Refractive Index Based Brix Measurement System for Sugar And Allied Industries

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A paper from the Proceedings of the
14th International Conference on Precision Agriculture
June 24 – June 27, 2018
Montreal, Quebec, Canada

Abstract

An attempt has been made to design optimization of Refractormetric based method for the measurement of Brix. Optimization of various constructional parameters including selection and location of source, prism and detector, position of source, angular position and height of source from prism plane, divergent angle of source, refractive index of prism, size of prism, the location of detector to pick up the optimum reflected light, refractive index of sample, critical angle, choice of suitable prism. With considering the above mentioned parameters, mathematical modeling and simulation of the proposed system has been performed and then experimental model is developed accordingly.

Key words: refractive index, Brix, prism, sugar, critical angle, modeling

The authors are solely responsible for the content of this paper, which is not a refereed publication.. Citation of this work should state that it is from the Proceedings of the 14th International Conference on Precision Agriculture. Dongare, M. L., Jadhav, B.T. & Shaligram, A. D. (2018). Refractive Index Based Brix Measurement System for Sugar and Allied Industries. In Proceedings of the 14th International Conference on Precision Agriculture (unpaginated, online). Monticello, IL: International Society of Precision Agriculture.

1. Introduction

The term "Brix" technically means the percent by weight of sugar solids in a pure sucrose solution. The refractometers are simple optical instruments for measuring dissolved solid contents by measuring the refractive index of a process solution by means of the total reflection created at the interface between an optical window and the sample solution. A beam ray from light source is directed to the interface between optical window and the sample solution. Part of beam of ray is reflected from the solution entirely and partly refracted and absorbed in a solution. This causes an image, in which the location of borderline between light area depends on the critical angle of the total reflection and thus on the refractive index of the process solution. As concentration of sugar increases, the Brix and its refractive index increases, and therefore critical angle increases. The light reflection on detector decreases, which increases LDR resistance. As it is in upper arm of potential divider it decrease output voltage. Analog to digital converter, signal conditioning unit and microcontroller is developed for proper calibration and displaying the reading on LCD. The results are reported in this paper.

2. The principle of operation of refractometers

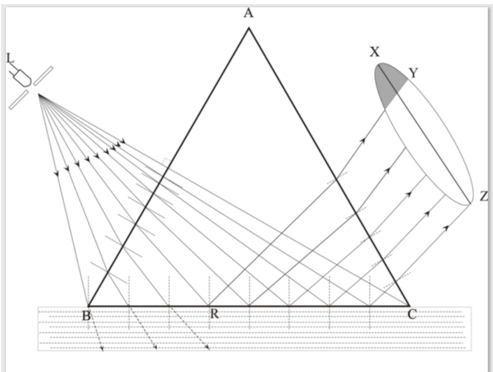

Fig. 1: Refractometer principle

. A conical beam of light source is directed to the interface between optical window and the sample solution. Part of the beam is reflected from the solution and partly it is refracted and absorbed in the solution. Reflected rays create an image, in which the location of a borderline between light and dark field depends on the critical angle of the total reflection and thus on the refractive index of the process solution. The actual measurement is achieved by photo detector (LDR) and converted to linear signal through signal conditioning unit and displayed on LCD through microcontroller, in the realized experimental module. Fig.1.shows the principle of operation of refractometers.

3. Mathematical model and Simulation

For the mathematical modeling purpose it is considered that a beam of light from source is directed to the interface between a prism and the process solution. The light rays meet this surface at different angle. The reflected rays form an image XYZ where Y is the position corresponding to the critical angle. The rays incident between RC are totally reflected at the interface, the incidence angle being larger than the critical angle and form the YZ portion of the image. The rays incident between RB are refracted in to the process solution and absorbed. In this way optical image obtained at sensor is divided into light area YZ and dark YX. The position of the borderline Y between the areas shows the correspondence with the critical angle and thus of the refractive index of the process solution. Variation of the Y position would alter the amount of light flux incident on the detector. The brix and refractive index of the sample solution increases with corresponding solute concentration. The critical angle varies accordingly with change of refractive index of sample and therefore reflected light to be received at detector varies. Fig.2.shows geometrical consideration for source, prism and detector arrangement. A prism ABC, having three planes, AB.BC and AC. One of the planes is treated as boundary plane BC which comes in contact with the sample solution, on one of the remaining two planes.

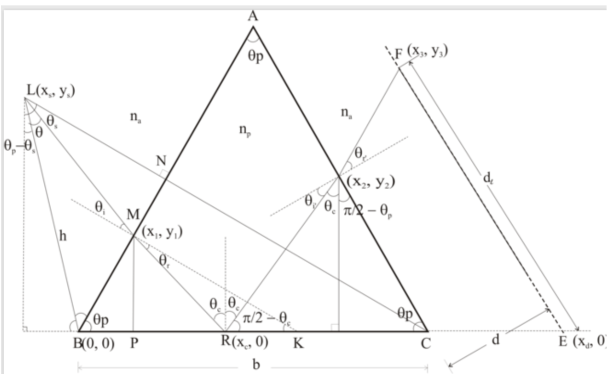

Fig. 2: Geometry for source, prism and detector arrangement

From the initial considerations high bright Red LED with an emission angle θs is mounted at point $L(x_s, y_s)$,in such way that, the beam of light covers the boundary plane BC. The ray LC is normal to surface AB and is incident at N, does not get refracted. On the other hand the ray LB travels through air medium only.

With the simple geometric considerations, the co-ordinates (x_s, y_s) are given by

$x_s = b\cos^2 \theta p - b/2[\sin (2\, \theta p)\cot \theta s$ (1)

$y_s = b\cos^2 \theta p \cot \theta s + b/2[\sin (2\, \theta p)]$ (2)

It is considered that the light ray passing through prism plane AB, and making critical angle θc at point R (xc, 0), will be representing the line of separation between dark and illuminated portion on the detector.

$\theta c = \sin^{-1} (n_s / n_p)$, (3)

The ray incident at point R making critical angle θc with respect to normal would then be found using the geometry considerations and Snell's law. The x_c is given by

$x_c = x_1 + y_1 \tan \theta p$

where $x_1 = \{xs + y_s \tan (\theta p - \theta i)\} / \{1 + \tan (\theta p - \theta i) \tan \theta p\}$

$y_1 = x_1 \tan \theta p$

If $\theta_i > \theta c$, light is totally reflected and if $\theta i < \theta c$, it gets partially refracted , accordingly the optical image is formed at detector side with dark and light area.

The reflected light will project on the plane EF. The detector is placed at distance d facing the surface AC. The coordinates of the line of separation F (x_3, y_3), are given by

$x_3 = \{x_2 + d\sin (\theta p - \theta r')\} / \cos \theta r'$ (4)

$y_3 = \{y_2 + d\sin (\theta p - \theta r')\} / \cos \theta r'$ (5)

Where(x_2, y_2) are given by

$x_2 = \{x_c + (b\tan \theta p \tan \theta c)\} / (1 + \tan \theta p \tan \theta c)$

$y_2 = (x_2 - x_c) / \tan \theta c$

The detector plane intersect the base line at E (x_d, 0), such that,

$$x_d = b + (d / \sin \theta p)$$

Thus the line of separation will be located at a distance d_l from E, The d_l is calculated as

$d_l = \{(xd - x_3)^2 + y_3^2\}^{1/2}$ (6)

The detector is mounted in such way that, it will be fully covered by the light

When the sample medium is air ,i.e. ns=1,thus the upper edge of the circular detector with radius 'r' will be situated at $d_{l\,ns} = 1 - r$.

When a sample with refractive index ns>1,is brought in for the analysis, the line of separation shifts downwards and some portion of the detector receives no light, as shown in fig.3.

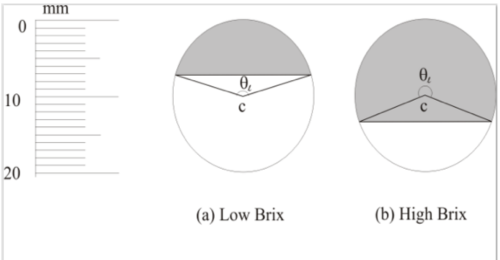

Fig. 3 : Area of detector showing dark and light field.

For low refractive index (low Brix) such dark portion will be small and will keep on increasing as refractive index (and Brix) increases.

Area of dark shaded (XY) portion is given by

$Area_{dark}=1/2\{ r^2(\theta\text{-sin }\theta)\}$

The illuminated total area of LDR covered by light (YZ) portion is,

$Area_{illumim} =\pi\ r^2\text{-}1/2\ r^2\ (\theta\text{- sin }\theta)$ (7)

The resistance of LDR will vary with illuminated area 'A_1'vary according to the following expression

$R\text{=-}K \log A+\ R_d$ (8)

R_d is the dark resistance of LDR. The LDR is connected in a potential divider arrangement and accordingly an output voltage is computed.

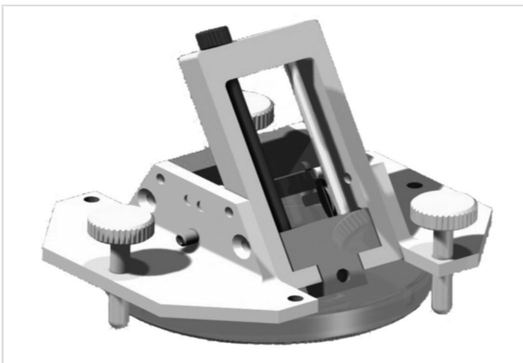
Fig. 4. Investgational setup for the Brix measurment

An optoelectronic sensor assembly with Prism is shown in fig 4 for the purpose of validation of Brix is correlated to refractive index by means of a reference table provided by a standard international scale i.e ICUMSA (International Commission on Uniform method of sugar analysis) table (2007) for pure sucrose.

4. Constructional details

The proposed architectural model as per requirement is shown in figure 5 and accordingly it is designed. Mathematical model based on optical geometry for the prism refractometer used in measurement of Brix. Simulation and experimental results show very good correlation [9].

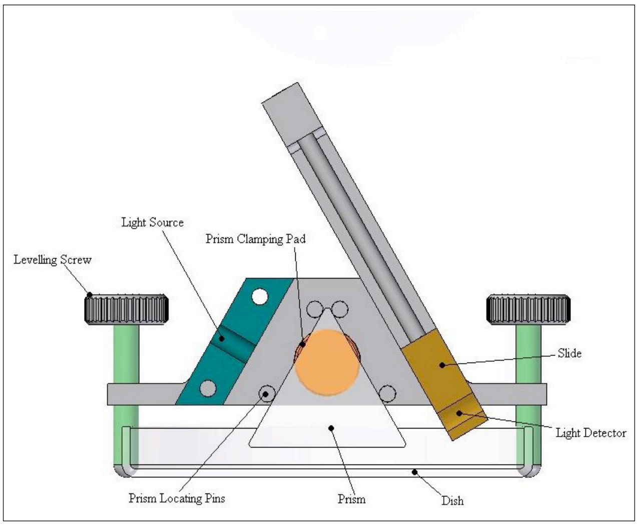

Fig.5. Proposed architectural model of Brix meter

The following parameters of components were selected for experimentation with mathematical model based on optical geometry of prism refractometer used in measurement of Brix and its modeling and simulation was carried out. The Base of prism b = 32mm, Angle of prism $\theta_p=60^0$, Refractive Index of RI prism n_p =1.72, LED of 650nm with $\theta s= 30^0$, and radius r =10 mm , LED mounted at c = 23mm. The response shown in figure 6, and fig 7 is experimentally corrected with common mode rejection (correction factor at zero Brix) against the estimated Brix. The linear nature of the plot indicates usefulness of this developed setup for direct Brix measurement. The response with different Brix sample was tested. Repeatability for different Brix sample is shown in figure 8.

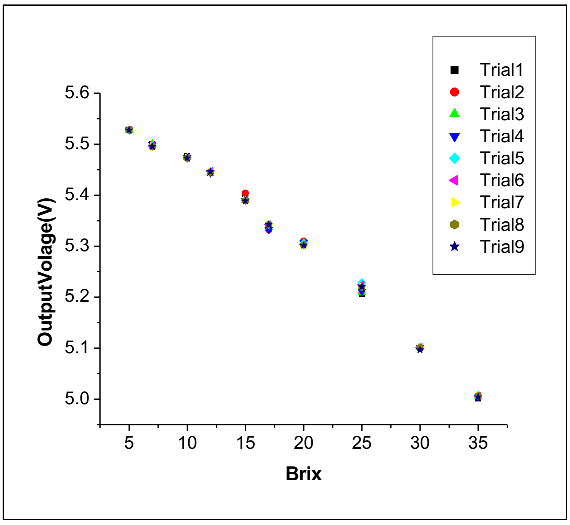

Fig 6.Output voltage variations with Brix of sample.

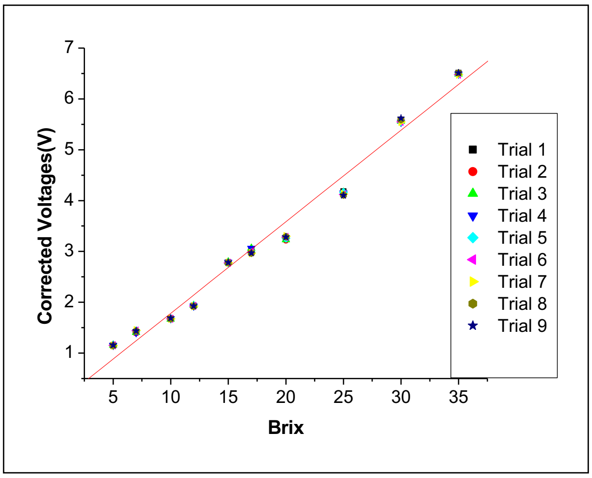

Fig 7. Experimentally corrected output voltage with common mode rejection

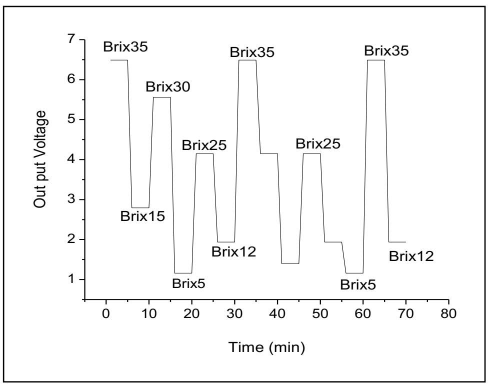

Fig 8: Repeatability of experimental setup for the measurement of Brix

4. Result and discussion

The measurement is based on total internal reflection and critical angle change. Normally critical angle changes due to change in sugar content in juices and syrups , color, gas, and dissolved particles, which do not affect on result. With using this model one can directly obtain the Brix of specimen. The various possibilities of mounting of source, detector, Prism are studied. Measurement of higher ranges (Brix and refractive index) possible by the simulation study and for installation of the experimental setup accordingly. Experimental results with the fabricated assembly shows, this instrument gives directly measurement of Brix in a given sample. The experimental response is shown in Fig 6 As the Brix of sample increases, due to change in critical angle, the light exposure on LDR is maximum, which decrease the LDR value. The experimental set-up developed with using mathematical model can be effectively used for the measurement of Brix up to from 1-35.

5. Conclusion

This paper presents a mathematical model based on optical geometry for the prism refractometer used in measurement of Brix. Simulation and experimental results show very good correlation. The system can be used extensively in food processing industry, for the measurement of concentration of sugar in aqueous solutions of soft drinks, juices, colas, nectars, and lactic acid beverages. It is hoped that the technique will help in process control and regulatory instrumentation in a food and sugar related industry for the design and development of robust device which can be useful on-line.

Acknowledgement:

The authors express their sincere thanks to the Head, Department of Electronics Science, Savitribai Phule Pune University Pune INDIA and Principal, RIRD Satara and Rayat Shikshan Sanstha's S.M Joshi college, Hadapsar, Pune -28, for allowing us to carry the research and development work and constant encouragement.

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