How to Use a Refractometer to Brew Beer

Easy-to-Use Refractometers have become the new standard for beer measurement

Our love of beer, one of the oldest products in the world, dates back some 7,000 years. From its humble beginnings as an industry, necessity warranted the creation of various standards and methods for measurement. The need for standards was driven by simple commercial requirements for accurately measuring the extract content of the wort for determination of excise taxes.

Most of these methods initially relied on the hydrometer, or some other primitive measure related to specific gravity, to provide an indication of sugar or alcohol concentration. However, refractometers have now proven themselves to be useful tools for the brewer.

This paper is intended to help you get the most out of the refractometer that you currently own and to help you decide what is most important in selecting a refractometer for future use.

Why Measure Beer?

In the US and Canada, beer is primarily taxed based on the volume removed from the brewery. In Europe, however, taxation is country dependent and is either based on the °Plato per hectoliters (strength of original extract by volume) or, in some cases, the alcohol content per hectoliter.

For most tax purposes, it is often assumed that 1 °Plato ≈ 0.4 percent alcohol by volume. However, in the UK, beer tax is calculated by multiplying hectoliters by the declared alcohol by volume as determined through distillation.

Primarily, measurement is about quality control. For instance, even though beer in the US is taxed based on its volume, it is still industry best practice for the beer chemist or brewer to keep accurate records of beer measurements.

Development of a Cohesive Measurement Standard

Archimedes was the first to observe the relationship between the densities of liquids sometime between 267 and 212 BC. Relying on the Archimedes principle, Hypatia of Alexandria, one of the first recorded female scientists, invented the first hydrometer between 390-415 AD. As an instrument, the hydrometer was largely ignored until it gained widespread acceptance after reintroduction by English scientist Robert Boyle in the late 17th century.

In subsequent centuries, a series of improvements to the basic hydrometer were made with the intention of providing a simplified system for the measurement of specific gravity by unskilled persons. These improvements related more to differences in units of measure than to the actual principle of measurement.

Different units of measure for specific gravity are akin to the difference in reporting temperature in degrees Celsius vs. Fahrenheit. Specific units of measure became standard in a particular beer making region or part of the world and were more cultural than significant.

Later, around the turn of the 20th century, it was found that refractometers offered a superior method for the measurement of sugar and alcohol compared to the hydrometer. Many of the units of measure originally developed for simplifying hydrometer readings were adapted as refractometer scales.

The most common international brewing units of measure consist of Brix, °Plato, Specific Gravity, Brewer's Points, Balling, and Total Dissolved Solids (See Appendix I).

Common Beer Measurement Terminology

For those new to brewing, there are some common brewing terms that are important to understand with respect to beer measurement. These terms are covered only briefly here. The reader should be familiar with these concepts and can find much more written about them in other publications.

Wort is the liquid extracted from the mashing process during beer brewing. Wort contains the sugars to be converted to alcohol during fermentation.

Specific Gravity (D20/20) is the relative density of a fluid at a reference temperature, relative to the density of water at a reference temperature. It can be measured using either a hydrometer or refractometer with an appropriate scale, providing fermentation has not yet started.

Original Extract (OE) is the mass in grams of sugars in 100 grams of wort, prior to fermentation, as measured on the °Plato, Brix, or dissolved solids scale. It can be measured directly on certain refractometers and hydrometers or converted from Original Gravity.

Original Gravity (OG) is directly related to OE, with the exception that it is a measure of specific gravity at a given reference temperature prior to fermentation. It can be measured directly on certain refractometers and hydrometers or converted from OE.

Apparent Extract (AE) is related to Final Gravity, and represents that portion of the OE present as residual sugars which were not converted to yeast biomass, ethanol, or CO2 during fermentation. It can be expressed interchangeably as °Plato, Brix, or dissolved solids and is usually determined through calculations based on OE, or specific gravity as read on a hydrometer.

Final Gravity (FG) is a measure of specific gravity, at a given reference temperature, at the conclusion of fermentation and is directly related to AE. Specific gravity readings can signal the end of fermentation when they stop moving. FG can be measured directly on a hydrometer or calculated based on OE and AE.

Apparent Attenuation (AA) is a measure of the amount of sugar consumed by yeast during fermentation and the extent to which the yeast has been able to successfully convert fermentable sugars into ethanol and CO2. It is calculated as the drop in extract during the fermentation divided by the OE.

Alcohol by Volume (ABV) is simply the percentage alcohol per volume of beer.

Hydrometer vs. Refractometer

The hydrometer is based on Archimedes principle that a solid suspended in a liquid will be buoyed up by a force equal to the weight of the liquid that it displaces. Therefore, the lower the specific gravity of the substance, the lower the hydrometer will sink.

Hydrometers are usually constructed of glass or plastic. They often have a cylindrical stem with a measurement scale sealed inside and a carefully weighted bulb to make it float upright. In use, the hydrometer is gently lowered into the liquid until it floats freely. The reading is taken at the point where the surface of the liquid (the meniscus) crosses the scale on the stem of the hydrometer.

Although the hydrometer is affected by the density of the fluid, it may have a scale inside with any particular unit of measure that is related to density. One important point to note is that whatever the unit of measure, the hydrometer scale is only valid at one particular temperature. Hence, they must be used in conjunction with a thermometer, and any variation from the reference temperature must be noted and compensated for.

Also, due to the nature of the hydrometer, a relatively large sample size must be used so that the hydrometer can float freely. Since the hydrometer is made of glass, great care must be taken to keep it from breaking. Obviously, the hydrometer is not designed to be used as a field instrument.

Refractometers

A refractometer is an optical instrument designed to measure the concentration or mixture ratio of water soluble fluids. It measures refractive index, the speed at which light passes through a liquid. The denser the liquid the slower the light will travel through it, and the higher its reading will be on the refractometer. Like hydrometers, many different scales are available that convert refractive index into a unit of measure that is more meaningful, i.e., Brix, specific gravity, °Plato, etc.

Refractometers designed for field use are usually rugged and portable. An advantage over the hydrometer is the relatively small sample size that is required for testing. This also saves time required for cleaning and sanitizing the hydrometer equipment.

Although refractometers are also dependent on temperature, certain refractometers are made with automatic temperature compensation; in fact, you shouldn't rely on results from a refractometer without temperature compensation.

Brewers are likely to encounter two different types of refractometers; Traditional Analog and Digital Handheld.

Traditional Analog Refractometer

The traditional analog refractometer is comprised of lenses and prisms that focus a shadowline on a tiny glass reticle with a scale etched on it. You point one end at a light source and look through the other end. The scale inside is likely to be Brix (a measure of sucrose), wort specific gravity, or both. These units, likely made in China, can be found for as little as $35 to $60.00 and are aimed at the home hobbyist.

The Traditional Analog Refractometer can be further split into two categories, those with and without automatic temperature compensation. However, since refractive index (the underlying method of measurement) is very temperature dependent, refractometers without temperature compensation <u>should not</u> be considered. However, analog refractometers with temperature compensation are compensated based on sucrose, which is problematic since there is so little sucrose in wort.

Digital Handheld Refractometer

The second type of refractometer is the digital handheld refractometer. Digital instruments read the refractive index of a fluid and use an internal scale to convert refractive index into a useful unit of measure, such as Brix, Plato, or specific gravity, and display that value on an LCD display. Like analog refractometers, there are many different brands of digital refractometers whose quality and accuracy can vary widely.

How can I use a Refractometer for Beer?

Refractometers are most useful at three points in the brewing process; before, during, and after fermentation.

Before fermentation, refractometers should be used to measure the OE or OG of the wort. Use the Dissolved Solids, Brix, °P, or specific gravity scales and record the value. The most accurate reading for wort will be obtained by using the Dissolved Solids scale since it is based on the type of sugars in actual wort.

During and after fermentation the specific gravity scales will not do you any good. Refractometers are very good at measuring binary (two-part) mixtures such as sugar and water, so they are good for measuring wort. However, once fermentation begins the solution consists of water, sugar, and ethanol and the three components interfere with accurate specific gravity measurements. That said, the refractometer is still a valuable tool during and after fermentation.

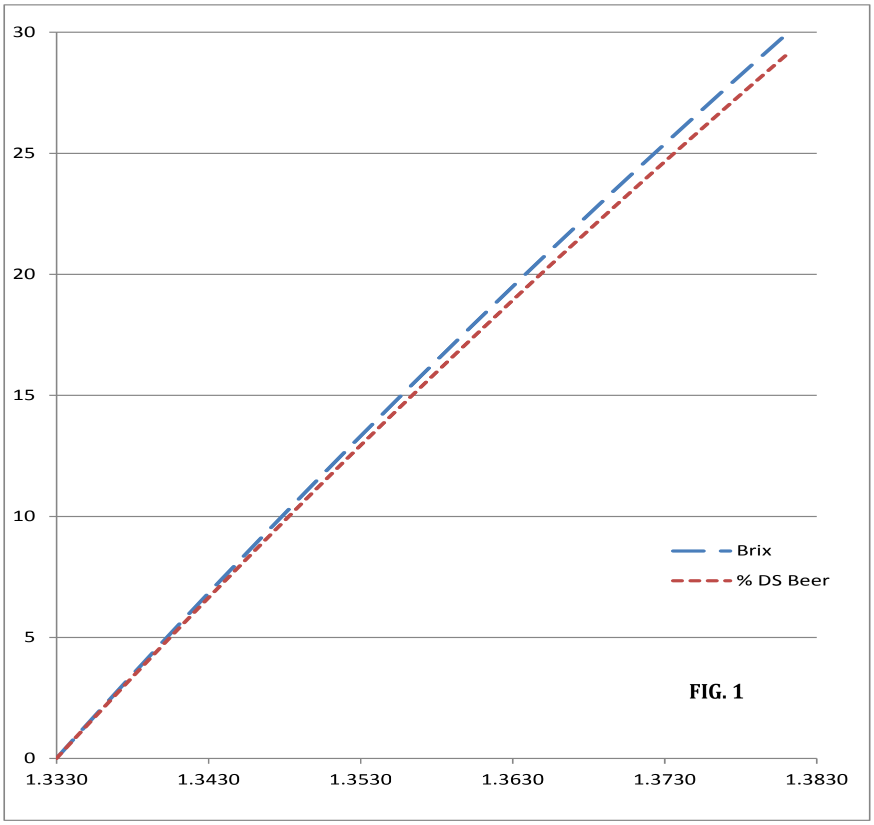

FIG. 1

Method #1: Take a measurement on a refractometer using a Brix, Plato, or dissolved solids scale. Then take a reading with a hydrometer. Finally, enter the readings into an online calculator to determine such things OG, AE, FG, AA, and ABV.

Method #2: Use a refractometer Brix, Plato, or dissolved solids scale to measure the wort OE before fermentation begins and record the measurement. Any time after fermentation has commenced you can take another reading on the same scale and then plug both readings into an online calculator or brewing software to determine AE, FG, AA, and ABV.

The Truth about Refractometer Correction Factors

In Figure 1, you can see the difference in the relationship between sucrose concentrations, true wort dissolved solids, and refractive index.

Wort is primarily a blend of maltose and other sugars with very little sucrose. Curiously, all refractometers used for beer measurement, with the exception of the certain scales on the MISCO Digital Beer Refractometers, are based on the mathematical relationship between refractive index and sucrose, and then temperature compensated for sucrose.

As a result, their readings are on average between 1.02 to 1.05 times above the real sugar concentration of wort. Therefore, unless you are using one of the aforementioned MISCO Pro-Brewing Scales, you should divide your Brix refractometer measurements by

MISCO Digital Beer Refractometer scales are scientifically derived from a complex sugar model based primarily on maltose and other common wort sugars – It's not just another re-purposed sucrose-based Brix refractometer.

about 1.04 to get a more accurate measurement. This is the reason there is a place in most brewing software and online calculators for a refractometer correction factor.

Since the MISCO Dissolved Solids and Specific Gravity Scales are scientifically derived from a complex sugar model based primarily on maltose and other sugars common to wort, you receive a more accurate reading without the need to use a correction factor.

How to use a Refractometer to Measure Beer

Regardless of the type of refractometer you have, they are used for beer making in relatively the same manner. Here are some tips for getting the most accurate reading from your refractometer:

1. Follow the recommended procedure to calibrate your refractometer to distilled water.
2. Make sure that the measuring surface is clean.
3. If measuring beer, degas a small sample by agitation or by pouring it from cup to cup 20-30 times. This will also help cool a sample if it has been boiling.
4. Use a clean disposable pipette to transfer a wort sample to the refractometer measuring surface and discard the pipette.
5. IMPORTANT: Allow time for the temperature of the refractometer, the ambient temperature, and the sample temperature to come to equilibrium.
6. Take five measurements and average their readings. If the readings are drifting in one direction then you probably have not allowed enough time for the temperature to stabilize.
7. Clean the refractometer and store it for its next use.

Problems with Beer Refractometer Readings

A frequent complaint in brewing forums is that someone's refractometer does not match their hydrometer. This can be caused by a number of circumstances:

1. The user failed to measure the temperature of the wort when taking the hydrometer reading or did not temperature correct the hydrometer reading.
2. Using an analog refractometer that is not temperature compensated.
3. Using a refractometer that was not calibrated before use.
4. Using a refractometer that may have been temperature compensated but the reading was taken outside the range of compensation (50 to 86 °F on most analog handhelds).
5. Using a refractometer that is temperature compensated for sucrose will cause an error that must be adjusted for since there is very little sucrose in wort.
6. Using a refractometer after fermentation has started without using brewing software or an online calculator.
7. The refractometer is of poor quality. Sadly, you get what you pay for.

Another frequent problem for refractometers advertised as beer refractometers, is that the internal scale for specific gravity is based on the old rule-of-thumb that specific gravity is equal to Brix multiplied by four. The problem is this is just an estimate and not the true relationship between Brix and specific gravity. Very few analog refractometers with specific gravity scales use an accurate relationship between Brix and specific gravity.

Yet another problem with using Brix/specific gravity refractometers for wort is the temperature compensation for these instruments is based on sucrose. However, wort is primarily maltose. The difference between maltose and sucrose is large enough to cause significant error in temperature compensation.

MISCO Beer Refractometer Benchmark Testing

A leading third-party beverage laboratory benchmarked the MISCO Digital Beer Refractometer against an industry standard Anton Paar DMA5000 Digital Density Meter (accurate to +/- 0.000005 specific gravity). On samples from a dozen different worts, the MISCO Beer Refractometer matched the DMA5000 specific gravity readings to +/- 0.001 or better in all tests. The MISCO refractometer matched Original Extract readings on the DMA5000 to +/- 0.1% or better, in all but one sample.

Using the beer calculator on the MISCO website, the MISCO beer refractometer was used to test a dozen different finished beers. The average difference between the MISCO refractometer and the DMA5000 was

<0.001 specific gravity (95% confidence interval). For alcohol content determination, the MISCO refractometer matched the DMA5000 to 0.5% ABV.

The complete study results are available on the MISCO website.

Why are MISCO Digital Refractometers better?

Besides the Pro-Brewing Scales, only MISCO refractometers utilize MISCO's proven OPTICAL-ENGINE®, which is at the heart of every Digital Beer Refractometer. Optical-Engine technology features high-precision sapphire optics, the next hardest substance to diamond, which improve the speed and accuracy of temperature measurements. Competing digital refractometers only use glass prisms. A 1,024 element high-definition detector array provides more than eight times the resolution of competing 128 element low-definition detector arrays. The MISCO array has more than 3,256 pixels per inch (ppi) resolution compared with 400 ppi resolution in competing digital refractometers. The net result is an instrument that is more rugged and more precise. Plus, MISCO Refractometers are made in the USA.

SUMMARY

Although hydrometers have historically been used longer than refractometers, it has been demonstrated that refractometers are tools that no brewer can afford to be without. Refractometers are sturdier and easier to use than hydrometers for many of the everyday tasks that face the brewer.

For more information on MISCO **MISCO Digital Beer Refractometer**, please visit www.misco.com/beer on the MISCO website.

A world leader in the refractometer field, MISCO is headquartered in Cleveland, OH, home to the company for 60+ years. MISCO designs, manufactures and sells a variety of refractometers, including: digital bench-top laboratory refractometers, inline process control refractometers, digital handheld refractometers, and traditional handheld instruments. For more information, please call (216) 831-1000, or access MISCO's web site at www.misco.com/beer.

TRADEMARKS & ACKNOWLEDGEMENTS

MISCO, OPTICAL-ENGINE, Pro-Brewing Scales, and Palm Abbe are trademarks or registered trademarks of MISCO Refractometer. DMA5000 is a product of the Anton Paar Co.

Following is a listing of the standard **Pro-Brewing Scales** available from MISCO, custom configurations are available upon request on the Build-Your-Own section of our website:

MISCO Pro-Brewing Scales						
Scale	Unit of Measure	Basis	Range	Resolution	Precision (+/-)	Temp. Comp. Basis
799	Brix	Sucrose	0 to 30	0.1	+/- 0.1	Wort Sugars
800	Dissolved Solids (Sugars)	Wort Sugars	0 to 30	0.1	+/- 0.1	Wort Sugars
801	°Plato	Sucrose	0 to 30	0.1	+/- 0.1	Wort Sugars
802	Specific Gravity (D20/20 °C)	Wort Sugars	1.000 to 1.127	0.001	+/- 0.001	Wort Sugars
803	Specific Gravity (D60/60 °F)	Wort Sugars	1.000 to 1.128	0.001	+/- 0.001	Wort Sugars
804	Brewer's Points @ 20 °C	Wort Sugars	0 to 127	0.1	+/- 0.5	Wort Sugars
805	Ethanol (by Distillation)	Ethanol	0 to 30	0.1	+/-0.2	Sucrose
806	Balling	Sucrose	0 to 30	0.1	+/- 0.1	Wort Sugars
MISCO Propylene Glycol (PG) Scales for Wort Coolers & Chillers						
006	Percent by Volume	PG	0 to 100 %	0.1	+/- 0.1	PG
008	Freeze Point °F	PG	+32 to -60 °F	1	+/- 2	PG
009	Freeze Point °C	PG	0 to -51 °C	1	+/- 1	PG

Appendix I

MISCO PRO-BREWING SCALES™

To accommodate brewers from different regions of the world, who desire to measure beer with their own preferred units of measure, MISCO has created a variety of beer scales from which to choose. The user may select up to five scales including Total Dissolved Solids (sugars), Brix, °Plato, Specific Gravity, Brewer's Points, Balling, and ABV.

Dissolved Solids Scale

The Dissolved Solids Scale was created specifically for beer; it is not just a repurposed sucrose scale, nor is it based strictly on maltose alone. The scale is instead scientifically derived from a complex beer model with a sugar profile that is specific to wort. The sugar profile accounts for maltose, maltotriose, dextrose (D-glucose), fructose, and sucrose, with the remainder consisting of larger saccharides, and other material which is non-fermentable by standard brewer's yeast (in general, saccharides larger than DP3).

The Dissolved Solids Scale represents the true mathematical relationship between actual wort dissolved solids and refractive index. This dissolved solids content is expressed in grams of sugars per 100 grams of wort and is equivalent to percent weight per weight. For most calculation purposes the measurement can be used in place of Brix or °Plato.

Measuring wort on the percent dissolved solids scale will give you a more accurate indication of true total sugar content of wort, rather than trying to estimate it using a Brix refractometer. Also contributing to more accurate readings is the fact that the MISCO dissolved solids scale is temperature compensated specifically for wort, compared with sucrose compensation in a Brix refractometer.

Brix Scale

The Brix scale is probably the most recognizable scale for most brewers in the US and Canada. It is simply the percent weight of dissolved solids (sucrose) in a sucrose/water solution. It is used in beer brewing because the Brix units are a convenient unit of measure found on many refractometers and hydrometers. Within the accuracy of most handheld refractometers, Brix is synonymous with °Plato.

However, the Brix scale is used more accurately in the wine industry, since grape must is composed primarily of sucrose, whereas beer is composed primarily of maltose with very little sucrose. The difference between the sucrose and malt-ose content is often estimated and used as the basis of a cor-rection factor in many popular beer calculators. Although the Brix scale is based on the sucrose/refractive index relation-ship it is temperature compensated for wort, just like the other Pro-Brewing scales.

°Plato Scale

Degrees Plato represents a unit of measure dating back to Brewers from the late 19th Century. The intention of the scale was to convert specific gravity, as measured with a hydrometer, into the weight percent of sucrose, as a measure of total fermentable material. The Plato scale is historically more popular in central European brewing and is very nearly equivalent to the Brix scale which is used predominantly in the US. Although the Plato scale on the MISCO Digital Beer Refractometer is based on the sucrose/refractive index relationship, it is temperature compensated for wort instead of sucrose, for a more accurate reading.

Specific Gravity Scales

Specific gravity is the relative density of a fluid at a reference temperature, relative to the density of water at a reference temperature. Specific gravity is often measured with a hydrometer. In order to obtain an accurate reading from a hydrometer, the solution measured must be at the reference temperature of that hydrometer or the solution temperature needs to be measured and a correction applied to the reading.

Specific gravity readings are typically denoted in the form "D t1/t2," where "D" represents relative density, t1 is the reference temperature of the solution, and t2 is the reference temperature of water. One problem faced by the brewer is that most brewing hydrometers are calibrated for a reference temperature of 60/60 °F and most reference data and calculations are based on a reference temperature of 20/20 °C (68°F). Therefore, we offer two specific gravity scales, Specific Gravity (D 20/20 °C) and Specific Gravity (D 60/60 °F).

The 60/60 scale should most closely match your brewing hydrometer and the 20/20 scale eliminates the need to make a correction when using the readings for calculations or comparing to reference data. Unlike your hydrometer, however, the refractometer scales are automatically temperature compensated and only require one or two drops for a sample.

One more note about the specific gravity scales. During fer-mentation, yeast converts wort sugars into carbon dioxide and ethanol. As fermentation progresses, sugar content de-clines, while ethanol content increases. Since ethanol is less dense than water, and less dense than the sugar it is replacing, the specific gravity decreases with time, until it stops declining, signaling the end of fermentation.

Refractometers are ideal for measuring binary (two-part) mixtures, such as wort, which is just sugar and water. Since the refractive index of water is a constant, the sugar becomes the variable. Therefore, the addition or loss of water, or an increase of sugar, will change the refractive index in a predictable way. The addition of another element, such as ethanol, creates a problem for a refractometer. With sugar, ethanol, and water there are now two variables and it is nearly impossible to determine whether the change in refractive index is caused by water, sugar, or ethanol. Therefore, a refractometer cannot be used to "directly" measure the specific gravity during or after fermentation.

Fortunately, if you know the original gravity (OG), Brix, °Plato, or dissolved solids of the wort you can simply plug that value, together with the current measured value (during or after fermentation) into a beer calculator to obtain accurate estimates of alcohol content and real extract.

The MISCO Pro-Brewing Specific Gravity Scales are based on the relationship between wort specific gravity and refractive index (not sucrose). They are also temperature compensated for wort.

Brewer's Points

Points are a type of shorthand used by brewers and are the equivalent of ((specific gravity - 1) x 1000). For example, wort with a specific gravity of 1.045 would be said to have 45 points. Using the old brewer's rule-of-thumb, it is easy to estimate Brix of Plato by dividing points by four. For exam-ple, a brewer would estimate that a 45 point wort would have an estimated °Plato or Brix value of 11.25. Alternatively, multiplying Brix, °Plato, or dissolved solids by four would give you a rough estimate of points.

The MISCO Pro-Brewing Brewing Points Scale is based on the relationship between wort specific gravity and refractive index (not sucrose). It is also temperature compensated for wort.

Balling Units

Karl Balling constructed a method and a series of tables relating specific gravity to the percent by weight of sucrose in a sucrose water solution in the mid-19th century. Fritz Plato improved upon the relationship and published his tables in the early 20th century. Balling units are seldom used anymore and for all practical purposes are the same as Brix and °Plato.

The Balling scale was a hydrometer scale developed by Ger-man chemist Karl Balling in 1843. It was designed to measure the concentration of a sucrose solution, as the percentage weight of sucrose at it is used primarily for beer making,

Ethanol Concentration

If you know the OE and AE, you can use an online calculator or brewing software to calculate the alcohol content to about 0.5% ABV. In the event that you need to know the alcohol content to a higher level of accuracy, you will need to distill the finished beer to boil off the ethanol, make up the volume with distilled water, and then measure the distillate with a refractometer equipped with an ethanol scale.

Propylene Glycol

Although there is no Propylene Glycol (PG) in finished beer, brewers often use PG in their chiller systems and need a way to measure the freeze point or concentration. MISCO has a number of PG scales that can be added to the MISCO Digital Beer Refractometer.