Milling technology selection for particle size reduction

The selection of the most appropriate milling technology for a particular application is not always straight forward and the most appropriate answer is not always the most obvious. Failure to identify feasible alternatives can be extremely costly over time. Identifying these alternatives often requires trials, not theory, and a potential purchaser of either equipment or processing services needs to ensure that their chosen supplier can advise and conduct trials across the appropriate range of alternative techniques.

Introduction

The controlled reduction of the particle size of solid materials is a process required in many industry sectors, and is applied to an astonishingly wide range of materials from inhalable active pharmaceutical powders through food ingredients and fine chemicals to large-scale mineral processing applications.

Not surprisingly, there are different technologies available on the market to meet these challenges, exhibiting different combinations of capability and cost (both capital investment and running costs). Some tasks can be carried out using more than one technique, the choice becoming a trade-off between the required performance (usually expressed as an output particle size distribution and throughput) and cost. Some materials require different techniques depending on the input particle size and/or shape, and the inexperienced can be surprised to find that the same material chemistry-wise may mill much less efficiently (or not at all) on a particular mill type in one physical format (e.g. extruded product) when the same mill type was quite effective on a different product format.

Handling heat sensitive materials, such as polymers with a relatively low softening point (typically a function of its chemical composition, molecular weight and glass transition temperature), can also be problematic, but the cost implications of failing to recognise that the conventional cryogenic milling solution[1] may not actually be required for the particular task in question can be profound.

Assessing the task

As a supplier of a wide range of equipment and an experienced operator of all the equipment types in our own plant as a contract processor, in our experience there are three key pitfalls to be avoided:

1. **Don't take the specification for granted** – the first step with customers who arrive armed only with a numerical specification (e.g. "d50 < 12 microns"; or "100% < 50 microns")[2] is to explore the derivation of this specification. Not only are there different definitions of what, say, "d50" means, but different measurement systems can also yield very different results. This can lead to confusion and it is, for example, much better to match against a known sample if it exists than to rely on a numerical expression to define it.

2. **Don't over-specify the end product** – having established that a particular particle size distribution of a material has the required functionality in application, it can be worthwhile exploring its specification limits. Sometimes a relatively small relaxation of one parameter can have a substantial impact on the milling performance or efficiency and can, in extremis, enable the switch from one technology to another. Working with an unnecessarily stringent specification might suit the equipment or service provider as it will be more costly, but it is not in the best interests of the customer, and some careful work to define what the specification limitations truly are can pay dividends in the long run.

3. **Don't presume you know the answer – try it!** Be sceptical of a supplier who quickly and confidently tells you what the right solution is going to be.

Technology types

There are several different underlying technologies used for milling, and then a multitude of variations and hybrids. The common underlying technologies which, between them, address the majority of milling applications in one form or another are as follows:

Air micronisers
Air micronisers (or 'jet mills') are used to grind a wide range of materials, particularly where the feed material is already relatively fine. The technique relies on particle-on-particle impact to break down the material, having been introduced into what are very high speed air jet streams in the body of the mill. There are two types of jet mill: (i) a spiral flow jet mill which is commonly used in pharmaceutical applications due to the absence of any moving parts; and (ii) an opposed jet mill which can handle harder materials (up to 10 on the Mohs scale[3]) with classification achieved by means of a high speed rotor.

Rotary impact mills
Rotary impact mills, also known as beater mills, use high-speed rotors with a rotor tip velocity of up to 120 m/s. Grinding takes place through the impact of the powder particles on the rotating and fixed grinding surfaces. Typically used for softer materials of up to 3 Mohs hardness, an impact mill provides an operationally cost-effective solution when hardness and particle size parameters fall within its range.

Ball mills
Ball mills, and other forms of tumbling mills such as tube mills and rod mills, comprise a cylindrical shell slowly rotating around a horizontal axis, partially filled with a grinding medium (such as ceramic or steel balls) to which the material to be milled is introduced. Typical in the ores, minerals, paints and general chemicals industries, ball mills can be designed to operate continuously (fed at one end and discharged at the other), or on a batch basis.

Each of these mill types can then be combined with external classifier stages, with or without feedback, to create an overall process that is as efficient and cost-effective as possible.

Case study

In expanding its operations to the European market, a global manufacturer supplying resin powders for use in composites and membranes for the aerospace, electronics and other high-tech industries, approached British Rema to address its milling requirements.

These end applications demanded a highly-regulated quality control environment and the customer had previously used cryogenic grinding followed by a screening process to achieve the particle size distribution. Although ultimately achieving the required results, the use of liquid nitrogen required complex enclosed systems and the application of stringent health and safety procedures.

Rather than presume to replicate the existing methodology, British Rema recognised that, in this particular case, cryogenic milling may have been unnecessary, and British Rema's solution was to use its classifier mill, albeit especially adapted for the purpose.

Classifier mills are a type of rotary impact mill (referred to above) which have the benefit of being a single machine with an integrated impact mill and classifier in the one housing. The CLM mill is commonly used for multi-stage, closed loop grinding and is ideal for products with properties of a more challenging nature and/or requiring a tightly controlled particle size distribution *(see figure 1)*.

This process achieved the desired particle size but, importantly, processing costs were significantly reduced. In addition, the stringent health and safety precautions associated with the use of liquid nitrogen were no longer required.

Conclusion

The selection of the most appropriate milling technology for a particular application requires experience, trials and an open mind. A failure to identify feasible alternatives can be extremely costly over time. Unnecessary over-specification of the finished product can also lead to higher costs than necessary, and a close, collaborative working relationship between customer and supplier is needed to develop the optimum long run solution to any particle size reduction project.

Notes

(1) Cryogenic milling refers to a technique whereby the subject material is cooled, typically using liquid nitrogen, prior to milling. In the case of processing plastics and resins, for example, the purpose is to ensure that the material becomes (or remains) embrittled, notwithstanding the introduction of high levels of energy from the milling process. However, the initial capital investment and the running costs for this process are high.

(2) The designation "d50", "d95" etc refers to the proportion of material falling below the relevant value hence d95=20 microns means 95% of the product falls below a nominal 20 microns. The definition of the percentage varies but is typically expressed in terms of product volume (rather than, for example, number of particles).

(3) Mohs scale of hardness measures a material's resistance to scratching by comparison against a standard set of reference materials from talc (Mohs hardness 1) to diamond (Mohs hardness 10).

Figure 1 – British Rema Classifier Mill

The classifier mill works on a four stage process as shown in the diagram:

Stage 1
The material is introduced into the mill via the primary air feed where the material is mixed with air, thereby minimizing the risk of agglomeration.

Stage 2
The material enters the grinding chamber where grinding takes place in the same way as a conventional rotary impact mill. The secondary air inlet further aerates the product and provides the option to introduce chilled air if the material has a low melting point.

Stage 3
The milled material passes into the classifier wheel. Material of the desired size passes through whilst oversize particles are rejected and pass to the next stage.

Stage 4
The rejected oversize material passes to a separate section of the grinding wheel where it is ground separately from the in-feed material and then once again directed to the classifier wheel.