when designing pumping and piping systems. When specifying pump requirements to a supplier, it is always necessary to quote the expected viscosity and temperature variations, together with the flow rate and pressure limitations for sensitive ingredients or vulnerable equipment such as tempering machines.

Viscosity is the measure of the internal friction of a chocolate. This friction becomes apparent when a layer of chocolate is made to move in relation to another layer. The greater the friction, the greater the amount of force required causing this movement, which is call "shear". Shearing occurs whenever the chocolate is physically moved or distributed, as in mixing, pumping, stirring, depositing and so on. Highly viscous chocolate, therefore, requires more force to move than less viscous chocolate.

Isaac Newton defined viscosity by considering the model shown in Figure 12.1. Two parallel planes of fluid of equal area "A" are separated by a distance "dx" and are moving in the same direction at different velocities "V1" and "V2". Newton assumed that the force (F) required to maintain this difference in speed was proportional to the difference in speed through the liquid, or the velocity gradient at the part of liquid under consideration.

The velocity gradient, (V2–V1)/dx, is a measure of the change in speed at which the intermediate layers move with respect to each other. It describes the shearing the liquid experiences and is thus called the "shear rate" and is often symbolised as "D".

Its unit of measure is the reciprocal second "(centimetre per second) per centimetre" (or, more simply, s^{-1}).

The term F/A indicates the force per unit area required to produce the shearing action and is known as the shear stress (τ).

Newton stated that the coefficient of viscosity remained the same at varying flow rates, but this only applies to Newtonian fluids at a fixed temperature. Using these simplified terms, viscosity (η) may then be defined mathematically by this formula:

Viscosity $= \eta = \tau/\mathrm{D} =$ shear stress/shear rate

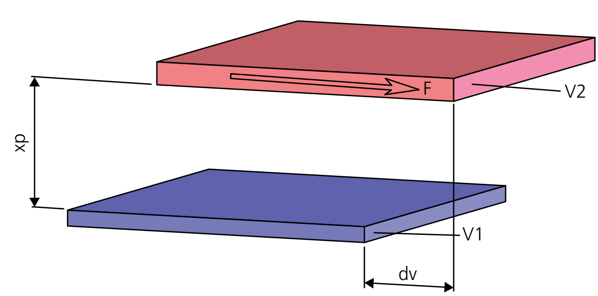

Figure 12.1 Diagram illustrating shear.

For confectionery products the units of viscosity are usually: centipoise, poise or Pascal seconds.

If η is a constant and does not vary with changing values of D, then the fluid is Newtonian. A Newtonian liquid is therefore one for which the graph of shear stress plotted against the rate of shear is a straight line, for example glucose syrup. For such materials the pump supplier only needs one viscosity figure at the temperature of use. *Note*: viscosity can vary a lot with temperature, so it may be necessary to carry out several measurements.

A non-Newtonian fluid is defined as one in which the relationship of shear stress/rate of shear is not a constant, as is shown in Figure 12.2. In other words when the shear rate is varied, the shear stress does not vary in the same proportion. The viscosity of such fluids will therefore change as the shear (flow) rate is varied. The measured viscosity at any particular shear rate is known as the "apparent viscosity" at that shear rate. The value of the shear rate should always be quoted. When providing the viscosity specification to a plant designer, measurements should be obtained at both a high and a low shear rate. The type of viscometer that is used can also affect the measurement obtained (see Chapter 11).

12.2.2 Laminar and turbulent flow

The flow of a fluid down a pipe may be either laminar or turbulent. In laminar (streamline) flow, the molecules within fluid follow well defined paths, which may converge or diverge, but their motion is in the general direction of the bulk flow. The viscosity is dependent upon temperature but largely independent of pressure and surface roughness.

If the shear rate becomes very high however, the movement of the molecules within the fluid becomes more random and some molecules can even move in the opposite direction to that in which they are being pumped and the flow becomes turbulent. This should never be allowed to happen within a chocolate pipeline as it can cause damage to the system. The shear stress down a pipe is proportional to its diameter, so larger pipes should be installed if any turbulence occurs. In addition, since many of the chocolate pumps and pipeline fittings available are only suitable for working pressures of 10 bar maximum, it is advisable to size the pipeline to be big enough to operate below this limit.

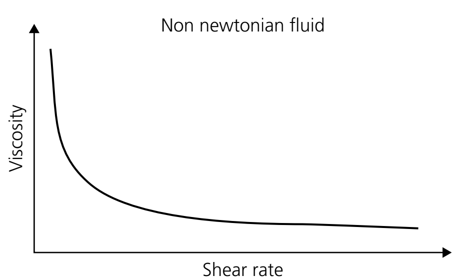

Figure 12.2 Diagram illustrating non-Newtonian flow.