Temperature-Dependent Viscosity of Silicone Bath Fluid

Viscosity is a material property that is readily observable in many households. Pouring honey into a cup of tea takes considerably more effort and time than the same task with water, indicating that honey has a higher resistance to deformation and flow, or a higher viscosity, than water. While side-by-side comparisons are useful to demonstrate the effect of differing viscosities, many industrial applications require quantitative values. Measuring and understanding flow properties can allow an engineer to effectively design a multitude of products and flow systems, ranging from an optimized shampoo bottle lid to entire oil transport pipelines.

At Ebatco, the Anton Paar MCR302e Rheometer can operate using several different geometries to accommodate different material quantities and viscosities. For any measurement, the prevailing idea is that a shear strain (γ) is introduced, and a corresponding shear stress (σ) is measured. In the case of two parallel plates with a liquid in between, this means that the top plate rotates while the bottom plate remains stationary, providing a shear strain, and the measured torque at the top plate is used to calculate the shear stress. With experimentally determined values for both shear stress and shear strain, viscosity (η) can be calculated from their ratio,

$$\eta = {}^{\sigma}/_{\dot{\gamma}}$$

Vertical force and displacement control of the top measuring plate also enables extension measurements, for properties like tackiness, which are important for applications involving repeated removal and reapplication of a material. The temperature control capabilities of the MCR302e, ranging from -150 – 400 °C, make polymer melt and solidification measurements possible with a high level of accuracy. The temperature control is useful when comparing the solid-like and liquid-like behavior of different samples, or when determining a glass transition and melting point. Performing oscillatory measurements for storage modulus, loss modulus, and tan(δ) in both solid and liquid samples provide~~s~~ highly sensitive and accurate data for glass transitions and flow points.

Silicone fluids are common for use in heat transfer applications, but they are also used for lubrication, vibration damping, power transmission, and polishes. Silicone fluids have demonstrated a wide operating temperature range, high thermal stability, low volatility, and low intermolecular forces, which contribute to its lubricity and permeability. Commercially available products can have molecular weights from 150 to over 500,000 g/mol, resulting in a high degree of variability in material properties. Two of the most notable properties that are heavily influenced by molecular weight are viscosity and operating temperatures, both of which increase with increasing molecular weight. To determine the effectiveness of a particular silicone fluid for heat transfer applications, we will measure the fluid's viscosity under variable temperature. Lower viscosities are generally desired for fluids in heat exchangers, especially plate heat exchangers, which typically require a viscosity less than 5 Pa·s. A lower viscosity fluid requires less pumping power and it allows for more efficient heat transfer.

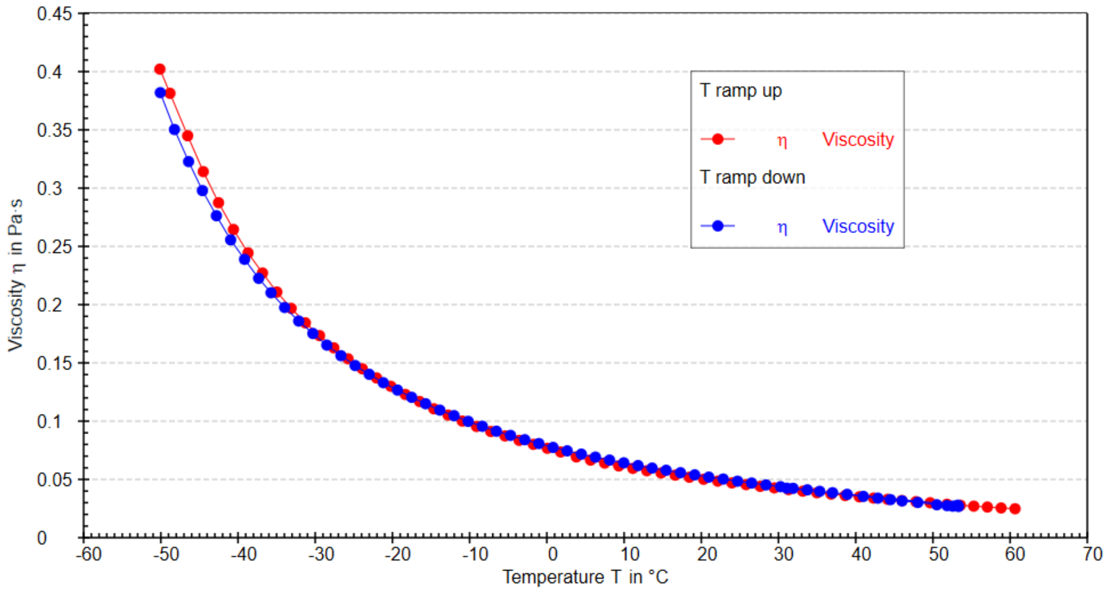

Figure 1. Viscosity of silicone bath fluid from -50 to 60 °C. The data show viscosity changes as temperature increases (red) and decreases (blue).

The temperature dependence of viscosity for the silicone bath fluid is presented in Figure 1, with denoted segments that were measured under heating and cooling conditions. The two segments show very good agreement, indicating a high level of precision for the instrument, as well as sufficient thermal conductivity and excellent thermal stability of the sample. The low sample thickness (geometry gap = 0.1 mm) promotes thermal homogeneity, as thermal gradients in samples with a lower thermal conductivity can show hysteresis between heating and cooling curves. Additional discrepancies can occur between the heating and cooling segments if there are temperature-dependent reactions that are present; however, the agreement between the measurement curves and the published thermal stability of silicone fluids indicate that such reactions should not be present.

The low viscosity values for the measured sample indicate that this fluid is suitable for heat exchange applications over the entire temperature range between -50 and 60 °C. The viscosity values are all below 0.5 Pa·s, well under the threshold for plate heat exchangers. The increase in viscosity at lower temperatures is consistent with published measurements on similar samples. The more rapid increase near -50 °C reflects that the sample is approaching its pour point, where it will transition to a semisolid and significantly resist flow. Extending the measurement range to even colder temperatures would allow for a quantification of the fluid's pourpoint. Further oscillatory measurements to determine viscoelastic properties over the full temperature range, if performed with the MCR302e Rheometer, would be particularly useful for the evaluation of lubricants and greases, especially in the automotive industry. As demonstrated, the range of liquid characterization capabilities at Ebatco allow for a more complete understanding of your material, enabling optimization and quality control for a product at any step in a manufacturing process.