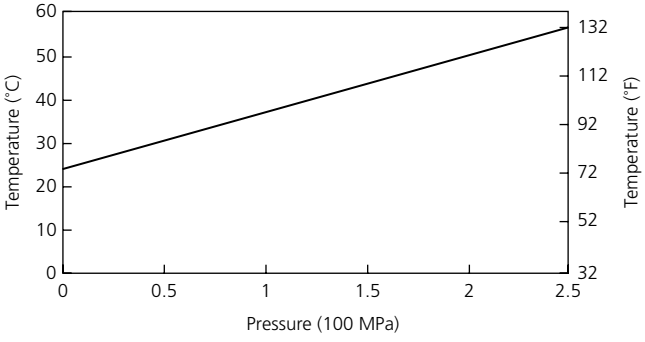

Figure 15.4 The effect of pressure on the melting point of cocoa butter (Yasuda *et al.*, 1992).

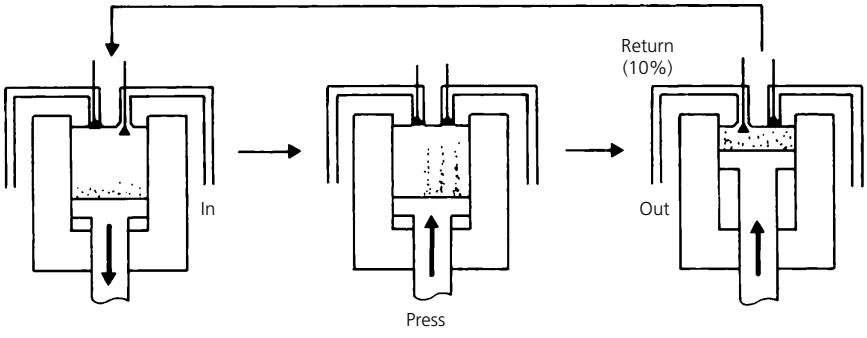

Figure 15.5 Diagram of prototype system for tempering chocolate using very high pressures (Yasuda *et al.*, 1992).

however, those unstable forms with lower melting points disappear leaving tempered chocolate. Experimentation showed that at least two pressure pulses are required with holding times of up to 5 min. This is obviously not suitable for industrial applications. Further trials indicated, however, that by returning 10% of the tempered chocolate to the feed system as seed crystals, a holding time was no longer required. A prototype continuous pressure temperer was therefore developed (Figure 15.5).

15.5 Extrusion

15.5.1 Types of extruders

Extruders are widely used in the food industry (Riaz *et al.*, 2007). They are excellent mixers, can give good heat transfer rates because of their high surface area to volume ratios and can handle high viscosity materials. The simplest form of extruder has a single screw conveying the material along a close-fitting, parallel or tapered barrel. Other machines have two interlocking screws which are either co-rotating or contra-rotating (Table 15.1 and Figure 15.6). These have the

Table 15.1 Comparative characteristics of co- and counter-rotating extruders.

Co-rotating extruders/screws	Counter-rotating extruders/screws
Mass transport by positive conveyance and drag	Positive conveyance acts like a "screw pump"
Longitudinally open flights leave open path from feed to discharge	Radially and longitudinally closed flights; screw flights form sealed chambers
	Limits mixing but quickly generates pressure
	Good transport of low viscosity material
Pressure generation depends upon the number and pitch of the reverse pitch elements and very much upon the die exit; the through "path" limits the upper pressure obtained	Pressure generation by the reduction of pitch length
Good mixer but less control over temperature and shear	Poorer mixer, but each small "pocket" of material can have a more precisely controlled temperature regime
	Within limits, temperature and shear can be controlled independently

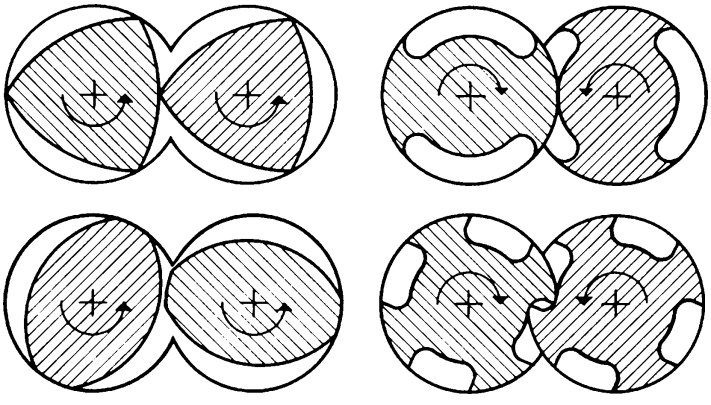

Figure 15.6 Examples of cross-sections of co-rotating and counter-rotating extruder elements.

advantage of being effectively self-cleaning. Still others have a "planetary" system in which a central screw drives a series of secondary screws running in grooves in the barrel.

The extruder screw profile will be configured to suit the processing conditions required. For example, the screw might provide sections of high shear to induce heating, sections with intense mixing shortly after the introduction of an ingredient or a low pressure section for removal of volatiles. Additional flexibility comes from the ability to add ingredients at almost any point along the barrel. Temperatures along the extruder barrel can also be controlled by having different cooling/heating regimes on each barrel section. Single and twin-screw extruders often have screws built from removable elements slotted