The more viscous the fluid, the more time will be required for the fluid to leak out of a container. *Saybolt Seconds Universal* (SSU) and *Saybolt Seconds Furol* (SSF) are scales of such viscosity measurement based on the smaller and larger orifices, respectively. Seconds can be converted (empirically) to viscosity in other units. The following relations are approximate conversions between SSU and stokes.

- For SSU $<$ 100 sec,

$$\nu_{\text{stokes}} = 0.00226(\text{SSU}) - \frac{1.95}{\text{SSU}} \qquad 1.15$$

- For SSU $<$ 100 sec,

$$\nu_{\text{stokes}} = 0.00220(\text{SSU}) - \frac{1.35}{\text{SSU}} \qquad 1.16$$

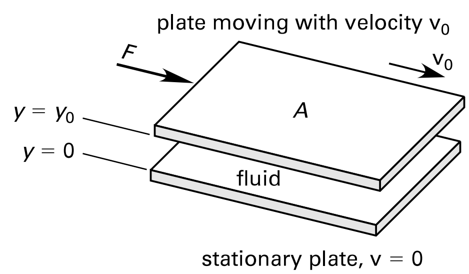
Most common liquids will flow more easily when their temperatures are raised. However, the behavior of a fluid when temperature, pressure, or stress is varied will depend on the type of fluid. The different types of fluids can be determined with a *sliding plate viscometer test*.[12]

Consider two plates of area A separated by a fluid with thickness y_0, as shown in Fig. 1.4. The bottom plate is fixed, and the top plate is kept in motion at a constant velocity, v_0, by a force, F.

Experiments with water and most common fluids have shown that the force, F, required to maintain the velocity, v_0, is proportional to the velocity and the area and is inversely proportional to the separation of the plates. That is,

$$\frac{F}{A} \propto \frac{d\text{v}}{dy} \qquad 1.17$$

Figure 1.4 *Sliding Plate Viscometer*



The constant of proportionality needed to make Eq. 1.17 an equality is the *absolute viscosity*, μ, also known as the *coefficient of viscosity*.[13] The reciprocal of absolute viscosity, $1/\mu$, is known as the *fluidity*.

$$\frac{F}{A} = \propto \frac{d\text{v}}{dy} \qquad 1.18$$

F/A is the *fluid shear stress*, τ. The quantity $d\text{v}/dy$ (v_0/y_0) is known by various names, including *rate of strain*, *shear rate*, *velocity gradient*, and *rate of shear formation*. Equation 1.18 is known as *Newton's law of viscosity*, from which *Newtonian fluids* get their name. Sometimes Eq. 1.19 is written with a minus sign to compare viscous behavior with other behavior. However, the direction of positive shear stress is arbitrary. Equation 1.19 is simply the equation of a straight line.

$$\tau = \propto \frac{d\text{v}}{dy} \qquad 1.19$$

Not all fluids are Newtonian (although most common fluids are), and Eq. 1.19 is not universally applicable. Figure 1.5 (known as a *rheogram*) illustrates how differences in fluid shear stress behavior (at constant temperature and pressure) can be used to define Bingham, pseudoplastic, and dilatant fluids, as well as Newtonian fluids.

Gases, water, alcohol, and benzene are examples of Newtonian fluids. In fact, all liquids with a simple chemical formula are Newtonian. Also, most solutions of simple compounds, such as sugar and salt, are Newtonian. For a more viscous fluid, the straight line will be closer to the τ axis (i.e., the slope will be higher). (See Fig. 1.5.) For low-viscosity fluids, the straight line will be closer to the $d\text{v}/dy$ axis (i.e., the slope will be lower).

Pseudoplastic fluids (muds, motor oils, polymer solutions, natural gums, and most slurries) exhibit viscosities that decrease with an increasing velocity gradient. Such fluids present no serious pumping problems.

Plastic materials, such as tomato catsup, behave similarly to pseudoplastic fluids once movement begins; that is, their viscosities decrease with agitation. However, a finite force must be applied before any fluid movement occurs.

Bingham fluids (Bingham plastics), typified by toothpaste, jellies, bread dough, and some slurries, are capable of indefinitely resisting a small shear stress but move easily when the stress becomes large—that is, Bingham fluids become pseudoplastic when the stress increases.

Dilatant fluids are rare but include clay slurries, various starches, some paints, milk chocolate with nuts, and other candy compounds. They exhibit viscosities that increase with increasing agitation (i.e., with increasing

[12]This test is conceptually simple but is not always practical, since the liquid leaks out between the plates. In research work with liquids, it is common to determine viscosity with a *concentric cylinder viscometer*, also known as a *cup-and-bob viscometer*. Viscosities of perfect gases can be predicted by the kinetic theory of gases. Viscosity can also be measured by a *Saybolt viscometer*, which is essentially a container that allows a given quantity of fluid to leak out through one of two different-sized orifices.

[13]Another name for absolute viscosity is *dynamic viscosity*. The name *absolute viscosity* is preferred, if for no other reason than to avoid confusion with *kinematic viscosity*.