

where in this case r is the diameter of the plates and h the gap between them.

Rheometers

From Equation 6.2 it can be seen that the viscosity of a fluid can be calculated by dividing the shear stress by the shear rate. However, in order to do this it is essential to have an instrument that is capable of imposing either a *constant shear rate* and measuring the resultant shear stress or a *constant shear stress* when measurement of the induced shear rate is required. The first type of instrument is referred to as controlled-rate (or strain) whereas the latter is known as controlled-stress. As is the case with most scientific measurements, the history of the development of the instrumentation can be instructive in understanding the way in which they work. The MacMichael controlled-rate (or controlled-strain) viscometer, which was patented in 1918, had a cup which contained the fluid under test and could be rotated at just one speed. A 5 mm thick disk suspended on a torsion wire was immersed in the fluid in the cup (Fig. 6.16). The viscous drag exerted by the fluid caused the disk to rotate, which in turn produced a deflection in the torsion wire to an equilibrium position which was inversely related to the viscosity. An early modification was to couple a gearbox to the synchronous electric motor so that a series of speeds (rates of shear) could be employed. The change from a synchronous, first, to a direct current motor and then a step (or stepper) motor

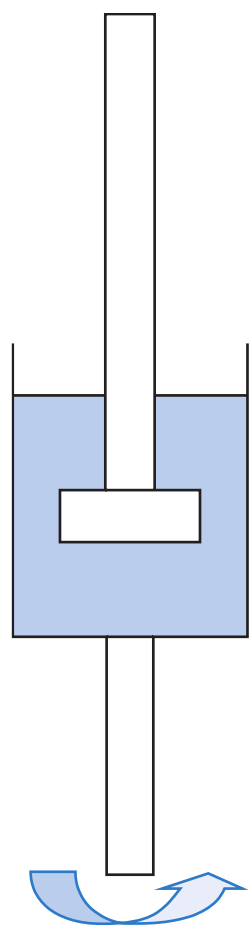


Fig. 6.16 • A diagrammatic representation of a controlled-rate rheometer.

has obviated the need to include a gearbox although these are still incorporated in some instruments as a means of extending the range of shear rates that can be applied.

The absolute viscosity could not be determined with these early instruments, but the use of a calibrated torsion wire and a defined measuring geometry (such as concentric cylinder or cone-plate) made this possible. Perhaps the most significant improvements which have been made to the technology are the replacement of the torsion wire with more sophisticated torque measurement devices, sometimes referred to as dynamometers. Their introduction meant that the cup in Figure 6.16 could be fixed and only the upper part of the geometry needed to be driven by the motor via a coiled spring (Fig. 6.17): the degree of flexure of the spring is, like the torsion wire that it replaced, inversely related to the resistance to flow (i.e. viscosity) of the fluid. Although this modification enabled the viscosity to be read directly off a scale and instruments to be automated, the spring had to have a low elastic modulus and the weight of the measuring geometry which it supported created inertia which had to be overcome once the motor was started. This resulted in a lag period before the bob began to rotate, followed by a rapid acceleration which, in turn, produced an overshoot. This type of behaviour was very apparent with the Ferranti-Shirley viscometer which was widely used with pharmaceutical semi-solids in the 1960s and 1970s. The instrument

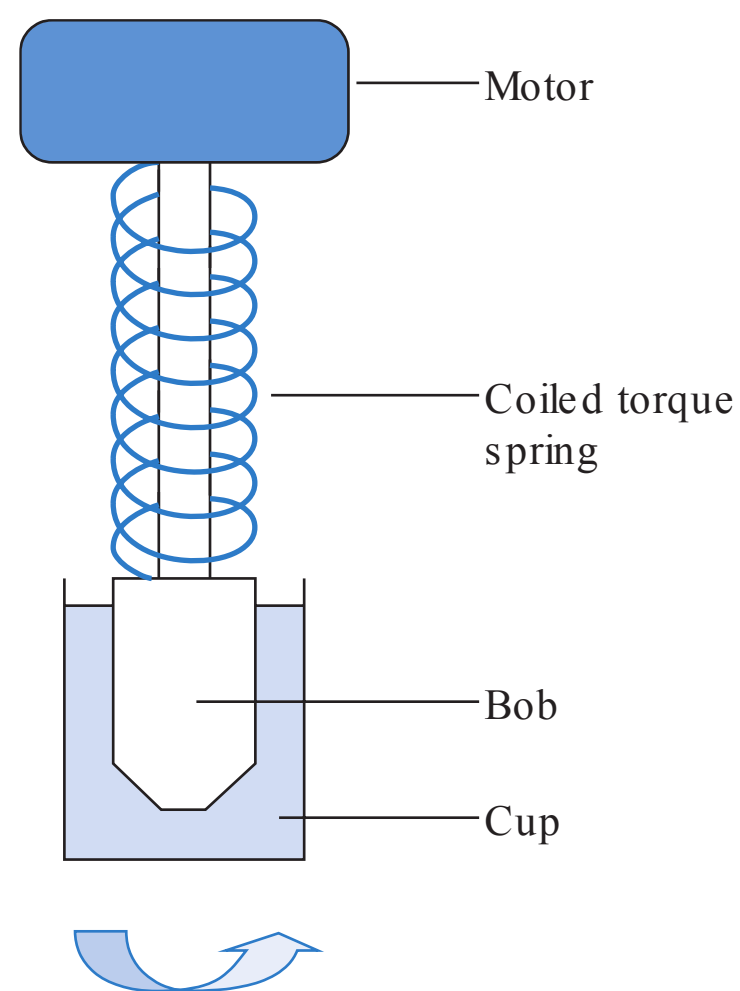


Fig 6.17 • A diagrammatic representation of a controlled rate rheometer with a coiled spring torque measuring device.