that many manufacturers of tempering machines give maximum shear rates, which may act only in a small volume, thus being not representative. Some tempering machines also contain undesirable features such as:

1 Intermittent and variable shearing/mixing flow;
2 Some chocolate can bypass the shear going directly from the inlet to outlet of the machine.

This type of feature means that different parts of the chocolate is treated to different amounts of shear for different times, so that it is impossible for the bulk of the masse to be homogenous at the microscopical scale.

The relatively high fluid viscosities of chocolate masses lead to low Reynolds (Re) numbers (denoting the ratio of inertia to viscous forces). Consequently flow in tempering devices is generally laminar. The fat crystal primary nucleation starts at the cooled walls, where there is the strongest cooling. Crystal growth normally takes place along the temperature gradient direction, thus forming dendritic (needle-like) crystals, which are scraped off or detached by flow shear stresses and mixed into the chocolate masse. In a tempering machine the action of shearing/mixing scrapes these needle-like crystals from the walls and breaks them up to form more seed. The higher the acting shear, the more efficient the process becomes. As this secondary nucleation action is continuous, this results in the formation of many more crystals and increases the crystal growth rate provided that the heat exchange and cooling temperatures are able to remove both the mechanical heat input and that generated by fat crystallising.

Following the first phase of striking seed, which generally consists of a semi-stable form (mostly α-type), a transition occurs when semi-stable crystals re-crystallise into a more stable mature form (mostly an α–β_V transformation). During this transition, further latent heat is generated. This transition is an important indicator for degree and efficiency of the tempering process. From the kinetics of latent heat generation the confectionery engineer can derive information for process optimisation (see Section 13.4.1). The shear rate or mixing action in a tempering machine is a function of the type of machine and the speed/design of the mixing elements. If the tempering machine is of the screw type, then the shear rate range along the mixing elements is narrowly distributed, with the first in first out principle being nearly fully effective as the chocolate passes down the screw and back-mixing is negligible.

If however the tempering machine is of the stacked plate design, then the shear rate distributions are intermittent and vary from the centre to the peripheral parts of the machine. If the machine has a rotary Archimedes disc (see Figure 13.16 in Section 13.6.2) mixing element, then there is continuous increase of the shear rates applied to the chocolate masse from the centre to the periphery during progression through the machine. The “contact” time at the higher shear rate at the periphery is only a few seconds during the tempering cycle.

A kettle-type tempering device can be considered to be a stirred vessel reactor in which complete re-mixing can be achieved, depending on the number and type of scraping/stirring elements and the throughput rate. This principle requires in general a long residence time to reach a homogeneously tempered state of the chocolate and this is seldom applied in practice.

13.5.4 Importance of residence time distribution

For conventional tempering it has been shown to be important to ensure the chocolate contains only the highest-melting crystal polymorphs. For typical tempering times the most stable cocoa butter polymorphs are the β_V, although some fraction of β_{VI} is possible for the longest tempering times. It was shown by Nelson (1999) that the mean residence times in conventional tempering required to ensure good product quality characteristics from moulding and enrobing processes are:

1 10–12 min for moulding plants;
2 20–360 min for enrobing.

The reasons for these differences between moulding plant and enrober plant requirements were described as follows: The *moulding plant* generally needs less fluidity and can make up for a higher viscosity by more intensive shaking and cooling systems. *Enrobers* should have the highest practical coating temperature that can be obtained from the tempering machine and from the enrober tank (to give the minimum viscosity; see Chapter 14). This requires a high maturity of the fat crystals, that is a long residence time. Defects easily show up in enrobed pieces and are less visible in a "moulding plant" where the product takes its shape and some gloss from the mould.

If a "matured" (e.g. long enough tempered) chocolate masse is produced by conventional tempering, then it is possible to raise the temperature in further processing without losing any crystals. As the temperature rises the viscosity falls, making it easier to coat the centre of a product. This means that, for any fat content, the thinnest chocolate is obtained at the highest temperature, which in turn requires a long tempering period. These temperature differences can be as much as going from 31–32 °C (88–90 °F) to 34-35 °C (93–95 °F) for dark chocolate with full maturation. In this case a substantial content of the β_{VI} polymorph has to be assumed. Specific operating conditions and product advantages have been reported for products coated with the "fully matured" seed tempered chocolate coating (Windhab and Zeng, 2002). From experience for optimum conventionally tempered chocolates with low viscosity the following aspects have been reported (Nelson, 1999):

1 Good decorative markings, especially on chocolates of high milk fat content that require extra time during tempering.
2 When bloom-resistant additives such as sorbitan tristearate and polysorbate 60 are used in a coating, time is essential to introduce stable nuclei in sufficient quantities to ensure a high coating temperature.