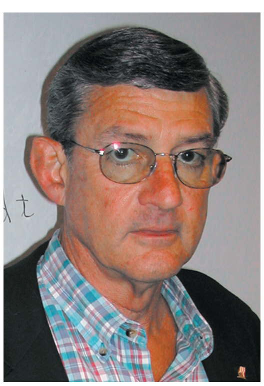
Learning more about Viscosity

There's more than meets the eye which can impact the behavior of viscosity and even rheology.



by Dr. Robert M. Gresham
Contributing Editor

Editor's Note: *This article was written in collaboration with Dr. Phil Guichelaar, Western Michigan University.*

We frequently say that viscosity is the most important property of fluid lubricants. Previously, we discussed the fundamental concepts that go into our understanding of viscosity in last month's issue.

You will recall that viscosity is equal to the shear stress/shear rate concept. Though, what happens if we stir a can of oil at different speeds? Does it seem obvious that more effort is required to stir the oil at a faster speed? More effort is required, but for some oils it is not proportionally more effort.

We can determine the effect of stirring rate with a rotary viscometer by rotating the spindle at different speeds. For each of these speeds, we calculate the shear rate (*related to the rotation speed of the spindle*) and measure the shear stress (*related to the torque needed to rotate the spindle*). Then we make a plot of the shear stress and shear rate as shown below (*see* Figure 1). The data might fit a straight line starting from zero. The slope of that line or its steepness is the viscosity for that oil at the temperature of the oil.

Remember that mathematically and, also, graphically: an oil whose viscosity remains constant as we increase or decrease the shear rate is a perfect fluid (*see* Figure 2). The term, Newtonian, is used to designate this behavior. Water, gasoline and most unmodified mineral oils display very

Figure 1. Flow Curve

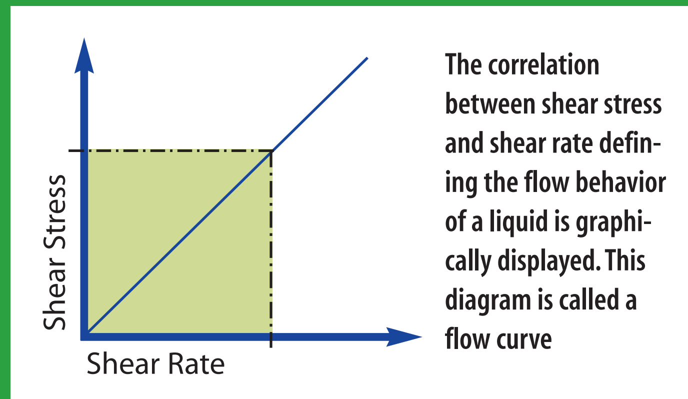
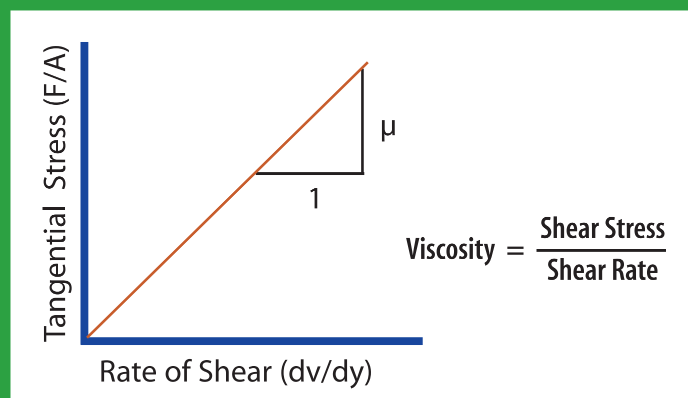


Figure 2.



nearly Newtonian viscosity curves.

Most fluids, including motor oils, are *not* perfect, or Newtonian. The shear stress is not directly proportional to the applied shear rate such that when the shear stress is plotted against the shear rate, the points are not in a straight line. Often, the points do not begin from zero shear stress and zero shear rate. Certain other fluids are sensitive to the length of time that the fluid is being sheared, resulting in changes in viscosity with the duration of the experiment. These kinds of fluids have interesting names:

- **Pseudoplastic Fluids.** The viscosity of pseudoplastic fluids decreases with increased shearing (*see Figure* 3). Molten polymers have this characteristic, which is used to advantage in injection molding when the material flows through small cross-section gates. Paper pulp suspensions also display pseudoplastic viscosity behavior.
- **Dilatant Fluids.** For these fluids, the viscosity increases with increased shearing (*see Figure* 4). A mixture of water and cornstarch can have the consistency of thick cream if it is poured slowly, but will form a thick paste if it is stirred briskly. Quicksand also has this quirky viscosity behavior, with the valuable lesson that slow escape movements consume less energy than violent movements against an instantly thick morass.
- **Bingham Plastic Fluids.** The viscosity curve for these fluids does not go through the origin. As shown in Figure 5, the shear stress can be substantial even at a small shear rate, but once the fluid is moving, the shear stress is directly proportional to shear rate in exactly the same manner as Newtonian fluids. Water suspensions of rock particles behave in this manner. More familiarly, mashed potatoes, a suspension of tasty solids in a liquid, flow in the bowl when you stir, flow harder when you stir harder, and assume a mountain peak shape if undisturbed.
- **Shear Time Dependent Fluids.** For these fluids, the shear stress changes with time of shearing. This behavior is related to breaking bonds between particles or molecules, or to changes from the at-rest shape of long molecules.
- **Thixotropic Fluids.** Fluids that are thixotropic are not simply small molecules aggregated together, such as water. They include molecules that have a longer range structure that can be altered with mechanical shearing. For most of these fluids, the viscosity decreases at higher shearing rates (*see Figure* 6). Mayonnaise, has this characteristic. It is not a Bingham plastic fluid because its viscosity decreases with higher rates of shearing, but only after a minimum amount of shear is reached. Yogurt (without the tasty fruit addition) is also reputed to have this behavior. Finally, good quality wall paint and motor oils are carefully compounded to be thixotropic. Can you explain why users of these fluids

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Figure 3. **Pseudoplastic Flow:**

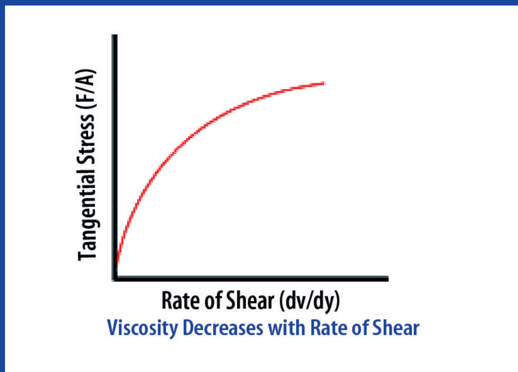
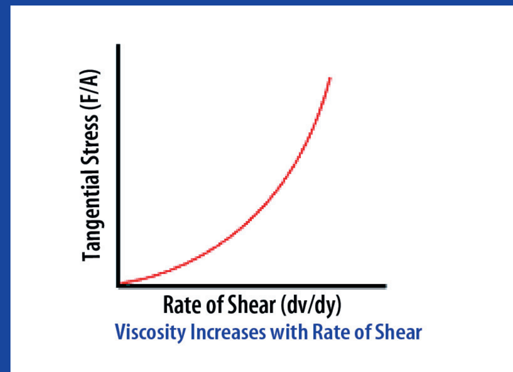


Figure 4. **Dilatant Flow:**



Clearly, viscosity and rheology are very important to the proper operation of mechanical equipment. An equipment design engineer designing a bearing or gearbox, or a lubricant dispensing device, needs to understand the implications of rheology on his or her design.

would be pleased to have thixotropic behavior?

- **Rheopectic Fluids.** This behavior is not common and is not very useful, because the viscosity increases with additional shearing after the minimum amount of shear is exerted. Some clay solutions in water behave in this manner. Can you imagine the behavior of rheopectic paint? It thickens into clumps when you apply it, and when you stop trying to smooth it out, it runs down the wall.

The non-Newtonian fluids discussed before have important behaviors. For example, in Pseudoplastic fluids, flow does not begin until a minimum shear stress level is reached. This is important for printing ink rheology where we would not like the ink to move until it is deposited on paper. Once the minimum shear stress has been reached, the fluid thins with increasing shear rate and penetrates the structure of the paper. When the shear stress goes back to zero, the ink does not move.

Meanwhile, with Thixotropic fluids, flow can vary with applied shear stress and/or shear rate, becoming rapidly thin with increasing shear time, but when the shear forces are removed the fluid rapidly becomes thicker or more viscous. Paint is usually compounded to be thixotropic — it applies easily (high shear stress and shear rate) but it does not sag or run when the brush is removed, yet has the time to flow and level out before thickening. At low temperatures, wax particles in lubricating oils can cause the non-Newtonian Thixotropic behavior of the oil to become even more pronounced.

How does a Pseudoplastic oil behave in a hydrodynamic bearing? At startup, the shear rate is slow and the oil has a high viscosity such that the transition to mixed lubrication is facilitated. As the shaft speeds up, the viscosity decreases but hopefully the increased speed compensates and the system remains in the mixed lubrication regime or transitions into the hydrodynamic regime. On the other hand, with a Thixotropic fluid, at start up, if the shear rate is slow the oil initially supports the bearing. If the shear rate remains constant, the oil will eventually thin and not support the bearing.

A Dilatant fluid is the opposite of a Pseudoplastic fluid in that its viscosity increases with shear rate. This would be very bad for a paint system, as it would be very difficult to spread the paint evenly. If a lubricating oil was dilatant, its viscosity would increase with speed and friction losses would increase, not a good outcome when the general objective is to decrease energy consumption.

Clearly, viscosity and rheology are very important to the proper operation of mechanical equipment. An equipment design engineer designing a bearing or gearbox, or a lubricant dispensing device, needs to understand the implications of rheology on his or her design. If the engineer knows the conditions under which the "converging wedge" is operating, the rotat-

Figure 5 . Pseudoplastic Flow:

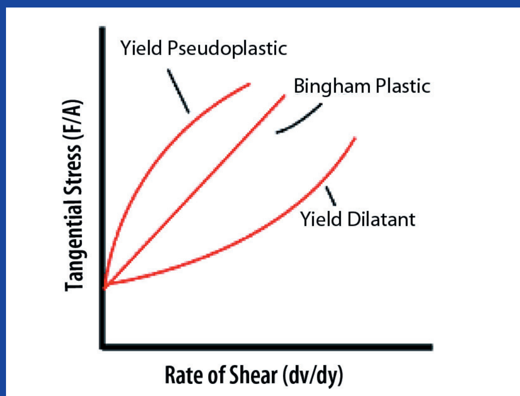
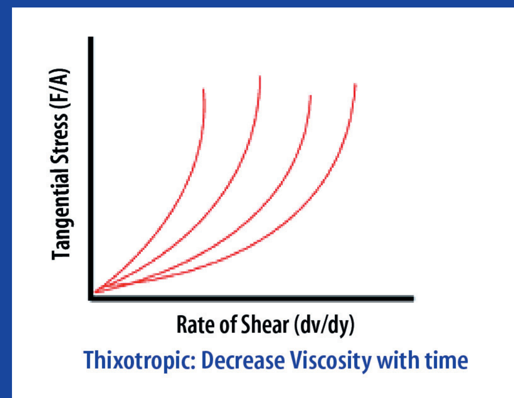


Figure 6 . Dilatant Flow:



ing speed, the load, and the possibility of any intermittent changes in pressure with time, and if they can predict the range of operating temperatures, they can specify a viscosity and viscosity index for effective lubrication. Conversely, if the engineer knows the viscosity profile of a lubricant, they can design a mechanical system to operate reliably.

Lubricant formulators keep all of these concepts in mind and under control when developing new products.<<

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