The DIRK PFA Classification Products
The Design of DIRK POZZOCRETE

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Introduction

Over the years there has been a growing demand for finer, more accurately sized and Quality Assured particulate-materials to meet the material specifications of industry. To some extent this has been due to a better understanding of the function that the complete size distribution of a material, and not just some aspect of it, contributes to the performance of a powder when applied to a particular process.

Generally speaking, most powders are the result of a comminution process. The design of the comminution process is usually dictated by characteristics such as the hardness or abrasive nature of the feed material. The driver is therefore the physical nature of the material rather than considerations of the process to which the comminuted material will be applied. There is a range of machines available for the comminution process, each having its own particular characteristics depending upon whether it relies on breakage by compression, impact or attrition or any combination. Further, the ways in which materials break down can vary greatly; hence it is unlikely that the optimum size distribution requirements of a particular process will be achieved directly. Often status substantial modification of the size distribution of a powder is necessary, and it is here that classification plays a key role.

In the case of Pulverised Fuel Ash, the general case described above is even more complex. At best, PFA is a by-product- and at worst -a waste. The ash-produced PFA by- product- quality varies widely dependant on fuel source and quality variations
on plant design combustion and dust collection processes plant engineering plant operational practice

International Standards for Cement Replacement Materials dictate that chemical, physical and particle size characteristics are controlled. Dirk Pozzocrete specifications establish more stringent requirements and limits.

Principles

The classification of dry powders using conventional sieving techniques becomes progressively more difficult as the size separation point is reduced, particularly if materials are of low specific gravity or contain a high percentage of ultra-fine material below 10 microns. Such materials have a tendency to agglomerate or build-up on the screen cloth causing blinding of the sieve and the result is a loss in separation efficiency. This is often the case when attempting to screen large quantities of material to below 130 microns and it is in these applications that the air classifier comes into its own.

Air classifiers work on the principle that wherever relative motion exists between a particle and a surrounding fluid, the fluid will exert a drag force on the particle. If the individual particle was falling under the influence of gravity in still air, it would accelerate until it reached a constant velocity which is known as the **Terminal Settling Velocity**. This occurs when the drag force exerted by the air balances the gravitational force exerted on the particle. Should the air be rising with this velocity then smaller particles of lower terminal settling velocity would be entrained and carried upwards.

Such velocities can be determined by Stokes law and others, which are well documented. Since the settling velocities of particles in the low micron range are themselves very small, only very low air velocities and volumes in a given space are necessary for entrainment. Further, since the difference in terminal settling velocity between particles in the sub sieve range becomes so small, then a simple gravitational system becomes impractical. To overcome these limitations it is necessary to increase the gravitational force. In this way the air velocity necessary for the entrainment of a given particle is increased, the difference between particles magnified and high efficiency classification becomes possible in a relatively small space.

In practice this is achieved by causing the carrying air and particles to follow a curved path which spirals inwards to a concentric discharge point. In this way forces of several hundred gravities may be generated and consequently high capacity and precise separation achieved in relatively small machines.

For an air classifier to be effective three factors need careful consideration.

- Firstly there must be a clearly defined and stable classification zone where particles can come under the influence of the separating forces and be free from external influences.
- Secondly the particles must be presented into the classification zone at a constant rate and in a specific manner and should remain in the zone just long enough for the desired classification to occur.
- Finally the feed to the classification zone must be suitably dispersed such that the size of the largest agglomerate is below the operating cut size.

Failure to achieve these requirements will inevitably lead to a reduction in separating efficiency. Either the quality of the fines fraction will suffer by showing a long “tail " at the top of the size distribution instead of a sharp cut off, or material which should be classified as fines will find its way into the coarse fraction.

Performance

Detailed consideration of the above factors has resulted in the development of machines which are now capable of operating at cut points ranging from approximately 150 microns down to as little as 1 micron, the finest cuts resulting in products where the largest particle is of the order of only 3 or 4 microns. Unfortunately materials of such extreme fineness are generally limited to laboratory or small scale production machines. As the classifier size increases problems emerge in generating the necessary separating forces due to mechanical limitations. However, work in this direction is progressing and high capacity machines are being developed to meet the requirements for fine powders. It is now feasible to design in terms of materials of top size approximately 5 microns being produced from feed rates in excess of 1 tonne/ hour.

Due to the variety of factors which have a significant effect on the classification process, it is virtually impossible to predict the performance of a particular machine on a material without carrying out a pilot scale test. The performance that can be achieved on one material may be completely out of the question when considering another due to the characteristics such as its cohesive properties, particle shape, specific gravity, purity of material, oil or fat content and particle size distribution.

For example, the cohesive nature of a material can have a deleterious effect on classification efficiency particularly in the low micron range. Often materials become almost impossible to disperse to the extent that the performance of a classifier on materials as titanium dioxide and zinc oxide can be very poor, particularly below 10 microns.

Extremes of particle shape can result in considerable deviation from the basic theory. A fine mica classified at machine settings capable of producing a limestone 100% passing 10 microns would still show a residue when measured on a 32 or 40 micron sieve.

For a given classifier, all other factors being equal, as the specific gravity of materials increases, the separation or cut size simply moves down the scale. However we are often faced with materials which are far from pure. They usually consist of a contaminant of different specific gravity to the main body and sometimes of different particle shape. Here the classifier is of particular use, and in cases where selective milling of the contaminated materials has been carried out, a considerable up-grading of the products has been achieved.

Finally the size distribution of feedstock, particularly if it is “narrow" can give rise to separation difficulties and inefficiencies. For certain materials a considerable fraction may occur in a narrow size range around the cut point. Therefore, in order to eliminate a residue on say a sieve, one would have to aim at an artificially low cut point with the result that useful fine product will pass to the coarse fraction.

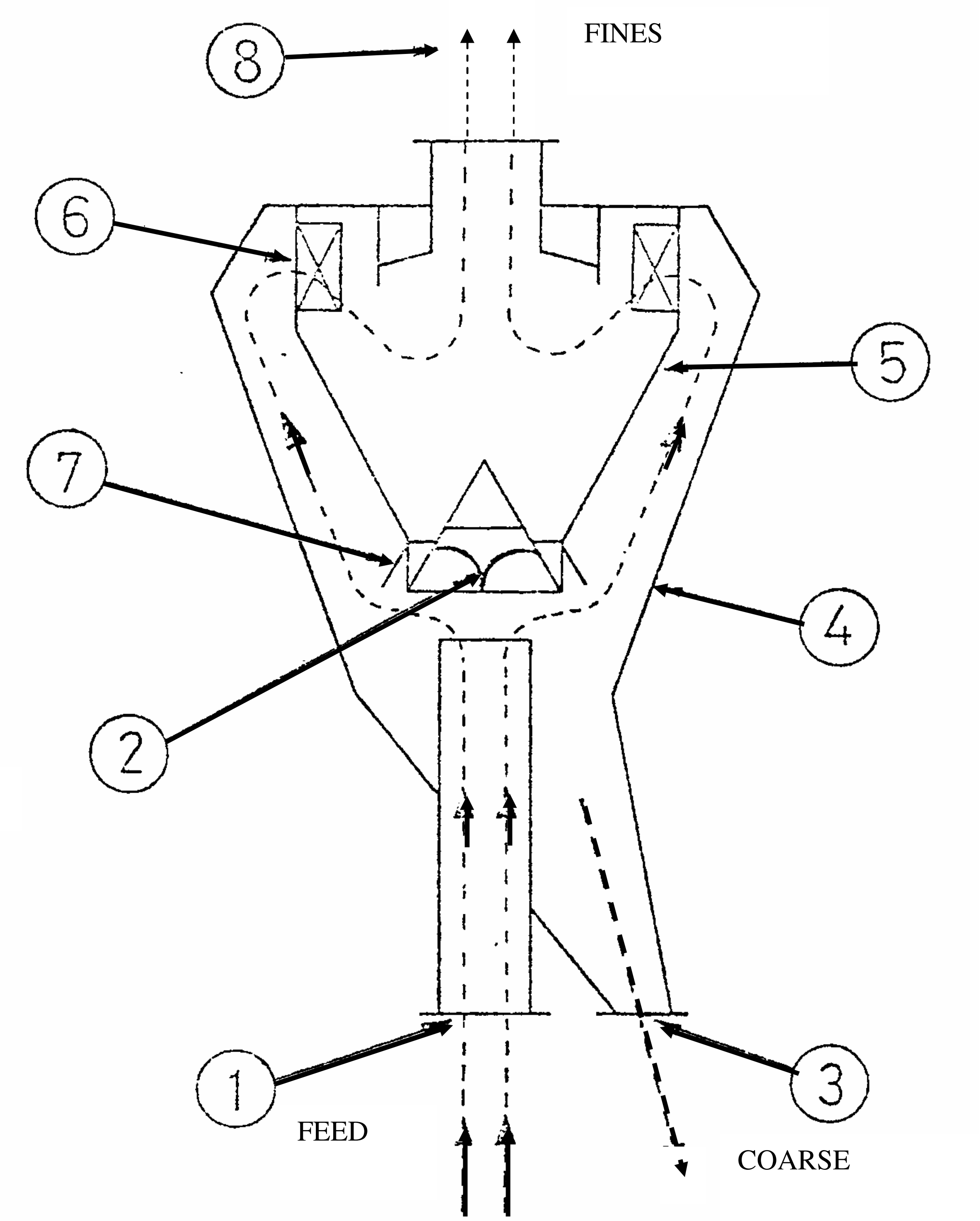
Air Separation Equipment

There is a variety of machines on the market today to cover the air classification range from about 150 microns down to 1 micron. Some of these machines are very limited in their operating size range and in the materials that they can handle, whilst a few can virtually cover the full range and can be adapted to suit most materials.
The machines available generally fall into three categories;

- the static types that depend solely on the passage of an air stream and casing design to generate the necessary separating forces;
- mechanical aided types again relying on the passage of an air stream but employing a mechanical rotating element to generate the separating forces

- and finally the unit machines which are completely self-contained generating their own internal air system and separating forces and having provision for collection of the separated fines and coarse material.

Figure 1- Double cone classifier



An example of the static type is shown in **Fig. 1**. This unit is often referred to as the double cone classifier. Here the feed and carrying air are introduced at the bottom of the machine and pass up the central vertical feed pipe (1). Coarse classification takes place as the material and air sweep around the baffle (2) at the top of the feed pipe and into the outer cone (4). The oversize material drops out of suspension and collects at the base of the cone (3) to be discharged under gravity through some form of airlock.

The roughly sized material continues upwards between the inner and outer cones with the air stream and passes into the inner cone (5) via the adjustable vanes (6). Because of the angle of these vanes a spin is imparted to the air stream and this induces the forces necessary for classification. Fine particles together with the air are drawn towards the central discharge (8), whilst the coarse particles descend down the inner cone pass through flaps (7), across the incoming air stream and descend to the base of the outer cone.

These machines are capable of classifying materials generally within the range 50% to 99% passing 200 mesh B.S.S. and require- a separate air fan and fines/product collection systems.

Figure2 High efficiency-mechanically aided air-borne fed classifier .

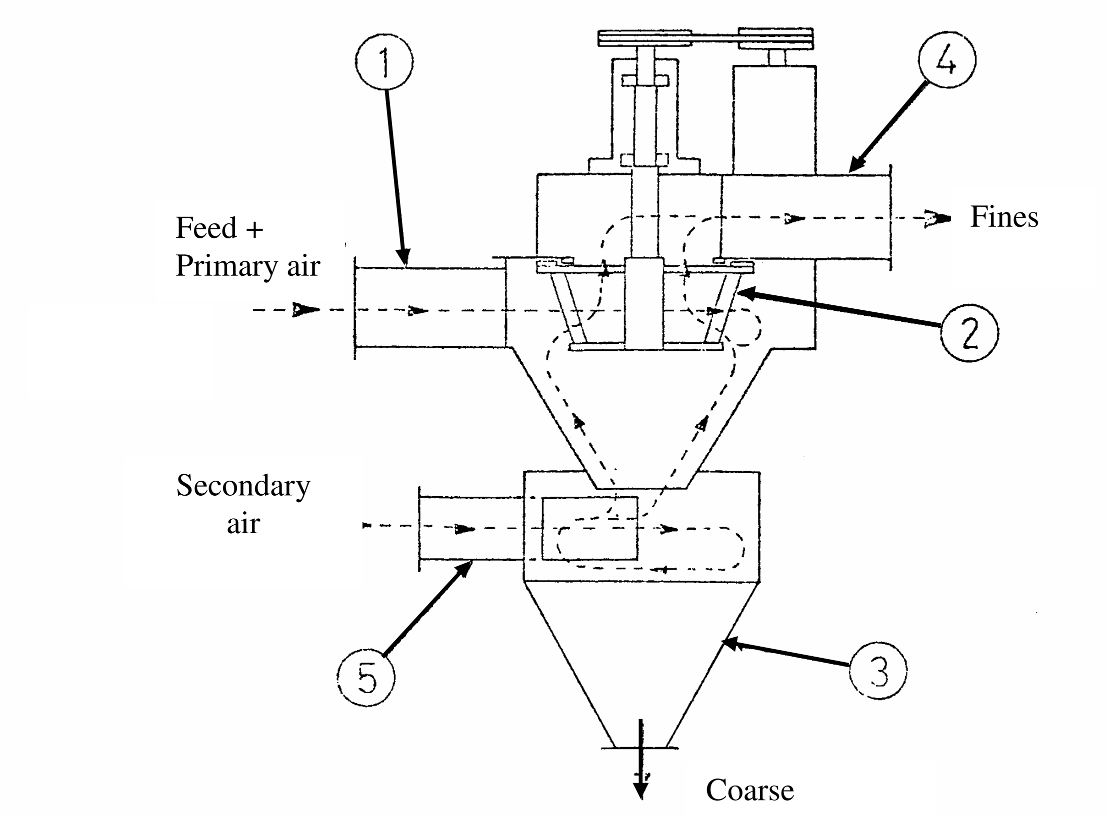
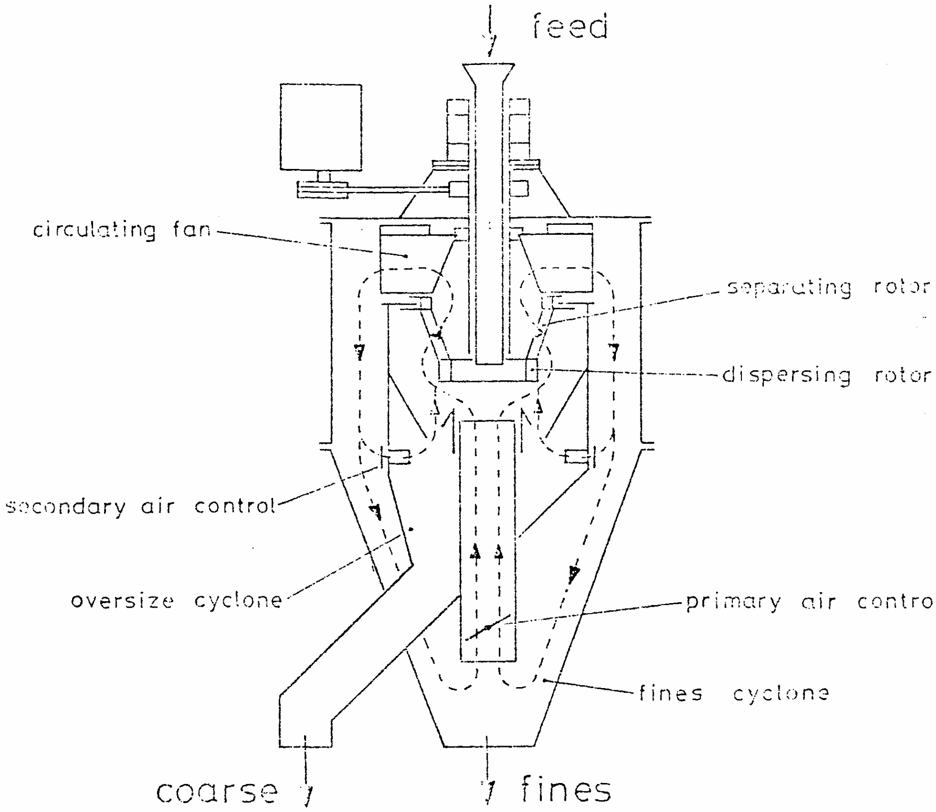


Fig. 2 shows an example of a high efficiency mechanically aided, airborne feed machine. In this design the feed material and carrying air enter the classifier tangentially to the rotor through a horizontal duct (1).

Due to the design of the casing and the rotation of the multi-vaned rotor (2) a spiralling air system is generated and it is here that classification of the particulate material into two size fractions occurs. As the particles approach the rotor they are subjected to a centrifugal force which may be of several hundred gravities depending upon the speed of rotation of the rotor. This force overcomes or is overcome by the centripetal frictional drag force exerted on the particle by the air as it spirals inwards through the rotor vanes. At the cut point these two opposing forces are in equilibrium

and for particles above the cut size the centrifugal force predominates and they fly away from the rotor to impinge on the casing and descend to be collected in the oversize cyclone (3). The particles below the cut size are carried inwards through the rotor finally leaving the machine through duct (4) together with the entraining air. As explained previously, the efficiency of separation of any classifier depends largely on the ability to completely disperse individual particles into the separating zone and with most materials this becomes increasingly difficult as the cut size becomes smaller. Fine particles tend to adhere to one another and as a result are classified in a similar manner to the coarse particles. The volute casing is particularly effective in this respect and to overcome the tendency further a secondary air system has been built into the machine. It consists of an additional induced and controlled air system entering the classifier tangentially through duct (5) and rising to the separating rotor. In this way it is possible to control the residence time of particles in the separating zone and also to sift the reject material as it descends to the coarse cyclone liberating any agglomerated fine particles and returning them to the separating rotor.

As with the static types, these classifiers require an external product collection system for the fines fraction and suitable suction fan however, with this machine it is possible to classify within the range 85% less than 200 mesh down to 99% less than 5 microns with high efficiency and capacity.



An example of the last group, the unit machines, is shown in **Fig. 3.** These machines work on a similar principle to the mechanically-aided classifiers described above except that the feed material enters the machine down a central tube and through a rotating dispersing cage. The air is circulated within the machine by a fan which is close coupled to the separating rotor, and the fines passing through the rotor and the fan are collected in the outer casing as in a cyclone.

A secondary air system is incorporated in this machine, however its ultimate performance is limited by its ability to collect the fines fraction once separated. Its range is however, very wide for a unit machine operating from about 90% less than 200 mesh down to 99% passing 10 microns.

Applications

There are many reasons why materials need to be classified and various ways in which the specification of the powder product may be defined . The criterion may be simply the size of the largest particle. This would be of particular importance should the powder be involved in decorative finish or surface coating. Here an unacceptably large particle would cause a surface blemish and destroy the appearance of the finish Similarly, a large particle or “nib” would be unacceptable in a powder used for grinding, polishing or cleaning due to the possibility of causing damage to applied surfaces by scratching.

At the other end of the scale we have the removal of a fine fraction from a product. This is sometimes necessary in order to reduce the surface area of the material to modify its chemical re-activity or to reduce the wetable surface in cases where the material is to be combined with a liquid.

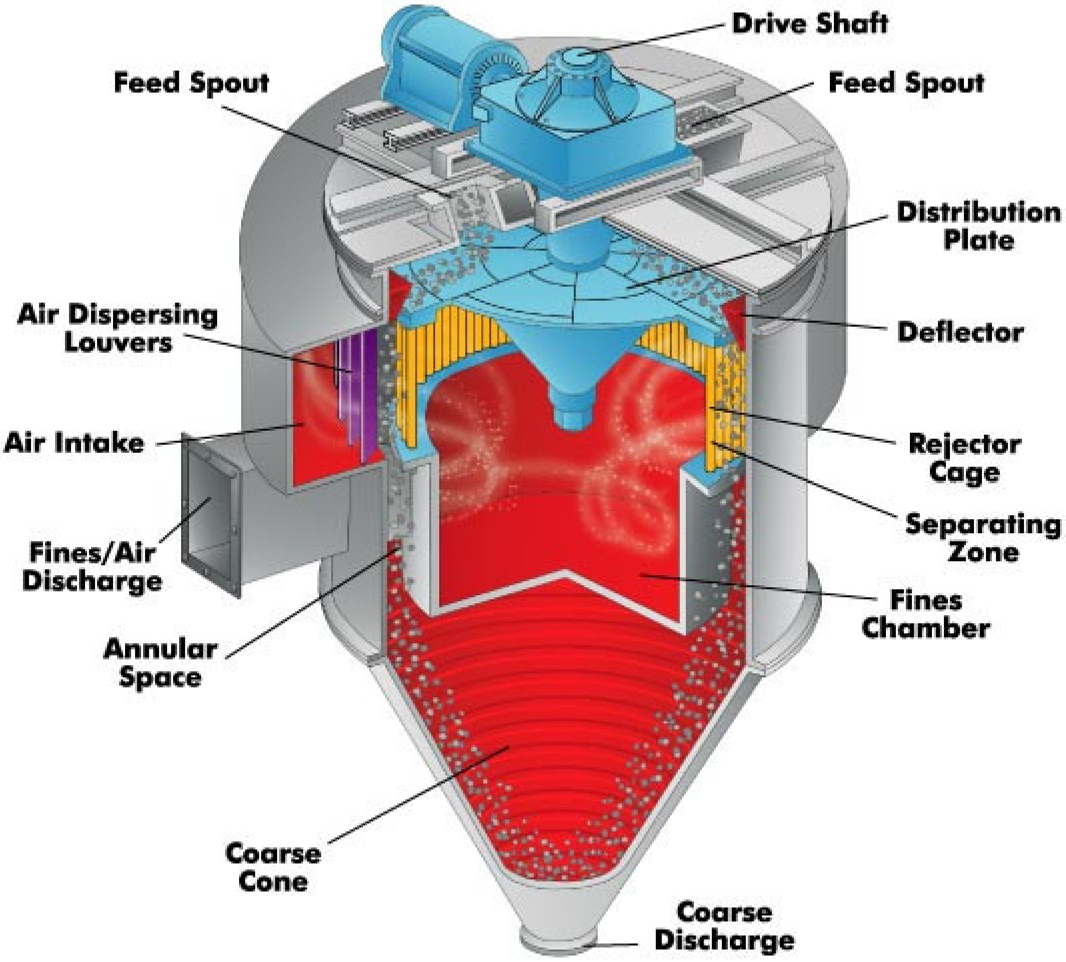
Generally, depending upon the specific application, there are requirements from classification for specific surface, mean particle size, bulk density and improvement of chemical quality. All these requirements dictate specific modifications to the raw material particle size distribution resulting from the production process.

Selection

Due to the wide variation in material characteristics, classifier selection is generally based on test work. For this to be effective it is essential that the exact product requirements including any tolerances on specification, are clearly stated.

Sample evaluation presents its own problems due to the fact that there is no universally accepted method of particle size determination, and even where similar sizing equipment is used, results can vary due to the method of operation.

Figure 4 High Efficiency Side Draft Classifier.



In producing Pozzocrete products we are faced with an extremely demanding performance specification for the classifier. Experience has led to Side Draft Air Separator. These units operate in the range 10 to 150microns, depending on material, and are capable of handling up to 1000 tonnes per hour. This design is suitable considering the following features,

a) It uses a multipin rejecter cage instead of Whizzer blades. This congifuration results in better control of maximum particle sizes and more efficient particle classification.

b) It uses a combination of an air inlet volute that distribur=tes airflow horizontally 360^0 around the rejecter cage and baffles that distribute the airflow vertically in front of the rejecter cage. This design minimises turbulence and improves the classifying efficiency of the rejecter cage.

c) The airflow is generated by a fan that is independent of the main drive and a variable frequency motor controller is used to change the speed of the rejecter cage. This feature allows the user to quickly adjust external settings according to the fineness.

To summarise: the modern air classifier has a significant role to play in the production of industrial powders. Correctly designed, selected, specified and operated, it leads to substantial economies in production and dramatic improvements both in product performance and quality control.

Fly-Ash Chemistry

The codes, particularly ASTM, have a very heavy emphasis on the chemistry of fly-ash. For example " Class F fly-ash must have more than 70% total of silica, alumina, and iron oxide, and Class C has more than 50% of these oxides" etc. This can lead to confusion since there is really no direct relation between the chemistry of fly-ash and its properties in concrete. Most of the properties of fly-ash in concrete are determined by the fly-ash mineralogy and particle size, and not by chemistry.

Fly-Ash Mineralogy

Most important is the fly-ash mineralogy, and in this respect fly-ash is 60-90% glass. It originates from impurities in coal, mostly clays, shales, limestone, and dolomite. They are incombustible and hence emerge as ash, and at high temperatures they fuse and become glass. Because of the dynamics and furnace temperatures of certain pulverised coal combustion systems, the molten glass turns into glass beads, or tiny spheres of glass.

For fly-ash in the U.S., there are two ASTM Classes, Class F and Class C, which are based on total amounts of silica, alumina, and iron oxide present. This doesn't have much significance. In Europe and the much of the rest of the world there is a recognition that if differentiation based on the chemistry is necessary, then fly-ash should be categorised on its calcium content. This principle reflects the fact that the calcium content of fly-ash has a significant influence on the characteristics of glass. Practically, if a material is mostly glass, we should be concerned primarily about what kind of glass it is. In general, in certain codes, there is too much emphasis on the material which is not glass.

Low calcium fly-ash also contains non-reactive crystalline minerals, If we assume 80% glass, then the 20% remaining would be non-reactive mineral such as quartz, mullite, (an aluminium silicate), hematite and magnetite, (iron oxides), and a less reactive alumino silicate glass. There are two glass types. With high calcium fly-ash then the alumino silicate glass contains calcium and that glass is more reactive This is why Class C fly-ash gives higher early strength compared to Class F, because Class C tends to have much more calcium oxide. High calcium fly-ashes also contain reactive crystalline minerals such as free-lime, tri-calcium aluminate, tetra-calcium alumino-sulphate, and calcium sulphate, depending on the sulphur content of the ash. All of these are reactive crystalline minerals and the glass is also much more reactive.

Fly-Ash Particle Size

There are two parameters determining reactivity of fly-ash, one is the mineralogy and the second is the particle characteristics. Particles are mostly glassy, solid and spherical. There is also some unburned carbon present, depending on the efficiency of burning. This carbon is in the form of relatively large micro-porous particles, they are large but are not round or spherical because they are not fused.

The particles of raw fly-ash range in size mostly from 1 to 100 microns. Particles under 10 microns, regardless of the type of fly-ash, are the ones that contribute to the 7 and 28 day strengths. Under 10 microns is a key parameter. Particles about 45 microns and larger may be considered as inert. They do not participate in pozzolanic reactions, even after one year, in concrete they largely behave like sand.

Therefore with fly-ash, the Blaine surface area is an indicator of secondary importance only. The most significant physical performance characteristic is the particle size distribution. Particles below 10 microns are those which are beneficial for early strength. Particles between 10 and 45 microns are those which react slowly (between 28 days and one year or so). A significant measure of fly-ash reactivity is the percentage of the particles which are below 10 microns.

Addressing the question of the significance of any unburned carbon particles - unburned carbon influences mostly the water demand and the air entraining agent required.

Calcium apart, fly-ash chemistry has little influence on reactivity, silica, alumina, iron oxide, etc. have little influence on desired properties. The superior reactivity of high calcium fly-ashes is related to the composition of glass and the presence of reactive crystalline phases.

There is misunderstanding in the field regarding the way that fly-ash improves workability. There is often a simplistic assumption that these “glass beads” act like ball bearings. To some extent this may be true, but the most important reason why fly-ash works as a plasticizer for concrete is that the cement particles are charged; due to broken bonds they tend to flocculate. When normal plasticizers (say lignosulphates), are used to disperse these cement particles, they tend to absorb on the surface and act as a repellent so that the cement particles do not attract each other. In the same way, reactive fly-ash particles are absorbed on the surface of cement grains and act as very powerful dispersants to the cement particles.

Many codes are outdated, reflecting concerns for low early strength, lack of durability, and other problems; the concerns reflect the use of earlier generations of unsuitable fly-ashes that were very coarse and had very high carbon content.

Dirk Pozzocrete material specifications reflect much of the forgoing, establishing product parameters to optimise the behaviour of the selected pfa fractions in concrete.

Dirk processing plant designs and production management systems translate these parameters into commercially sound products.

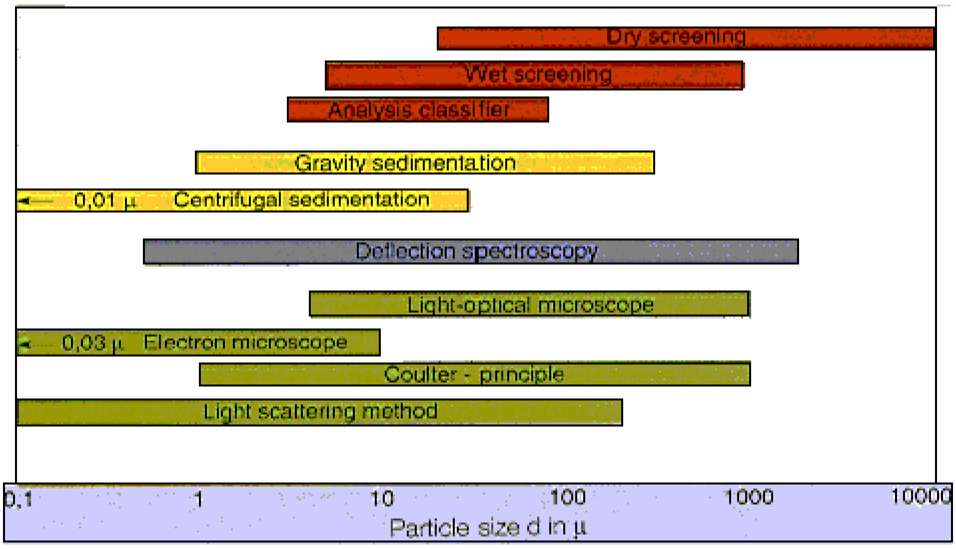
Technical Information: Particle Size Analysis

Particle size analysis

Many technical discussions regarding the processing methods used to produce fine powders start off by defining how a certain fineness requirement is to be understood or how the powder fineness is to be tested A great variety of processes and equipment is available for these purposes, some of which have been state-of-the-art for many years. And it is especially in the area of equipment for testing ultrafine particles smaller than 5 microns that measuring technology has made great progress.
A universal device which is suitable for every material does not yet exist. Each piece of equipment covers only a part of the problem complex regarding material usability, measuring and analysis, accuracy, reproducibility, and handling, etc.

Considerations on equipment selection and application:

☐ Which fineness range is of major interest ?
☐ How important is the analysis duration ?
☐ Which material(s) have to be analysed ?
☐ What degree of absolute accuracy does the device offer ?
☐ What degree of reproducibility is necessary ?



Summary of Processes used for Particle Size Analysis

Colour code

red = Separation process
yellow = Sedimentation
blue = Laser diffraction
green = Counting process

Particle size analysis

Simplified approach to processes and equipment from a user's viewpoint

All measuring methods used for particle size analysis function reliably if the powder to be analysed is present in the form of individual spherical particles. For particles which are not spherical, as is usually the case in technical processes, an equivalent particle diameter is determined. The equivalent diameter is the diameter of spherical particles which, for example, have the same settling rate, or which generate the same diffraction spectrum or the same interference of an electrical or electromagnetic field.

In the case of particles which have a totally different shape, e.g. platelets or needles, the determined equivalent diameter can vary strongly from measuring method to measuring method (e.g. laser diffraction, sedimentation).

Technical Information: Air Classification

Air classification is a method of separating powdery, granular, or fibrous materials according to the particle settling velocity combined particle size, density and particle shape.

Ideally, the separation effect of an air classifier should be such that at all particles which exceed "the separation or cut point" are transported into the coarse fraction, and the smaller particles are transported to the fines fraction.

However, such accuracy is virtually impossible to achieve. Regardless of the type of classifier used, a certain amount of fines is always going to be present in the coarse fraction and vice versa. This overlap constitutes a judgement critieria when it comes to assessing the separating quality or capacity of air classifiers. The following are some of the characteristic values used when evaluating the separation effect of air classifiers.

A word about the separation effect of air classifiers

Symbols

x = Particle size
f = Fines fractures
c = Coarse fraction
c + f = 1

Density distribution
$q_F(x)$ = Feed material
$q_f(x)$ = Fines
$q_c(x)$ = Coarse

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Cumulative distribution
$Q_F(x)$ = Feed material
$Q_f(x)$ = Fines
$Q_c(x)$ = Coarse
T(x) = Degree of separation as per Tromp

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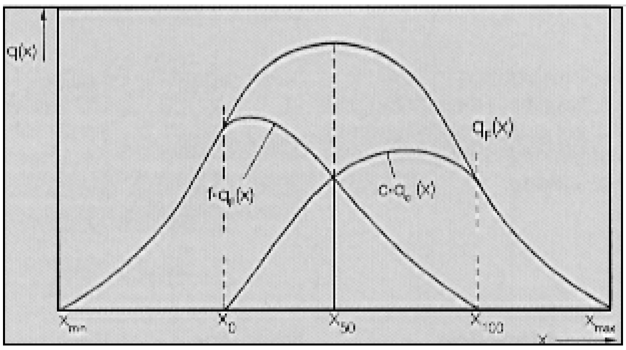
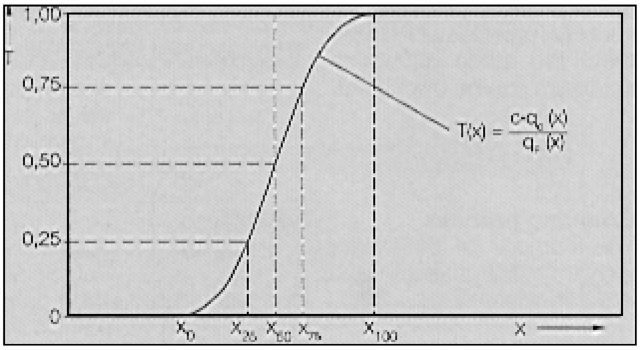
Plotting a separation

Both the cumulative and density distributions of feed material, fines, and coarse are used to plot a separation.



Density distribution curves (Fig. 1)

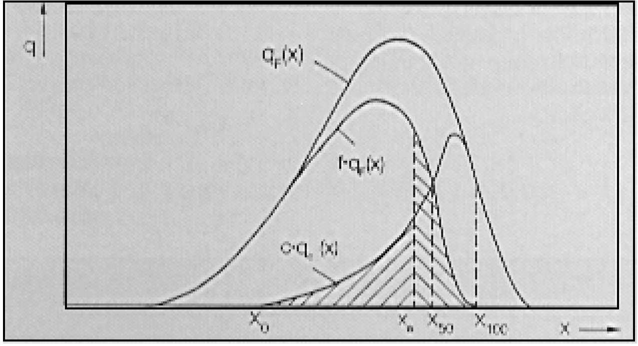
More often than not, the performance and capacity of an air classifier is judged by the grade efficiency curve T(x) with the resultant cut point size x_{50} and the precision of cut (**K**).



The gradient of the separation curve characterizes the precision of cut of a classifycation

Separation curve T(x) as per Tromp(Fig. 2)

Definitions of the cut point



☐ Preparatory or median cut Point x_{50} (Fig. 3)

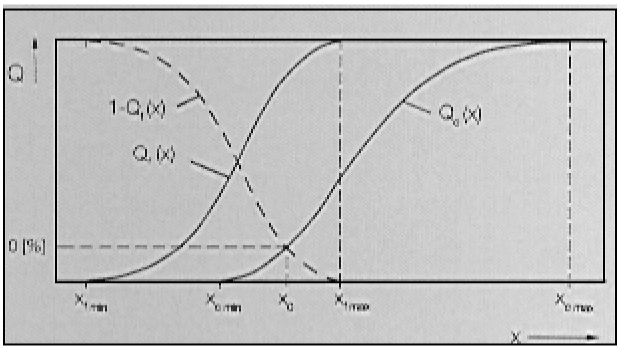
The median value x_{50} of the separation curve is defined as the cut point. This is the particle size at which half of the constituent amount passes into the coarse fraction and the other half the fines.

☐ Analytical cut point x_a

The analytical cut point x_a is the particle size at which the misplaced particle throughputs, i.e., those particles larger or smaller than the cut point are identical (Fig. 3 shaded areas).

☐ Reference cut point, e.g. x_{90}, x_{97}, x_{99}, etc.

A good classifier will be able to keep the fine material particle size distribution almost constant in spite of increasing feed amounts.The other side of the coin is that more fine particles pass into the coarse fraction, which causes the median cut point and the analytical cut point to shift into the fines range. Because of this, the so-called reference cut point, e.g. x_{90}, x_{97}, $x_{99.9}$ etc. was introduced into practical operation to aid in evaluating the fine fractions. The reference cut point is the particle size at which the cumulative fines portion amounts to 90%, 97% and 99.9% etc.



Overlap cut point x_o (Fig.4)

The quality of the classification is judged by the percentage of misplaced particles (Overlap O). If the constituent of fines is not known, then the overlap cut point xo is frequently determined. This is done by laying the cumulative oversize curve of the fines 1-Q_f(x) over the cumulative undersize curve of the coarse Q_c(x); the point of intersection xo is the overlap O in %.