

2.3 VISCOSITY

When a fluid is subjected to an external stress, its molecules readily yield and slide past one another, resulting in shearing action. However, one fluid will resist shear stress more than another, giving rise to the property of fluids called **viscosity**. Viscosity can be described as a fluid's resistance to shear stress. It can also be thought of as the influence of the motion of one layer of a fluid on another layer a short distance away. Therefore, viscosity has no meaning in a motionless fluid.

Viscosity is sometimes confused with density, but it is very different. Whereas density refers simply to the amount of mass per unit volume, viscosity refers to the ability of fluid molecules to flow past each other. Thus, a very dense fluid could have a low viscosity or vice versa.

The properties of viscosity and density are well illustrated by the example of oil and water. Most oils, as we know, are less dense than water and therefore float on water's surface. Yet despite its lack of density, oil is more viscous than water. This property of viscosity is called **absolute viscosity**. It is designated μ and has units of lb-s/ft² (kg-s/m²). Because it has been found that in many hydraulic problems, density is a factor, another form of viscosity, called **kinematic viscosity**, has been defined as absolute viscosity divided by density. Kinematic viscosity is designated by ν and has units of ft²/s (m²/s). Kinematic viscosity of water is taken as 1×10^{-5} ft²/s (9.29×10^{-7} m²/s).

The concept of viscosity can be further illustrated by the sliding plate viscometer. This device, shown in Figure 2-4, can be used to measure absolute viscosity. Assume that the lower plate is kept motionless and the upper plate is moved at a certain velocity, v , by applying a force. The portion of fluid in contact with the upper plate moves with velocity v , while the fluid in contact with the lower plate has zero velocity. Therefore, a velocity gradient will be induced throughout the thickness of fluid. If you think of the fluid existing in thin layers parallel to the plates, these layers slide past each other in a shearing action. Different fluids produce different shear stress between layers for a given velocity. Therefore, different fluids have different viscosities.

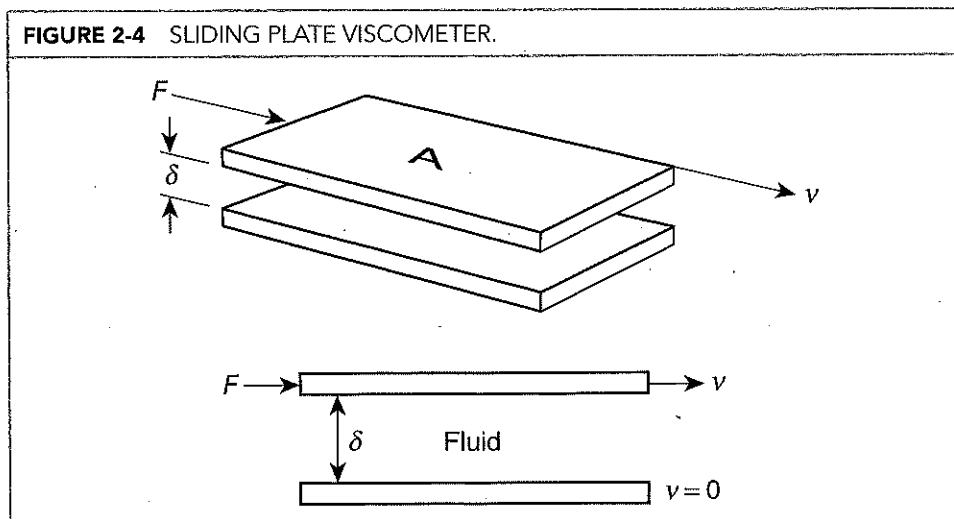
Referring to Figure 2-4, notice that shear stress, τ , is the force per unit area, or

$$\tau = \frac{F}{A} \quad (2-4)$$

where τ = shear stress, lb/ft² (N/m²)

F = applied force, lb (N)

A = area of plate, ft² (m²)



Also note that the variation of velocity across the plate separation is v/δ . Experimentation shows that the applied force needed to maintain the velocity v is proportional to the velocity and the plate area and inversely proportional to the plate separation, δ . Thus,

$$F \propto (\text{proportional to}) \frac{vA}{\delta} \quad (2-5)$$

Rearranging Equation 2-5 gives

$$\frac{F}{A} \propto \frac{v}{\delta} \quad (2-6)$$

or

$$\tau \propto \frac{v}{\delta} \quad (2-7)$$

The proportionality constant is called absolute viscosity, μ . Thus,

$$\tau = \mu \frac{v}{\delta} \quad (2-8)$$

Fluids that behave in accordance with Equation 2-8 are called Newtonian fluids. The viscosity of a Newtonian fluid does not vary with the shear stress or the resulting velocity gradient. The viscosity depends only on the condition of the fluid, such as temperature. Most fluids encountered in engineering, such as water and oil, are Newtonian fluids.

EXAMPLE 2-1

Problem

The viscosity of a fluid is to be determined using a sliding plate viscometer. The plate area is 0.16 ft^2 , and the separation between plates is 0.070 ft . A force of 0.00020 lb moves the upper plate at a velocity of 6.0 ft/s . What is the absolute viscosity?

Solution

From Equation 2-4, shear stress is

$$\begin{aligned} \tau &= \frac{F}{A} \\ &= \frac{0.0002}{0.16} \\ &= 0.00125 \text{ lb/ft}^2 \end{aligned}$$

Absolute viscosity is then found by rearranging Equation 2-8. Thus,

$$\begin{aligned} \mu &= \tau \frac{\delta}{v} \\ &= (0.00125)(0.07)/6.0 \\ &= 0.000015 \text{ lb-s/ft}^2 \quad (\text{Answer}) \end{aligned}$$

The absolute viscosity found in Example 2-1 corresponds to crude oil. To find kinematic viscosity, divide by the density of crude oil, 1.66 slugs/ft^3 . Therefore, the kinematic viscosity for Example 2-1 is $0.000015/1.66 = 9 \times 10^{-6} \text{ ft}^2/\text{s}$.