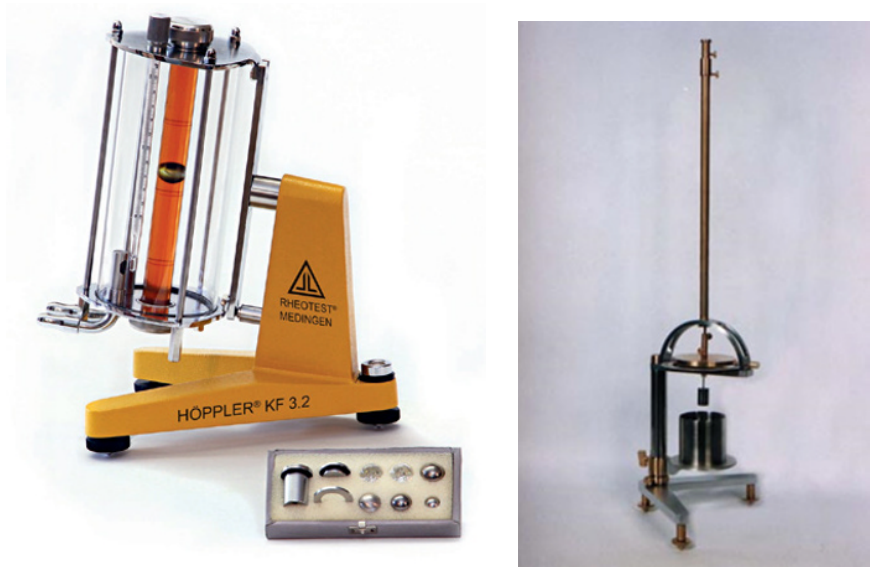


(a) (b)

**Figure 11.9** (a) Falling ball viscometer (google image labelled for re-use). (b) Gallenkamp viscometer (www.ejpayne.com).

release the pointer swings back beyond its original zero position. The amount of the over-swing relates to the viscosity of the chocolate, being small for thick chocolates and very much larger for thinner ones. Care must be taken to ensure that the instrument is operated in a vertical position.

### 11.4.2 MacMichael viscometer

This device is somewhat similar to the Gallenkamp torsion viscometer. In 1949 it was adopted by the United States chocolate industry as the standard instrument for measuring the viscosity of chocolate for bulk commercial use. The specifications for its use for chocolate requires a 26 gauge wire and a bob with a 2 cm (0.8 in) diameter cylinder that is immersed into the sample to a depth of 3 cm (1.2 in) in a 7 cm (2.8 in) diameter cup. The cup with chocolate is turned at a rate of 15 rpm. The product temperature must be adjusted separately – usually to 38 °C (100.5 °F). The viscosity of the chocolate causes the wire to twist, which is measured via a circular scale on the spindle that holds the wire.

The scale is 0 to 300 (not 360) and the amount of twist is referred to as °M (degrees MacMichael). It can be converted to an apparent viscosity of centipoise (equivalent to mPa.s), but it rarely is. The design of the MacMichael makes the 26 gauge wire highly vulnerable to bending, which then renders the measurement unreliable. Furthermore, the torsion constants of the 26 gauge wires vary over a range of 20%. The geometry of the bob and cup and the low rotational speed means that the shear rate of the MacMichael is low and is thus highly influenced by the yield value.

During the 1980s the United States industry replaced the instrument with the rotational Brookfield viscometer. It can duplicate the MacMichael measurement, avoiding many of its short-comings and in addition can measure the Casson yield value and plastic viscosity.

## 11.5 Rotational viscometers

In order to plot a flow curve it is necessary to measure the rate a chocolate moves under a predetermined stress, or to move it at a given rate and measure the force required to do so. Both types of instrument exist, and these are referred to as stress- or rate-controlled rheometers respectively. A rheometer is a more sophisticated device which can perform simple rotational tests as well as oscillatory measurements (see Section 11.7). Devices located in quality control and new product development laboratories are often simpler viscometers.

Three principle types of measurement geometries exist for rotational viscometers: cup and bob, cone and plate and parallel plate, see Figure 11.10. There are advantages and disadvantages to all three types of geometry and the reader is referred to rheology textbooks (e.g. Mezger, 2006; Goodwin and Hughes, 2008).

The most important factor when analysing the viscous behaviour of chocolate is the size of the suspended particles. Chocolate is usually manufactured with a maximum particle size of around 30 μm (Chapter 9), although the particles may aggregate to form larger pieces. For rheological analysis it is desirable that the gap size of the measuring head should be at least 10 times larger than the maximum particle size in the sample to avoid measurement artefacts. An exception is the cone-and-plate geometry where the tip of the cone is truncated by around 50–100 μm, depending on manufacturer giving the size of gap "a" indicated in Figure 11.10b. A gap size for the parallel plate geometry may be chosen large enough compared to the maximum particle size; however, the shear rate in the centre of the geometry is zero while it is maximal at the outer edge of the plate, which may be a source of particle migration within the gap. Settling of particles can also be of concern as it may create a layered sample structure, effectively decreasing the gap size and, in an extreme case, only the liquid phase will contribute to the instrument signal. The measurement is then meaningless as it is calculated assuming uniformity across the pre-set gap height. Settling of particles can be important although it is less of an issue in the cup and bob geometry, also referred to as concentric cylinder geometry.

The temperature of the chocolate sample must be kept constant and uniform. Control tends to be more reliable for the cup and bob geometry compared to parallel plates, where the upper plate is usually exposed to the laboratory environment. Although some modern rheometers feature temperature-controlled covers for the upper plate, this is rarely the case for equipment found in quality control laboratories.