UNDERSTANDING ER FLUIDS AND THEIR PROPERTIES

Simple oils are specified by viscosity, density, and temperature properties. ER Fluid parameters may be less familiar; this Note is intended to explain them.

Fig. 1 shows the most basic rheological test. A flat plate, area A, is held a distance h from a flat surface with the test sample beneath it; a horizontal force, F, causes it to slide at a velocity V. The "Shear Rate" (V/h) is measured as a function of the "Shear Stress", (F/A), as shown in Fig 2. For example, in a pure liquid, or in an ER fluid without an electric field, Shear Rate is directly proportional to Shear Stress, as shown by the straight line through the origin; the slope of this line is the "Newtonian" viscosity. Other materials, including ER fluids in a field, show more complex behaviour.

If the plates in Fig. 1 are pressed together dry, the top plate will not slide at all until the force F exceeds a limiting value, but once it is sliding, F is independent of the velocity V. In Fig. 2, this plots as a horizontal line with an intercept, Z, on the stress axis, proportional to the force pressing the plates together. In practice, "sticking" friction is usually higher than "sliding" friction, so there is a cusp on the line in Fig. 2 near the stress axis, and Z has "static" (Z^*) and dynamic (Z) values.

With no field, ER fluids are usually Newtonian, like normal oils. In a field, on the other hand, their behaviour resembles friction:- they will not flow at all until the Shear Stress exceeds a certain value, called the "Yield Stress", (τ). Like Z in friction, τ usually has two values, τ^* (static) being greater than τ (dynamic). However, whereas the Shear Stress/Shear Rate graph (Fig. 2) for friction is horizontal, that for ER fluids usually has a slight slope, called the "Plastic Viscosity". Static Yield Stress (τ^*), Dynamic Yield Stress, (τ) and Plastic Viscosity (μ_{pl}) are all dependent on the field (E, volts/mm) as shown in Fig. 3 - τ^* is a linear function of E above a threshold, E_0, whereas τ usually varies as E^2. μ_{pl} usually falls with E, but is sometimes constant. The coefficients in all these relationships are temperature-dependent.

Fig 1

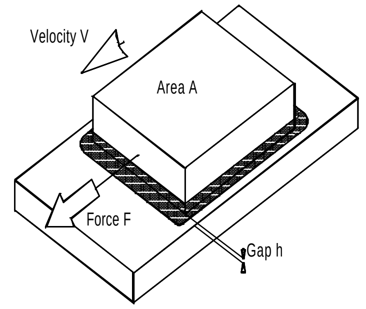


Fig 2

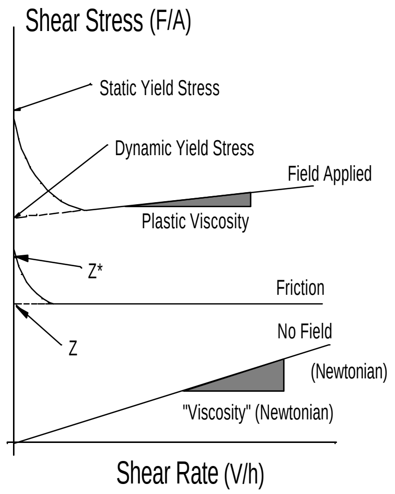
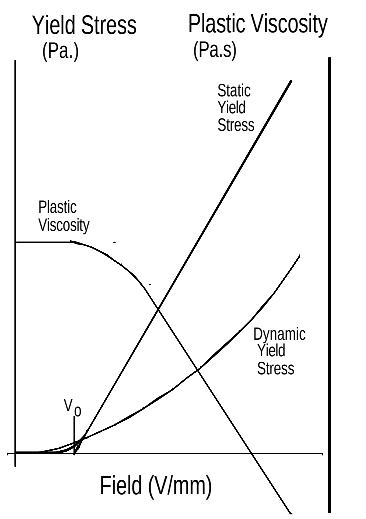


Fig 3



Current

Although the current density is usually low, it is of considerable practical importance, since it determines the size (and cost) of the power supply; furthermore, high voltage units producing more than about 10mA are potentially lethal, so ER fluids and equipment must be designed to minimise current. ER fluids do not obey Ohm's law, so the current must be presented either graphically, or by reference to a model. Smart uses a quadratic model: -

J (current density) = $PE + QE^2$

This applies to static ER fluids. This is the "worst case" since the current usually falls when flow commences. P can usually be ignored, but Q is strongly temperature-dependent. A plot of log (Q) against 1/T (°K) is linear.

No-Field Viscosity

Without a field, most ER fluids are Newtonian. No-field viscosity is an important consideration in many applications, since it determines the **minimum** torque (or pressure) that the device can produce under given conditions, just as the Yield Stress determines the maximum. The variation of no-field viscosity with temperature is usually similar to that of pure oil.

General

The features discussed above are specific to ER Fluids. In addition, an ER Fluid must also be a "user-friendly" engineering material. The fluid should have a high boiling point and low freezing point; it should not be abrasive or attack common engineering materials; it should have a long storage and working life; it should show a minimal tendency to settle out. Above all, it must be non-toxic and safe to use.

ER fluids cannot be realistically compared on the basis of a single parameter. For example, a high yield stress at low field is obviously desirable, but if the fluid also has a high no-field viscosity, passes a high current, or cannot be used with ordinary rubber seals, it may be more trouble than it is worth in practical applications. The "best" ER fluids are those, which have the best COMBINATION of desirable properties. The fluids made by Smart Technology Ltd have been optimised in this way over more than 20 years.