

1 Introduction

Particle technology may be described as being the study of materials dispersed within a continuous fluid. The particles may be solid, but they can also be oil droplets in water, water droplets in air, etc. So, by a particle we mean any dispersed material within a fluid. In many cases deformable particles have a slightly different behaviour to rigid ones, but the starting point for the description of deformable particles is that of the rigid, and simpler, case. Hence, particle technology includes the understanding of raindrops, oil emulsions, powders, slurries, etc., and just about every industrial process uses the subject at some stage. For example, in petrol production the catalytic cracking of petroleum is achieved in fluidised beds of catalyst particles (Chapter 7). An understanding of fluidisation relies upon knowledge of particle characterisation and fluid flow through porous media (Chapters 2 and 3). The petroleum processing is performed in the vapour phase, not the liquid, hence the fluidised beds require appropriate gas cleaning equipment for recycling and retention of the catalyst particles (Chapter 14). The catalyst is stored and conveyed into the system (Chapters 10 and 9) and, of course, due care must be exercised over powder hazards (Chapter 15). So, even in the case of an obviously liquid product, petroleum spirit, we encounter a significant proportion of material covered in this book.

An even greater reliance on particle technology is provided by the increasing trend towards high value batch processing in the chemical and pharmaceutical industries. A prime example is the production of a tablet. In many cases a reactant is provided in a solid form and product recovery involves nucleation and then crystallization of the product. These two processes are not covered here, but the interested reader is directed towards other works [J.W. Mullen, 1997, *Crystallization*, Butterworth-Heinemann, 3rd edition; R.J. Davey and J. Garside, 2001, *From molecules to crystallizers*, Oxford Chemistry Primers, No. 86]. Most of the remaining aspects of product recovery are covered in this work. The crystals may be settled, to increase the slurry concentration going on to a filter, or filtering centrifuge; the resulting cake will need washing free of reaction products and unreacted feed material and mechanically dried, to minimise the amount of thermal energy required to complete the drying. After thermal drying (not covered here), there is likely to be a need for product storage, crushing and classification, solid/solid mixing, conveying and agglomeration for the purpose of forming the tablet. Any one of these processes may be the cause of a process bottleneck, or throughput limitation, and the intention of this book is to provide a sound understanding of the underlying principles behind these operations to enable reliable operation and appropriate decisions to be drawn.

The Reynolds number

Is a measure of the amount of turbulence within a system. It is numerically the ratio of the inertial to viscous forces. Flow Reynolds number for a fluid through a circular pipe is:

$$\text{Re} = \frac{d u \rho}{\mu}$$

see the Nomenclature for definitions. Values above 2000 are usually taken to indicate very significant turbulence.

1.1 Prerequisites and objectives

In common with most engineering subjects particle technology requires a basic competence in calculus and algebraic manipulation. A first course in fluid mechanics would also be helpful, as it will be assumed that the reader is familiar with concepts such as Reynolds number (see box), Bernoulli's equation, Hagen-Poiseuille, Newton's law ($F=ma$), friction factor and flow regimes. Knowledge of very basic statistics would be useful for a complete understanding of solid/solid mixing, but the essential elements are included in Chapter 12. Likewise, the concepts of mean, median and mode are used when discussing particle size distributions.

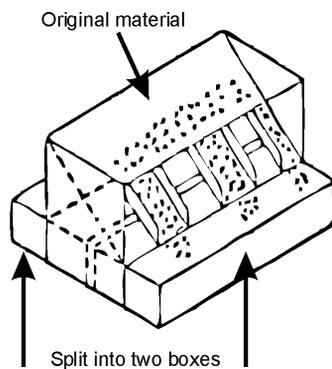
The primary objective of this work is to provide a sound basis on which the more interested reader can build. Particle technology is a very broad subject and there have been many very good books describing specialised aspects of the subject published over the last twenty years.

All sizes in microns	
fine sand:	20 to 200
hair diameter:	100
clouds/fog:	30
red blood cells:	8
silt:	2 to 20
clays:	<2
tobacco smoke:	<1
bacteria:	0.2 to 40
viruses	<0.5



Grab or scoop sample

Fig. 1.1 A grab sample



Chute riffler - divides sample in two

Fig. 1.2 A chute riffler

1.2 The micron

Most industrial processing is performed on small particles with a diameter typically in the range of 10^{-6} to 10^{-3} m; i.e. 1 to 1000 microns or μm . The box provides some sizes, i.e. particle diameters, of commonly encountered materials. You will become very familiar with working in a length scale of microns in particle technology. However, there are often times when the centimetre, gram, second (cgs) system of units may be easier to apply.

1.3 Sampling

Processing is usually performed on small particles contained in bags, drums, 1 tonne Intermediate Bulk Containers (IBC) or trucks. Analysis for particle size, and other characteristics, usually requires only a few grams. The most convenient method of obtaining a sample of a few grams is to take a *grab sample* from the bulk, often scooping the few grams off the top of the pile, or sack, see Figure 1.1. However, *segregation* during particle motion is very common; examples include the tendency for larger particles to rise to the top in breakfast cereals such as muesli – and finer particles to fall between the gaps to the bottom of the packet. Hence, a simple grab sample is rarely adequate for a reliable analysis. The absence of a truly *representative sample* invalidates any further work on the particles, be it laboratory tests for some process (i.e. unit operation) or for particle size analysis and characterisation.

When sampling from a suspension the viscous nature of the fluid may assist in representative sampling; e.g. particles settle slower so that stirring is often effective in suspending the particles for an adequate time to obtain a good sample. However, at low concentrations the hindering (Chapter 6) effect of other particles is not strong and vigorous stirring can lead to centrifugal separation

(Chapter 8). In air, or any gaseous medium, motion can help the segregation of particles by differences in size, density, moment of rotational inertia, coefficient of restitution, etc. Hence, sampling of free flowing particles should be performed according to accepted standards (BS 3406) and using well-known techniques such as: sample cutters, cone and quartering (25 kg solids and above), chute riffles (50 kg solids down to 25 g), see Figure 1.2, spinning riffler (1 kg down to 25 g), see Figure 1.3. Ultimately, a scoop, or grab, sample from the suitably reduced mass of powder will be required for use in an instrument if, as is usual, 25 g is still too much powder to be used. When sampling a dilute stream of powder entrained in a gas stream, *isokinetic* sampling is often recommended; i.e. equal fluid velocities in the bulk flow and within the sample probe. Isokinetic sampling is discussed in greater detail below.

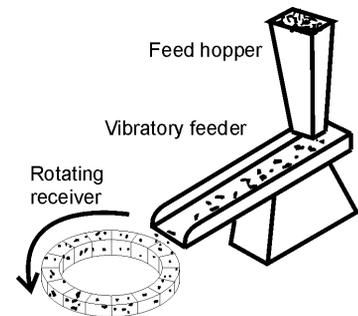


Fig. 1.3 Spinning riffler with vibratory feeder from hopper

A sample cutter is used to take a sample from a flowing stream of powder, such as on a conveyer belt. At a *transfer station*, from one belt to another, the powder will be dropped from the first belt on to the second, and the sample cutter will intermittently move into the falling powder to remove a sample. It is important that the cutter removes a sample across the entire width of the falling powder, or width of the belt, because segregation during transit may result in particles of a certain size preferentially positioned on the belt.

Cone and quartering is a technique used extensively within the minerals industries for coarse sized material up to several centimetres in diameter, to obtain a more tractable sample size, and is often applied before riffing. The entire contents of the container, or bag, to be sampled are discharged on to a clean flat surface, which could be a swept floor. The material is then made into a cone by shovelling material from the sides to the centre to form a cone. The cone is usually then flattened to minimise the likelihood of pushing material at the top in any one direction. It is common for the larger particles to roll to the periphery of the cone and the finer ones to stay near the centre. However, so long as the cone is made evenly there should be an equal distribution of larger particles all around the periphery of the cone, with no bias towards any position. Thus, quartering the heap by dividing it into four roughly equal portions should provide samples representative of the original material. It is usual to then take two quarters at opposite sides of the heap and remove them from the sample. The remaining two form the sample and the process can be repeated to reduce further the overall sample size. A similar technique can be applied to smaller amounts of finer particles, subject to adequate safety – health and environment considerations, coned and quartered on a bench, but the process is operator dependent and it is unlikely that a sample would be as representative as one provided by the other techniques described above.

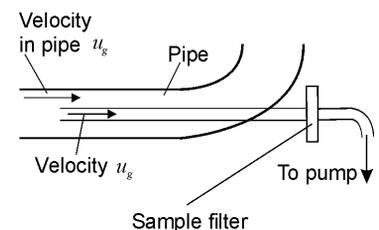


Fig. 1.4 Isokinetic sampling from a duct or pipe

When sampling airborne particles from flow within ducts it is important that the flow entering the sample filter is the same as that in the duct, or pipe, see Figure 1.4. This is to prevent particles

inertially separating at the entrance to the sample pipe, see Chapter 14 for details on inertial separation. If particles do inertially separate the concentration in the sample tube will not be the same as within the duct and any further analysis will be in error. Another important factor evident on the illustration of isokinetic sampling is the lack of sharp changes in direction between the sample entrance and the sample filter. If a sharp direction change occurs the particles may again separate from the gas flow by their inertia, leading to deposition within the tube and a lower than true concentration of dust found on the sample filter. It is easier to avoid sharp direction changes in a three dimensional structure than can be represented on a two dimensional illustration, such as Figure 1.4. Thus, it need not be necessary to position a sample tapping just up-stream of a bend. However, it is important that a sample stream should not be placed just downstream of a bend. Most dust sample systems have a pump and valve to control the flow entering the sample tube to ensure isokinetic conditions and it may be possible to use a timer; whereby the sampling is active for a fixed time, which corresponds to a fixed volume of gas at a given flow rate. The particles deposited on the sample filter may be weighed and they may be washed off the filter and counted. This provides a concentration of dust particles within the duct and a size distribution. However, it is important to adequately disperse the dust sample after it has been washed off the sample filter. This may require some practice with differing types of chemical dispersing agents. Alternatively, microscope counting of the test filter may be adequate, in the dry state, if the concentration of particles is very low.

In some instances, two filters may be used in the sample holder: one directly after the other. Thus, provided no particles are present on the second filter and the masses of each filter were carefully recorded before use, it is possible to weigh both filters and to deduce the overall concentration of dust by the difference in mass between the filter which acted on the sampled dust and the second filter which should remain clean – after having corrected for any initial difference in mass of the two filters. By placing both filters in-line any difference in mass due to humidity, or similar, effects should be cancelled out.

Isokinetic sampling is important in gas streams, but not so relevant to liquid streams because of the greater viscosity of the fluid medium and the lower density difference between the particle and fluid. Hence, particles are not so likely to separate inertially in liquid systems. However, considerable care still needs to be exercised in deciding where to withdraw samples from liquid systems, to ensure that a representative sample is taken for analysis. Without a representative sample the results from even the most expensive particle characterisation techniques will not represent the particle dispersion properties adequately.