Paper No. 130626

Using Refractometers to Increase the Efficiency of Vineyard Management and Winemaking

INTRODUCTION

The old business adage, "If you can't measure it, you can't manage it," couldn't be more true in the wine industry. From planting and harvesting grapes, through fermentation to finished wine, there are many steps and processes that, when managed properly, produce superior product.

Wine is one of the oldest products in the world. From its beginnings as an industry, various standards and methods emerged for measuring grapes and wine. The need for a measurement standard arose from the commercial necessity to accurately measure sugar levels for payment to growers and for determination of excise taxes and duties based on alcohol content. Most of these methods initially relied on the hydrometer or some other measure related to specific gravity to provide an indication of sugar or alcohol concentration.

However, in the last hundred years, refractometers have proven to be a better option for the vineyard manager or winemaker. Refractometers have proven valuable for measuring the sugar content of grapes in the vineyard, the concentration of must prior to fermentation, for predicting final alcohol concentration, for monitoring fermentation and as a gauge for determining the final alcohol content and residual solids in finished wine.

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 the future.

DEVELOPMENT OF A COHESIVE MEASUREMENT STANDARD

Archimedes was the first to observe the relationship between the densities of liquids between 267 and 212 BC. Relying on 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, between 1665-1675.

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 winemaking 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 winemaking units of measure consist of Brix, Balling, Baume, Plato, Oeschlé, and Klosterneuburger Mostwaage ("KMW"). See Appendix I for more information.

HOW REFRACTOMETERS & HYDROMETERS DIFFER

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 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 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.

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, Baume, 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. Although they 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 auto temperature compensation.

USES FOR REFRACTOMETERS

Refractometers may be utilized at several points in the winemaking process. They may be used to measure the ripeness or maturity of grapes on the vine or the sugar content of must. They may also be used to predict the potential alcohol content of the finished wine. During fermentation they may be used to monitor the fermentation process, and once fermentation has ceased, a refractometer may be used to determine the final alcohol content and residual solids content.

The remainder of this paper will explore the different uses for refractometers and provide methods to help maximize the usefulness of these instruments.

DETERMINING RIPENESS & MATURITY

The quality of the grape at harvest is one of the most important determinations of the quality of finished wine. Picked too soon, the must will have low sugar and high acidity; too late, and it will have high sugar and low acidity. Either way, flavor will be sacrificed, and the must will not have the full potential to produce a good wine.

Grape ripeness is a subjective matter. It is more the “art” than the science of winemaking. Numerous research studies have failed to find a magic formula for ripeness.

Flavor, aroma, sugar content, color, and pH are all factors that have been used in attempts to quantify both ripeness and peak harvest time. However, grape ripeness relies heavily on the individual experience of a particular grape grower or winemaker. Ripening, therefore, should be thought of as a process and not a magic number.

A refractometer cannot magically identify when a particular grape has reached ripeness and is ready to harvest. It is, however, an effective tool that can provide critical and timely information about the maturity process to vineyard managers, helping them make decisions concerning harvest time. It should be emphasized that this is a process.

Grapes will begin to soften and increase in mass during the final stages of development. In the end stage, the sugar content usually increases quickly while the acidity begins to decrease and the flavor compounds begin accumulating. The grape will also begin to lose chlorophyll and take on a characteristic varietal color due to the buildup of phenolic compounds. Upon reaching full maturity, the grape size will reach a maximum, and the rate of increasing sugar will slow and then completely cease.

Grape maturity can be monitored through a process of continually testing the sugar content of the grapes with a refractometer. To be effective, this process should commence approximately one month prior to the estimated harvest time and increase with frequency as the harvest approaches. The process should include systematic collections of random samples of grapes that are "truly" representative of a particular block.

The trick is in selecting a truly representative sample. Since there is always a high degree of variability within a particular block, or even a particular cluster, an effort must be made to sample as many blocks and clusters as possible.

Discrepancies between Brix as measured by buyers and growers may vary by as much as one or two Brix. This is easily explained by the use of inferior refractometers or growers who employ inadequate field sampling techniques.

There are two sampling methodologies that can assist in getting better measurements and in making better decisions concerning maturity.

Individual Collection Method

This method consists of collecting random samples of individual grapes from many different clusters within a vineyard. However, due to the orientation of a particular block to the sun, differences in soil conditions, watering, drainage, and weather, there may be a large variation in the sugar concentration of grapes from different parts of a vineyard.

The sugar content of different clusters within a block may vary by as much as several Brix. To a lesser degree, there will even be variation in sugar content between individual grapes within a cluster. For example, the sugar content of grapes higher on a cluster is usually greater than those at the bottom. Also, grapes exposed to the sun tend to have a higher sugar content than those in the shade.

Try and select samples that are truly representative of the block. Collect samples from both sides of a vine, collecting equally from sun-exposed and shaded areas. Avoid collecting from the edge rows or the first two or three vines on the end of a row.

It is paramount to sample many different parts of a block, including grapes from many different clusters, and to select grapes from different positions within clusters. The samples should be bagged, and it should be noted approximately where they were collected. The minimum sampling should include approximately 100 grapes per acre (or 1/2 hectare).

Mass Collection Method

The Mass Collection Method varies from the Individual Collection Method in that samples of whole clusters are taken from random positions within blocks. This method tends to provide a more representative sample since grapes from all positions within a cluster are represented. The samples should be bagged, and it should be noted approximately where they were collected. The sample size should typically be about four clusters per acre (or ½ hectare).

Post Collection Testing

Samples should be tested within an hour after collection. Where possible, they should be crushed and hand pressed; however, larger samples may need to be rolled, crushed, and pressed. If the sample size is large enough, acidity and pH should also be measured.

The following information should be recorded:

1. Date & Time
2. Varietal
3. Collection method
4. Collection location
5. Sugar content of pressed juice
6. Sugar content of free-run juice (usually higher)
7. Titratable acid & pH (if sample permits)
8. Aroma and taste

This information should be saved in an archive so that it can be reviewed year-to-year. Make a note of the sugar content of the final sampling and compare it to the measurement taken by the winery. Dividing your final sugar measurement by the winery's measurement will yield a measurement ratio. The higher the ratio, the more agreement there is between your sampling process and the final yield. A lower ratio indicates that you should reexamine your testing protocol. It is also useful to compare this ratio year-to-year.

INSTRUMENTATION

What is it worth to you to have accurate sugar measurements that match those of the grape buyers? Of course, you cannot expect to have a high measurement ratio without a precision measurement instrument.

An inexpensive analog refractometer, without temperature compensation, will give you a reading that is nothing more than a guess. In fact, you are probably wasting your time and money using it. In recent years the cost of high-quality digital refractometers has come down considerably and is now within the reach of every vineyard manager.

In the US, Brix is the primary unit of measure for determining the ripeness or maturity of grapes. Payment to vineyards for grapes or must is also based on the Brix unit.

Outside the US, the primary unit of measure may be actual sugar content in grams per liter or grams per kilogram, Klosterneuburger Mostwaage (KWM), Babo, Oecshle, Plato, Baume, or Balling (See Appendix I). Refractometers are available with direct reading scales for all of these units of measure.

No matter what refractometer you use for testing, here are a few tips to help you get the most accurate measurements.

1. Use only temperature-compensated instruments.
2. Be sure to calibrate the refractometer to water before each use.
3. Check the measuring surface before use to ensure that there is no residue from previous tests.
4. Always clean the instrument before putting it away.

MONITORING FERMENTATION

Recent work conducted by the Valley Vintner suggests that a refractometer may also be used to predict the specific gravity of must during fermentation. The method works by compensating for the progressive influence of alcohol on the refractive index of a sugar solution during fermentation.

This process has proven successful in predicting specific gravity to within 0.5% and works on all grape fermentations regardless of varietals, including Cab S., Syrah, Petite Syrah, Zin and Gerwurtz.

During fermentation, a vintner typically monitors the fermentation process by taking samples of the wine and measuring and recording the specific gravity with a hydrometer. The following is a typical example of the sampling process:

1. Sanitize the hydrometer, thermometer, beaker, and siphon to prevent introduction of contamination;
2. Pull a 250mL sample out of the fermentation tank;
3. Carefully insert the hydrometer and thermometer into the beaker;
4. Spin hydrometer to dislodge CO2 bubbles, which will cause errors;
5. Try to read spinning hydrometer before the bubbles reform and skew reading;
6. Manually calculate the temperature correction for the hydrometer reading;
7. Finally, return the wine back to the fermenter and hope that no contaminants were introduced into the batch.

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NEW DIGITAL WINE REFRACTOMETERS

The new Palm Abbe line of handheld digital refractometers was engineered specifically for the international wine industry. Palm Abbes provide an instant digital "field" determination of grape ripeness, grape-must concentration, grape-must density, and sugar content, as well as the potential and actual alcohol content of the finished wine. Measurements are made with twice the precision of competing instruments and are comparable to mid-range bench-top refractometers costing thousands of dollars more.

The Palm Abbes break a price and performance barrier previously unattainable by handheld digital refractometers. These wine refractometers represent the most complete line of dedicated wine testing instruments ever assembled.

Priced between $325 and $525 (US), the Palm Abbe digital refractometers break the price barrier that previously divided digital refractometers from traditional analog handheld refractometers, while also breaking the performance barrier separating digital handheld instruments and expensive bench-top laboratory refractometers.

Certain models display prompts and measurements in English, Spanish, French, German, or Russian. Other models are available with scales for various international units of measure including Baume, Brix, Oechsle, KMV, Babo, specific gravity, alcoholic strength, etc. Users have the flexibility to mix and match up to five different scales on some Palm Abbe models, giving them the ability to create truly custom wine testing instruments.

Protection against inaccurate readings due to temperature differences, a major concern in refractive index measurement, is assured with nonlinear temperature compensation specific to grape juices. Temperature compensation is automatic for fluids read between 0 and 50 °C (+32 to 122 °F).

The stainless-steel sample well requires only a couple of drops of fluid to take measurements. A simple, user-friendly interface consists of two buttons: one to take readings and the other to step through various menu options. A large, dual-line, multilingual LCD display is easily read, even in dim light.

The digital refractometer removes the subjectivity associated with analog refractometers that require users to interpret where a boundary line crosses tiny scale divisions. Calibration of the Palm Abbe is automatic and does not require special calibration solutions or tools; they automatically calibrate to water.

The following standard instruments and scales are available from MISCO:

PA201 - Brix Only
VINO1 - Brix, Baume, Oechsle, KMV, and Sugar Content (g/L)
VINO2 - Brix and Sugar Content (g/L)
VINO3 - Baume and Sugar Content (g/L)
VINO4 - Oechsle and Sugar Content (g/L)
VINO5 - Mass Fraction, Sugar Content (g/L), Estimated Alcohol, Actual Alcohol, Specific Gravity
VINO6 - Brix, Sugar Content (g/L), Estimated Alcohol, Actual Alcohol, Specific Gravity

Depending on how often you monitor the process, this is a lot of work. Fortunately, there is a better way.

1. Using a Palm Abbe Digital Refractometer, measure and record the Original Brix (OB) reading;
2. At each sampling, use a sterile disposable pipette to withdraw a few drops of wine;
3. Using a Palm Abbe Digital Refractometer, measure and record the New Brix (NB) reading;
4. Compute the specific gravity as follows:

Specific Gravity (D 20/20) =

[1.001843 - 0.002318474 (OB) - 0.000007775 (OB^2) - 0.000000034 (OB^3) + 0.00574 (NB) + 0.00003344 (NB^2) + 0.000000086 (NB^3)]

Where:
OB = Original Brix Reading
NB = New Brix Reading

Since the pipette is disposed of after each reading, nothing is reintroduced back into the fermenter, greatly reducing the risk of contamination. To speed calculation, the formula may be entered into an Excel spreadsheet.

FINAL ALCOHOL CONTENT

Computing Alcohol by volume in finished wine.

Now that the wine is complete, you need to measure the alcoholic strength or alcohol by volume. This is easily accomplished using one of two methods:

1. Roesener Method based on specific gravity and refractive index.
2. Following the distillation method of the AOAC or OIV.

It is impossible to directly measure the ethanol content of wine using either a refractometer or hydrometer alone. That is because, by their nature, these two instruments are designed for measuring binary, or single component, solutions. The direct measurement by a single instrument is precluded since the combination of water, alcohol, and sugar in the wine represents disparate factors, each differently influencing the readings of these instruments.

For example, the ethanol in wine increases the refractive index as measured by a refractometer but decreases the specific gravity as measured by a hydrometer. Sugar, on the other hand, increases both refractive index and specific gravity. Therefore, if measuring a wine sample with either instrument alone, it is impossible to determine whether the reading has been influenced more by the ethanol or by the sugar.

Roesener Method
– Determining Alcoholic Strength & Residual Solids

This method was developed by Werner Roesener of the Aurora Wine Circle, in Ontario, Canada. It produces a predictable alcoholic strength and residual solids measurement by exploiting the opposite effect that ethanol and sugar have on refractometers and hydrometers.

To Measure Alcohol by Volume:

1. Using a narrow range hydrometer, measure and record the specific gravity of the finished wine at as close to 20'C (68'F) as possible;
   a. Hydrometer range should be 0.980 to 1.022
2. Using a Palm Abbe Digital Refractometer, measure and record the Brix reading;
3. Compute alcoholic strength as follows:

Alcohol (% v/v) =
(BRIX * 4.16 – (Specific Gravity*1000) + 1000) * 0.365

Or, more simply:

Alcohol (% v/v) =
(1.5184 * Brix) + (-365 * Specific Gravity) + 365

To Measure Residual Solids:

1. Determine the Alcohol by Volume as described above.
2. Calculate residual Sugar as follows:

Solids (g/L) =
((Specific Gravity * 1000) - 1000 + ABV * 1.264)) * 2.52

Or, more simply:

Solids (g/L) =
-2520 + (3.18528 * ABV) + (2520 * Specific Gravity)

Where ABV is Alcohol by Volume

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Official Methods

There are two official methods to measure the alcoholic strength of wine.

1. International Organisation of Vine & Wine (O.I.V.), COMPENDIUM OF INTERNATIONAL ANALYSIS OF METHODS-OIV, Edition 2006, Vol. I, Alcoholic Strength by Volume of Wine Distillate.

2. AOAC Official Method 950.04, Alcohol by Volume in Distilled Liquors.

Both methods are similar, so only the first method will be discussed here.

O.I.V. Alcoholic Strength by Volume of Wine Distillate

The most accurate method of obtaining the absolute alcohol by volume ("ABV") is through the distillation process. Although cumbersome and time consuming, this process typically yields the most reliable and precise measurements of alcoholic strength.

In simple distillation, a solution of two liquids is separated based upon differences in their boiling points. Boiling stones are often added to the distillation flask to ensure even heating of the solution.

In the case of wine, the boiling point of ethanol is reached before that of water, so when heated, the ethanol vapors come out of solution and are carried into the condenser. In the condenser, the ethanol vapor is cooled, and then changes phase back to a liquid. It is then collected and can be measured on a Palm Abbe refractometer with a special scale for the alcohol content of the wine distillate.

Required equipment:

1. Palm Abbe Digital Refractometer with an Actual Alcohol Scale for Wine
2. 200 mL volumetric flask
3. Thermometer
4. Condenser
5. Steam distillation apparatus and/or burner
6. Distillation or Boiling Flask
7. Supply of Calcium Hydroxide
8. Supply of Pumice stone
9. Supply of Distilled Water

The Procedure to obtain distillate:

1. Measure out 200 mL of the wine using a volumetric flask.
2. Record the temperature of the wine.
3. Transfer the wine to the distillation flask and attach the steam-pipe of the steam distillation apparatus.
4. Rinse the volumetric flask four times with successive 5 mL washings of water added to the flask or the steam-pipe.
5. Add 10 mL of calcium hydroxide (2 mol/L) and several pieces of inert porous material (pumice etc).
6. Collect the distillate in the 200 mL graduated flask used to measure the wine.
8. Collect a volume of about three-quarters of the initial volume, if standard distillation is used, or a volume of 198 to 199 mL of distillate if steam distillation is used.
9. Make up to 200 mL with distilled water, keeping the distillate at a temperature within 2°C of the initial temperature.
10. Mix carefully, using a circular motion.
11. Test two or three drops of the distillate on the Palm Abbe refractometer using the Actual Alcohol Scale for Wine.
12. The Palm Abbe will display the final alcohol content by volume.

SUMMARY

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

Refractometers provide a valuable means for measuring the sugar content of grapes in the vineyard, the concentration of must prior to fermentation, to predict final alcohol concentration, to monitor fermentation, and as a gauge for determining the final alcohol content and residual solids in finished wine.

ABOUT THIS PAPER

MISCO, in business since 1949, is a leader in a very small world-wide community of professional refractometer manufacturers and is very visible within that industry. MISCO has great respect for its competitors and, although comparison between products is inevitable in a free market economy, an attempt has been made here to offer only fair and objective head-to-head comparisons. In the end, it's the customer's ultimate decision to select the company they wish to honor with their business.

The data presented for competitive instruments was compiled from their respective websites, product literature, and experience with the instruments.

This information is being presented to assist a potential buyer in comparing measurement methods, and although we have done our best to present the most accurate information known to us, we do not make any claims as to the accuracy of the data.

We have tried to present the data in such a way that it compares the strength and weakness of all the comparison instruments. Some instruments will naturally fare better in different categories than others. In the event that a customer or competitor finds an error in the data presented here, please contact us and we will gladly update this document.

RESOURCES

MISCO Refractometer
6275 Cochran Rd.,
Solon, Ohio 44139 (USA)
TEL: 440-349-1500
FAX: 440-349-1511
Email: Contact Us
Website: www.misco.com

TRADEMARKS & ACKNOWLEDGEMENTS

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Valley Vintner is a register trademark of the Valley Vintner, Inc.

Appendix I

<u>**Common Wine Units of Measure**</u>
Ordered by Date Developed

Baume: The Baume scale was originally developed by French pharmacist Antoine Baume in 1768. It was designed as a method of making hydrometers easier to read. The Baume method uses two separate hydrometers: one for measuring fluids heavier than water and another for fluids lighter than water. Originally the scale was based on sodium chloride / water solutions at 15.5 °C (54.5 °F); however, vague instructions and/or errors in translation introduced a large margin of error when the scale was adopted. Further, confusion between hydrometers makers, which still persists today, has lead to many well documented cases of hydrometers with inaccurate scales.

There are three types of Baume hydrometers in use: a US measure based on 145, a Dutch measure based on 144, and the newer Gerlach scale based on 146.78. It is necessary to know which type of hydrometer you are using to make conversions accurate and meaningful. The problem is that most hydrometers are just marked Baume and there is no indication of the basis. Another problem is that different Baume hydrometers use different reference temperatures making it necessary to also know the temperature basis in order to apply manual temperature compensation.

The Baume scale, used mostly in France, is also used in the beer brewing industry in the US. Noted as: degrees Baume, degrees Baumé; B°, Be°, Bé°, Baume

Sp. gr. = m /(m-d) where

m = 145 (in the United States)
m = 144 (old scale used in Holland)
m = 146.78 (New scale or Gerlach scale)
d = Baume reading

Twaddell: The Twaddell hydrometer was developed in England, by William Twaddell, between 1812 and 1839. It consisted of a series of spindles with graduations from 0 to 174. The graduations on the Twaddell scale are spaced closer together as the reading increases. A simple calculation is used to convert Twaddell to specific Gravity. The Twaddell scale is still in use in England and in some former English colonies.

Gay-Lussac Scale (°GL): Invented by French Chemist, Joseph-Louis Gay-Lussac between 1798 and 1850, the GL scale was used to measure the percent of ethanol by volume of a solution. Zero on the scale represents water, and 100 represent 100% ethanol by volume. One °GL is roughly equivalent to one percent alcohol by volume in wine. It is the same as the Tralles' scale but is measured at 15° C (59° F) instead of 15.6° C (60° F).

Tralles: Like the Gay-Lussac Scale, The Tralles Scale was a special hydrometer scale designed for the direct reading of percent ethanol by volume. Zero on the scale represents water, and 100 represent 100% ethanol by volume. One unit is roughly equivalent to one percent alcohol by volume. It is the same as the Gay-Lussac Scale but is measured at 15.5° C (60° F) instead of 15° C (59° F). The Tralels scale found usage with customs' officials primarily in the U.S. and in Germany.

Öechsle Scale (°Oe): The Öechsle scale was invented in 1836 by Ferdinand Öechsle, in Pforzheim Germany. It is used to measure the ripeness or grapes or the sugar content in must. It is used predominately in Germany and Switzerland. German wines are strictly classified by Öechsle. Five °Oe is roughly equivalent to one percent sugar by weight.

Balling: The Balling scale was a hydrometer scale developed by German chemist Karl Balling in 1843. It was designed to measure the concentration of a sucrose solution, as the percentage weight of sucrose at 17.5°C (63.5 °F). It is used primarily for beer making, however, the scale still appears on old saccharimeters and is still used in the South African wine industry.

Plato: The Plato scale was developed shortly thereafter by Fritz Plato, as an improvement to the Balling scale. It provides a more accurate indication of sugar content than Balling and is used mostly by European beer brewers.

Brix: The Brix scale was developed by Austrian Adolph Brix in between 1850 and 1870. It too was yet another improvement on the Balling scale. Brix has become the defacto standard in the US and most the world for measuring sugar concentration.

Klosterneuburger Mostwaage scale (KI°, °KMW, Babo): The KMW scale was introduced by Baron August Wilhelm von Babo in Klosterneuburg, Austria, in 1861. It was later adopted by the Italians and is called the Babo scale in Italy. Mostwaage literally means "Must Scale," and is the measure of the sugar content of must. One °KMW is roughly equivalent to one percent sugar by weight. The °KMW is critical in the categorizing wine in Austria.