be subject to repeated stress. To some extent, the breakage probability can be maximised by appropriate control of the ratio of media to particles. A general guide is to maintain the volume of material being ground at about the void volume in the packed media bed.

Media size is an important variable in these mills; smaller media increase the frequency of media–media collisions, but reduce the energy associated with each impact. The result is that smaller media increase breakage rates for those particles that they are capable of breaking, but the limiting size that can be broken is reduced. As a rough guide, a media diameter to particle diameter of greater than about 20:1 seems appropriate. The decreased impact energy of smaller media can be offset by increased overall energy input by increasing impact velocity (mill rotation) or media density.

Stirred media mills increase energy input through agitation by an impeller. They are typically vertical or horizontal cylinders, filled to as much as 90% of the available volume with grinding media (steel balls, ceramic beads, etc.). During wet processing in stirred media mills, the feed material in the form of a suspension is pumped into a grinding chamber and comminuted between the moving media, the stirrer and the grinding chamber by compression and shear. Relative media motion can be maintained throughout the charge and, with high-speed operation, energy input per unit volume can be very high. This leads to high grinding capacity but can also introduce overheating problems. In many applications, it is necessary to use a combination of water jacketing and slurry recirculation for temperature control. Quite high pressures are sometimes required to achieve the necessary feed rates, and contamination due to media wear can be a serious problem. The effects of media size and density appear to follow a very similar pattern to that observed in tumbling mills. Grinding efficiency, particle size distribution and suspension rheology are inter-related. Alamprese *et al.* (2007) provide an example of optimisation of process parameters for the ball milling of chocolate. The relatively large contribution from shear in the agitated media may make these devices especially suited to tough, non-brittle materials like cocoa nibs.

9.3.3 Impact mills

Hammer mills, pin mills and similar devices generally rely on impact with parts of the machine itself to induce particle breakage. Often particles are forced to exit the machine through a grate or screen that serves both as a built-in classifier and as an impact site. Such designs probably include a significant contribution from shear in addition to simple impact thus permitting their use for tough, non-brittle solids. Screen wear can become a serious problem in such applications. The screen openings are limited to relatively large sizes, and small-particle impacts tend to be reduced by their being drawn away in the airstream passing through the mill. Therefore, mechanical impact mills are not generally appropriate for very fine grinding (micron) applications. However, impact devices like pin-disc mills are ideal for pre-grinding of non-brittle material like cocoa nib.

9.3.4 Fluid energy mills

Often referred to as jet mills, the fluid energy devices use a high velocity fluid (usually air or steam) to accelerate particles. Breakage occurs through impact between individual particles (autogenous grinding) or with the walls of the grinding chamber. The absence of grinding media and other moving parts helps reduce product contamination and machine maintenance. It is claimed that these mills produce a relatively narrow product size distribution. This may be due in part to very low breakage rates for the finest particles, but may also reflect a loss of fines in the solid–fluid separation step required for collection of the product. Energy efficiency of these mills is relatively low. A schematic illustration of a fluid energy mill is given in Figure 9.2.

9.3.5 Guidelines for equipment selection

Different types of mill typically involve combinations of mechanisms for particle placement and stress application. While each type has certain advantages and disadvantages for any specific application, there is rarely one particular device that is ideal. Many factors contribute to the choice of an appropriate mill for a particular application. Primary considerations are material characteristics, product specifications and required throughput. In turn, the selection process requires the choice of mill type and mill size. Other features such as reliability and ease of maintenance also vary to some extent from type to type, and may also depend on the specific manufacturer.

The extent of size reduction required, that is the ratio of the feed size to the product size, is also an important consideration for system design. Depending on the material, most mills are effective over a limited range of particle sizes; reduction ratios should rarely exceed 10–20, and 4–7 may be ideal. For this reason, grinding operations are usually accomplished in stages. Higher ratios require two or more mills, perhaps of the same type but different size, but often of different type. Size reduction in stages may help limit the excessive production of fines.

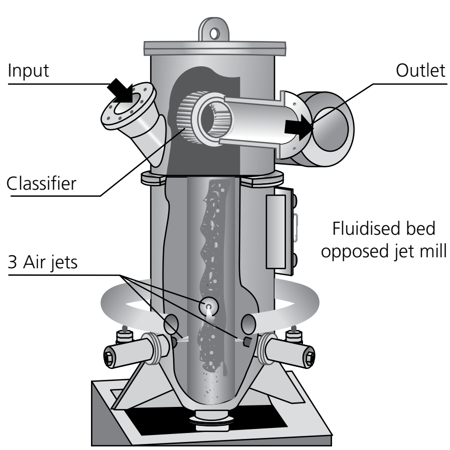

Figure 9.2 Cut-away diagram of a fluid energy mill as manufactured by Hosakawa Micron.