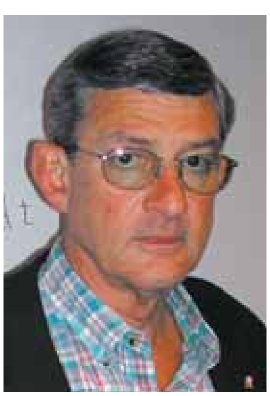
VISCOSITY: The resistance to flow

Understanding the importance of viscosity can be analyzed through two concepts: shear stress and shear rate.



by Dr. Robert M. Gresham
Contributing Editor

During our earlier discussions we have talked about the contributions of Pascal, Bernoulli and Reynolds. Because of their work we now have a pretty good understanding of hydraulics and lubrication theory. Their work spanned about 250 years from 1653 to 1900. Now, we'll look at how some additional scientific greats have helped with our understanding of viscosity.

Most of us involved in the general lubrication industry know that viscosity, the resistance to flow of a fluid, is a pretty important property of lubricants—in fact probably the most important.

Why is it important to understand viscosity? Because viscosity is central to the performance of lubricated machinery, such as your car:

- If you use high-viscosity engine oil in your car, the oil puddles in your driveway will be smaller, but your engine will run hotter and it probably won't start on a cold winter morning.
- If you use low-viscosity engine oil in your car, the piston rings may wear out in a few thousand miles, the crank-

shaft bearings may seize and the puddles in your driveway will amaze your neighbors!

As we said, the simplest definition of viscosity is resistance to flow. Sir Isaac Newton defined it as "the resistance that arises from lack of slipperiness in a fluid." Cold maple syrup is thick and not slippery, but cold water is thin and slippery.

Words such as thick, slippery, thin and sticky are not distinguishing when we have to describe dozens of different oils. Instead, we use numbers to compare different lubricating oils. When scientists talk about oils or fluids, we talk in terms of shear stress and shear rate at a given temperature. When we talk about greases, we have two overlaying concepts: the viscosity of the oil used to formulate the grease and the consistency of the thickened grease. So, let's take a look at this shear stress and shear rate concept.

Consider the experiment shown in the sketch (*see* Figure 1). The force F that is applied at the edge of the top plate to move the plate, divided by the area of the plate A, is defined as shear stress. The movement of the fluid between the plates that results from the application of the force is the shear rate. The shear rate has to do with the speed with which the layers of fluid between the plates move. The top layers, the ones closest to the moving plate, move the fastest and the layer nearest to the stationary plate moves the slowest. Thus, there is a velocity gradient from fastest to slowest. This gradient is the shear rate for that fluid at a given shear force.

So? Well, if we plot the shear stress and shear rate, we get, using a perfect fluid called a Newtonian fluid, a straight line starting from zero (*see* Figure 2). Visually, the slope, or steepness, of that line is the viscosity for that fluid at a given temperature. Mathematically, viscosity is the ratio of shear stress to shear rate (viscosity = shear

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Figure 2. Viscosity related to shear stress and shear rate.

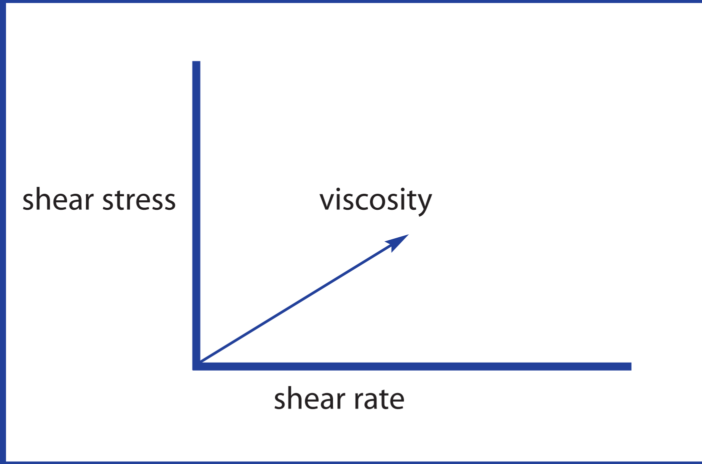

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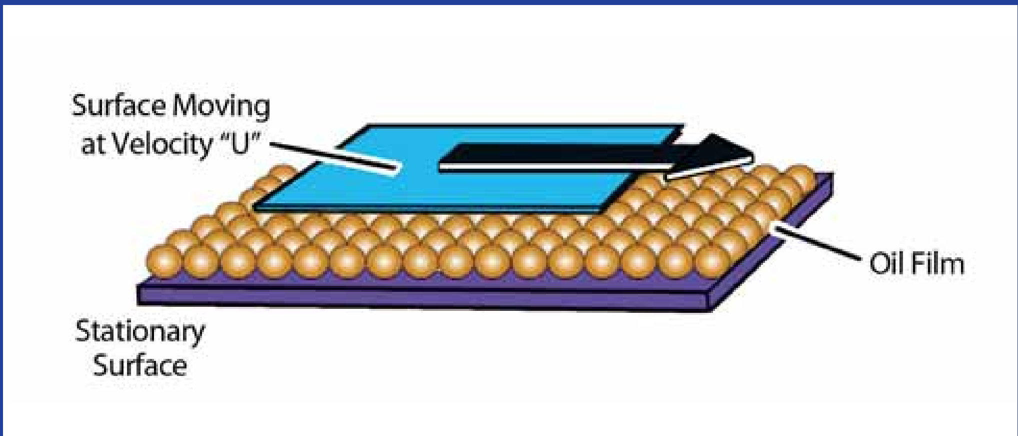
Figure 1. Example of shear stress and shear rate.



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stress / shear rate). For whatever it is worth, this plot is also a demonstration of Hooke's Law.

Enough mathematics, we know viscosity is important, but how do we measure it? If we can build a machine that simulates two plates with a fluid between, we can measure viscosity in absolute terms. The terms scientists use get a little strange as well. Originally, the units of measure were in poise, (named after Jean Louis Marie Poiseuille, who was a French physician and physiologist), or for convenience in centipoise (cP), but now we mostly use the pascal or millipascals (mPas). Fortunately, cP and mPas are equivalent.

One more thing scientists in the lubricants industry do, and that is to divide the dynamic viscosity by the density of the fluid to get what is called the kinematic viscosity. The units of kinematic viscosity are called stokes or commonly centistokes (cS), named after George Stokes. Stokes was an English mathematician who published his groundbreaking work in fluid mechanics during his early 20s and, thus, deserves to have the units for viscosity (cSt) named after him.

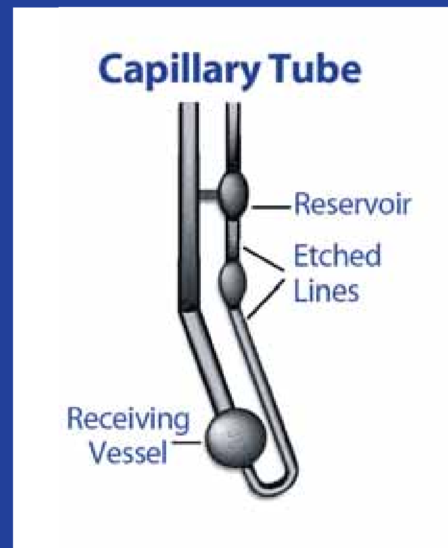
There are many other methods used to measure viscosity, such as measuring the time that a glass marble needs to fall through a lubricant — a falling-body viscometer.

As it happens, building absolute viscometers to measure viscosity is a bit involved. We have learned in the lubricant industry that we can measure viscosity more easily taking advantage of the properties of viscous fluids and their density. This turns out to be a lot easier to do and provides the needed information with units in centistokes.

We can measure the viscosity of lubricants quite easily by measuring the time required for a known amount of oil to flow through a small diameter (capillary) tube at a known temperature (*see Figure* 3). This turns out to be a lot easier to do than the moving plates model described in Figure 1. The test measures the kinematic viscosity (moving-fluid-viscosity – get it?) and the units of measure are in centistokes.

There are many other methods used to measure viscosity, such as measuring the time that a glass marble needs to fall through a lubricant — a falling-body viscometer. The marble falls more slowly in a viscous lubricant. This method has a huge disadvantage, the marble disappears if the lubricant is cloudy or opaque. Several indirect methods have been developed to allow continuous monitoring of viscosity by process control computers. These devices provide a current or a voltage that is proportional to viscosity; they must be calibrated with oils that have been previously measured with a rotational or capillary viscometer.

Figure 3. Diagram of a capillary viscometer.



Unfortunately, most fluids are *not* perfect, or Newtonian. When plotted they do not have straight lines and often do not begin from the origin—zero. These kinds of fluids have some pretty interesting names: plastic, dilantant, pseudoplastic and thixotropic. These non-newtonian fluids have properties that can be pretty important. But that will be the subject of another article. **<<**

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