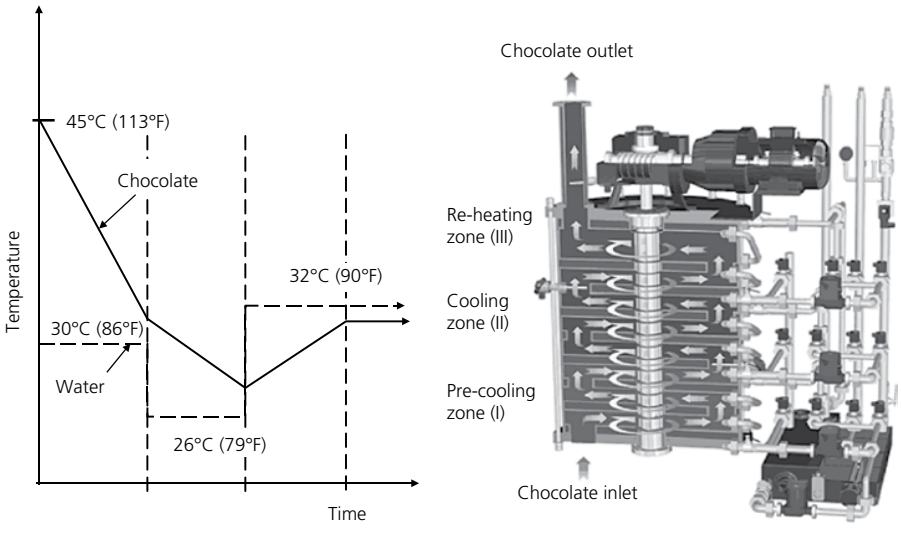

Figure 13.8 Characteristic temperature versus time plot during conventional tempering treatment and schematic drawing of a continuous stir-/shear-tempering device.

solid. The amount depends upon the source of the cocoa butter and this means that the nucleation potential may differ between different chocolate masses.

The major goal of tempering is to gently cool the warm chocolate through a multi-stage tempering machine, gradually reducing the temperature to "strike seed" and initiate the first stages of nucleation and crystal growth.

Primary nucleation is performed at cooled walls (or shearing elements) in the cooling section of the tempering machine from which fat crystals are scraped off and mixed into the chocolate suspension, where secondary nucleation takes place. This is mostly due to fat crystals/fat crystal agglomerates being broken down between the solid particles (sugar, cocoa and milk powder particles) in the fat-based suspension. The cooling wall temperature determines the type of fat crystal formed at the wall. At temperatures below 22 °C (72 °F) in the cooling section, these are mainly unstable α, whereas between 22 and 27 °C (72 and 81 °F) unstable β_{III}/β_{IV} polymorph nuclei are formed as well as a small fraction of the stable β_V polymorph. During mixing into the chocolate masse the unstable polymorphs get gradually transformed into the β_V type due to the applied shear stresses and the temperature increase in the subsequent reheating section. The reheating happens gradually via the heat exchange at the wall of the tempering device and in addition by the latent heat released from the fat that is crystallising.

In some systems there is a subsequent holding (retention) stage within or after the tempering machine with associated temperature and mixing control. This is a crystal "maturation" step, in which the fat crystal nuclei polymorph and size distributions develop further by crystal growth and ongoing polymorph transition from unstable forms to the stable β_V form towards an equilibrium,

which is almost never reached – often the temper is very far from optimum. Some "maturation" may also occur, but generally in an uncontrolled manner, within subsequent moulding, enrobing or coating process steps. In the case of a new type of seed crystallisation process (see Section 13.6.3 and Chapter 15) such maturation produces between 30 and 95% of β_V to β_{VI} within a pure cocoa butter fraction or within a mixed fat fraction containing a minimum of about 10% of cocoa butter. This crystal suspension is subsequently used for seeding the bulk of the chocolate. When added and homogeneously mixed into the non-tempered chocolate a well controlled "matured" degree of temper is achieved.

13.5.3 Impact of shear

Since the 1980s, many authors have demonstrated that higher shear in tempering equipment is a "prime" consideration for producing high nucleation rates, with more stable crystals at higher temperatures than normal (Ziegleder, 1985; Windhab, 1986; Windhab *et al.*, 1991; Zeng and Windhab, 1999; Windhab and Zeng, 2000). From empirical tempering experience, it was found that there is a difference between what is described as optimised tempering in a low residence time temperer (4–6 min) and a fully matured stabilised tempered chocolate (12 min to 2 h) and that claims that a fully matured chocolate, milk or plain, can be obtained from a low residence time (<6 min) temperer merely by shear rate and water temperature are simply incorrect.

Now we are able to interpret or revise such statements based on improved insight into the crystallisation mechanisms and the process–structure relationships taking place during tempering: The tempering degree of a chocolate masse depends on the *structure parameters*: (i) crystal fraction, (ii) crystal size distribution and (iii) crystal polymorph distribution. In addition (iv), the viscosity of the pre-crystallised suspension system has to be taken into account, because it is desirable to reach an optimum tempering degree with the lowest possible increase in viscosity. The following relationships can be used in order to get the lowest viscosity increase compared with the non-tempered state: The lower the solids crystal fraction, the smaller size of the crystals is required and/or the more the crystal polymorph distribution has to be shifted to the stable β_V. The *process parameters* providing adjustment to get such an optimum include a lower residence time and lower wall cooling temperature for higher and more homogeneous shear. Figure 13.9 demonstrates qualitative "optimum spaces" for the structure $[S(\psi,\xi_{50},\varphi_V)]_{OPT}$ and the process $[P(\gamma,t,\upsilon_K)]_{OPT}$ parameters to be quantitatively correlated for each specific fat/fat-mixture system. Figure 13.10 illustrates the relationships between the fat crystal structure characteristics, related physical characteristics of a chocolate system, resulting processing characteristics and the final product quality properties.

A good temper, as measured by conventional tempermeters (e.g. Sollich-, Tricor-, Systech-Analytics tempermeters) can be generated by a crystal nuclei fraction of less than 0.5–1.0% of the total cocoa butter fat with more than about