Chapter 30 in CRC Press'
"The MEASUREMENT, INSTRUMENTATION,
AND SENSORS HANDBOOK"

30 Viscosity Measurement

G.E. Leblanc
McMaster University

R.A. Secco
The University of Western Ontario

M. Kostic
Northern Illinois University

30.1 Shear Viscosity

An important mechanical property of fluids is *viscosity*. Physical systems and applications as diverse as fluid flow in pipes, the flow of blood, lubrication of engine parts, the dynamics of raindrops, volcanic eruptions, planetary and stellar magnetic field generation, to name just a few, all involve fluid flow and are controlled to some degree by fluid viscosity. *Viscosity* is defined as the internal friction of a fluid. The microscopic nature of internal friction in a fluid is analogous to the macroscopic concept of mechanical friction in the system of an object moving on a stationary planar surface. Energy must be supplied (1) to overcome the inertial state of the interlocked object and plane caused by surface roughness, and (2) to initiate and sustain motion of the object over the plane. In a fluid, energy must be supplied (1) to create viscous flow units by breaking bonds between atoms and molecules, and (2) to cause the flow units to move relative to one another. The resistance of a fluid to the creation and motion of flow units is due to the viscosity of the fluid, which only manifests itself when motion in the fluid is set up. Since viscosity involves the transport of mass with a certain velocity, the viscous response is called a momentum *transport process*. The velocity of flow units within the fluid will vary, depending on location. Consider a liquid between two closely spaced parallel plates as shown in Figure 30.1. A force, F, applied to the top plate causes the fluid adjacent to the upper plate to be dragged in the direction of F. The applied force is communicated to neighboring layers of fluid below, each coupled to the driving layer above, but with diminishing magnitude. This results in the progressive decrease in velocity of each fluid layer, as shown by the decreasing velocity vector in Figure 30.1, away from the upper plate. In this system, the applied force is called a *shear* (when applied over an area it is called a *shear stress*), and the resulting deformation rate of the fluid, as illustrated by the *velocity gradient* dU_x/dz, is called the *shear strain rate*, $\dot{\gamma}_{zx}$. The mathematical expression describing the viscous response of the system to the shear stress is simply:

$$\tau_{zx} = \frac{\eta dU_x}{dz} = \eta\dot{\gamma}_{zx} \tag{30.1}$$

where τ_{zx}, the shear stress, is the force per unit area exerted on the upper plate in the x-direction (and hence is equal to the force per unit area exerted by the fluid on the upper plate in the x-direction under the assumption of a no-slip boundary layer at the fluid-upper plate interface); dU_x/dz is the gradient of the x-velocity in the z-direction in the fluid; and η is the *coeficient of viscosity*. In this case, because one is concerned with a shear force that produces the fluid motion, η is more specifically called the *shear*

0-8493-8347-1/99/$0.00+$.50

THE MEASUREMENT, INSTRUMENTATION, AND SENSORS HANDBOOK

Editor-in-Chief
John G. Webster

CRC PRESS IEEE PRESS

A CRC Handbook Published in Cooperation with IEEE Press