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Modification and Performance Evaluation of a Portable Hand-Held Refractometer

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Abstract

The portable hand-held refractometer was modified, fabricated and its performance was evaluated. The modified refractometer consists of six main parts which include adjustment focus, calibration point, light cover, magnifying eye piece, bi metal strip and primary prism. Hand held refractometer was modified by incorporating a metallic strip and Charge-coupled Device (CCD) sensor, which measure high total soluble solid and also correctly determines the intensity of the light reflected and also the exact critical angle that reflect the light completely. A few drops of water will be placed on the prism surface for cleansing and calibration. The light cover will be closed and the refractometer will be holding on the direction of light source and the scale will be set to zero by using calibration point and looking through the magnifying eye piece. The modified refractometer has been compensated automatically for the temperatures of the samples. The actual tests were conducted using samples of water melon, cashew and mango juices at certain levels of pH values. The average percentage Brix values of water melon, cashew and mango juices are 7.47%, 13.20% and 13.50% respectively. It was observed that mango juice has highest percentage Brix than water melon and cashew juices. This means that it can deteriorate faster than other two juices. The analysis of variance (ANOVA) for the effect of temperature and pH used for the experiment show that F-calculated (3.883) is greater than F-table (3.35) at 5% probability level; therefore, the conclusion is that at least one of the treatment means is difference. It appears that the rate of pH or temperature sensitivity of the modified refractometer used could not be the normal rate for the experiment.

Keywords: Modification, Performance Evaluation, Portable, Hand-Held, Refractometer.

Introduction

Refractometers are a simple optical instrument that measures the amount of light refracted in a liquid. Refractometers measure on a "Brix" scale and measuring the Brix level of fruits and vegetables is very important because it is a great indicator of flavor and quality [1]. The higher the brix level of your fruits juices is, the higher the dissolved solids in the foods juices such as sucrose, fructose, vitamins, minerals, amino acids, proteins, hormones and all the other goodness that the plant puts into the food is. It is estimated that in a healthy fruit or vegetable, approximately 80% of the brix is represented by the natural sugars which give the food its great flavor and goodness. It is believed by many people to be the best indicator of quality available in one quick and simple test [2].

Refractometers are a standard piece of equipment for many Agronomists and is a standard tool used in the fruit and citrus industries. Juice factories and vineyards especially use refractometers so they can measure the level of flavors in the juices and blend them to consistent brix level every time. Many companies are also now offering big bonuses to farmers who can produce high brix fruits because it means they have to add less artificial sweetener to the juices which are devoid of any nutritional value [3].

The refractive index depends on the temperature of the media, the higher the temperature of a media, the higher the speed of light in the media and the lower its refractive index. In vacuum light travels at a constant speed (c), independent of its wavelength. In all other media, however, the speed of light depends as well on its wavelength: The shorter the wavelength of the light, the higher its speed. This frequency dependency of the refractive index is known as dispersion and causes a prism or a rainbow (where the light travels from air through water) to divide white light into its constituent spectral colors [4]. The refractive index has thus always to be stated together with the wavelength of the light used for the measurement and the temperature of the media. The refractive index is normally measured at a temperature of 20°C using light with the wavelength of the sodium D line (589.29 nm) and is therefore expressed as nD20 [5].

The refractometer sensor consists of a transmitted light measurement and it can reach a precision and zero-point stable. Temperature compensation in accordance of the customer-specific fluid data that can be implemented with a software tool. The unit determines the customer specific output number of the mass concentration of a solution [6]. It also provides useful tools to detect errors. The refractometer is method of choice to determine the concentration, density and purity of many liquids. The device operates in accordance to the transmitted light principle. It determines the refractive index of the liquid as the basis of the measurement of the angle. The device can be used in the most diverse applications [7].

They are fast, convenient, and easy to use. Simply place a drop or two of fluid in the well and press a button on the keypad. The custom-designed microprocessor delivers a nearly instantaneous readout in refractive index, degrees Brix, or any one of a thousand different units of measure, allowing you to read directly in the units you desire. Nonlinear temperature compensation is automatic and insures that fluids read between 0 and 50 °C (+32 to 122 °F) are measured accurately [8].

The large dual-line LCD display is easily read, even in dim light, and removes the subjectivity associated with interpreting where a boundary line crosses tiny scale division. And, it is so easy to use. A strong plastic enclosure is sealed to guard against liquid and dust penetration, while an integrated prism cover helps prevent sample evaporation and protects the sapphire measuring surface from possible damage. The cover also shields the optics from the influence of strong ambient light, making it for use indoors or in direct sunlight [9].

Calibration is automatic and does not require the use of special calibration solutions, or tools. The refractometer automatically calibrates itself to water and is ready to use in seconds. No more screws to turn and nothing to adjust. Because it offers great performance and accuracy at a very affordable price, there is no need to make trade-offs between accuracy and affordability [10].

A refractometer is an optical device that, like a hydrometer, measures the specific gravity of your beer or wort. It does so by sampling a small amount of liquid, and looking at its optically. If you start with a glass of clear water, you will notice that the water and glass bend the light passing through it in a certain way. The bending of the light by the water is called refraction. Light bends to different degrees as it passes through different substances [11]. This is the same effect that glasses lenses in eyeglasses are based upon – the lenses bend the light allowing glasses to adjust the focus of an image and make it clearer to your eyes. If you add sugar to your glass of water, the light will bend more. The refractometer takes advantage of this effect to measure the amount of bending (refraction) which indicates the amount of sugar in the sample. Most refractometers use a prism and a light source to illuminate the sample [12]. On inexpensive refractometers, you hold the instrument up to a natural light source. More expensive models have internal light sources. Most brewing refractometers measure samples in Brix, which is a scale used to measure specific gravity primarily by wine makers. Some also use a Refractive Index (RI) scale. Both the Brix and RI indexes need to be converted to standard specific gravity or Plato scales using a formula, as wort does not have the same reflective properties as plain sugar and water [13].

Hand held refractometer is real devices usually contain additional optical elements, like lenses and optical wedges that help to obtain sharp shadow boundary. Instead of having an illuminating prism, hand held refractometers have an illuminator flap which produces a diffused light at a grazing angle and helps to keep the sample in place. Light passes through the sample, enters the measuring prism and possibly other lenses, and finally falls on the measuring scale where it can be read. Depending on the reason for using the refractometer, its scale can be graduated in Brix degrees, percentage of alcohol or glycol percentage, etc. [14].

Brix measurements are mostly done in the food industry for quality control reasons e.g. sucrose solution (sugar syrup). Sugar syrup intended for beverage and similar products is sold by weight and sugar content. The exact determination of Brix is therefore very important for cost and quality control in the beverage industry (soft drinks). For the finished product in the beverage industry the, High Fructose Corn Syrup (HFCS) content is important for the quality control as one of determined quality value. Checking the harvest time and maturity of fruits. 90% of the raw fresh juice is sugar so that Brix measurement is proportional to the sugar content [15]. The brix value or refractive index of fruits juice is important for determination of storage duration of the juice. The higher the brix value of fruit juice, the higher the dissolved solid contents in the juice. The level of dissolved solids in fruit juice determines the storage duration of the particular juice. The research work is to modified portable Hand-Held refractometer that is easy to use.

Materials and Method

Hand held refractometer as modified using these materials as follows, Prisms, Cylinder, Biometric strips, Scale, Lens, light cover, Reflector, Lamp, Mirror, Rubber Grip, Calibration Screw, Charge-coupled Device(CCD) Sensor, thermometer etc.

Design Considerations

Pure distilled water was used to test the sample and also to learn how to use the refractometer and its index of refraction was taken as1.3297 at 250C of temperature. Hand held refractometer was modified based on the reflection of light from the boundary between the primary prism and the sample. The compensating prisms was modified so that they can be adjusted for compensate in temperature. Dispersion of the sample was modified to reproduce the refractive index that would be obtained with monochromatic light with the sodium D line. The refractometer is equipped with a thermometer and there is a means of circulating water through the refractometer to maintain a given temperature.

Design Calculations and Selections

Refractometer Cylinder

A right circular cylinder having a finite height with circular ends perpendicular to the axis. If the ends are open, it is called an open cylinder. If the ends are closed by flat surfaces it is called a solid cylinder. The formulae for the surface area and the volume of such a cylinder are given below [16].

Surface Area

Still using a radius r and length (height) h, the surface area of a cylinder is made up of three parts:

The area of the top: $\pi r2$

The area of the bottom: $\pi r2$

The area of the side: $2\pi rh$

The area of the top and bottom is always the same, and is also called the base area, B. The area of the side is also known as the lateral area, L.

The surface area of a closed cylinder is made up the sum of all three components: top, bottom and side. Its surface area is

$A = 2\pi r2 + 2\pi rh = 2\pi r(r + h) = \pi d(r + h) = L+2B$.

Selection of Triangular Prism

A prism has a triangular base was chosen in which the joining edges and faces are perpendicular to the base edges. All the lateral faces are rectangles and are perpendicular to the bases. Lateral surface area of the triangular prism = Sum of the areas of 3 triangles = $(a + b + c)\ H$ = Perimeter of base × height of the prism, and, area of one base = ½ b× h

b = base side of triangle and h = height of triangle

Total surface area of the triangular prism = Lateral surface area of the prism + Area of two bases = $((a + b + c)\ H + b \times h)$ square units.

Selection of Charge-Coupled Device (CCD) Sensors

A sensor is any device that takes a physical quantity, measures it, and converts it into information that can be read and understood by an observer. There are a wide variety of means by which a sensor collects and converts data, many of them not involving any electronics at all. All sensors share one general characteristic: they are transducers. A transducer is a device for transforming one type of energy into another. For example, even a simple mercury thermometer works by taking heat energy and changing it to the expansion or contraction of liquid for the purposes of measurement. Therefore, all sensors can be categorized according to the kind of energy they detect and convert. These categories are: acoustic, chemical, electromagnetic, ionizing radiation, mechanical, Charge-Coupled Device (CCD) sensor, and thermal.

Modification and Assembly of the Equipment

The modified refractometer consists of six major parts which include adjustment focus which is used to adjust the reading at center, calibration point is used to set the reading at zero before any experiment, light cover is where the water or the juice material to be determined its brix values is placed, magnifying eye piece is where eye is located to take the reading, rubber grip, which was changed to bimetal strip, joins adjustment focus, light cover and the calibration screw and main prism assembly. These parts are assembled together using fasteners and electrodes. Hand held refractometer was also modified by incorporating a Charge-coupled Device (CCD) sensor, which measure high total soluble solid for different food materials other than fruit juices.

Calibration of Modified Refractometer before Using

Before taking readings on each specimen, it's very important to calibrate the refractometer. Some refractometers require the use of a special calibration liquid to perform this task, while others are calibrated with distilled water. The calibration of modified refractometer is by lifting up the light cover and placing 2-3 drops of distilled water on top of the prism assembly. Close the light cover so the water could spread across the entire surface prism without any air bubbles or dry spots. The refractometer is held in the direction of a natural light source and look into the eyepiece. A circular field with graduations down the center will be seen. The eyepiece will be focus to clearly see the graduations. Turn the calibration screw until the boundary between the upper blue field and the lower white field meets exactly at ZERO on the scale. Once the refractometer has been properly calibrated, it will be ready to take readings of any juice or whatever else you want to sample.

Principle of Operation of the Modified Refractometer

As light passes slowly into more optically dense media, and speeds up as it passes into less optically dense media. The change in speed is accompanied by a change in direction, and at a certain angle of incidence, the light does not refract in the second medium at all, but is entirely reflected. The angle at which this occurs is known as the critical angle, and it is this angle that the refractometer measures. A refractometer consists of a light source, filtered to a single wavelength, which is directed towards the prism-sample interface by a converging lens. This creates a range of incidence angles, some of which (those less than the critical angle) will be completely reflected. A Charge-coupled Device (CCD) sensor precisely measures the intensity of the reflected light and determines the exact angle at which light begins to be completely reflected. Because this angle is dependent on the ratio of the refractive index of the prism to that of the sample, the refractive index of the sample can be determined using the known refractive index of the prism [17].

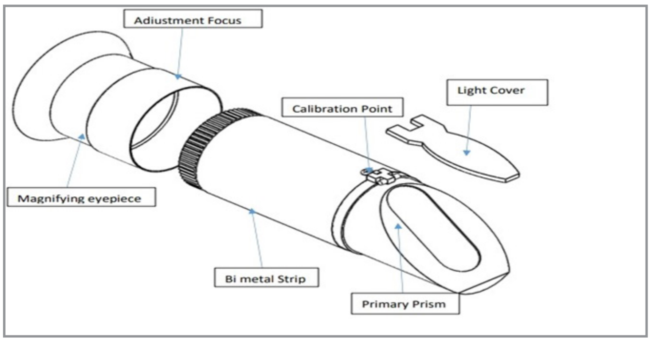

Figure 1: Isometric View of Modified Refractometer

After calibration, the instrument will be cleaned (both the daylight plate and the top of the main prism assembly) with a soft, damp cloth, then place 2-3 drops of the desired sample of juice on top of the prism. The light cover will be closed and take your reading as before. The field of view in the modified refractometer remains blue when only light passes through the prism. The entire scale is colored blue; no white at all will be seen. When looking through the monocular, be sure you are using natural light to view the readings; you should not read a refractometer in the presence of fluorescent light.

Performance Evaluation of the Refractometer

The actual tests were conducted using samples of water melon, cashew and mango juices at certain levels of pH values. The average percentage Brix values of water melon, cashew and mango juices were determined and tabulated. The obtained results were compared with the standard and analysis of variance (ANOVA) for the effect of temperature and pH used for the experiment was determined at 5% probability level [18].

Results and Discussion

The results obtained for the determination of refractive index and percentage Brix of water melon juice, cashew and mango juice are shown in the tables below.

Table 1: The pH, Percentage Brix and Refractive Index of Water melon Juice.

S/N	Water melon pH	% Brix	Temperature oC	Refractive Index
1	3.66	6.1	25	1.435
2	3.70	6.4	25	1.439
3	3.75	6.7	25	1.438
4	3.79	6.8	25	1.440
5	3.82	7.1	25	1.442
6	3.85	7.7	25	1.446
7	3.87	7.9	25	1.446
8	3.93	8.5	25	1.449
9	3.98	8.4	25	1.457
10	4.02	9.1	25	1.458

Table 2: The pH, Percentage Brix and Refractive Index of Cashew Juice.

S/N	Cashew pH	% Brix	Temperature oC	Refractive Index
1	3.36	10.9	25	1.337
2	3.44	11.8	25	1.341
3	3.49	12.5	25	1.345
4	3.61	12.8	25	1.347
5	3.67	13.2	25	1.350
6	3.84	13.5	25	1.349
7	3.89	13.6	25	1.350
8	3.88	14.3	25	1.352
9	3.97	14.6	25	1.354
10	4.2	14.9	25	1.361

Table 3: The pH, percentage Brix and Refractive Index of Mango Juice.

S/N	Mango pH	% Brix	Temperature oC	Refractive Index
1	3.98	9.6	25	1.346
2	4.09	11.3	25	1.368
3	4.28	11.8	25	1.389
4	4.37	12.9	25	1.399
5	4.45	13.9	25	1.415
6	4.63	14.4	25	1.421
7	4.69	14.8	25	1.439
8	4.70	15.1	25	1.447
9	4.77	15.4	25	1.451
10	4.89	15.7	25	1.454

Table 4: Analysis of Variance (ANOVA) of the Brix Value of the Three Samples Determined

Sources of variation	Degree of Freedom	Sum of square	Mean Square	F-calculated	F-table
Among Treatment	2	79.445	39.723	3.883	3.350
Within Treatment (Experimental Error)	27	276.227	10.231		
Total	29	355.672			

Discussion

The table 1 showed the results obtained during the test of water melon juice with the modified refractometer, it was discovered that, the lowest pH of 3.66 has the refractive index of 1.435 and the highest scale of pH of 4.02 has the refractive index of 1.458. It means that the higher the pH of water melon juice the higher the refractive index at 250C of temperature. It was also showed that water melon juice can be consumed at average percentage brix value of 7.47%.

The results obtained during the test of cashew juice with the modified hand-held refractometer were presented in table 2. It also showed that the lowest pH of 3.36 has the refractive index of 1.337 and the highest pH of 4.20 has the refractive index of 1.361. The results also showed that cashew juice has higher acid, total solid content and sugar than water melon juice. This means that it can deteriorate faster than water melon and .average percentage brix value was 13.20%.

The results obtained during the test of mango juice with the refractometer were shown in table 3. It was found that the lowest pH of 3.98 has refractive index of 1.346 and the highest pH scale of 4.89 has the refractive index of 1.454. It was observed also that mango has the highest acid, refractive index and sugar contents than water melon and cashew juices. The average percentage brix value of the juice at refractive index temperature of 250C was 13.50%.

The table 4 presented the results on analysis of variance (ANOVA) for the effect of temperature and pH used for the experiment. The results show that F-calculated (3.883) is greater than F-table (3.350) at 5% probability level; therefore, the conclusion is that at least one of the treatment means is difference. It appears that the rate of pH or temperature sensitivity of the modified refractometer used could not be the actual or maximum rate for the experiment.

Conclusion and Recommendation

It is clear that the temperature correction is concentration dependent and therefore it is necessary to measure such a complex solution always at the desired temperature of 250C. This Handheld refractometer has built-in temperature compensations for Brix measurements. This temperature compensation will be valid for other food materials other than fruit juices solutions. The results obtained using the modified refractometer were in line with the standard measurements of the percentage Brix and refractive index of water melon, cashew and mango juices. The standard refractive index of all the samples (fruit juices) ranged from 1.335 to 1.634 and the three samples measured are in line with standard. This value could be useful for quality control assessment during preparation of juices and other food materials in food industry.

The average percentage Brix measured of water melon, cashew, and mango juices of fresh fruit at the same temperature were observed from the readings with the modified refractometer that mango has highest pH and refractive index than other two juices.

Modified hand-held refractometers are convenient because they do not require an energy source. However, they may not be accurate if used outside the specified temperature range. Using an analog refractometer that does not automatically compensate for the temperature of the sample, the readings will be off or will not show at all.

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