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BROOKFIELD
AMETEK
Instrumentation & Specialty Controls Division

Grenadine Viscosity Testing

food and beverage

Viscosity is a significant concern in the Food & Beverage industry, because it affects product processing and packaging and may affect customer acceptance of a product. Viscosity is the resistance to flow. Grenadine is commonly used to flavor various mixed drinks, with or without alcohol. The original version comprises pomegranate juice with added sugar, boiled to remove water and thereby form a more concentrated syrup. Many commercially-available versions are made from high fructose corn syrup with colorants, preservatives and flavor additives. If a syrup is overly-concentrated, then its corresponding viscosity may be too high. This not only may make pumping more difficult, but it may affect customers' perception of the final product when pouring. Something too viscous may seem "too thick", while an overly-low viscosity may give a "too runny" impression, during pouring or dispensing.

Hotel employees were setting up a bar in an exposition room, during a conference. So, I asked one bartender, "What is the 'thickest', most viscous liquid that you have?" A red-colored Grenadine was selected from the two choices offered. A portion, about 7 mL, was transferred into concentric/coaxial cylinder accessory having an integral temperature probe. A cable, connected to the probe and the rheometer, allowed the temperature to be displayed and recorded by the instrument.

This accessory offers the advantage of small sample size, instead of testing a few hundred mL in a beaker. This helps significantly when testing expensive materials, or when thermal equilibration times must be kept relatively brief at specified temperatures. The instrument range is highly sensitive, having the capability of measuring low-viscosity liquids. One feature is a coupling that allows easier attachment and removal of spindles, compared to a threaded coupling that requires screwing spindles on or off. A sleeve is merely lifted up to release the spindle, and slid down to hold the spindle in place. This is shown in Figure 1, below:

Figure 1: Concentric/coaxial cylinder accessory with easily-locking coupling
(a). Spindle immersed in sample chamber, held in cooling/heating jacket
(b). Spindle hanging from coupling
(c). Coupling collar lifted up to allow spindle insertion or removal

Tests were run at room temperature, approximately 21-22 °C, after the sample equilibrated for several minutes. Single-speed tests were initially performed, to find a range of speeds producing on-scale torques. Speeds were selected so that Torque, %, readings were 10-100% of Full-Scale Range or "FSR" – per Brookfield recommended procedure. The instrument accuracy is ± 1% FSR, over this range. The touch-screen interface easily allowed run parameters such as spindle number, speed, and test step time, to be entered. A speed ramp – increasing and then decreasing speeds –

was created. The Power-Law [math] Model was selected as the Analysis. The data were displayed in real-time, during the tests. The best-fit model line was automatically graphed through the data, at the end of the test. Three speed ramp runs were performed. An example of the model fit, on the instrument display, is shown below:

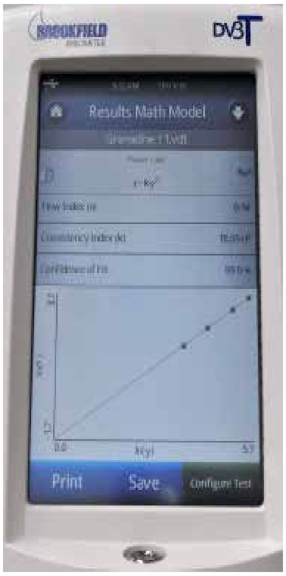

Figure 2: Power-Law model fit to Grenadine data, displayed on the rheometer.

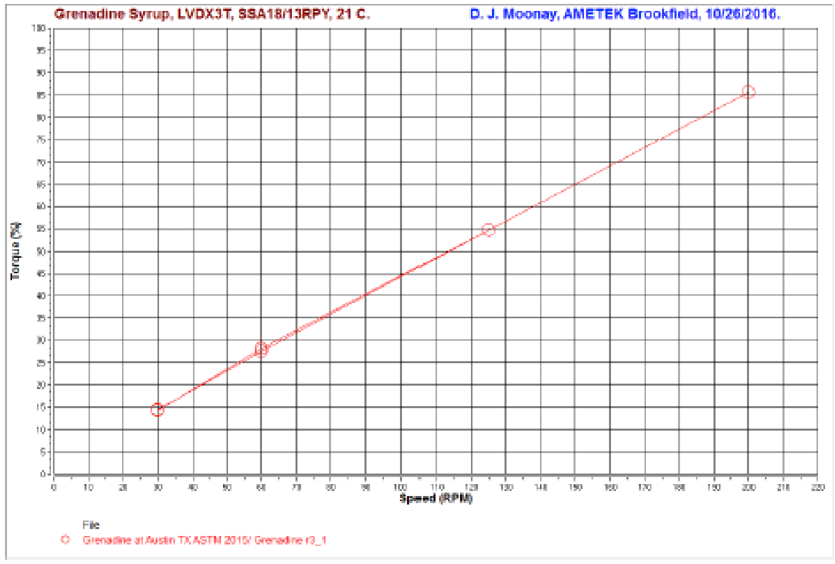

Figure 3: Torque, %, vs. Speed, rpm, for Grenadine at room temperature.

Data and program files were saved in the rheometer and then copied onto a "flash drive" or "USB stick", and then transferred to my PC. Software was used to import the files, manipulate and graph the data. Torque vs. speed data are shown above in Figure 3.

The Grenadine was slightly shear-thinning or pseudoplastic. That is, its Apparent Viscosity decreased with increasing shear rate [or speed]. This is shown in Figure 4, below:

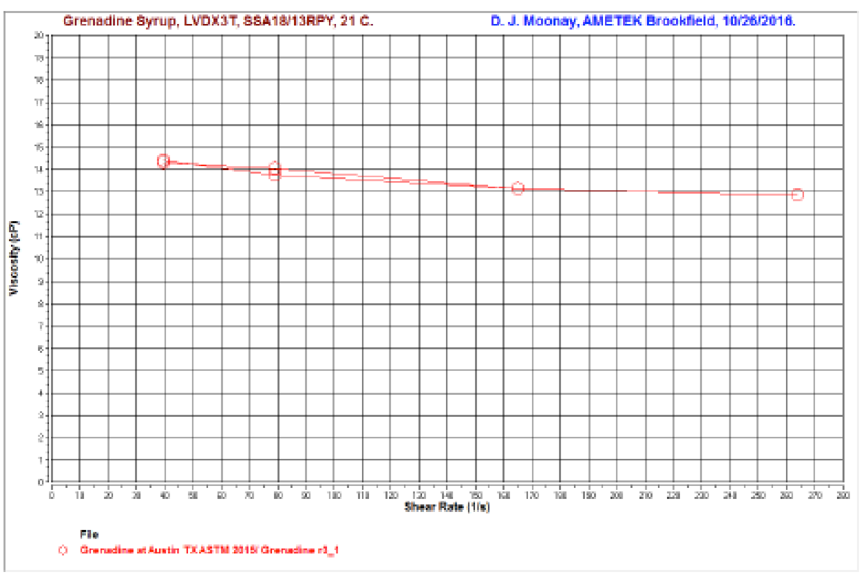

Figure 4: Figure 4: Apparent Viscosity, cP, vs. Shear Rate, s^{-1}, for Grenadine at room temperature.

Shear rate is a measure of how quickly or slowly a sample is sheared or "worked". It is determined by both the geometry and speed of the test. The SSA has a concentric- or coaxial-cylinder geometry; it is well-defined and, therefore, allows shear rate to be easily calculated. A Newtonian liquid has a viscosity that is independent of shear rate. Non-Newtonian materials, on the other hand, have Apparent Viscosities that depend upon shear rate. The data, above, show that this Grenadine was somewhat non-Newtonian, under the test conditions used.

The rheometer's built-in Power Law model fit the data well. The results were also plotted in software. The fit to data from run 3 are shown below, in Figure 5:

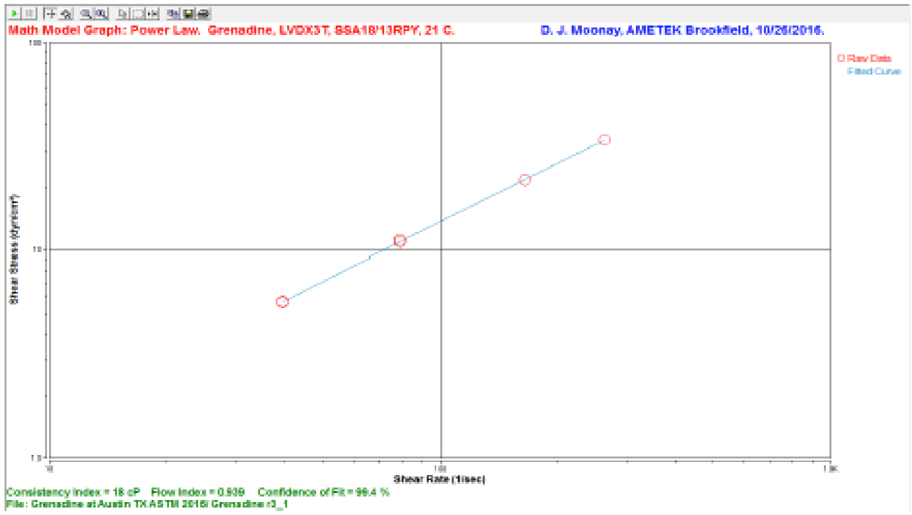

Figure 5: Power-Law math model fit to Grenadine data, at room temperature.

Math models are fit to viscosity data because they help linearize the data – that is, show the data in a straight-line form, rather than curved. They allow operators to interpolate, to calculate viscosities or shear stresses at shear rates other than those used in the simple tests. Shear Stress is the stress applied through the fluid layers during flow. Newtonian liquid flow may be described by the following simple equation:

$$\tau = \eta\dot{y} \tag{1}$$

where τ – the Greek letter "tau" – is the shear stress, η – "eta" – is the viscosity, and $\dot{y}$ – "gamma dot" – is the shear rate.

The Viscosity vs. Shear Rate data are curved in Figure 4, but are well-fit by a straight line in Figure 5. The latter is a Log-Log plot. The Power-Law equation is:

$$\tau = k\dot{y}^{n} \tag{2}$$

where τ is the shear stress, k is the Consistency Index, and n is the Flow Index. k provides an indication of the Apparent Viscosity at very low shear rates, while n indicates the degree of non-Newtonian behavior. Newtonian liquids have n = 1. The log-log plot is equivalent to graphing:

$$\log(\tau) = n \times \log(\dot{y}) + \log(k) \tag{3}$$

The Consistency Index = 18 cP, Flow Index = 0.939, and Confidence of Fit = 99.4%, in our example. The Grenadine n = 0.939 is slightly less than 1, reflecting the sample's mildly shear-thinning behavior. The calculated Confidence of Fit, 99.4%, is close to 100%, indicating a good fit to the data. Such data and model fits are important because they are very often used to specify and design processing equipment, such flow systems, mixers, and dispensing systems, for example.

In summation, viscosity measurements are useful for checking product quality and performance. Use of the well-defined, concentric- or coaxial-cylinder geometry, allows shear rate and shear stress data to be obtained during viscosity testing. That permits math models to be fit to multi-speed data, more fully characterizing the material flow behavior, and allowing calculations for process design. Grenadine, a commonly-used flavoring syrup in mixed drinks, exhibits non-Newtonian, shear-thinning behavior.

Author: David Moonay - Sales Engineer - Rheology Laboratory Supervisor
Email: david.moonay@ametek.com
AMETEK Brookfield, Instrumentation & Specialty Controls Division
11 Commerce Boulevard | Middleboro, MA 02346 USA | Tel: 800.628.8139 or 508.946.6200 | Fax: 508.946.6262
www.brookfieldengineering.com