1.0 Coffee and Refractive Index

Refractive Index measurements have been used for process control in the food industry since the 1940's. Typical measurements are usually for sugars in fruits, such as melons, orange and other juices, sugar content in grapes for the wine industry and many other examples. Refractive Index is directly related to the Total Dissolved Solids in solution of coffee, espresso or coffee extracts. The VST Coffee and Espresso refractometers are easy to use, accurate and portable high quality devices calibrated specifically for coffees. The VST LAB II Coffee-Espresso refractometers are typically accurate to +/- 0.03% with typical precision (repeatability) of better than +/- 0.02% within the coffee range.

Previous methods for TDS measurement of coffee include the oven drying dehydration method, which is slow and expensive but reasonably accurate if a large enough sample is dehydrated, and the sample is cooled in a desiccator. Conductivity instruments have proven unreliable for coffee, and measure ionic conductivity. Not all dissolved solids yield ions, as in the case for coffee. Generally, conductivity instruments are best applied to measuring lower values, well below 10,000ppm, such as TDS in water used for brewing, typically in the range of 50-400ppm (note: Coffee is typically 13,000ppm for 1.30% TDS). The hydrometer is another instrument that can be customized for use in measuring TDS of coffee at a specific temperature, is made of glass which is delicate, and requires a large sample be maintained within a few degrees of its design temperature. It is impractical in most environments.

To provide a meaningful solution to this problem, VST developed a state-of-the-art**,** hand held, digital refractometer designed specifically for coffee and espresso in 2008. The VST Coffee Refractometers and related coffee tools software products have won technical achievement awards for their innovative design, accuracy and practical use in the lab as well as in the field for brewing coffee and espresso and for many coffee and espresso beverage equipment design applications.

1.1 Coffee Process Control and the importance of TDS in Quality

Internationally accepted quality standards in the specialty coffee industry established [in the 1950's] that extraction of approximately 20% by weight of the ground coffee will achieve the best quality brewed coffee, using various brew methods and brewing parameters. The precise extraction percent may vary for particular coffees, brewing parameters and grind profiles, along with the strength (concentration or % total dissolved solids), to achieve finely tuned recipes for particular coffee cultivars, growing regions, climate, a.k.a.,terroir, and roast characteristics.

Up to 30% of the available soluble solids in [ground] coffee can be extracted, with most of the remaining 70% being cellulose, and not soluble in water. However, generally speaking, extracting more than 21% will begin to sharply increase those components in coffee that contribute to bitter taste defects associated with over-extraction. Extracting less than 18% is generally associated with weak, under-developed taste defects. Exceptions exist for certain coffees and grind profiles.

In order to determine the *actual level of extraction* reached for a particular coffee brewing method, one must know the brew formula and the soluble solids in final solution, or Total Dissolved Solids (% TDS) within an accuracy of +/- 0.06% or preferably better.

The **Brew Formula** is expressed as a curve on a brewing control chart, seen as the green line in **FIG. 1,** below. The **TDS** of the brewed beverage is measured using the VST-Coffee Refractometer at 1.30%, and plotted on the Brew Formula line in red. The **percent extraction** can then be read directly off the chart. In **FIG. 1**, the extraction in this design example is exactly 20%.

Another way of expressing this example is that 20% of 58 grams of coffee, or about 11.6 grams of coffee were extracted and dissolved into approximately 858 grams solution, or about 1.35% soluble solids in solution.

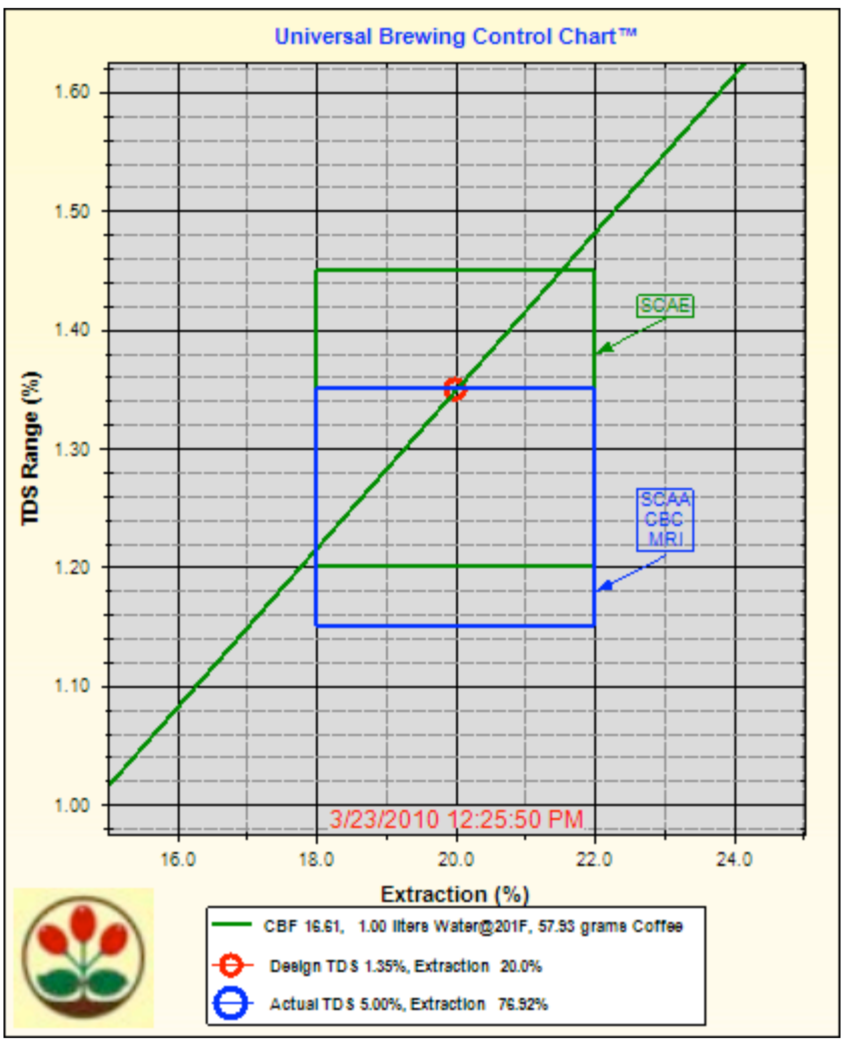

FIG. 1

1.2 Refractometers and Temperature

The VST Coffee refractometer is temperature corrected. Each unit is tested for accuracy against a known standard and typically reads to an accuracy of +/- 0.03% from 15-30 Deg C (LAB Coffee model, warranted accuracy is +/-0.05%).

Though temperature corrected, this does not mean that hot coffee can be placed on a cooler refractometer prism. Temperature correction means that the coffee sample and the instrument prism are stable at the same temperature, and in the temperature corrected range of 15 to 30 Deg C, and the measurement is taken at the same temperature the instrument was last zero-set to using distilled water.

Maintaining Accuracy

In order to get the most accurate TDS measurements, one should zero-set the refractometer using deionized or distilled water stored along with the refractometer at room temperature. Typical measurements of DI water after zero-set should be 0.00-0.02%. Before making a measurement of coffee TDS, stir the beverage, cool a small coffee sample (0.5 mL) to room temperature in a glass for 45-60 seconds, and then transfer into the refractometer sample well. Allow time for the coffee sample and prism to reach the same temperature (30 seconds). Then take a reading.

To maintain accurate measurements, re-zero the refractometer if ambient temperature changes by more than 1 Deg C. Avoid moving the instrument to sharply cooler or warmer ambient environments. If necessary to do so, use an insulated case (such as the optional Hard Case) during transit, remove from the case and allow time for the refractometer to reach ambient temperature then zero-set before use.

1.3 Using the VST Coffee Refractometer

When using the Coffee, and most other refractometers, the sample MUST be at the same temperature as the PRISM for an accurate measurement. Automatic Temperature Compensation (ATC) compensates for shifts in ambient temperature, not for the difference between coffee sample and prism temperature. Read the simple calibration and measurement technique sections, below, for an understanding of how to make accurate measurements.

Calibrate Using Distilled Water

Store the Refractometer, several cooling glasses and distilled water at room temperature. Zero-set before each measurement session. Re-zero if there is a change in ambient temperature of more than 1 degree C. The VST instrument is temperature corrected for use within a range of 15-30 Deg C, which should accommodate most “room temperature” conditions.

Measurement Technique

After brewing your coffee, be certain to stir the final solution before sampling. Then, pour a few grams of coffee into a clean and DRY glass or porcelain cup, allowing the cups mass to absorb thermal energy, and cool the sample. If necessary, transfer into a second glass, and allow to cool. When cooled to ambient temperature transfer the sample to the refractometer sample well using a pipette, using a few drops more than necessary to completely cover the glass.

Leave the sample on the prism for 15-30 seconds before taking an initial reading. This allows the sample to acclimate to the temperature of the prism. Check it a second time for a final reading.

Further Reading

1.4 What is Refractive Index?

Refractive index is a property of any substance that slows the velocity that light propagates through it. From a practical standpoint, we see the effect of refractive index in the form of a beam of light bending as it traverses the interface between two mediums such as air and water. For this reason a straw looks like it bends when placed in a glass of water. As an illustration of the bending of light, consider the ray in **FIG. 2** propagating at an angle of q_1 in Medium 1 which has an index of refraction of n_1. This ray bends to an angle of q_2 as it passes into a Medium 2 of index of refraction n_2. The mathematics that describes this amount of bending are given by Snell's Law according to

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 . \tag{1}$$

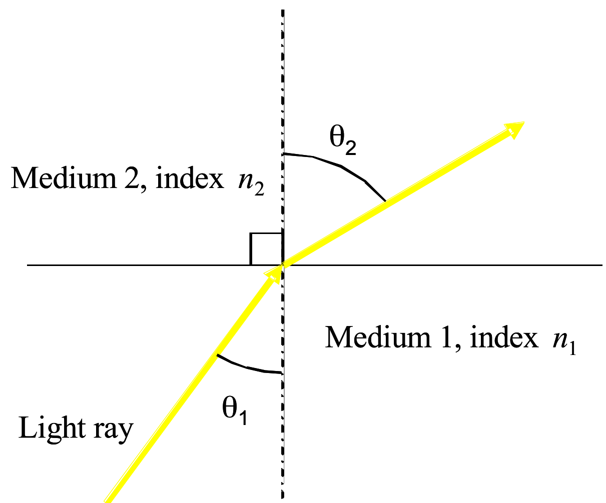

FIG. 1

Manipulating Eq. (1), one finds that the refracted beam in Medium 2 travels at an angle q_2 according to

$$\theta_2 = \arcsin\left(\frac{n_1 \sin\theta_1}{n_2}\right). \tag{2}$$

Therefore, the larger n_1 and q_1 are and the smaller n_2 is, the larger q_2 becomes.

It should be noted that the index of refraction for all material changes with wavelength. In other words, the index of refraction of glass, water, coffee, or any other material is different (actually higher) for blue light than it is for red light. It is for this reason that water droplets in the sky create a rainbow from sunlight and why sunlight passing through the beveled glass of a window or through chandelier glass will create a spectrum of colors on the wall or floor of a room.

1.5 What is a Refractometer?

A refractometer is an instrument designed to measure the index of refraction of a sample of material such as coffee, water, glucose, or other liquid or gel. Since the index of refraction of any material changes as a function of the wavelength of light, refractometers generally measure the index of refraction of light at a known wavelength. All liquid materials also exhibit changes of refractive index as a function of temperature, accordingly, refractive index measurements are corrected for temperature.

In the food industry, refractometers are used to measure solution concentrations, where these solutions can include soft drinks, fruit juices, tea, and coffee. For any of these solutions, as more material (sugar or other solids) are added to water, the index of refraction increases. By correlating how the percent solids, temperature for a particular solution changes the index of refraction at a particular wavelength, the measurement of index of refraction can later be used to determine the percent solids or TDS in a given solution.

Note that in the food industry, it is common to typically refer to the degree Brix of a given solution. Strictly speaking the º Brix is only accurate for a solution composed strictly of pure sucrose and water, as it is a measure of the percent sugar by weight in a sugar-water solution (eg., a solution with 10 gm sugar and 90 gm water is a 10% sugar solution and therefore a 10 º Brix solution). Temperature correction for Brix or sucrose is different than temperature correction for other materials. For other solutions that contain sugar as well as other solids, as is the case for coffee, the Brix scale is not usable. Coffee requires a separate correlation to a known set of reference standards. Separate correlations exist for sucrose, glucose, fructose, invert sugars, high fructose corn syrups and hundreds of other solutions.

Physically a refractometer is composed of a light source, a prism, and a linear detector array. As illustrated in **FIG. 3**, an illumination lens is used to direct the light from the light source to the prism and a collection lens collects the light that is reflected from the prism-sample interface and directs it towards the linear detector array. In modern digital refractometers the light source is typical a semiconductor laser or LED. The purpose of the illumination lens is to create a focusing beam or cone of light incident upon the prism-material interface that ranges in angles of incidence between q_{min} and q_{max}. The critical angle q_c of the prism-sample interface must be such that $q_{min} < q_c < q_{max}$, where q_c is the angle q_1 at which q_2 becomes 90º. From Eq. (2), in order for $q_2 = 90º$, the argument of the arcsin on the right hand side of the equation must equal unity. Using $n_2 = n$ for the index of refraction of the material under test and $n_p = n_1$ for the index of refraction of the prism, the critical angle can be expressed as

$$\theta_c = \arcsin(n_2 / n_1) = \arcsin(n / n_p). \tag{3}$$

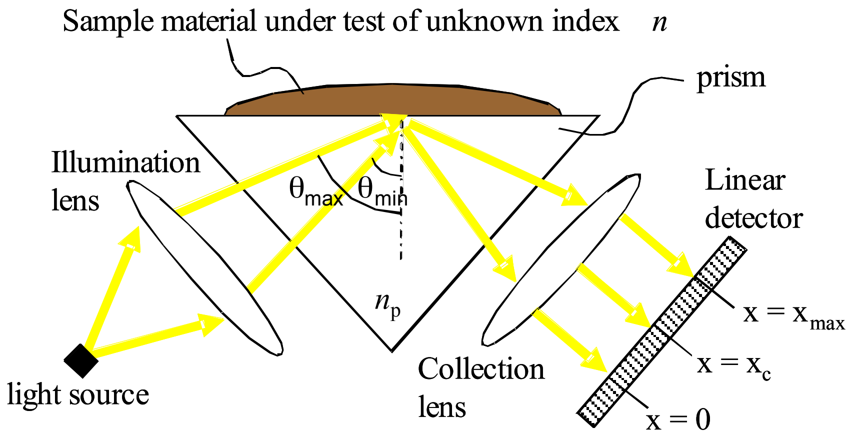

FIG. 3

A unique property of the critical angle is that for all angles larger than q_c, 100% of the light is reflected from the interface and none transmits. For angles inside of the prism that are less than q_c some light transmits into the sample material and therefore less than 100% of the light is reflected. In other words, for all rays in the beam of light focusing in the prism that are greater than the critical angle, 100% of the light is reflected off of the prism-material interface and propagates towards the collection lens and then on to the linear detector. The ray that is incident upon the prism-sample interface at q_c will strike the linear detector at a point $x = x_c$. By analyzing the detected light levels from $x = 0$ to $x = x_{max}$ on the detector, the software of the refractometer detects the position x_c since for $x_c < x < \underline{x}_{max}$, the light level is constant across the detector array (cannot get any more than 100% of the light reflected!). With a well-calibrated refractometer, the detector position x_c is mapped back to a critical angle q_c, which from Eq. (3) and knowing the index of refraction of the prism n_p, the index of refraction n of the sample can be calculated and reported.

In addition to being wavelength sensitive, the index of refraction for any material changes with temperature. For coffee, the measured index of refraction will change the reported TDS value by > 0.25% if thermal affects are not accounted for over approximately 5 Deg C. It is not uncommon to start a measurement session at normal ambient of 20 Deg C in the morning, and be at 25 Deg C a few hours later. This is why VST recommends re-zero setting when ambient changes by more than 1 Deg C, or +/- 0.5 Deg C.