain strength or significantly change volume under compressive loads and will fall apart as soon as the *compacting stress* is relaxed.
Examples of Group 1 products are dry sand, plastic pellets, aggregates, dry salt, granulated sugar and coated prills in dry conditions. They have a *flow function*, ff, greater than 10. Materials that have these characteristics, except that they have a non-uniform size distribution, are strongly prone to *segregate* during their passage through unconfined *flow regimes.*

Group 2 These materials behave in a sluggish manner and gain *shear strength* with *compaction*. Usually the particles are too small to be easily discerned. Their slight *cohesive* properties are due to irregular *particle* configuration and/or minor molecular forces. The products will change volume and gain strength under compressive stress, typically will hold together as a weak 'snowball' if squashed in the hands. Typical examples are flour, ground limestone, light soda ash, ground coke and dry castor sugar. They have *flow function* values, ff, between 4 and 10.

Group 3 These materials are usually of a fine composition and are more sluggish than group 2, but still retain sufficient porosity to be fluidised. Gas entrained during dilated handling will not readily settle out due to the fine structure of the *voids*, so that they can remain in a *fluid* condition for an extended period. However, once settled by the loss of air they attain a poor flow condition that is exacerbated by *compaction*. Their *flow function* value, ff, lies between 2 and 4.Typical product in this class are hydrated lime, cement, silca gel, starch, fly ash, polymers and carbon black.

Group 4 These materials resist deformation and tend to have high *cohesive* values due to *Van der Waal forces*, electrostatic forces, surface texture or surface tension effects, or because of a strong interlocking nature due to particle shape configuration.
Typical examples are organic pigments, centrifuge or filter cake, Soya bean meal, and high-fat bakery products. Their *flow function* value, ff measures between 1 and 2.

Group 5 The toughest type of bulk products to handle due to tenacious matting or interlocking tendencies, strong surface bonds, high inter-particle molecular forces, surface tension or a combination of these with other binding effects. Thread-like materials with elastic structures, flocculent, amorphous solids, and fibrous materials come into this class. Also products that form crystal bridges to set onto firm cakes, products that knit together or sinter.
Typical examples are wood chips, sawdust, plastic regrind, asbestos fibres, fibreglass strands, chopped paper and agricultural residue such as bagasse. Group 5 products have *flow function* value, ff, less than 1.

cohesion The *shear strength* at *yield* of a *compacted powder,* after the removal of the forces causing the specific *state* of *compaction*,. One value of which is shown by the intersection of the *yield loci* with the ordinate. Eurocode 1 part 4, Silos and Tanks, defines a particulate solids as having 'low *cohesion*' if the *unconfined yield stress* is less than 14 kPa after the solid has been pre-compressed by a uniaxial *consolidation stress* of100 kPa.

Note. 1 – The magnitude and orientation of the *formation stresses* must be defined relative to the alignment of the plane in which *failure* occurs.

Cohesive forces normally reduce to a negligible value during sustained *unconfined shear,* due to *dilatation* of the *particulate* structure.
Note 2 - This phenomenon is a combination of the consequence of residual *tensile stresses* acting on the *particulate solid* and mechanical interference with *shear* due to the overlapping of *particles* in the *bed* structure, compounded with any temporary effect of void pressure differential with ambient. See *tensile strength, void pressure*

compaction — The process of volume reduction by the application of *stress*

compaction, biaxial — *Compaction* produced by the application of *stresses* in two directions at right angles to each other, not necessarily equal.

compaction, isostatic — *Compaction* produced by the application of a stress which is the same in all directions. (A condition rarely achieved in solids handling)

compaction uniaxial — *Compaction* produced by the application of a *stress* in one direction

composition, of bulk — The constitutive structure of a mass of *particles* that may be collectively described as a *bulk material*. Typical expressions include: -

Uniform - whose *particles* are of similar size and shape.
Non-uniform - consisting of *particles* that vary in size, shape or other physical attribute.
Homogenous - A mass if non-uniform *particles* that are uniformly diffused in the *bulk.*
Heterogeneous- A mass of non-similar *particles* that are unevenly distributed in the *bulk.* See *segregated*
Mixture - Two or more different *bulk materials* that have been uniformly inter-dispersed by a *shearing* process.
Blend - Two or more *bulk materials* that are uniformly inter-dispersed by a process of low work input.
Isotropic - Non-uniform *particles* that are not preferentially oriented in the mass.
Anisotropic - A mass of non-uniform *particles* that are directionally oriented in the mass, such that the bulk physical properties vary in different planes.
Granular - A mass of *particles* of such size that the individual *particles* can be visibly discerned.
Powder - A mass of *particles* of such size that individual *particles* cannot be visually discerned in the *bulk.*
'Wet cake' - A mass of *compacted particles* that are held together by *surface tension* of contact of the moisture film on the surface of the *particles.*
Paste - A mass of *particles* bound by a liquor that does not fill all *interstitial void space* between the *particles.*

Sludge - A mass of *particles* mixed with a liquor that completely saturates the *interstitial void space* between the *particles*

Slurry - A mass of *particles* within a liquor that fills the *interstitial void space* to excess, such that the *particles* are unable to develop *shear strength*.

Suspension - A mass of particles within a liquor base that exceeds the volume required to fully occupy the *voids*.

Dispersion - A mass of *particles* diffused in a volume of liquor quantity such that the *particles* are not held in contact with each other.

compound stress — (relating to bulk strength) The sum of external and internal *stresses* acting on a *powder compact* to influence its *bulk strength*. Internal *stresses* may be due to chemical, physical, electrical or other forces acting to draw the particles together or tending to hold them apart. Typical origins are *surface tension, van der Waals* molecular forces, and electrostatic forces. Note that for all practical purposes, internal forces that are normally termed *tensile* forces act as externally applied *compressive* forces on the *particulate solid*.

compressibility — The ability of a *powder* to be compressed, expressed by the ratio: -

$$C = 100\,(Pv - P)\,/\,Pv$$

Where P = The loose poured bulk volume of the material.
Pv = The bulk volume in defined conditions of compaction.

consolidated, over — See *over-consolidated*

consolidation, critical — See *critical consolidation*

consolidation locus — Locus of the *shear* and *normal stress* causing an *under-consolidated* particulate solid of a given initial *bulk density* to deform plastically.

consolidated, under — See under-*consolidated*

critical consolidation — (of *shear test sample*) The condition where the *consolidating* load acting on a sample at *shear failure* is just adequate to contain the sample at constant volume during the *shearing* process. See *critical state.*

critical sample size — The minimum *sample* required to obtain the same value from repeated measurements by a given test apparatus. See *representative sample.*

critical state — The condition of a *bulk material* during steady state flow at an equilibrium *density* condition of the *bulk material,* where there is a unique relationship between the stresses causing *shear* of the *bulk* and the stresses acting at 90 degrees to the plane of *shear.* A sample of *bulk solid* is in a *critical state* when it *shears* under the *stresses* applied without change of density. For a given density condition the *critical state* is the at the end point of a *yield locus.* See *critical state line, yield locus. Hvoslev surface.*

critical state line	The locus of end points of a family of *yield locus* of differing *density* conditions in axis of *normal stress, shear stress* and *void ratio*. A change of stress would cause the mass to adopt a different *bulk density*.
critical void ratio	The *void ratio* of a *particulate solid* at *critical state.*
deformation, elastic	A deformation that is totally recoverable when the *stress* causing the deformation is removed.
deformation, plastic	1 The permanent deformation that remains after elastic recovery is complete, following the removal of the *stress* that caused the deformation. Plastic *deformation* and *yield* are the more general expressions whereas the term 'incipient failure' is associated with plastic deformation of an over-consolidated particulate solids and the term '*flow*' is used for *steady state flow*. 2. Continuous deformation under the influence of an applied *stress* in excess of the *yield stress*.
Note: -	*Yield*, *failure* and *flow* are widely used synonymous expressions for *plastic deformation*. The term '*yield*' is normally associated with *incipient failure* and the commencement of deformation, being the lowest limit of *stress* that will incur permanent deformation, whereas *flow* relates to continuous deformation, which is by nature a dynamic, irreversible condition.
density, apparent powder	The mass of a *powder* divided by its apparent volume.
density, aerated	The mass of a quantity of *bulk material* that is in a defined state of fluidity divided by the volume that it occupies. (This condition reflects that achieved during rapid flow in an unconfined channel and as discharged from a lean phase pneumatic conveying system. This value is used for calculating a conservative, mass-holding capacity for a storage container.
density, bulk	(See *bulk density*).
density, effective solid	The density of *powder* particles as determined by a given *fluid* displacement method.
density, green	The *apparent density* of a green *compact.*
density, immersed	The mass of *powder* per unit volume of suspended media displaced.
density, poured	(See *aerated bulk density*).
density, pressed	The mass per unit volume of a *powder bed compacted* by way of a defined uniaxial stress.

density, settled — The lowest stable *density* conditions attained by a *bulk material* when *settling* from a *dilated* condition.

density tapped — The *apparent density* obtained under prescribed conditions of tapping within a container of given dimensions.

deviator stress — The difference in values between the *major* and *minor principal stresses* in a *triaxial test*.

discontinuity surface — Any surface across which the properties of the solid are not continuous, such as a fracture or plane separating a flow channel from a static bed.

effective angle of friction — Synonymous with the *angle of effective yield locus*

effective solid density — (See *density, effective solid*)

effective solid volume — The mass of the *particles* divided by the *effective solid density*.

effective yield locus — Straight line passing through the origin of the *shear stress/principal stress* plane and tangential to the *Mohr circle* corresponding to steady state flow conditions of a *particulate solids* of given *bulk density*.

elevator — A synonym for *silo,* commonly used in the grain industry.

end point — (of *yield locus*) The peak *shear stress* value of a steady state re-shear.

factor, recovery — (See *recovery factor*).

factor spring — (See spring factor).

fill weight; — Mass of *powder* in a container of stated dimensions, when this had been filled under stated conditions.

fine sand — (See *sand, fine*)

flow factor — A factor, *ff*, originally defined by Andrew Jenike, relating to the geometry of a hopper's ability to apply stress to the flow channel, expressed as the ratio of the *major principal stress* in material flowing in a converging channel to the *major principal stress* that would cause it to cease flowing.

The value of this factor depends on the *angle of wall friction*, the form and slope of the hopper walls and the *angle of internal friction* of the *bulk solid*, as described by the *angle of the effective yield locus.*

flow function — The ratio, *FF*, defined by Jenike, of the *major principal stress* at *steady state flow* to the *unconfined yield strength* of a specific *particulate solid.* $FF = \sigma_1 / F_c$.

A ‘flow’ classification proposed by J.Thomas is : -

$FF < 1$	‘hardened’
$FF < 2$	very cohesive
$FF < 4$	cohesive
$FF < 10$	easy flowing
$FF > 10$	free flowing

(These descriptions of flow condition relate to a *compacted bed*).

formation stresses — The *stresses* applied that conditioned the *particulate* material to its specific, current state, as normally characterised by its *bulk density*.

Freeman rheometer — A dynamic *powder* testing device that measures the torque to rotate a blade or impellor that is submerged in a confined mass of *particulate solids*. This device may be used for qualitative comparisons of material behaviour but the complex *stress* conditions generated within the *bulk* cannot be quantified.

‘Guide to the specification of bulk solids for storage and handling applications’ Book prepared by Bulk Materials Handling Committee of I.Mech.E.

hang-up indicizer — (See *Johanson indicizer*).

hazards — See *attributes*

Hosokawa Tests — A series of basic measurements and empirical tests devised by Carr, an engineer at BIF, to correlate *powder* behavioural factors to *flowability*.

incipient failure — The onset of permanent deformation. See *yield.*

Indicizer — (See *Johanson indicizer*).

instantaneous compaction — The condition of a sample of *bulk material* that has been subjected to a *uniaxial compacting* load for a short period in preparation for a *shear test*.

instantaneous yield locus — The *yield locus* measured immediately following consolidation.

internal friction — The portion of *shear strength* indicated by the term $\rho.\tan\phi$ in Coulomb’s equation $s = C + \rho.\tan\phi$ due to the combination of the effects of particles interlocking and their resistance to slip over each other.

isostatic compaction — See *compaction, isostatic.*

Jenike cell — A *shear cell* developed by Andrew *Jenike* to provide data for *hopper* design. See Bul. 123. Univ. of Utah. 1964

Jenike & Johanson quality control test — An empirical test based upon determining the flow behaviour of a sample under pressurised stimulation.

Jenike test — A procedure developed to determine the *stress* conditions at *failure* of an *unconfined surface* in order to establish the *critical orifice size* of a given form of flow channel that will sustain reliable flow, once a flow regime has been fully mobilised. See *SSTT, ASTM Standard D – 6128.*

Johanson indicizers — A set of test devices for indicating the flow related properties of a bulk solid. Comprising:-

1 Shear Test Device. (Johanson) — Measures the initial *failure strength* of a *compacted* sample. Note that this test reflects initial *failure* conditions, not steady State, (*critical state*), behaviour that is achieved during *flow.*

From these measurements, certain factors are derived that are used to assess the size of orifice required to secure reliable flow. No supporting theory is provided to justify these criteria.

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2 Wall friction tester (Johanson) — This operates on a tilting plate mechanism reflecting static, rather than dynamic *friction.* This measurement is utilised to determine the required steepness of inclination of a *hopper* wall to stimulate *mass flow* of the container contents.

3 Porosity tester (Johanson) — The rate of air flow through a *compacted bed* is used to assess the expansion characteristics of a *settled bed* during the initiation of flow. is used for assessing the effect of *flow* rate of a fine *bulk material from the outlet of a storage container.*

Johanson porosity tester — See *Johason Indiciser, item 3*

Johanson wall friction tester — See *Johason Indiciser. Item 2.*

limestone CRM-116 — **See *CRM 116***

Limitations Directive — Substances classified as dangerous and can only circulate freely when packaged and labelled in accordance with Directive 67/548/EEC, (for dangerous substances), and Directive 99/45/EC, (for dangerous preparations). In a relatively small number of cases the rules for classification, packaging and labelling are insufficient to reduce risks and must be supplemented by Directive 76/769/EEC

load/compaction test — A test in which an increase in uniaxial stress applied to a confined sample of *bulk material* is related to the change of volume of the sample. The rate of increase in resistance of the material to *compaction* is used as a measure of how the product will gain in strength under load major consolidating stress The *major principal stress*, as denoted by the largest value intercept of the *Mohr stress* circle of *steady state flow* that is tangential to the effective yield locus with the axis of principal *stress* on a *shear stress/normal stress* diagram.

Material Safety Data Sheets See *ANSI-MSDS*

mean stress The expression if often used to denote the mean of the normal stresses on two mutually perpendicular planes. This stress is independent of the orientation of the planes and the mean stress, as normally quoted, is the mean of the corresponding principal stresses. The mean stress corresponds to the centre of a *Mohr stress circle* on the axis of normal stress. This value should not be confused with the intermediate principal stress, which can have any value between the major and minor principal stresses according to the pertaining conditions.

mechanical arching (See *structural arching*)

Mohr circle A circle drawn in the co-ordinates of *normal stress* and *shear stress* for a specific *bulk density* condition, that is the locus of equivalent *normal stress* and *shear stress* combinations for a specific state of applied *stress*.

moisture content The proportion of moisture, or other liquor, that is part of the composition of a bulk material may be expressed as a percentage of the total weight or a percentage of the weight of the solid content, (weight to weight basis). The difference in these values is small at low levels of moisture content but increases significantly at higher liquor levels, therefore care must be taken to identify the correct format. For example, equal quantities of solids and liquor may be expressed as containing '50% moisture', whereas the latter is defined as having '100%' moisture content on a weight to weight basis.

Moisture content values normally relate to free moisture, (constitutional water), excluding bound water of crystallization. This occurs as a surface film that, in quantities below about 1%, is in the form of water held by specific hydrophilic sites on molecules of the particles, (ie other than on water itself), as a monolayer on the surface of particles. From about 1% to 5% moisture, the water takes a multi-layer form, with additional layers forming over the monolayer. This surface film forms liquid meniscous bridges cusps at *points of coordination,* to create a pendular state of induced tensile strength due to the surface tension effect of the contact film curvature. For a given state of *particle packing*, as characterised by the dry content *density* of the bulk material, increases of fluid content raises the *bulk material* strength, but above a specific, critical value of moisture content the *bulk strength* declines.

The transitional condition at which the bulk strength declines is because higher proportions of liquor tend to fill local regions *of interstitial voids*, forming pockets of saturation that are incompressible amid regions of partially filled voids as a fenicular condition. A change of total volume as a result of c*ompaction* reduces the available *voidage* space, leading to a higher degree of the available space being filled with the *fluid*. The degree of *void* occupancy by the liquor increases with higher fluid content, until fluid occupies the total *voidage space* to form a *capillary* fluid network. At this stage external stresses on the *bulk* are hydrostatically contained and there is no gain in strength of the material. The product essentially changes in nature from a wetted *bulk solid* to an incompressible paste. The water is however entrapped from flowing freely from the bulk, being held by capillary attraction by a matrix of gel structures or tissues. Damp material in a deep bed will suffer different compacting loads and the fluid may drain to leave excess fluid in a lower saturated bed, and entrapped moisture in the upper layers.

The weakness of a fully saturated *particulate bed* does not ensure that the material is free flowing. In fact, the virtual impenetrability of the bulk offers a high resistance to dilatation due to lack of relief for *void* demand of expansion imparting a high *tensile strength* to the bulk. Should the overall volume change through particle re-orientation to allow the liquor to fill the total *voidage* with surplus free liquor, the excess fluid leads to separation of the constituent *particles* and a progressively change of nature from a *particulate solid* to a *paste*, then to a *slurry* with no incipient shear strength.

These conditions arise with some ores transported by sea, which settle and are 'worked' by movement of the vessel. The stability of the mass is compromised and movement of the cargo may erode the integrity of buoyancy by shifting of the vessels centre of gravity. (See '*safe transportable moisture content*'.)

Any further increase in the fluid content beyond the critical saturation value serves to separate the *particles* and reduces the *shear strength* of the bulk material, eventually changing the condition to *paste* and then to a *slurry,* that is unable to sustain a *shear stress* and behaves as a viscous, non-Newtonian fluid. A slurry is further weakened by excess fluid to becomes a suspension, and eventually a dispersion of disconnected particles in a sea of liquid.

The condition of a nearly saturated cake or paste, such as some filter cakes and centrifuged products, is sensitive to *compaction*. If there is inadequate liquor to fill the *voids*, the bulk will gain strength rapidly with *compaction*. If the *voids* are completely saturated, external forces are then supported by hydrostatic continuity of the liquor and the volume will not decrease nor the strength increase further with increased applied stress values

Bulk materials that contain salts or other soluble components of composition are prone to significant changes of nature. Deposition from solution that occurs when the product dries out tends to form crystal bridges at *points of co-ordination* that bind the *particle structure* to a rigid 'caked' mass of considerable *bulk strength*.

mono-axial cell — A cell in which a uniaxially *compacted* sample is stressed to *failure* in line with the *compacting* load. E.g. *unconfined failure test*

MSDS — See *ANSI MSDS*

negative void pressure — An effect produced by the expansion of a *particulate solid*. As the total volume increase is occupied by the original solids content, the fluid occupying the interstitial *voids* must expand to fill the balance of space. In the case of a fully liquor saturated mass, which will not expand, the *void* expansion demand is the full ambient pressure.

For coarse, dry *powders* the reduced air pressure is alleviated by the *permeation* of air through the bed. The resistance to expansion therefore depends upon the degree of change in void volume and the *permeability* of the *particulate bed*. During such time as there is a negative differential between pressure in the *voids* and ambient pressure, the effect is similar to a tensile stress acting on the mass or an external *compressive stress*. See *positive void pressure.*

normalised stress — The total of internal and external stresses acting on a *particulate* mass. i.e. adding *tensile stress* and *void pressure* differential to *compacting stresses,* to sum all loads on a *particulate bed* as a unified whole. See *compound stress ,tensile stress, negative void pressure, positive void pressure.*

over-consolidated — A *state* of *consolidation* and applied *stress* where the confining loads acting at *shear failure* of a (of *shear test* sample) sample are inadequate to prevent the *particulate structure* expanding during *shear*.

passive stress — The *stress* generated by a *bulk solid* in resisting an external force. Note that this decays on removal of the external force. See antonym *active stress.*

Peschl shear cell — A proprietary form on rotating *shear cell,* similar to an *annular shear cell* but with zero internal diameter.

plastic deformation — Deformation that does not recover on the removal of *stress*.

planar repose surface — The flat surface repose formed by pouring or draining to a straight edge. This value is useful for non-*cohesive particulates*, being independent of the convergence or divergence inherent in flow on conical surfaces.

plane stress — The term commonly used to describe the condition of deformation taking place in one plane only, as with a Vee shaped hopper. The effect of the end walls of the rectangular flow channel distorts the plane stress, but the influence diminishes to a negligible value if the length exceeds three times the width of the section.

porosity, (of bulk) — The volume of *voids* within a quantity of *particulate solids* divided by the total volume of the mass. I.e. The volume of *voids* divided by the volume of *voids* plus the volume of the solid content.
Synonym for *voidage.*

positive void pressure — Pressure of the ambient *fluid* in the *interstitial voids* of a *particulate solid* opposes the external *stresses* acting on the bed, thereby reducing the *particle*-to-*particle compacting* forces. Excess gas under sufficient pressure to sustain the weight of the *bed* will negate *particle* contact loads and allow the bulk to deform with minimal resistance, in a fluid-like manner. The rate of escape of such pressurised gas depends upon the pressure differential between the *void* gas and ambient, the *porosity* of the *bed* and the geometry of the system. Fine *powders* are prone to such fluidised behaviour when poured or strongly agitated.

pressure-void ratio curve — A curve representing the effective pressure and *void* ratio as obtained from a *consolidation* test. The curve has a characteristic shape when plotted on semi-log paper with pressure on the log scale. The various parts of the curve and extensions to the parts have been designated as recompression, compression, virgin compression, expansion, rebound and other descriptive names by various authorities.

principal plane — Each of three mutually perpendicular planes through a point within a *particulate* mass on which the *shearing stress* is zero. These planes are unique for a given state of *stress*. The planes are described as follows: -

Major principal plane - The plane normal to the direction of the major principal stress

Intermediate principal plane – The plane normal to the direction of the intermediate principal stress.

Minor principal plane - The plane normal to the direction of the minimum principal stress.

principal stress ratio — The ratio of the minor principal stress to the major principal stress acting within a particulate solid.

progressive failure — Failure in which the ultimate shearing resistance is progressively mobilised along the *failure* surface.

properties (of bulk material) — A *bulk* material has many type of properties. These may be classified under - physical, (which includes mechanical, chemical, thermal and electro-static properties that affect the rheological nature of the *bulk)*, and *attributes,* which introduce other characteristics of interest).

pseudo-stereo photogrammatic analysis

A technique of investigating planar *flow regimes* by way of time lapse photographs that, when viewed as a stereo-pair, translates the *strain* deformation to the image of a virtual contour map of displacement. Static regions appear as plains at the reference depth, coherent motion show as raised flat surface or plateau, *shear* discontinuities are seen as cliffs and the inclination of the apparent slope reflects the local rate of strain of the sample.

relative density	The ratio between the *void* ratio of a cohesionless *particulate* mass in its loosest stable condition to that in its most *compact* condition.
ring shear tester	(See *annular shear cell*).
safe transportable moisture content	A degree of moisture held by a *bulk solid* which is inadequate to fill the interstitial *voids*, to create an unstable, *plastic* mass when the *bulk* is *compacted* and *sheared* to a maximum *particle packing structure*. (See *moisture content*).
Schulze ring shear cell	A proprietary *annular shear cell*
shear	The permanent dislocation of a *particulate* structure in a plane subjected to a *shear stress*
shear force	A force directed parallel to the surface element across which it acts.
shear plane	A plane along which *failure* occurs by *shearing*.
shear strain	The change in shape, under the influence of *stress*, expressed by the relative change of the right angle at the corner of what was, in the un-deformed state, an infinitesimally small rectangle or cube. *Strain* may be elastic or plastic, the latter being a form of irrecoverable deformation, or *flow*, when the applied *stress* exceeds the elastic limit of the bulk. *Strain* is essentially *anisotropic* in nature.
shear strength	The strength of a *compacted powder* to resist *shear* in defined conditions. Note - When *shear* takes place without change in volume of the *bulk material*, as occurs in a solids flow situation, there is a unique relationship between *the shear stresses* and the stresses acting normal to the *failure surface* and the material is said to be in a *'critical state'*. In circumstances where the volume is changing to a denser or more dilate condition during *shear*, whether commencing from a static condition or not, the *failure* conditions are transient and the relationship between the shear stress and normal stress varies. In all cases of powder testing, the *stress history* of the prepared sample must be clearly defined.
shear stress	A force acting parallel to the surface of a plane of a *particulate bed,* divided by the area over which it acts.

spring-back factor
1. The proportional change in dimensions of a metallic *compact* on ejection from its die or mould.
2. The degree of *strain* recovery on the removal of a compacting *stress* from a *powder bed.*

SSTT — Standard Shear Cell Testing Technique. A standardised procedure for the conduction of *Jenike shear cell test* developed by the Working Party for the Mechanics of Particulate Solids of the European Federation of Chemical Engineers and published by the I.Chem.E. See *ASTM D – 6128*.

strain — Deformation or displacement, causing a change in length per unit of length in a given direction, due to the application of a *stress*

strain energy — The total work input to deform a mass. The work done by forces affecting a change in volume comprises the work content absorbed by *friction,* that retained by elasticity in the *bulk*, and that absorbed by plastic deformation, and sometimes, to a limited extent *particle* fracture. In the case of gravity flow, the energy balance is that the loss of potential energy equals the work input to the bulk, less the frictional loss on the flow boundary contact surface.

Note that the volume of the mass may increase or decrease during *flow*, depending on the *stresses* acting on the *bulk* within the *flow* channel. The energy change involved in expansion or contraction must be taken into account. A work balance approach offers a fundamental understanding of the mechanistic nature of *particulate solids* behaviour.

tapped density — (See *density, tapped*).

tensile strength — The strength of a *compacted powder* to resist separation of the *particle bed* under the influence of a *tensile stress*. It is the external manifestation of attractive forces between the constituent *particles*. The magnitude of these forces depends on the closeness of particles packing, hence tensile strength is related to the *state* and *stress history* of the particulate solid. Tensile stress is equivalent to a *compressive* stress acting on the mass.
See *compound stress, normalised stress, negative void pressure*

Note: – The magnitude and orientation of formation *stresses* must be defined in relation to the alignment of the plane in which *failure* takes place.

E.g.
- ‘Co-axial’ *tensile strength* relates to *failure stress* in the opposite direction to the compacting stress of formation.
  See *Univ. of Bradford tensile tester*
- ‘Transverse’ *tensile strength* relates to *failure stress* at 90 degrees to the orientation of the formation stress. See *Ajax tensile tester*
- ‘Ultimate’ *tensile strength* measure of the *failure stress* of a tri-axially *compacted* sample. (A theoretical, rather than a practical test)

tensile test — The stressing to *failure* of a compacted *sample* by the application of a *tensile stress*. The relationship between direction of *compacting stress* and that of *failure stress* must be defined. (see *tensile strength*).

time consolidation — The *compacting* of *a bulk material* due to stresses applied over a period of time, such as may happen in long-time bulk storage or in preparation of a *sampl*e for *shear testing* purposes to represent bulk conditions experienced after extended periods of storage.

time yield locus — Plot of *shear stress* versus *normal stress* at *failure* of a *bulk solid* that has been subjected to *time consolidation*.

tri-axial tester — A test device common to soil mechanics where the sample is stressed along a cylindrical axis whilst the cylindrical body section is subjected to hydrostatic *compaction* by way of a tubular membrane.

unconfined compressive strength — The load per unit area at which an unconfined cylindrical specimen of compacted *powder* will *fail* under a simple axial load. See *unconfined failure test*

unconfined failure test — A test on an axially *compacted sample,* usually in a cylinder, that is stressed to *failure* by an axial load after the confining cylinder is removed.
Note that this test reflects initial *failure* conditions, as under the surface of a static arch, not those of steady flow, *critical state* conditions,

Uniaxial test — (See *unconfined failure test*).

University of Bradford tensile tester — A device that measures the *tensile strength* attained by a *powder bed* compacted at 90 degrees to the *plane of failure.*

vertical shear test — The *shearing* of a *compacted powder bed* by way of a vertical load applied on an unsupported, defined cross section

voidage — See *porosity.*

Walker cell — The original *annular shear cell* for *powder* strength investigations named after its inventor.

wall cohesion — The resistance to slip offered by a material, separate and additional to, frictional resistance due to a normal load acting on the contact surface.

wall friction — The relationship between the force necessary to cause slip on a contact surface and the force acting on the *bulk* normal to the surface. The effect should be measured under a range of applied normal forces and the results graphed to produce show the relationship and the effect of *surface cohesion* in circumstances of zero normal load. The value of *wall friction* is a major factor in the determination of wall inclination for a *mass flow hopper.* (See *friction, wall friction- dynamic* and *wall friction- static*).

wall friction-dynamic The relationship between the force necessary to sustain slip on a contact surface and the force acting on the *bulk* normal to the surface.

wall friction-static The relationship between the force necessary to initiate slip on a contact surface and the force acting on the *bulk* normal to the surface. The angle between the abscissa and the tangent of the curve representing the relationship of the shearing resistance to the *normal stress* acting between the *bulk solid* and the surface of another material.

wall normal stress The *stress* acting at 90 degrees to the *bulk* at a wall boundary surface.

wall shear stress The *shear stress* mobilised by frictional resistance to slip at a confining wall

wall yield locus A plot of the *wall shear stress* against the *wall normal stress*. see *wall friction.*

yield The boundary of fully elastic behaviour. A condition on which the applied *stresses* exceeds the *bulk strength* of a particulate mass causing the material to *fail* and plastically or catastrophically deform

yield locus The plot of a series of *failure shear stresses* of commonly *consolidated* samples to a specific *bulk density*, measured by a *shear cell* under the influence of a range of applied *normal stresses*. Note that the magnitude of the *normal stresses* are all less the *stress* of *consolidation* of the sample as adding an extra shear stress to the *consolidating stress* would change the density of the sample. The shape of the curve as the *shear stress* increase is noted, to establish the *normal load* condition at which the *stress* will increase to a sustained value without change of volume as the sample shears.

This represents the *critical state* of the *powder*. as flowing under these stress conditions any increase of normal load would cause the sample to increase in *density* and hence be in a different *bulk* condition. If the *shear stress* increases to a maximum value and then reduces, it implies that the sample has inadequate normal force to hold the sample in its prepared state. See *under-consolidated.* The yield locus, (YL), is sometimes called the *instantaneous yield locus* to differentiate it from the *time yield locus*.

yield strength The *stress* that a *particulate bed*, in a defined condition of density and loading, will sustain before deforming to *failure*. (See *yield stress*).

yield stress The value of *stress* that will cause *failure* of a bulk compact in a defined state of prepared *compaction* and of applied loading normal to the plane of stress application.

yield surface

The envelope of the *yield loci* on a three dimensional plot of *density, shear strength* and *principal stress.* It extends from the *tensile strength* value to the *critical state line* in the *shear/principal stress* plane, and from a point at the origin in a condition of dilatation that has zero *shear strength*, to a degree of *consolidation* at maximum solidification in the *density* plane.
See *Hvoslev surface.*

Section 13 - Bulk Flow

air-retarded flow	The resistance to surface *failure* and expansion of the *bulk material* due to low *permeability* of the *bulk material* that inhibits the rate at which *flow* can take place from an *unconfined surface*.
arching	The transfer of *stress* from a yielding region of solids to an adjoining restrained section of the mass. This is characterised by the formation of a stable *bridge* across a flow channel due to the effect of either a structural assembly or a *cohesive* structure. See *structural arching* and *cohesive arching.*
asymmetric flow	A *flow channel* that is biased to one side of the stored contents in a *silo* or *hopper*. Note that differences in walls pressure that arise from a *asymmetric flow* regime can result in extra-ordinary wall *stresses* that threaten the integrity of a *silo* structure designed for symmetric *stresses*.
avalanching	Intermittent surges of loose material on *poured* or *drained repose* surfaces due to transient instabilities of the flow restraining surface. See *repose flow*
bed flow	A *flow* pattern characterised by the movement of a mass of *bulk solids* in a parallel *flow channel*. Wall slip must take place on all contact surfaces but the *flow* velocity is not necessarily uniform across the whole cross section of flow. See *coherent flow.*
bin activator	A device for stimulating discharge from a *bulk* storage container by vibrating a base conical bowl section that has a conical convergence to the outlet neck. This section is supported from the bin walls by a number of links having flexible end fittings. The rim of the bowl is connected to the outlet of the main bin by a flexible skirt. Within the bowl is a concentric inverted cone to shield the outlet and create an annular flow gap.
Binsert®	A proprietary form of *Cone-in-Cone.* Used to secure *mass flow* in hoppers with shallow walls and regulate flow velocities to achieve flow *blending* or mitigate the effects of *segregation.*
bridging	The formation of arches of *particles* keyed, jammed or cohered together across the pathway of flow to form a stable obstruction. (See *arching, structural arching* and *cohesive arching*).
bullet insert	A rigid, circular *flow insert*. It is shaped with a top section as a steep inverted cone connected to a lower reverse cone section that may or may not be truncated. It is normally supported from the bin walls by vertical, radial ribs to form a *flow* annulus above the outlet. These generate mass flow at reduced cone wall angles of the bin and/or minimise *segregation.*

caking — The bonding of *particles,* normally by way of *crystal bridges* between points of contact in the bed, to form a hard, brittle *compact*.

coherent flow — Mass movement of the *bulk material* without re-ordering of the *particulate* structure. See *bed flow.* This is not strictly a flow process but is typically the manner of movement of product in the body section of a mass flow hopper until it nears entry to the converging section of the hopper, at which point the velocity tend to increase in the centre of the flow channel.

cohesive arching — The formation of a stable blockage in a flow channel resulting from the *bulk strength* of the material being sufficiently high to form a stable *arch* with an *unconfined* under-surface. (See also *structural arching*).

cohesive strength — The resistance to incipient shear of a *compacted* mass in the absence of a normal load on the shear surface. The *stress conditions and history* of the sample must be known for the value to have any meaning. See *cohesion*.

'Cone-in-cone' insert — A technique of incorporating a secondary hopper inside a bulk storage container to modify the *flow pattern* by changing the velocity gradient across the flow channel. One use is to convert a hopper that would otherwise not operate in a *mass flow* mode to one that will *mass flow*. Further uses are to induce *blending* of the container contents and mitigate *segregation* that would otherwise take place during discharge

confined flow — *Flow* taking place within a channel that is constrained by firm boundaries.

conical flow — A *flow* channel that converges in planes at 90 degrees to each other.

convective mixing — The separation and displacement of regions from a zone of material in a mixer, to new locations within the bed of powder.

converging mass flow — A *flow* channel that uniformly converges in one or two horizontal planes with slip taking place on all the *confining boundary* surfaces.

core flow — A *flow* channel that develops within a static mass of *bulk material* during discharge, that is replenished from the surface layers of the stored material by way of *drained repose*. The expression was coined by Arnold Redler in a patent application of 1921.

critical arching diameter — The size of largest size of opening over which a stable *arch* can form in a stored *bulk solid* that has developed a fully mobilised flow channel. This measurement is derived from Jenike shear tests and the application of his formula and charts. It relates to a *mass flow hopper.* If the hopper is not *mass flow*, flow secession occurs at a larger cross section as a *rathole* within a body of static material, See *critical rathole diameter. SSTT.*

critical ratehole diameter The maximum size of stable hole that can form through a bed of stored *bulk material*. In the case of a *non-mass flow hopper* the size of outlet opening must exceed this size in order to sustain gravity flow and a rathole cannot form. The *powder shear cell test procedure* developed by *Jenike* to establish this dimension is given in *SSTT.*

dead region, of flow A static zone with a stored mass that has developed a flow channel within the bulk. Note that this is incompatible with *mass flow*. The prospect of *mass flow* is negated if any region of the container outlet is not mobilised to flow, as with the case of a feeder that does not develop a progressive extraction profile along the length of a *hopper* outlet slot.

de-aeration The process of excess air escaping from the *voids,* to eventually bring the *void* pressure to ambient in a settled state of *particle* structure.

de-aeration constant A measure of the decay rate of *de-aeration* of a *fluidised bed* proposed by Mainwaring and Reed for the evaluation of the materials potential for *dense phase* conveying.

diffusive mixing A description of small scale interchange of *fractions* of a *mix* brought about by local migration and interactions between adjacent zones in an agitated *powder bed.*

dilated bed A bed of *particles* in an expanded state due to agitation, flow conditions, or the presence of excess air in the *voids* that develops a state of *quiescent fluidisation*.

drained cone See *drained repose*

drained repose The surface inclination of a conical depression formed by material emptying from the surrounding area into a *core flow* channel or orifice, or the slope formed when material is taken from the bottom of a pile.

This feature is associated with the surface profile of a non-mass flow hopper as it empties. It may also develop during the emptying of the portion of material in the converging hopper section of a *mass flow hopper*, due to the velocity gradient of flow across the cross section. This latter characteristic can negate the remixing of segregated product on the final stages of discharge, as the peripheral, segregated region empty is last to empty.

dynamic arching The formation of unstable flow obstructions caused either by : -

a. Transient cohesive *arches* that form within the flow channel, or
b. Air retarded flow, causing waves of *dilation* to progress through the mass causing temporary flow fluctuations, or
c. Erratic flow obstructions resulting from intermittent and unstable *particulate* structures that form in the *flow channel*.

dynamic repose The surface profile of a *powder bed* in a defined state of motion.

eccentric flow — A *flow pattern* that is not concentric with the boundary walls of the container. The *flow channel* may, or may not, intersect with the wall surface but if it does the intersection can be at differing heights and possibly fluctuating around the container walls. It should be noted that this pattern of flow gives rise to unbalanced wall pressures that cause complex, and possibly dangerous, wall stress situations.

effective transition — The location of change in the flow channel from *bed flow*, with active boundary stresses, to converging flow, where passive confining stresses act on the flow boundary. In the case of a *mass flow hopper* this occurs at the change from a body section to a hopper section of a bulk storage container. For a mixed flow type of bulk storage unit, the effective transition is unpredictably varies on the wall of the body section. The sudden change of confining *stress* raises high 'kick' pressures at the transition, which may place high structural loads on the container. See *appendixII note on flow*

expanded flow — A *flow pattern* comprising of a lower *mass flow* region that converts to a *non-mass flow* construction of container in the upper region of storage by transition of the wall geometry to a more shallow wall inclination on which the material will not slip in a confined state. This construction is normally selected to secure the reduced size of outlet, anti-*arching* and anti-*ratholing* benefits that are given by *mass flow* and securing the additional storage capacity given by lower wall angles at a cross section greater than that at which *arching* can take place, without the penalty of extensive headroom requirements for a total *mass flow* design.

fines expression (of segregation) — The process of large *particles* in a *flow stream* pushing away *fines* on impact with a *dilated bed* that has a preponderance of *fine particles.*

flooding — (See *flushing*).

flow — Plastic deformation of a *bulk material*, due to the influence of external forces. (See *gravity flow, confined flow and unconfined flow*).

flow channel — A cross section of moving bulk material bounded by confining surfaces or a static *bed* of similar product

flow inserts — Fittings added to the internal construction of a *bulk* storage container to change the *stress* distribution within the material stored or the *flow regime* generated in order to secure some favourable feature. See *cone-in-cone, Binsert, Lynflow inserts, homogenising inserts.*

flow pattern — The shape of a local *flow channel* that develops through a solids flow route. See *poured and drained repose, core flow, mass flow, flow regime.*

flow regime — The fully mobilised form of *flow channel* developed by a *particulate solid* during discharge from a container. A primary classification may be made between *mass flow* and *non-mass flow*. *Mass flow* may be completely *converging mass flow* or incorporate a region of *bed flow*. Non mass flow variants includes *expanded flow, mixed flow, core flow with drained repose and funnel flow,* all of which are combinations of sequential flow patterns.

flow, steady state — Continuous plastic deformation of a *particulate solid* in a *critical state* condition.

flowability — A expression is cited as a measure of how easily a material will *flow*. This property may be expressed in comparative terms, or as an index with defined examples to form a scale but, in the case of a *compacted particulate solid*, is better quantified by the *flow function*.

Note that this expression may be concerned with both the instantaneous and *time consolidated* values of the *flow function*, but the instantaneous value is normally the figure used to express the potential flow behaviour of a *bulk material* in a fully *de-aerated* and *compacted* conditions.

Also, the flow potential of a particulate solids may be stress dependent, be influenced by time effects, particle-to-particle caking, bonding, fusion, elastic or plastic deformation at the points of particle contact and the degree of confinement. In essence, flow potential cannot be expressed by a single value, but by relating its prospects to specifically defined conditions, taking account of the relevant properties of the bulk material.

fluidisation — A condition of zero internal strength of a *powder bed* brought about by the presence of excess fluid, usually air, in the *interstitial voids* of a *fine bulk solid* that dilates the *bulk* sufficiently to offer the constituent *particles* unrestrained freedom for rearrangement and hence behave like a fluid of low viscosity. (See *flushing*).

fluidisation, aptitude — The ability of a bulk material to be fluidised. See *Geldarts classification*

fluidisation, minimum speed of, — The minimum speed of *fluidisation* , theoretical method, is given by the formula : (Valid only in laminar rating i.e. if inequality below applies)

$$v_0 = \frac{1.\varepsilon_0^3 \cdot g\,(\partial_s - \partial_g)\,\Psi^2 \cdot d^2}{200 \cdot (1 - \in_0)\ \eta} \qquad \text{if} \qquad \frac{v_0 \cdot d \cdot \partial_g}{\eta} > 10$$

Where : -

D = Average diameter of particles, equivalent to the diameter of a sphere having the same volume.

g = acceleration of gravity

$\in_0$ = vacuum rate = $\frac{\text{volume of interstices}}{\text{Total volume filled by bulk product}}$

$\in_0$ can vary from 0.4 to 0.6 for homogeneous particles of same dimensions).

Ψ = shape factor = $\frac{\text{diameter of sphere of same surface}}{\text{diameter of sphere of same volume}}$

Ψ = 1 for a sphere

∂_s = density of solid particles

∂_∂ = density of gas

η = factor of dynamic viscosity of gas

The theoretical minimum speed of *fluidisation*, v_0 is compared to the aptitude of a product real speed of *fluidisation*, v_{fm} deducted from the gas flow q_{vfm}

$v_{fm} = q_{vfm}/S$ Where S in the area of the porous cloth.

If $v_0/v_{fm} = 1$ The product is easily fluidisable

$1 < v_0/v_{fm} < 1/2$ The product is fluidisable

$1/2 < v_0/v_{fm} < 1/4$ The product is difficult to fluidise

If $v_0/v_{fm} > \underline{1}$ The product can be considered unfluidisable

flushing The fluid-like behaviour of a dilated *fine particulate* material flowing with negligible restraint to deformation. The *internal friction* of the *bulk* is negated by the presence of air or other gas holding the *particles* sufficiently apart as to allow them total freedom of relative movement. The condition can arise from high agitation, as with free fall, the collapse of a *cohesive arch* or as delivered from a pneumatic conveying system. Note, that such a *flow* condition is subjected to hydrostatic pressures. It is highly searching and cannot be restrained other than by gas tight seal mechanisms, such a rotary valves or cut-off valves.

free flowing of bulk material A particulate solids that offers no cohesive or rigid structural resistance to deformation under gravity flow.

funnel flow An expression originally coined by *Jenike* in Bull 123 to describe the characteristic funnel shape flow pattern having a composite form. This comprises of a *core flow channel,* formed by a narrow cross section of flow emanating from the outlet, that is replenished by a *drained repose surface*. The term is often utilised to generically describe all *flow patterns* that are not *mass flow.* In this context it is held to be a misnomer and the use of '*non-mass flow*' is a preferred expression to describe *flow regimes* in a *hopper* of any form that are not of a *mass flow* character.

Geldart's classification A chart devised by D.Geldart to group the *fluidising* potential of *powders* into four classes according to their relationship on a graph of *particle density* against *particle size*.

Geldart Group A — The powders most easy to aerate are generally fine, but of very limited cohesion. They are slow to settle from an expanded condition and uniformly permeable in the expanded state. In their eventually settled state they may form a firm bed but this can be expanded and broken up by an upward gas flow.

Group B — The sand-like particle size of materials in this group are considerably larger than in group A for any given particle density. Bubble of gas grow with bed depth and gas velocity and any expanded bed formed collapses quickly when gas flow ceases.

Group C — Powders in group C are difficult to fluidise because inter-particle forces exceed the hydrodynamic force created by the rising gas stream. Gas escape channels develop through cracks or fissures through planes of local weakness, or by bubbles, to inhibit the penetration necessary to separate the particles to a fluid condition.

Group D — Are generally coarse and tend to be of high particle density

due to the easy with which air can pass through the interstitials and gas velocity needed to carry the weight of the particles, these powders are difficult to fluidise without the expenditure of great volumes of air that tends to spout through the bed.

gravity flow — *Flow* of a mass of bulk stimulated by the force of gravity. (This is such an important aspect of bulk technology that a detailed review of the process is given in appendix 2). See *flow*

homogenising hopper — A hopper used to *blend* the stored contents by means of air injection or the inclusion of *flow* modifying devices that change the zone order of filling and/or emptying the container.

homogenising silo — See *homogenising hopper*.

impact penetration (of segregation) — The process of *bed* penetration and capture of large or dense *particles* from the *flow stream* within the impact zone of a forming *repose pile* thereby giving rise to a concentration of these particles in the centre of the pile and fine being displaced to the periphery of the pile or container. This behaviour pattern arises when the forming bed is of weak composition and the kinetic energy of the larger, denser *particles* penetrate to a depth than prevents their unconfined rolling down the repose slope.

intensity of segregation	The degree of differentiation, due to *segregation* processes, of *particulate fractions* that have different physical properties. Note that the discretion of intensity tends to be related to the *scale of scrutiny*, therefore the acceptable degree of *segregation intensity* may have different values at different *scrutiny scales*.
internal flow	The formation of a *flow channel* within a mass of static product. (See *core flow, funnel flow*).
live flow	An active flow channel
mass flow	A *flow pattern* in which the entire contents of storage are mobilised to flow when discharge takes place from a bulk storage container. It is characterised by the fact that no stagnant zones are present during discharge when *flow* is fully mobilised. Slip essentially occurs on all wall contact surfaces. The *flow pattern* may relate to a container that has a converging region only, or to a two-stage pattern where the lower region converges and the upper portion moves in a *bed flow* pattern. The flow velocity is not necessarily uniform across the *flow channel* and is invariably not so in a converging channel It should be noted that this mode of flow is dependent upon a combination of a specific *bulk material* in a container of given geometry and construction media and is not a feature of a specific form, type or geometry of storage vessel in isolation.
mass flow bin	See *mass flow hopper*.
mass flow bunker	See *mass flow hopper*.
mass flow hopper	A storage container where the contents move in a *mass flow* pattern.
mass flow silo	See *mass flow hopper*.
mixed flow	A *flow pattern* comprising of two zones in a *bulk* storage container. The lower region of *flow channel* is a *core flow* regime that expands within an outer zone of static material to intersect with the container walls some distance below the upper surface of the stored mass, to give an upper zone that extends as a *bed flow* pattern. Note, vertical movement of the total surface cross section should not allow this mode of *flow* to be confused with *mass flow*, where the total contents of the container are in motion. The term may also be applied to an *expanded flow* form that expands to intersect the container wall to create an upper *bed flow* section.
non-mass flow	A preferred generic term for any *flow pattern* that does not embrace the movement of the total contents of a bulk storage container.

percolation	1 - (of segregation) The penetration of smaller *fractions* through a static bed of larger *particles.* 2 - (of gas permeation) Leakage of gas into, through or from a bed of *particles*.
pipe flow	A region of initial discharge down a narrow flow channel that is not sustained because the cross section is smaller than the *critical rathole diameter*. (See *rathole, piping* and *core flow*).
piping	A narrow *flow channel* that develops within a static mass of bulk material that exhausts itself to leave an open void channel from the container outlet to the upper surface of the stored *bulk material.* See *core flow, funnel flow.*
plane flow	*Flow* in a *confined channel* that converges in one plane only, as with a Vee or wedge shaped hopper.
poured cone	The profile of heap a *bulk solid* created by a single point fill. Note that, even with a steady feed stream, the slope is formed by material cascading in a series of surges, or small *avalanches*, in successive radial dispositions around the point of fill. Materials that tend to *segregate* deposit *fines* in strata of decreasing thickness from the peak as these surges peter out down the widening slope. The cross sectional disposition of the segregated fractions within the formed pile is characterised by a 'Christmas tree' type of dispersion. Any bias of segregation in the feed stream leads to severe diversion of the fractions in the circumference of the pile. This effect can be mitigated by regular, minor variations of the fill position
poured repose	The surface inclination of a pile formed by material building up from a feed point of steady supply. Normally of conical shape surface, but may be a plane surface if the boundary of the slope is a linear overflow plane or a moving dispensing device. In view of the variable flow condition of many *bulk materials* it is essential to closely define the conditions of the feed stock and the circumstances of the supply stream. See *angle of repose, drained repose.* cont. The *poured repose* and *angle of repose* measurement have <u>no</u> direct relation to the flow behaviour of a *bulk material* in a *confined flow channel*. Unless the inclination of the surface formed is independent of the method of preparation, or the test procedure reflects the specific application conditions of interest, the measured value has little meaning.
powder bed	A mass of *powder* in a *settled state,* unless otherwise defined.

quaking — A cyclic pattern of movement and stoppage of *flow* of a significant quantity of a stored *bulk* product that induces substantial inertial forces upon a storage container and its foundation. The phenomenon arises from various causes, such as frictional *stick-slip*, *slip-stop*, cyclic oscillation of a *flow pattern* that is marginal between *mass* and *non-mass flow*, '*slurping*' and *surface repose* instability, as in a discharge chute or *bin activator*.

radial flow — A *flow pattern* whereby the cross section reduces uniformly in radius as the channel progresses. See *conical flow.*

rathole — The void left when a *core flow* pattern or pipe evacuates all the material in the *flow channel,* to leave a stable *unconfined surface*. Note: this behaviour is not applicable to a *plane flow channel*, unless the wall inclination is not self-clearing, as the absence of a central continuity across the *flow channel* leaves an un-restrained mass resting on each side wall. (See *piping).*

scale of segregation — The magnitude of the overall mass that is affected by *segregation.*

segregation — The migration of disparate *fractions* along separate paths of a *particulate solids flow* route as a result of the influence of common applied forces on the differing physical properties of the constituent *particles* that leads to a diversion of the *particle* paths such that the various fractions accumulate in different locations. The consequence is such that a *bulk material* of initially homogeneous composition becomes heterogeneous in nature.

Mechanisms prevailing in various regimes of *flow* lead to many types of *segregating* processes. The *intensity* and *scale of segregation* are dependent on the nature and scale of the operation. For further information on this behaviour, means to reduce, counter and rectify the effect, see 'User Guide to Segregation', published by the British Materials Handling Board.

self clearing — A bulk solids container that empties without leaving residue.

shear mixing — The process of random migration of *particles* across a plane of *shear* generated within a mixer. (See also *diffusion* and *convective mixing*).

sifting,(of segregation) — The process of the dynamic penetration of smaller *fractions* through larger ones, in a dynamic bed of *particles*. See *percolation*.

sigma-two relief — A *flow pattern* that converges in one plane and diverges in the plane at right angles thereby relaxing the minor principal stress of confinement. This feature allows the major dimension of deformation to occur at lower stresses, such that a *particulate material* will slip on converging hopper walls at reduced inclinations, have a smaller critical arch span in a Vee shaped hopper, reduce the prospect of structural arching and discharge material at higher flow rates through a given slot width.

slip-stick	A 'Chattering' motion of a solid on a *contact surface* due to the relaxation of flow generating stresses when movement takes place. The difference between *static and dynamic friction* brings the contact layer to rest, until the elasticity of the *flow system* accumulates adequate slip generating forces to again overcome *static friction*. See *slip-stop.*
slip-stop	A behaviour pattern whereby a *wave of dilatation* moves through the *bed* from a discharge opening, until the forces supporting the static bed on the growing span of the flow boundary are relaxed sufficiently for the weight of the superimposed mass to exceed the mobilised wall friction. A sudden, gross movement of the contents compresses the dilated region and the mass is brought to a sudden rest because the gross rate of flow far exceeds the capacity of the outlet. Note, this differs from *Slip*-stick because the restraint is a *compacted* mass, and not *static friction.* The scale of inertial impact is generally greater than developed by *slip-stick*. See *quaking.*
slurping	A phenomenon of erratic discharge arising from the *unconfined failure* surface above the outlet orifice of a container suffering dilated or *air-retarded flow.* The rate of disengagement of *particles* from the body of *bulk material* is limited by the low *permeability* of the bed, which offers resistance to penetration of the ambient gas to allow void expansion for the *particles* to separate. The effect of this cyclic increase in span of the draining or dynamic arch at the approach to the container outlet, followed by collapse, is to develop a fluctuating rate of flow as the surface area of *failure* increases with surface release until it reduces rapidly to a smaller value. When the *unconfined* span attained is larger than the *critical orifice size*, the internal stresses overcome the strength of the *bulk material*, such that the *arch* collapses. The cycle of progressive *surface failure* is re-commenced from the material deposited around the container outlet. See *Slip-stop, quaking.*
solifluction solifluxion	Creep of *repose slopes.* Characteristic of, but not restricted to, regions subjected to periods of alternate freezing and thawing.
steady state flow	Flow in a condition of steady *density* as each section of the flow channel is characterised by a unique relationship between the *shear stress* and the *normal stress* acting on the *yielding* surface.
structural arching	The formation of a flow obstruction caused by the coming together in the flow path of discrete large *particles, agglomerates* or *lumps* that interact by physical contact to form a stable structure over the dimensions of the flow channel. This is a stochastic process. The probability of a stable *arch* forming is dependent upon many variables, of different importance, as -

- The size and shape of the orifice in relation to the particle size(s). (Major factor)
- The inclination and surface conditions of the approach walls of the flow channel.
- The rate of flow, whether commencing or sustained.

- The size, shape, size distribution of the constituent particles. (Major factor)
- The surface condition of the particles, (internal angle of friction of the bulk).
- whether the material is slipping on the approach walls to the opening .
- The viscosity of the interstitial fluid in the voids (A minor influence).

A general rule of thumb is that structural blockages, held by mechanical forces only, will not occur if a round orifice is greater than eight times the largest particles size, or five times in the case of a slot shaped opening. (*cohesion* introduces extra considerations)

Some prudence and interpretation is required to assess suitable opening sizes when there is a wide particle size distribution, the lumps are infrequent or erratic, or are of indeterminate lump size. Precautions are best made by the introduction of lump traps or flow channel shapes, such as slots or an annulus that will not block by a single lump. See*, structurally retarded flow* and *dynamic arching*.

structurally impeded flow The. See *structural retarded flow, structural arching*.

structurally retarded flow Restraint to smooth flow and reduction of *flow* rate due to the transient formation and collapse of *dynamic* or *transient structural arches* in the *flow* stream induced by structural re-ordering of the *particulate array* that intermittently form a temporary obstacle to reduce the flow velocity within a *confined channel* by way of an unstable mechanical blockage. A stochastic process that results in an erratic rate of discharge.

Note that the boundary between structurally retarded flow and the prospect of formation of a stable structural arch is indeterminate, being dependent on fine interactions of many factors. See *structural arching.*

surcharge Material piled above the level of the peripheral storage edges of the confined contents of a container.

surface repose The maximum sustainable inclination of surface profile adopted by a *bulk material* under given conditions of formation. See *angle of repose*

transition The junction between the *body section* and the converging *hopper section* of a bulk storage container.

transitional state The interim condition of a deforming *bulk material* during *flow* initiation or change whereby the *bulk density* is changing in response to variable stress condition acting on the material.

unconfined flow The *flow* of a *bulk material* where part of the *flow channel* is not constrained by confining boundaries.

unconfined surface A product bed or flow stream boundary that is not restrained by a contact surface.

aves of dilation The progression through a bed of *bulk material* of a gravitational wave of *dilation* and local collapse following the opening of an outlet valve or the commencement of a feeder or other discharge device.

Section 14 Pneumatic Conveying

actual gas velocity — The conveying gas volume flow, at the existing pressure and temperature of location, divided by the area of the empty pipeline. It is normally expressed in unit distance in unit time. Whereas the mass of conveying gas is usually constant over the entire length of the conveying pipe, the actual gas velocity increases as the pressure reduces with distance from the origin. The figure normally cited is an average value, because the local gas velocity differs in different parts of the cross section.

air retention — The ability of the material conveyed to retain air, (or another gas), in the *voids* after discharge from the pneumatic conveying system in a dilated condition. This ability depends upon the *permeability* of the bulk material for the specific viscosity of the gas concerned. See *fluidity, de-aeration*

'angle hairs' — Long thin 'streamers' that are formed in the lean phase handling of low melting point granules, such as plastics, due to the high velocity frictional contact of the particles on the pipe walls melting the particle surface and forming extended length of narrow thin films or fibres that become entangled in the subsequent bulk.

average gas velocity — The mean of the *actual gas velocity* at the commencement of the pipeline and the *terminal gas velocity*.

blinded bend — A change of direction affected by a closed end of pipe in the initial direction of flow. The gas stream is re-directed by a static *bed* of captured *particles* in the closed end of the pipe to a side outlet.

choking — The phenomenon of the formation of a slugging, fluidised bed forming in a vertical section of a pneumatic conveying line as the gas velocity falls below the level at which it can entrain the solids.

choking velocity — The superficial gas velocity at which *choking* occurs.

Note: 1. However, for mixed sized particles the velocity at which choking occurs is usually lower than the saltation velocity

Note: 2. An alternative definition for choking velocity takes the superficial velocity at which the entire suspension collapses into slug flow as the choking velocity. However not all powders can be made to collapse into slug flow and the former definition is preferred.

conveying line exit velocity — See *terminal gas velocity* combined vacuum/pressure system — Pneumatic operation under suction to a single gas and material receiving vessel with the same unit providing a pressure system to one or several gas and material receiving vessels.

dense phase — A pneumatic conveying system characterised by low gas velocities, (1 – 5 m/sec), high solids concentrations, (. 30% by volume), and high pressure drops per unit length of pipe, (typically > 20 mbar/m).

Note: The products carried in this mode uses gas velocities lower than those required for lean phase conveying. The nature of dense phase flow is very varied, for it depends upon the properties of the bulk solid and the conveying gas velocity.
Typical dense phase flow patterns include flow over a deposited layer, which may itself be moving slowly, and flow in discrete slugs of material that may form naturally, sometimes with material falling away from the 'tail' of one slug to be picked up and carried forward by the following slug.
Whilst this mode is more energy efficient than lean phase and treats the product more gently, the system design is more demanding and the range of bulk solids that can be transported in this mode is limited

dilute phase — See *lean phase*.

dune flow — Movement of a saltated layer on product along the conveying pipe in the form of waves of the material.

ending gas velocity — See *terminal gas velocity*

fluidised flow — The pouring or otherwise causing to move of fluidised solids under the influence of gravity or pressure gradient.

free air conditions — Those conditions at which p = 101.3N/m^2 absolute (standard atmospheric pressure) and t = 15^0 C (standard atmospheric temperature)

Note: Free air conditions are generally used as the reference for the specification of positive pressure air movers.

free air delivered. (FAD) — See *volumetric gas flow*

free air velocity — The velocity of the air at *free air conditions*.

interstitial gas velocity — See *actual gas velocity.*

lean phase — A pneumatic conveying system characterised by high gas velocities, (< 20m/sec), low solids concentrations, (< 1% by volume), and low pressure drops per unit length of conveying line. (typically < 5mbar/m).

Note: It is necessary to exceed a minimum value of conveying line inlet gas velocity to produce sufficient drag on the solid particles to convey by lean phase. The vast majority of particulate materials can be conveyed in this mode.

material massflow rate — The mass of material conveyed over a specific time period. Also known as *conveying rate* or *system capacity.*

material velocity — The velocity of the solid conveyed. This is always less than the local gas velocity and is usually specified as either an average (or mean) velocity, or the terminal velocity of the product from the conveying pipe. This is almost invariably an estimated figure because reliable means to measure the progress of individual particles are very limited.

mean gas velocity — See *average gas velocity*

minimum conveying velocity — The lowest gas velocity that can be used to ensure stable pneumatic conveying conditions for the material. This velocity must pertain at the feed point of the system, because the gas accelerates with the reduction in pressure along the flow route. Hence it is also known as the *pick-up velocity.*

multi-discharge system — Pneumatic conveying operation by blowing or suction, with discharge into several gas and receiving gas and material separators and material receiving vessels.

multi-pick up system — Pneumatic conveying operation under suction with multiple feeder units.

null point — The position in a system where the pressure is equal to the ambient pressure.

Note: This is often used in relation to closed loop systems and can identify a natural point of access to the system for monitoring or conditioning.

pick up velocity — See *minimum conveying velocity*

plug flow — The movement of plugs of solid that occupy the full cross section of the conveying pipe

saltation — Deposition of product in pipe as it is no longer carried forward within the gas stream.

saltating flow — Progression of the product along the lower boundary of the conveying pipe. Particles are conveyed in suspension above a layer of settled solids. Particles may be deposited and re- entrained from the static or slow moving layer.

saltation velocity — The gas velocity in a horizontal pipeline below which particles mixed homogeneously with the conveying gas will fall out of the gas stream.

simple pressure system — Pneumatic conveying operation under pressure by blowing with discharge into a single gas and material separator and material receiving vessel.

simple vacuum system — Pneumatic conveying operation under suction, with discharge into a single gas and material separator and material receiving vessel.

slip velocity — The difference between the gas and particle velocity.

superficial gas velocity — The velocity of the gas disregarding the volume of solid particles or porous media at the temperature and pressure conditions under consideration within the pipeline.

Note: In a pipeline it is the velocity based upon the cross sectional area and neglects the space occupied by the conveyed product. For flow through a membrane or across a filter, it is the open duct velocity normal to the surface. Gas velocity is dependent upon both pressure and temperature, and so when conveying gas velocities are evaluated at any point is a system the local values of pressure and temperature at that point must be used.

suspension flow — See *lean phase*

terminal gas velocity — The velocity of the gas as it exists the system.

volumetric gas flow — It should be noted that several different terms can be used to describe volumetric gas flow. The volumetric gas flow during conveying is expressed as *free air delivered*, (FAD). The output of most air movers are specified in terms of FAD, being the volumetric gas flow at the suction port of a positive-pressure blower or compressor, or at the discharge port of a vacuum blower or vacuum pump. This reflects the volumetric gas flow in the actual conditions where the equipment is located.

wall heating — The gain of local temperature on contact surfaces by virtue of high velocity frictional contact during lean phase conveying. This energy input may cause unwanted heating of the product, e.g. when handling frozen or heat sensitive products See '*angle hairs*'.

Appendix I - Rand Report Summary

Rand report — Ed Merrows 1985

A review of performance in 37 new Solids Handling plants showed remarkable shortfall compared with the industrial norm in plants handling liquids and gasses.

Main findings: -

Two thirds operated at less than 80% capacity at end of first year and a quarter at less than 40%. The average working capacity at end of year, one was 64%, compared with 90 – 95% for industry as whole. Only 6% of the facilities had no 'major problem' in first year of operation, (defined as a shutdown for one week or more).

Most difficulties lay in flow and material behaviour problems, rather than due to the quality of engineering or basic process chemistry.
No general improvement showed over earlier study in 1960.

Most R & D is invested in process chemistry. Physical problems often not considered worthy of study. Handling problems that may arise are expected to be resolved during start-up.

Conclusions

- More research needed on the behaviour of solids.
- More education required in solids behaviour.
- Better feedback needed from plant to design.
- More routine solids testing needed for plant design.

Editors View

- The current position shows only limited improvement.
- Performance requires total flow route reliability.
- Capital cost tends to dominate purchasing decisions, probably because handling is perceived as a non-value adding item, rather than a fundamental necessity to be optimised in cost and effect
- Industry requires a simple and inexpensive 'screening' test to determine the nature and magnitude of potential flow problems, to evaluate the extent of further investigation that is warranted.
- Attention to detail most often lacking on low cost items.

Appendix II - Gravity Flow Stresses in bulk materials

A grasp of the difference between active and passive stresses is necessary to understand how bulk materials behave in storage hoppers and silos. An active stress is one that presses onto a contact surface due to the forces generated within the body of the material. If the surface were to be slightly moved away from the material, such stresses will follow and continue to act with virtually the same pressure. A passive stress is caused by the resistance offered to a bulk material against any surface that is trying to compact the mass of product. If the surface is withdrawn slightly, this pressure ceases. A simple case to illustrate the difference is that of retaining walls for a stockpile. Product that is piled against the walls exerts a force caused by the horizontal stresses generated within the bulk material. If the wall is withdrawn slightly, the material will normally collapse and form a new shape pressing with a similar force. An exception may occur if the material were cohesive, in which case the pile may stand as a vertical cliff because the internal strength of the material is sufficient to contain these internal stresses.

A contrasting situation is if an attempt were made to push the walls into the pile. This would give rise to a passive resistance with a magnitude larger than the original active stress. It is easy to see that the effort required must be enough to overcome the original force pushing out and have the extra work of compressing the bulk and/or pushing up the level of the pile. Contrary to what the words 'active' and 'passive' may suggest, this example graphically indicates that passive stresses can be substantially greater that active stresses.

What generates an active stress in the first place? Well, a void gas under pressure is a classic form of an active stress. When a bulk material is delivered into a container it is usually in a dilate condition. The particles move closer together as the bulk settles into a stationary bed. Air is expressed from the voids through the remaining interstitial gaps, the escape path becoming longer as the bed depth increases. With fine particles it can be a long process for the void air pressure to come to equilibrium with the surrounding ambient atmosphere. Until this happens the void pressure supports part of the superimposed weight of the mass, thereby delaying the particle-to-particle contact pressure from achieving its ultimate value. Initially, the particle contact forces maybe so small that they can move against each other with ease, and the bulk can behave as a fluid. In these circumstances the active pressure on the wall is hydrostatic, dependent on the bed depth and the effective density of the product in this state.

With coarse materials this effect is less dramatic and short lived because the air can readily percolate through the larger void gaps. Nevertheless, there is almost invariably a temporary, declining void pressure in a recently filled bed of loose solids. The other, growing and longer lasting source of active pressure is that arising from the particles being 'squashed' by the overburden. Any solid will tend to deform under stress, reducing in dimension in line with a compressive stress and, unless restrained, expanding to a less degree at right angles to the axis of the compressive stress. The ratio of this dimensional change is termed the 'Poission ratio', and is generally of the order of 0.4. A simple compressive load of this type causes the 'major principal stress' in the mass and the transverse stress generated by this is called the 'minimum principal stress. The force needed to contain the 'sides' of the material to its initial position is equal to this minimum principal stress.

Now consider what occurs when a stored product slides from a parallel, body section of a hopper into the converging section. In the parallel section the material moves in 'bed flow' without change in cross section, so the walls need only contain the active bulk stresses, which remain virtually unchanged during this phase. Moving into the converging section, forces are exerted by the walls to compress material to a smaller cross section. There is a resistance to this deformation requiring work input, in addition to that needed to overcome the original active stresses. It is considerably more difficult to overcome the initial structural resistance to deformation than it is to continue the failure process. There is also a reduction in the containment pressure as the material approaches the final outlet. For these reasons, the severe change in stress that occurs at the transition point is followed by a reduced value as the material continues downwards.

In this converging section the stress pattern has radically changed from that pertaining before flow commenced. Originally, the greatest stress was due to the vertical pressure of material weight. Now, the maximum stress direction is across the bed, causing the cross section to reduce in width during flow. A shear force also acts on the wall boundary due to the frictional drag on the contact surface. The combination of compressive and shear stress forms a maximum principal stress direction inclined upwards from the wall surface. This stress line bends over into an arc within the bulk to meet the opposing wall at a similar angle. The magnitude of this stress diminishes as the material nears the outlet, because the material is eventually not confined at the outlet location as the material falls or is taken away. The most likely location for a stable arch t0 form is near the outlet, where the span is small. This will happen if the unconfined failure strength of the material in this region exceeds the stresses available to cause failure.

Such a situation is more probable from first-fill condition because, as previously described, the stress required to ‘switch’ the state of wall stress from active to passive is much greater that the stress needed to sustain the passive stress. This situation will apply to material in the whole converging section, including the critical outlet region of smallest span, unless flow has taken place. For this reason, the Jenike method requires that a small amount of material is withdrawn from the outlet to initiate flow stresses in the region local to the outlet, before the vertical stresses raised by the weight of the material being loaded develops a stronger bulk material. It is not usually important to initiate a flow field through the total converging hopper section because the span of the flow channel at the upper levels is normally greater than that of a potential arch. Flow opposing stresses within the material in this upper region are readily are overcome by the large work content available from the prevailing forces when flow eventually takes place.

The stress pattern developed in the bulk during flow remains in place as flow stops. The Jenike method of hopper design is founded upon measuring this state of stress on the basis that once this flow state has been achieved, it will reliably restart again when similar circumstances re-occur, i.e. when the outlet once again allows material to escape. This is provided the material is not allowed to stand for some time and allow the bulk to gain strength as the dilated flow condition settles to a firmer bed. Measurement of any increase in bulk strength with time under a steady compacting load is measured by ‘time compaction’ tests, where test samples are loaded in a static condition for an equivalent period to the time of standing without discharge taking place.

An understanding of these flow mechanisms is a useful introduction to the terminology relating to mass flow and the basics of modern practice in hopper design.

Appendix III - Relevant Standards

B.S. 410:1976, Specification for test sieves
B.S. 598-104:1989, Sampling and examination of bituminous mixes for roads and other paved areas.
Method of test for the determination of density and compaction.
B.S. 812: Methods for sampling and testing of mineral aggregates, sands and fillers
Part 1: 1975, Sampling, size, shape and classification
Part 2: 1975, Physical properties
Part 3:1975, Mechanical properties
B.S. 1016, Methods for analysing and testing colas and coke.
Part 1: 1973, Total moisture of coal
Part 2 Total moisture of coke
Part 3 Proximate analysis of coal
Part 4 Moisture, volatile matter and ash in the analysis sample of coke
Part 13:1980, Tests special to coke
Part 17:1979, Size analysis of coal
Part 18:1981, Size analysis of coke
Part 19:1980, Determination of the index of abrasion of coal
Part 20:1981, Determination of Hardgrove grindability of hard coal
B.S. 1017, Methods for sampling coal and coke.
Part 1:1977, Sampling of coal
B.S. 1377:1975, Method of test for soil for civil engineering purposes.
B.S. 1460:1967, Method for determining apparent density after compaction of precipitated calcium carbonate
B.S. 1703:1977, Specification for refuse chutes and hoppers.
B.S. 1743:1992, Method of analysis of dried milk and dried milk products.
Determination of bulk density.
B.S. 1796:1976, Methods for test sieving
B.S. 1902. Part. 3 Method of testing refractory material. General and textural properties.
Section 3.4:1981, Determination of true density, (photometric method).
Section 3.5:1981, Determination of true density, (powder method 1902-304).
Section 3.6:1984, Determination of grain density, (method 1902-305).
Section 3.7:1989, Determination of bulk density and true porosity of shaped insulating products. (method 1902-308).
Section 3.8:1989, Determination of bulk density and apparent porosity of shaped insulating products. (method 1902-317).
Section 3.7:1989, Determination of bulk density and true porosity of dense shaped products.
Section 3.17:1990, Determination of bulk density and volume of dense shaped products.
B.S. 2701:1956, Specification of Rees-Hugill powder density flask.
B.S. 2782-Method 824A:1966, Method of testing plastics. Other properties. Sheet and film.
Determination of the coefficient of friction.
B.S. 2975, Method of analysis and sampling of glass making sands.
B.S. 2955:1958, Glossary of terms relating to powders
B.S. 3029:1958, Method for determining the compressibility of metal powders.
B.S. 3272:1960, Aluminium food storage bins.
B.S. 3400:1967, Method of test for dust in filling materials
B.S. 3406: Methods for the determination of particle size of powders
Part 1:1961, Sub-division of gross sample down to 0.2ml
Part 2:1963, Liquid sedimentation methods
Part 3:1963, Air elutriation methods

Part 4:1963, Optical microscope method

Part 6:1985, Recommendations for centrifugal sedimentation method for liquids and powders.
Part 7:1988, Single particle light interaction method.
Part 8:1997, Photon corrolation spectroscopy.
Part 9:1989, Recommendations for filter blocking method. (mesh obscuration).

B.S. 3482:1991, Method of test for desiccants. Determination of bulk density. (dry basis).

B.S. 3483, Methods for testing pigments for paints
Part B8, Determination of density relative to water at 40C

B.S. 3625:1963, Eyepiece and screen graticules for the determination of particle size of powders

B.S. 3810-2:1965, Glossary of terms in materials handling. Terms connected with conveyors and elevators. (excluding pneumatic and hydraulic handling).

B.S 3762-4:1986, Analysis of formulated detergents. Physical test methods. Methods for determination of apparent bulk density.

B.S. 3900:1993, Method of test for paints. Testing of coating powders.
J.2, Determination of particle size distribution of coating powders by sieving.
J.4, Determination of storage stability of coating powders.
J.6, Determination of density of coating powders by gas comparison pyknometer. (Referee method)
J.7, Determination of density of coating powders by liquid displacement pyknometer.
J.8, Calculation of lower explosion limit for coating powders
J.9, Determination of flow properties of a coating powder/air mixture.
J.11, Determination of flow properties of a coating powder. (Incline plane method).
J.13, Particle size analysis by laser diffraction.

B.S. 4140, , Method of test for Aluminium Oxide.
Section 8:1986, Determination of absolute density using a liquid displacement pyknometer.
Section 8:1986, Determination of un-tamped density.
Section 21:1980, Method of test for aluminium oxide particle size analysis.
Section 22:1987, Determination of fine particle distribution (method using electroformed sieves).

B.S. 4317, Method of test for cereals and pulses.
Section 23:1990, Determination of bulk density of cereals called 'mass per hectolitre'. (reference method).
Section 32:1990, Determination of bulk density of cereals called 'mass per hectolitre'. (routine method).

B.S. 4359: Methods for determination of specific surface of powders
Part 1:1969, Nitrogen adsorption (BET)
Part 2:1971, Air permeability method
Part 3:1970, Calculations from the particle size distribution

B.S. 4409-1:1991, Screw conveyors. Specification for feed trough type.
-2:1991, Screw conveyors. Specification for portable and mobile type. (augers).
-3:1982, Screw conveyors. Method for calculating drive powers.

B.S. 4550, Methods of testing cement
Part 3:1970, Section 3,2:1978, Density test, Section 3.3.1978, Fineness test

B.S. 5551:Part 3, Section 3.5:1986, Fertilizers. Physical properties. Method of determining particle size by test sieving.

B.S. 5600, Powder metallurgical materials and products. Method if testing and analysis of hard metals
2:1981, General information. Glossary of terms.
Part 4, Section 4.17:1981, Compression test

B.S. 5663:1979, Method of testing ores - Determination of moisture content

B.S. 5667:1979, Specification for continuous mechanical handling equipment – Safety requirements.
- 1, Loose bulk materials.
- 2, Pneumatic handling equipment.
- 3, Storage equipment fed by pneumatic handling equipment.

- 4, Mobile suction pipes suspended by derrick jibs using pneumatic hoses.
- 5, Couplings and loose components used in pneumatic handling.
- 6, Rotary feeders.
- 7, Rotary drum feeders and rotary valves.
- 8, Hand operated power shovels.
- 9, Bulk throwers.
-10, Vertical screw conveyors

B.S. 5752:10:1986, method of test for coffee and coffee products. Instant coffee size analysis.

B.S. 5958-1:1991 Code of practice for the control of undesirable static electricity. General considerations

B.S. 6043: Method of sampling and test for carbonaceous materials used in aluminium manufacture.

2.9:2000, Determination of particle size distribution

2.12:1994, Determination of particle size distribution. Fine coke.

2.31:1996, Determination of tapped bulk density of green and calcined coke.

3.3:2000, Determination of bulk density (apparent density) of cathode blocks and pre-baked anodes.

3.4:2000, Determination of the open porosity and bulk density (apparent density) of cathode blocks and pre-baked anodes.

B.S. 6049-8:1998, method of testing for tea. Classification of grade by particle size analysis.

B.S. 6147:1979, Method of test for bulk density of iron ores

Part 1:1982, Determination of the bulk density of iron ore samples having a maximum particle size of 40mm or smaller.

Part 2:1981 Determination of the bulk density of iron ore samples having a maximum particle size greater than 40mm

B.S. 6318:1982, Classification of bucket elevators.

B.S. 6379:1984, Sampling of coffee and coffee products. Method of sampling of instant coffee in cases with liners.

B.S. 6989:1989, Guide to safety of storage equipment for loose bulk materials.

B.S. ISO 130.9276., Representation of results from a particle size analysis.

Part 1, Graphical presentation.

Part 2, Calculation of average particle size/diameter and moments from particle size distribution.

Part 4, Characterisation of a classification process.

ISO 3435-1077 (E) Continuous mechanical handling equipment – Classification and symbolization of bulk materials

B.S. ISO 11323:1996, Iron ores. Vocabulary.

B.S. ISO 13317, Determination of particle size distribution by gravitational liquid sedimentation methods.

Part 1, General principals and guidelines.

Part 2, Fixed pipette method.

Part 3, X ray gravitational technique.

B.S. ISO 13320:19999, Particle size analysis, Laser diffraction method. General principals.

B.S. ISO 14887-2000 Sample preparation. Dispersing procedures for powders in liquids.

B.S. EN, 481:1993, Workplace atmospheres. Size fraction definitions for measurement of airborne particles.

BS EN 617:2002, Continuous handling equipment and systems- Safety and EMC requirements for the equipment for the storage of bulk materials in silos, bunkers, bins and hoppers

BS EN 618:2002, Continuous handling equipment and systems- Safety and EMC requirements for mechanical handling of bulk materials except fixed belt conveyors

BS EN 620:2002, Continuous handling equipment and systems- Safety and EMC requirements for fixed
belt conveyors for bulk material
B.S. EN 725:1986, Advanced technical ceramics. Method of test for ceramic powders.
Determination of particle size distribution.
BS EN 741:2000, Continuous handling equipment and systems- Safety and EMC requirements for
systems and their components for pneumatic handling of bulk material
B.S. EN 933:, Test for the geometrical properties of aggregates. Determination of particle size distribution.
Part 1:1997, Sieving method.
Part 2:1996, Test sieves. Normal size of apertures.
Part 3:2001, Assessment of fines. Grading of fillers.(air jet sieving).
B.S. EN 1015-1:1999, Method of test for mortar for masonry. Determination of particle size distribution.
(by sieve analysis).
BS EN 1093 Safety of machinery. Evaluating the emission of airborne hazardous substances.

Selection of test methods.
B.S. EN 24497:1993, Metallic powders. Determination of particle size by dry sieving.
99/123348 DC B.S. ISO 13318-1, Determination of particle size by centrifugal liquid sedimentation
methods. Part 1, General principals and guidelines. (ISO/DIS 13318.1).
99/402492 DC. Determination of particle size distribution. Single particle light interaction method.
Part 1. Light interaction considerations .B.S. ISO 13323-1).
00/120697 DC ISO/DIS 13318-2 Determination of particle size by centrifugal liquid sedimentation
methods. Part 2. photocentrifugal method).
00/122547 DC BS/ISO 13338-3 Determination of particle size by centrifugal liquid sedimentation
methods. Part 3. Centrifugal X ray method.
00/562027 DC ISO 17090-3 Polymer based absorbent materials. Measuement of characteristics.
Part 3, determination of particle size distribution by sieve fractionation
01/120730 DC BS ISO 13323-2 Determination of particle size distribution. Single particle light interaction
method Part 2. Light scattering single particle interaction device design, performance,
specification and operation requirements
01/120731 DC BS ISO 13323-2 Determination of particle size distribution. Single particle light interaction
method Part 3.Single particle light-extinguishing device design, performance,
specification and operation requirements
01/124616 DC BS ISO 2926, Aluminium oxide primarily used for the manufacture of aluminium..
Particle size analysis (45 micro m to 150 micro m) Test method using electroformed sieves
Federation Europeenne de la manutention, (FEM), - Section II, List of bulk products

Silos – Draft design code for silos, bins, bunkers and hoppers.
B.S. ISO 10725:2000, Acceptance sampling plans and processes for inspecting bulk materials.
B.S. ISO 11648:2000, Statistical aspects of sampling from bulk materials.
Part 2., Sampling of particulate materials. ISO/DIS.11648-21
92/70320 DC, Specification for continuous handling equipment and systems. Equipment for handling both unit loads and bulk materials. Special safety requirements for design, manufacture, erection and commissioning.
92/70322:2000, Specification for continuous handling equipment and systems. Equipment for handling bulk materials only, (including mobile machines). Special safety requirements for design, manufacture, erection and commissioning.
Directive 99/45/EC Weighting of risk phases
Directive 67/548/EEC Criteria and data interpretation that are used for classification
ANSI(Z2400.1-1993) Structure of format for Material Safety Data Sheets (MSDS) prepared by: -
The American National Standards Institute, (accepted in USA, Mexico and Canada.).

Appendix IV - Andrew W. Jenike

No publication listing terms relating to bulk solids would be complete without reference to Jenike, who publication 1964, Bull.123 of the Utah University Experimental Station, is the most widely quoted references in any publication or Conference relating to Bulk Technology. This document laid the foundation for understanding the flow and behaviour of loose solids and introduced a theory, measuring technique and design formula for modern hopper design.

Before the work no significant strides had been made in this field since Janssen's one and only paper on silo pressures in 1895. By contrast, Andrew Jenike and his research student Jerry Johanson went on from this pioneering work to develop these and other concepts and introduce practical applications through a host of industries that handle particulate materials. The contribution to industrial efficiency by major and many minor users of bulk materials is immense.

This tribute to his skill and insight is extended to the dedication with which he pursued the ideas. Having selected the subject from a personal analysis that reviewed the outstanding industrial problems of the day he dedicated his career to understanding and providing a solution to solids flow problems. From first hand experience at US steel, he realised that the empirical methods in use for the design of bulk storage hoppers and silos did not address the fundamental nature of the material being handled. His timely attention to the technology, and ability to read Russian for the interpretation of a crucial technical paper, fell into place with the fortunate choice of a talented student, Johanson, to aid the mathematical and practical workshop demands.

From completing the ground breaking thesis, Andrew and Jerry went on to found the consulting organisation, Jenike and Johanson Inc. that continues today. Jerry brought a number of innovative developments to the market and continuous to apply his experience to industrial problems and developments. Their work spawned centres of specialisation in many countries through the world. In Germany it furthered the thorough, but less prominent, work of Hans Rumf and his co-workers. UK formed schools of particle and powder technology under Brian Scarlett and John Williams, whilst bulk handling in Australia was advanced under the methodical analyst Alan Roberts and his co-worker, Peter Arnold. A trail of enthused devotes to the subject has made an international change in industrial performance well out of proportion to their numbers.

The challenges are far from complete. The sheer scale of application may be contemplated by the fact the almost half the products used and consumed by society is, or has been at some time, in particulate form and that there are invariable multiple occasions that these products and stored and handled from source to use. Broad education in the subject, at least in a basic form, is a monumental task to bring awareness of the both the benefits of good design and the hazards, both financial and personal, of operational failure because of apparently simple and inexpensive capital items. The technology itself embraces many disciplines and demands refinement in many areas, such as evaluation and quantification techniques. Greater tests lie ahead. The glowing opportunities beckoning from nano-technology has to be soberly countered with the realisation that these particles not only have to be made, but then handled in a reliable manner. The ingenuity of man is far from exhausted, but will continue to be well tested.

Lyn Bates

List of Terms