## 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. To the best of our knowledge, no one has ever provided an easy to use, accurate and portable refractive index device calibrated specifically for coffees.

Previous methods for TDS measurement of coffee include the oven drying **dehydration method**, which is slow and expensive but highly accurate, **conductivity instruments** which are difficult to calibrate and have proven unreliable and the **hydrometer method**, which is delicate, temperature sensitive and impractical in most environments.

To provide a meaningful solution to this problem, VST has partnered with a world leading manufacturer of optical instruments to develop a state-of-the-art **refractometer designed specifically for coffee,** called the **VST-Coffee Refractometer** manufactured by Reichert Analytical Instruments. Reichert is a well known optical instrument manufacturer, and their products have won technical achievement awards for their innovative design, accuracy and practical use in the field for hundreds of 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. The precise extraction percent may be varied for particular coffees, along with the strength, 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.

In order to determine the **actual level of extraction** reached for a particular coffee batch, one must know the brew formula and the soluble solids in final solution, or Total Dissolved Solids (% TDS). The brew formula is simply the water amount by weight, and the ground coffee weight used in the batch.

The **Brew Formula** is expressed as a curve on a brewing control chart, seen as the green line in **FIG. 1,** below. The **TDS** 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.

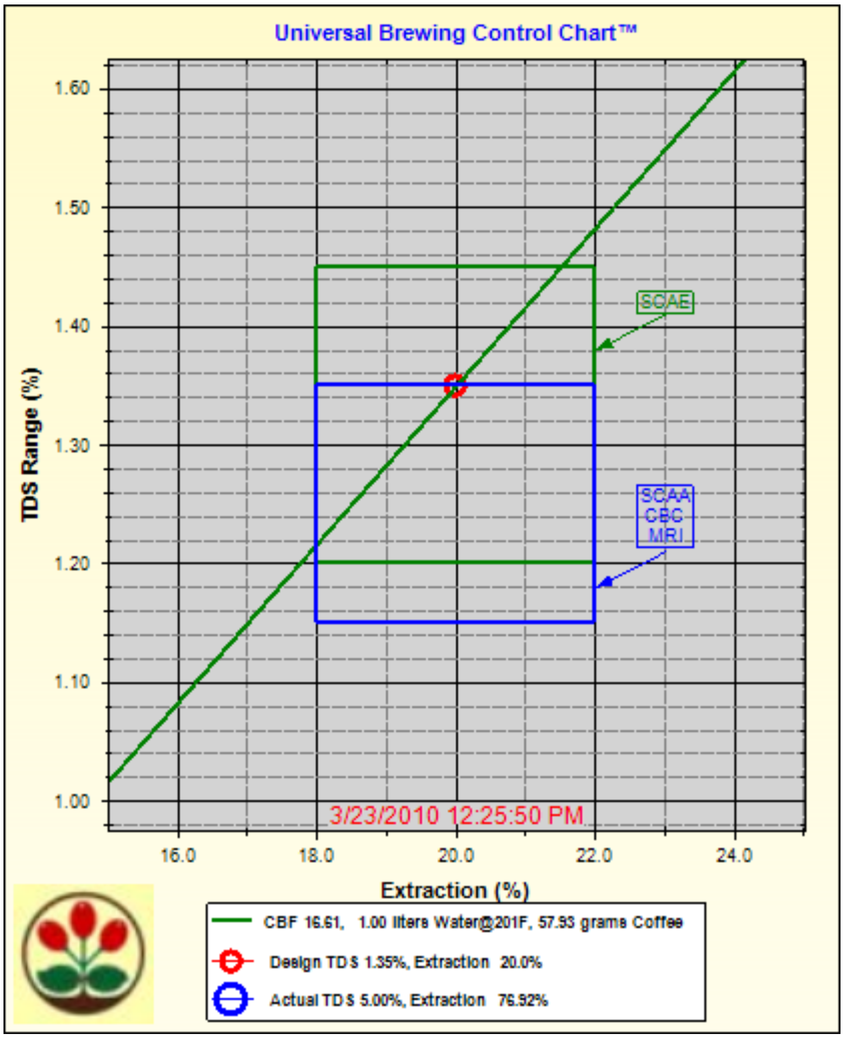


FIG. 1

### 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 extrapolated accuracy of +/- 0.05% from 15-30 Deg C (although the warranted accuracy is +/-0.1%). This is accurate enough for most applications for coffee in the field. Higher accuracy refractometers for research and laboratory use are available at www.mojotogo.us

Though temperature corrected, this does not mean that hot coffee 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.

**Maintaining Accuracy**
In order to get the most accurate TDS measurements, one should calibrate the refractometer using deionized or distilled water stored at room temperature, along with the refractometer. Check the refractive index (nD) against a table for DI water at the temperature indicated when using the refractometer in its native mode (i.e., reading nD and TEMP). Then, cool the coffee sample to room temperature and transfer into the refractometer sample well, and allow time for the coffee sample and prism to reach the same temperature. Then take a reading.

Therefore, in order to obtain best accuracy, do not take the refractometer out of your warm pocket or out of a cold car (in winter) and immediately expect it to work accurately. Allow time for the refractometer to reach ambient temperature and calibrate 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 and a container of distilled water at room temperature, and calibrate if there is a change in ambient temperature of more than a few degrees C. VST recommends calibration and use within a range of 15-30 Deg C, which should easily 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 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

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 . \qquad (1)$$

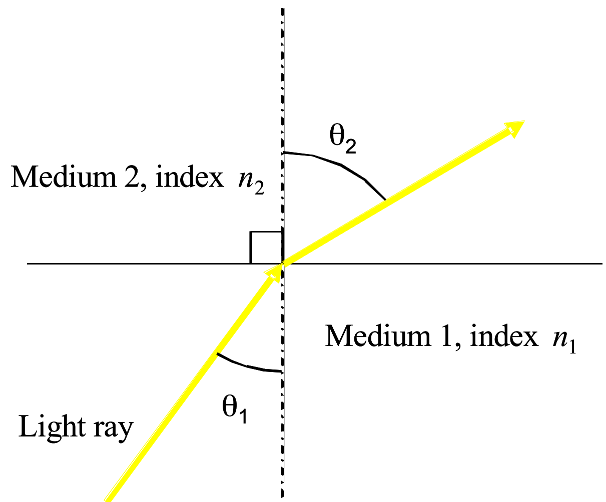


FIG. 1

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

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

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 wavelength close to 589.3 nm, which is yellow light.[1]

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 for a particular solution changes the index of refraction, 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 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). For other solutions that contain sugar as well as other solids, as is the case for coffee, the Brix scale is not accurate and requires a new correlation to a known set of reference solutions. 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 at about 589.3 nm (yellow light). 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

$$\theta_c = \arcsin(n_2 / n_1) = \arcsin(n / n_p). \quad (3)$$

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[1] Historically yellow light of a wavelength of 589 nm is used because before lasers were invented, scientists could generate such pure yellow light using a sodium arc lamp. These yellow lamps are sometimes seen today to illuminate parking lots or alleys at night.

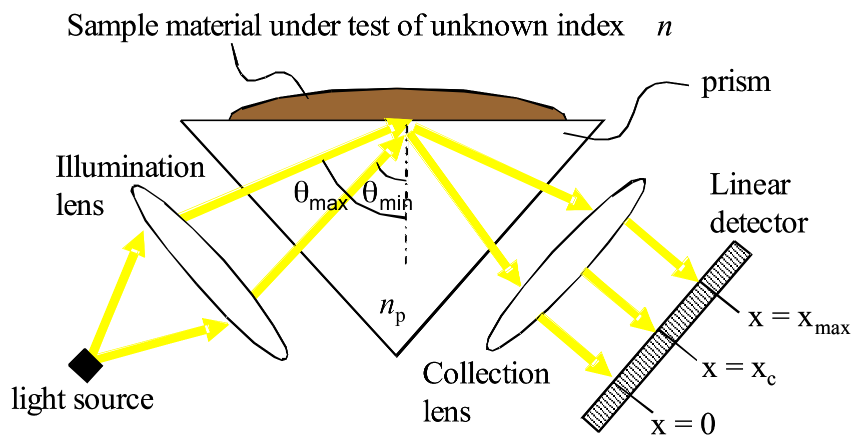


FIG. 3

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 slightly with temperature. For coffee at 20ºC the index of refraction is ~1.3353 and changes by -0.0001 for every degree C. This may not seem like much, but for a 5ºC change in temperature of a coffee solution, the measured index of refraction will change by -0.0005 and the reported TDS value will change by 0.25% if thermal affects are not accounted for.

## What is ATC? (from www.refracts.com/FAQ.htm)

ATC is an abbreviation for **automatic temperature compensation.** ATC allows the user to take accurate scale readings at varying ambient room temperatures.

**Benefits of ATC:** Without ATC, if the temperature of the room changes by a degree or two, the refractive index shifts. The scale is only accurate for the temperature at which calibration was done. ATC allows the refractometer to maintain accuracy at a wider range of ambient temperature shifts (between 20-50 degrees Celsius). So ATC refractometers require calibration much less often than models without automatic temperature compensation.

**Temperature of the sample:** The sample MUST be the same temperature as the prism for an accurate reading. ATC compensates for shifts in ambient temperature, not for the difference between sample and prism temperature. If you are working with samples at a temperature different than the ambient room temperature, leave the sample on the prism for 30 seconds before taking the reading. This allows the sample to acclimate to the temperature of the prism

**Ambient air temperature:** ATC models are best suited for settings where the room's air temperature may vary more than one degree. Even as much as a single degree of temperature variation can affect the reading of a refractometer without ATC.