Emerson & Cuming
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Technical Data Sheet
Technical Tip

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Understanding Rheology

What is Rheology?
Rheology is the study of how a material deforms during and after a force is applied. Rheology directly affects product handling and flow characteristics. Some common measurements used to describe rheology are viscosity, thixotropic index, dispense rate, and sag resistance.

Why is Rheology Important?
Controlling rheological properties is essential for polymeric processing and application.

- **Mixing** - Rheology effects ease of mixing whether by hand, with a premeasured package, or with a static mix tube.
- **Dispensing** - Rheology dictates how a material is applied whether by spatula, spray, pump, syringe, cartridge, screen/stencil printing, or pouring. It is influenced by how rapidly viscosity changes once mixed due to the mixture's chemistry.
- **Settling** - Rheology affects the degree and rate at which fillers settle. Also important is filler type, particle size, shape, and size distribution. This is especially important for coatings and heavily filled encapsulants.
- **Flow Control** - Rheology affects the way a material flows. High flow allows easy entry into intricate spaces versus a low flow which prevents flow into critical areas. Flow control is very important during initial application and during the curing process as well.

What Affects Rheology?

- **Resin -** resin type and molecular weight affects viscosity and surface wetting.
- **Formulation -** additives and fillers (type, shape, size, size distribution, and surface smoothness).
- **Temperature -** with epoxies every 1°C change can cause up to a 5-10% change in viscosity.
- **Shear -** the duration and amount of any force applied to the material. Shear rate measures a constant force.

Rheological Classifications
There are two types of fluids: Newtonian and Non-Newtonian.

Newtonian Fluids
These are truly viscous "ideal liquids", which means as the shear rate changes the viscosity remains constant (water, oils, solvents). Hence if you double the strain rate you will double the stress required.

Non-Newtonian Fluids
These fluids are affected by shear and are divided into Power Law Fluids (Pseudoplastic or Dilatant) and Time Dependent Fluids (Rheopectic or Thixotropic). Most polymers are pseudoplastic and thixotropic.

- **Pseudoplastic:** As shear increases, viscosity decreases. No matter how long a pseudoplastic material is sheared at a given shear rate, the viscosity will remain the same. Many polymeric systems are pseudoplastic, perhaps the most classic example is mayonnaise.
- **Dilatant:** These are the opposite of pseudoplastic that is, as shear increases the viscosity increases. Some highly filled materials are dilatant.
- **Rheopectic :** Viscosity increases as a function of time. Examples would be a mixed epoxy increasing in viscosity as curing takes place or a solvent based adhesive or coating where the viscosity increases as the solvent evaporates.
- **Thixotropic:** Viscosity decreases over time when using a constant shear rate. As shear rate decreases the material will gradually recover the original internal structure before shear, this can take seconds or days to fully recover. Many times, when a material sits, it will "structure", this will give a "false" high viscosity reading if the material is not premixed.

Note: These are text book definitions, in common usage pseudoplastic and thixotropic may be used interchangeably or in combination. They are also not mutually exclusive.

Measuring Rheological Properties

Viscosity: A measure of the internal resistance of friction when a material moves against itself. Viscosity can be effected by the resin chemical structure, or the type and amount of filler added. The lowest viscosity materials are unfilled, short chained compounds.

The internal resistance or viscosity is typically measured using a rotating spindle instrument such as a Brookfield viscometer. The amount of force needed to turn the spindle (torque) at a selected speed (RPM) is measured. A simple calculation converts this "internal resistance" to viscosity. There are different surface area spindles used to measure different viscosity ranges.

The higher the torque value, the higher the viscosity. The force is measured as Pascal seconds, Poise or Newton seconds per meter^2. One milliPascal second (mPas.) equals one centipoise (cP) or $1x10^{-4}$ Newton seconds per meter^2. ASTM D 2393 is an example of a common viscosity test procedure used in North America.

Rotational spindle viscometers and cone and plate viscometers are used for most adhesives, encapsulants , inks, and some coatings. The Zahn Cup, Ford Cup, DuPont Parlin, and ISO Cup are some of the methods commonly used for coatings. Their general principal is to measure the time it takes a given volume to gravity feed through a given orifice.

Viscosity Profiles: A viscosity value is usually just one reading taken at a specific shear and temperature. The most descriptive method is the viscosity profile. Cone and plate viscometers can provide continuous, precise measurements over a wide range of shear rates and temperatures. Viscosity profiles can also be very useful for knowing how viscosity changes during cure. This can be essential in some applications with tightly toleranced flow properties.

Thixotropic Index: A more accurate term would actually be "Pseudoplastic Index", however, thixotropic index or shear thinning index (STI) have become accepted terms. It gives an indication as to how stiff and non-sag a material will be. A common measurement runs viscosity at two different shear rates such as 1 RPM and 10 RPM. The value recorded at the higher RPM is divided into the value at the lower RPM to obtain the index. Generally materials have thixotropic index values between 1 (high flow) and 5 (low flow or non-sag).

Dispense Rate: A test that usually specifies the orifice size, dispensing pressure and dispensing temperature. Then one either measures the amount of material dispensed in a particular time or the time to dispense a particular amount. Press Flow (often for cartridges), orifice flow, and syringe dispense rate are common dispense rate tests.

Sag Resistance: A special rheological measure for highly thixotropic products. Sag resistance is a measure of the resistance to flow with no shear on the material. Generally a bead of material is applied to a flat surface and the final flow or spread is measured and recorded. The surface angle, temperature, and time are specified by the particular test method.

Common Viscosity Comparisons	
Material	**Viscosity (cP)**
Water	1
Kerosene	10
SAE #10 Motor Oil	500
Castor Oil	1,000
Corn Syrup	5,000
Honey	10,000
Hot Fudge Syrup	25,000
Molasses	50,000
Heavy Molasses	100,000

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