For conventional tempering machines, it has been reported that 2-4% of the fat solidifies during tempering according to the type of temperer and hence an increase in viscosity can be seen, because there is now significantly less liquid fat present. As a general rule for such tempering machines, the viscosity increases by a factor of about two from the incoming chocolate to that leaving the tempering unit, although this may be greater if cooling conditions are exceeded. 1.5–3Pas (Casson plastic viscosity) has been reported to be a typical increase (Windhab *et al.*, 1991).

New tempering processes, like seed tempering, produce very finely dispersed cocoa butter seed crystals contained in a cocoa butter melt. Such suspensions contain about 10–20% of solid fat and, if 0.2–1.0% of this is added to untempered chocolate (equivalent to 0.02–0.15% of solid crystals), it still guarantees a good temper and gives excellent product characteristics (Windhab and Zeng, 1998). Work on conventional chocolate tempering with improved analytical instrumentation, such as nuclear magnetic resonance spectroscopy (NMR) and differential scanning calorimetry (DSC), has also demonstrated that there can be less than 1% of fat in crystallised form after "good" tempering (Padar and Windhab, 2007).

Due to the fact that tempered chocolate is not in a thermodynamic equilibrium, another factor, time, has a crucial influence on the temper state or quality. Time and temperature are the key parameters and of paramount importance when designing tempering systems.

In chocolate tempering literature the need for maturation of fat crystals after tempering and before moulding or enrobing is frequently emphasised. This was related to the fact that the tempering time in many conventional tempering processes was insufficient, particularly for chocolate systems with formulation-related slow crystallisation kinetics, such as those containing a high level of butter fat. For such systems it was found that some residence time under temperature controlled conditions was required (e.g. in the connecting pipe between tempering machine and enrober) in order to keep a satisfactory temper during enrobing or moulding, particularly if slightly increased temperatures were applied. This so-called maturation of the fat crystals is essentially post-tempering, which is needed because of insufficient capacity or mixing power of the tempering device being used.

Incomplete, or bad tempering, results in unstable crystal growth (α or β_{IV} polymorphs instead of β_V) and, as a consequence, results in poor solidification, contraction and setting characteristics, as well as differences in colour and even whitish surface spots or a streaky grey-white finish known as "fat bloom" (see also Chapter 7). Chocolate prior to coating or moulding, therefore, must be tempered to contain sufficient stable fat crystal nuclei of the β_V type in order to generate more than about 90% of β_V in the resulting product. In optimum conventional tempering processes all the seed generated within the chocolate masse is in the β_V form after tempering.

Newer seeding techniques however use seed crystals consisting of 30-95% β_{VI} polymorphs in addition to the β_V, leading to optimum tempered chocolates and high quality finished products (Windhab and Zeng, 1997). Beside the total seed fat crystal fraction, the polymorph distribution of the seed crystals is of major importance, particularly for an optimised process with the fastest possible solidification-crystallisation kinetics obtained under the lowest possible cooling temperature conditions, whilst avoiding the formation of unstable polymorphic forms. In conventionally tempered chocolate systems the fat crystal size distribution cannot be properly analysed. Mean crystal diameters are occasionally found by microscopic techniques to be in the range between 10–30 microns, depending on the volumetric mechanical power or energy input in the tempering machine. For the seeding based tempering techniques using seed crystal suspensions, optical analysis of the mean fat crystal size can be easily carried out and provides seed crystal mean sizes in the range of about 2–5 microns. For a constant total crystal fraction, smaller crystals lead to an improved temper, accelerated crystallisation kinetics during cooling and eventually an increased structure density in the final product.

For conventionally well tempered chocolate systems the temper (= tempering degree) is related to crystal fraction and crystal size distribution of the β_V crystal polymorphs. As demonstrated in Figure 13.1 and Table 13.1, the melting temperature range of cocoa butter in the β_V form is about 29–31.5 °C (84–89 °F) Following conventional chocolate processing in the temperature range of 30–31 °C (86–88 °F) subsequent to tempering (e.g. coating/enrobing, depositing or moulding) the temper of the chocolate will be affected by a temperature fluctuations as small as ±0.5–1 °C (1–2 °F) occurring in the process. As a consequence conventional tempering has to produce a well developed temper (eventually even slightly over-tempered) equivalent to a crystal mass volume fraction of up to 1%, or even more, in order keep sufficient seeding crystals throughout the post tempering processing. The temperature to which a chocolate can be raised for a certain time, without losing the good degree of temper correlates with the amount of crystal seed present in a particular chocolate.

From this it can be shown that if β_{VI} polymorphs with a melting temperature range of 34–37.5 °C (93–100 °F) can be produced in the tempered masse, they are not significantly affected by subsequent processing, so long as the temperature does not exceed about 33.5 °C (92 °F) that is 2.5–3 °C (5–6 °F) above the typical processing temperature (Windhab and Zeng; 1998 and Bolliger *et al.*,1998).

13.4 Measurement of temper and its related characteristics

How do we know if chocolate is correctly tempered and ready to be used? There are four basic analytical methods which indicate the degree of temper: (i) temper curve measurements using a calorimetric tempermeter, ii) heat flux curve or