JES, Vol. 50, No. 3, May 2022 DOI: 10.21608/JESAUN.2022.115375.1108 Part C: Mechanical Engineering

Journal of Engineering Sciences
Faculty of Engineering
Assiut University

مجلة العلوم الهندسية
كلية الهندسة
جامعة أسيوط

journal homepage: http://jesaun.journals.ekb.eg

Evaluation of Digital Brixmeter Performance for Brix Measurement in Raw Sugar Solution

Received 9 January 2022; Revised 5 May 2022; Accepted 5 May 2022

M. Elewa[1]
G. El-Saady[2]
K. Ibrahim[3,4]
M. Tawfek[5]
H. Elhossieny[6]

Keywords

Sugar Industry, Brix, Hydrometer, Calculate Specific Density, digital brixmeter.

Abstract

The Brix value is an important factor in the sugar industry's extraction processes. Brix refers to the amount of sucrose in the raw sugar solution. The concentration of dissolved solids in a solution is measured by the degree Brix (symbol °Bx). One gram of sucrose in 100 grams of solution equals one-degree Brix. a New Suggested method for measuring brix was designed to be low-cost and accurate Brix measuring in raw sugar solutions. it was depended on electronic sensors can directly measure the mass and temperature of the sugary solution to express the brix and give the result on the screen. Digital suggested brixmeter was made based on this method. It can be used manually on the production line and in various food industries. The aim of this paper was to evaluate the digital brixmeter performance for measuring brix in raw sugar solutions. Brix measurements were tested for a group of samples at different sizes to find the optimal measurement sizes can verify accurate brix degree value. The factors affecting the accuracy of the measurement were also studied. The results were compared with the brix read from accurate optical refractometer to check and a prove the accuracy of the proposed digital brixmeter.

1. Introduction

A Brix value is defined as the quantity of sucrose in grams present in every 100 grams of liquid and is represented in degrees Brix (°Bx). This parameter's value can range from 1 to 100, and it's important for determining the sugar content of sugar solutions. It's widely utilized in the sugar industry around the world. The most common soluble solids in fruit and vegetable juices are sugars, organic acids, and amino acids, all of which contribute to °Brix values. In many fruit and vegetable

[1] melewa@aun.edu.eg - Faculty of Sugar and Integrated Industries Technology, Assiut University.
[2] Gaber1@yahoo.com - Professor, Department of Electrical Engineering, Faculty of Engineering, Assiut University.
[3] khalil.ibrahim@aun.edu.eg - Associate Professor, Dep. of Mechatronics Engineering, Faculty of Engineering., Assiut University.
[4] khalil.ibrahim@aun.edu.eg - Associate Professor, Dep. of Mechatronics Engineering, Faculty of Engineering, Sphinx University.
[5] Director of Devices and Control, Abu Qurqas Sugar & Integrated Industries Company, South Minya.
6 hosamalhosiny2011@hotmail.com, Devices and Control Engineer, Hawamdiya Sugar & Integrated Industries Company, Cairo.

https://doi.org/10.21608/JESAUN.2022.115375.1108

juices, however, sugars are the most abundant soluble solid. As a result, °Brix measurements are mostly used to assess the amount of sugar in fruits and vegetables. Sugar level, of course, has an impact on sweetness, which is a key factor in consumer evaluations of product quality. It's worth noting, too, that sweetness can be overshadowed by other flavors. As a result, a high °Brix score does not imply that the flavor will be sweet [1]. The dissolved solid content is then only approximated by the °Bx. Wine, sugar, carbonated beverages, fruit juice, maple syrup, and honey have all used the °Bx [2]. Adolf Ferdinand Wenceslaus Brix was a German mathematician and engineer (1798 - 1870). Degree Brix (°Bx), the unit for liquid specific gravity, is named after him. Brix worked as a civil servant in the fields of civil engineering, measures, and manufacturing. He was the director of the Royal Prussian Commission for Measurements, a member of the Ministry of Trade's technical committee, and a member of the technical building committee. He also taught applied mathematics at the Gewerbeinstitut zu Berlin. In addition, he studied higher analysis and applied mathematics, both of which were forerunners to the Technical University of Berlin. He was involved in several public works projects in Berlin and Potsdam [3].
Brix hydrometers and refractometers are the most used equipment for measuring Brix. Hydrometers are commonly used to measure Brix. They have a high degree of precision and are reasonably priced. One downside of hydrometers is that the readings might vary greatly due to different operators and methods of operation. Because the hydrometers are constructed of glass, they are easily broken. Brix refractometers are used to determine the degree of light refraction (as part of a refractive index) of transparent substances in either a liquid or solid form. This is then used to identify a liquid sample, analyze the purity of the sample, and calculate the amount or concentration of dissolved chemicals in the sample. Light will slow down as it passes through the liquid from the air, creating a 'bending' illusion. The severity of the 'bend' will be determined by the amount of substance dissolved in the liquid [4]. This paper aims to test and evaluate the proposed device to measure brix degree in raw sugar solution. This device uses smart microcontroller to collect data which come from these sensors and make mathematical algorithms previously programmed to find accurate brix value. The proposed device "digital hydrometer" was design and published its paper in ESJ take it into consideration to be cheap, fast, gives accurate result. The results of the proposed device compared with accurate reference brix degree [5].

2. Methodology and Mathematical Formulations

Based on Table 109 (degrees brix, specific gravity at 20°C), National Bureau of Standards puts basis of the relationship between brix and specific density [6]. The researcher used Microsoft Excel 365 by fed it with all Brix values from 0 to 95, and using Excel functions, the following equation was produced, which will be adopted by the proposed device to measure Brix:

$$°Bx = -90.064\ SD^4 + 569.15\ SD^3 - 1396.9\ SD^2 + 1705.2\ SD - 787.36$$

When SD: specific density at 20°C

This equation is the most suitable equations for measuring Brix of raw sugar samples, and the researcher adopted it in the proposed device.

when $SD = \frac{\rho_{sample}}{\rho_{H_2O}}$, $\rho_{sample} = \frac{Mass}{Volume}$,

$$\rho_{H_2O} = 1 - \frac{(T+288.9414)(T-3.9863)^2}{508929.2\,(T+68.12963)}$$ where T is the sample temperature [7]

Using Excel, this equation was tested again with full range of brix and found the coefficient of determination R2 = 100%, and the Root Mean Squared Error (RMSE) = 0.02.

The previous table and the previous equation to get Brix through specific density at a temperature of 20°C, therefore when measuring at a different temperature, the equation needs to be corrected according to the sample temperature. Temperature sensor was used to measure the sample temperature and entered it directly into the equation to get real brix degree without needing any temperature correction. The concept of the suggested device in this study is measuring the mass of Specific known volume of the sample then measure the temperature of the sample by modern accurate electronic sensors. And send that data to the previously programmed microcontroller, which receives data from sensors and calculates the degree of brix directly and appears on the screen.

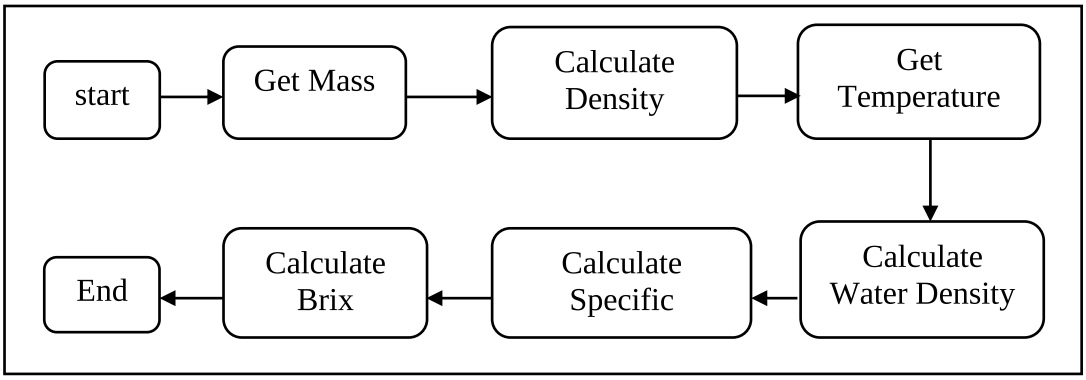

Fig. 1: Steps of Suggested device to Measuring Brix

Steps of Tasks for Measuring Brix by Digital Brixmeter

- Preparing recommended volume for pure sample.
- Microcontrollers receive sample mass value from mass sensor.
- Microcontrollers receive sample temperature value from temperature sensor.
- Microcontrollers calculate the sample density from relation: $\rho_{sample} = m/v$
- Microcontroller calculate the water density at measuring temperature from relation [7] $\rho_{H_2O} = 1000(1 - T+288.9414/(508929.2*T+68.12963)*(T-3.9863)^2)$ where T is temperature.
- Microcontrollers calculate sample specific gravity by relation: $SD = \rho_{sample} / \rho_{H_2O}$
- Microcontrollers calculate sample Brix by relation: $°Bx = -90.064\ SD^4 + 569.15\ SD^3 - 1396.9\ SD^2 + 1705.2\ SD - 787.36$
- Microcontroller send brix value to LCD screen to display.

3. Practical Experiences

These experiments were conducted, and the Brix value was obtained from the proposed device "digital brixmeter" and the results were compared with the Brix readings for the same sample on the refractometer as type (PTR 46 XP) in Abu Qurqas, laboratory Sugar and Integrated Industries Company, South Minya, Egypt. The PTR range of refractometers has been designed for high accuracy, excellent temperature stability, reliability, and ease of use. The temperature range is controlled electronically using Peltier Cell technology

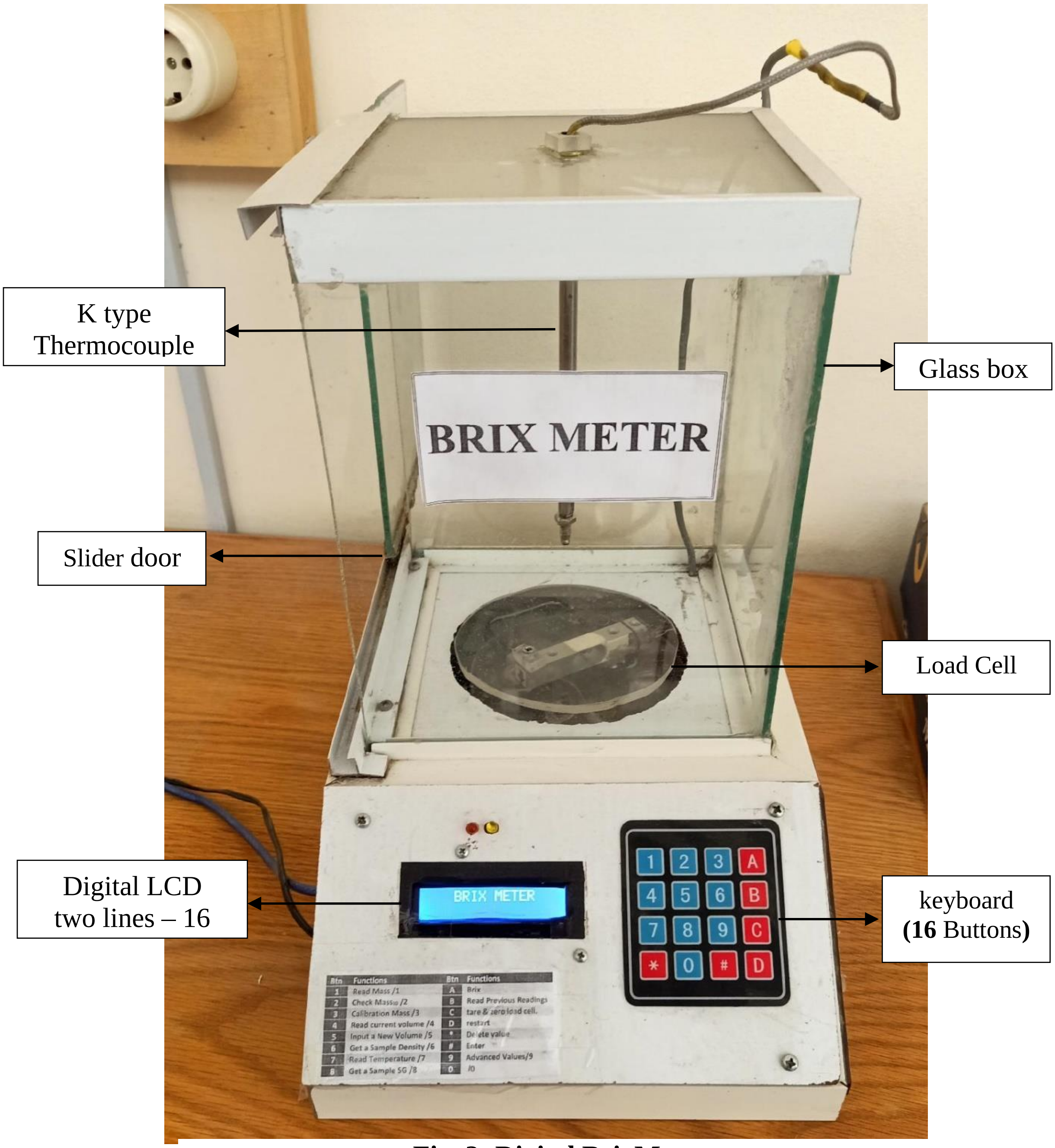

Fig. 2: Digital BrixMeter

3.1 Brix Measurement Steps for The Sample:

- Make sure the surface of the load cell is free (empty).
- Make sure that the device is powered on and the screen is light.
- Put the empty vessel or flask and press (C) button to tare load cell to zero mass.
- If you decide to use custom volume press (5) and write volume value, you will use.
- Take vessel or flask away and fill it with sample with certain volume.
- Put vessel or flask on the load cell inside glass box and close the glass box door.
- Press (A) button to run brix function. This function will take mass reading and calculate sample density.
- When red light and buzzer in on, you must turn temperature bar down inside the sample, and input second number you will wait before the device take temperature degree.
- The device will take temperature and calculate sample specific density.
- Finally, the device calculates the sample brix and its correction.
- If you want to review the previous values press (B) Button.

3.2 Steps to Enter Custom Volume:

If you want to change default volume value for any reason, you can use a new custom volume value by execute this step:

- Make sure that the device is powered on, and the screen is light.
- Press (4) button to know current stored volume value.
- Enter new custom volume function by Press (5) button.
- Write the new custom volume value and press (#) to enter new value and exit.

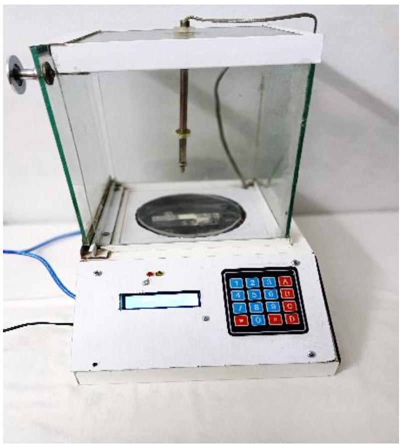

Fig.3: Digital BrixMeter

Fig.4: PTR 46 XP Refractometer

Scale: Specific Density (SG), Brix, Mass, Temperature.
Range: Brix 0 to 95%.
Readability: 0.0001 SG, 0.01 Brix.
Readout time: about 60 seconds as maximum response time to read the sample temperature
Temperature control: No need Temperature control.
Temperature accuracy: ± 0.25°C
Power requirements: AC-to-DC adapter - recommended range is 7 to 12 volts.
Selling price: 87.5$

Scale: Refractive Index (RI), Brix, Temperature corrected Brix.
Range: 0 to 100%.
Readability: 0.00001 RI, 0.01 Brix.
Readout time: 9 seconds + cooling time accordin to sample temperature.
Temperature control: Internal electronic control by Peltier cell
Temperature accuracy: ± 0.05°C
Power requirements: 86 to 265V AC, 47 to 63Hz less than 30 watts
Manufacturing cost: 795.0$

PTR 46 XP Refractometer has internal electronic temperature control, it will take some time to control in sample temperature to reach 20°C, but digital brixmeter can read current sample temperature and insert it in brix calculations. the brixmeter has K type Thermocouple can read accurate sample temperature. it will take some time to move sensing form room temperature to sample temperature, this time called as a response time for temperature sensing. the Response time is a variable depending on the temperature to be reached. Through experiments, it was found that it takes about 60 second to read accurate sample temperature

4. Standard Accuracy and accepted Tolerance Range

Most Soft Drinks firms' quality control (QC) standard allows for a tolerance of only 0.15°Bx above or below the target Brix for maintaining the sugar level of the drink at the target Brix. For example, the firm must manufacture and fill the beverage between 10.85°Bx and 11.15°Bx. This tolerance allows for any acceptable "experimental errors" in actual manufacturing processes and laboratory testing procedures. Weight or volume measurements, ocular readings, equipment calibrations, and,

of course, plain, and simple "human error" are all possibilities. Brix specification's tight 0.15°Bx tolerance range appears to address the organoleptic problem. Within this range, the consumer is unlikely to notice a difference in the sweetness and overall taste of the drink.
In practice, the ideal situation is when both QC and production collaborate to keep the target filling Brix in the lowest range permissible, achieving a significant portion of the potential cost reduction in sugar usage [8].

Reasons for Possible Expected Deviation in (°Bx) From the Real Values:

1- ± 0.03 may come from temperature sensor Sensitivity as the maximum possible deviation at the maximum possible temperature deviation about 0.45 °C.
2- ± 0.35 may come from mass sensor Sensitivity as the maximum possible deviation at the maximum possible mass deviation about 0.15 g. to overcome possible deviation of the mass, the researcher had to increase the volume which was followed the increase the sample mass.

For example, if mass sensor gives as maximum possible mass deviation about 0.15g at sample mass 100g, and gives the same mass deviation at 1000g, the error percentage at each will be:
Error percentage at 100g = 0.15%, Error percentage at 1000g = 0.015%
As a result, the larger the sample size, and thus the larger the sample mass, the lower the error generated by the mass sensor reading.

5. Results and Discussion

These experiments were performed under normal operating conditions at normal temperatures. Samples were tested at 100, 200, 300, 400, 500 cm^3 to Select the recommended sample volume and minimum volume can get accurate brix degree. and determining the optimum conditions for operation and measurement.

Statistical description of the Samples:

- Expected brix of the sample: 15: 65 °Bx.
- Sample Temperature: 10: 30 °C.
- All suspended material must be removed, and the purity of the sample confirmed.

5.1. Difference of Brix Degree (°Bx) at Samples Volume 100 cm^3

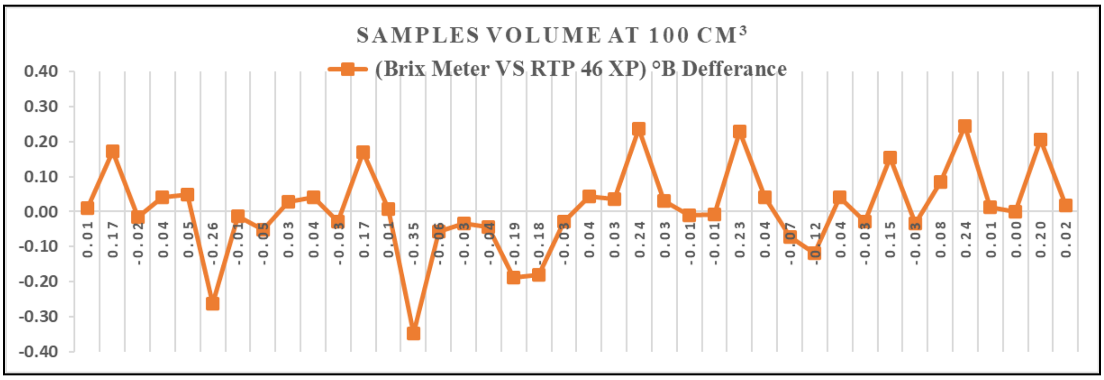

Fig. 5: Difference of Brix Degree (°Bx) at Samples Volume 100 cm^3
Max Positive Difference = 0.24 °Bx   Max negative Difference = -0.35 °Bx

5.2. Difference of Brix Degree (°Bx) at Samples Volume 200 cm^3

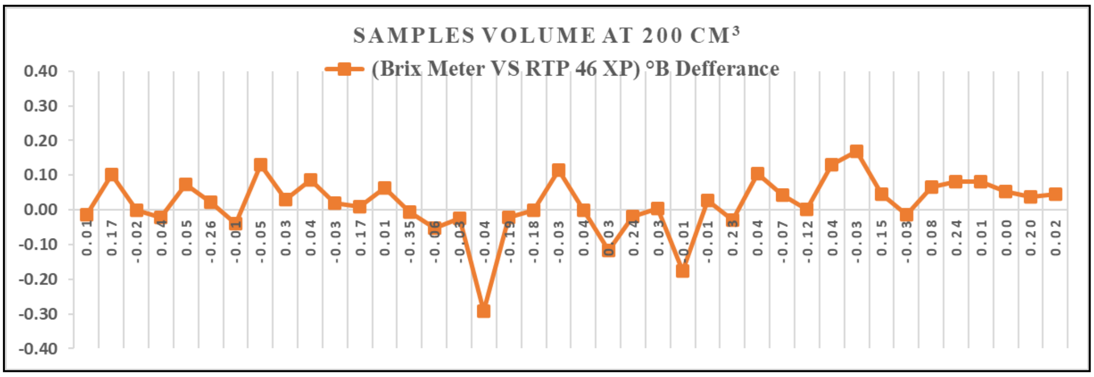

Fig. 6: Difference of Brix Degree (°Bx) at Samples Volume 200 cm^3

Max Positive Difference = 0.17 °Bx Max negative Difference = -0.29 °Bx

5.3. Difference of Brix Degree (°Bx) at Samples Volume 300 cm^3

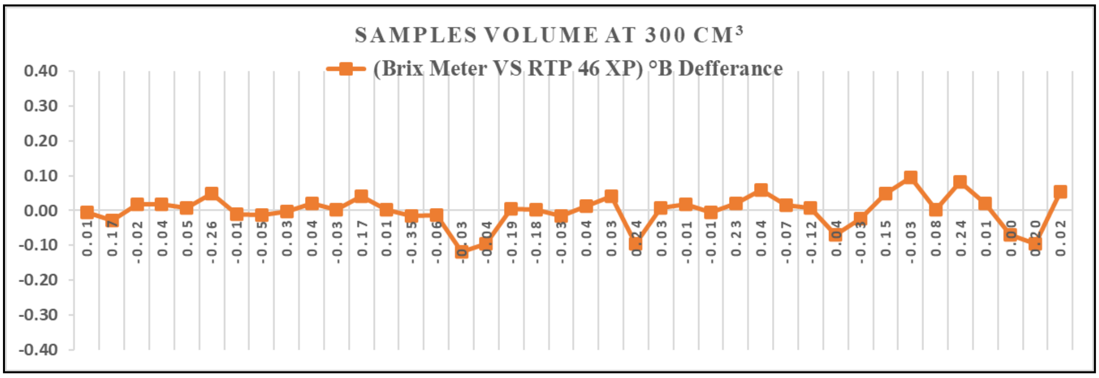

Fig. 7: Difference of Brix Degree (°Bx) at Samples Volume 300 cm^3

Max Positive Difference = 0.1 °Bx Max negative Difference = -0.12 °Bx

5.4. Difference of Brix Degree (°Bx) at Samples Volume 400 cm^3

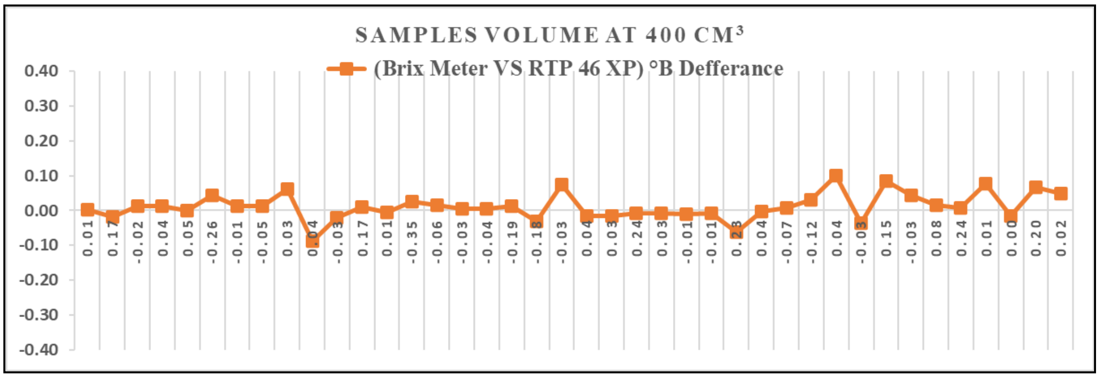

Fig. 8: Difference of Brix Degree (°Bx) at Samples Volume 400 cm3

Max Positive Difference = 0.1 °Bx Max negative Difference = -0.09 °Bx

5.5. Difference of Brix Degree (°Bx) at Samples Volume 500 cm^3

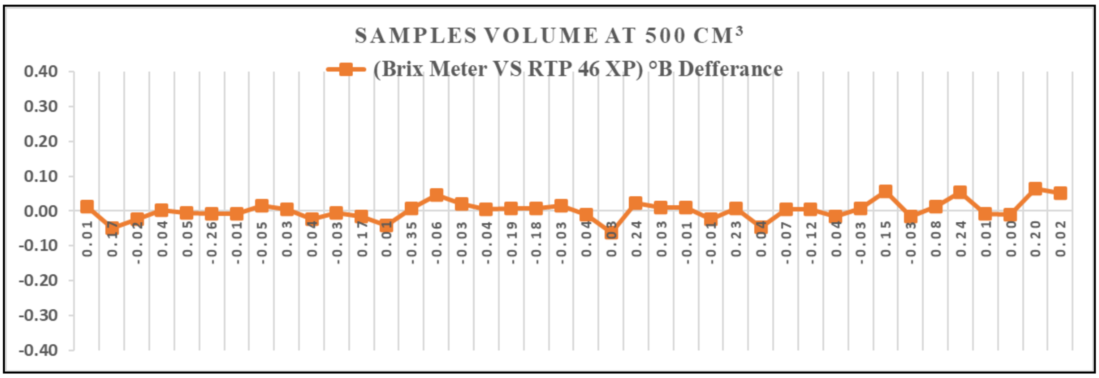

Fig. 9: Difference of Brix Degree (°Bx) at Samples Volume 500 cm^3

Max Positive Difference = 0.06 °Bx   Max negative Difference = -0.06 °Bx

Based on the previous results, the recommended volume for the measurement is 500 cm^3, so the operator must manually adjust the sample to the recommended volume, and the device has been programmed to have the default volume as the recommended volume.

5.6. The Discussion of the Results

- The results indicated that the brix value obtained from the suggested digital brixmeter are approaching with the exact value obtained from the refractometer device, noting that the refractometer device used has a refrigerator to cool the sample to a temperature of 20°C and needs more time to give the exact value. While the suggested device for measuring brix gives the value directly without the need to cool the sample, despite the overall difference in the theory of work of the two systems.
- The results also were indicated that the maximum differences between the brix values between the two devices is 0.06 Brix degree at 500 cm^3, which is a very acceptable rate in the sugar industry. Therefore, the results also are matched often.

Table 1: Difference Brix Degree between Brix Meter and PTR 46 XP

Sample Volume (cm^3)	Max Difference$^+$ (°Bx)	Max Difference$^-$ (°Bx)
100	+0.24	-0.35
200	+0.17	-0.29
300	+0.1	-0.12
400	+0.1	-0.09
500	+0.06	-0.06

- The minimum allowed sample volume to be used is 300 cm^3, but the recommended volume allowed to use to take accurate brix value is 500 cm^3.
- Neglecting the correction equation when using the digital hydrometer because the result of the close convergence between the direct results of Brix from the proposed device with the calculated value after replacement in the correction equation. So, it does not need to be corrected.
- The results confirmed that the slight change in weight measurement greatly affects the outcome of brix, while the change in temperature does not strongly affect brix.
- The results indicated that we could measure the Brix degree of raw sugar solutions in generally in food and sugar industries using inexpensive, fast-measuring electronic devices using sensors to measure mass and temperature.
- Confirmed the previous recommendations from National Bureau of Standards that all suspended material must be removed, and the purity of the sample confirmed.

- The sample size is directly proportional to the accuracy of reading the brix value, since in this study it is not possible to measure a sample with a size less than 100 cm^3 because it will cause the results to be diffused from the truth.
- It is necessary to review the sensors used and ensure the correct measurement of them and it must be constantly reviewed.
- The scope of this study exceeds solutions containing other melted substances in the sample other than sugars and non-protective samples that contain impurities.

6. Conclusions

1- This study presents a digital brixmeter. Its idea depends on the same theory, tables and equations for the hydrometer but using electronic sensors and a microcontroller. It automatically processes data and gives accurate brix degree values and displays it on the LCD screen. It can be developed to store or send to the central laboratory. This device is cheap price, fast, and accurate result. The suggested device can be developing to work directly online on the production line.
2- The system can be used widely in the sugar industries and food based on these conclusions processing industry, to measure the sugar concentration in aqueous solutions, determine the density of liquids and calculate specific density, estimate any quantities related to density.

7.Recommendations

1- To improve the results of the device, it is possible to work on finding more sensitive and stable sensors to achieve more stable results.
2- The device can be developed to work on production lines directly, and the reading brix values can be sent wirelessly to the central control room.
3- Working to improve the design to make it portable and lightweight.
4- The ability of the device to measure the brix of heavy sugary solutions such as honey, molasses and mesquite can be tested.

References

[1] Matthew D. Kleinhenz and Natalie R. Bumgarner, “Using °Brix as an Indicator of Vegetable Quality: An Overview of the Practice | Ohioline,” *Ohio Agricultural Research and Development Center*, 2013. https://ohioline.osu.edu/factsheet/HYG-1650.

[2] A. R. Macon, “Brix Measurement,” PPD Inspection Series, 2011. [Online]. Available: https://www.fruitsmart.com/wp-content/uploads/Brix-Table-USDA-Conversion-Chart.pdf.

[3] D. Trumbore and D. J. Nelson, *The Science of Breaking Bad*. London: The MIT Press, 2019. https://direct.mit.edu/books/book/4311/The-Science-of-Breaking-Bad

[4] M. TOLEDO, “BRIX-Sugar Determination,” 2014. Accessed: Jul. 02, 2020. [Online]. Available: https://beta-static.fishersci.com/content/dam/fishersci/en_US/documents/programs/scientific/technical-documents/technical-bulletins/mettler-toledo-brix-sugar-determination-techinical-bulletin.pdf.

[5] H. E. M. Elewa, G. El-Saady, K. Ibrahim, M. Tawfek, “A novel Method for Brix Measuring in raw Sugar Solution,” *Egypt. Sugar J.*, vol. 15, no. 2636–2694, pp. 69–86, 2020, [Online]. Available: http://www.aun.edu.eg/sugar_tec_institute/Arabic/Journal/vol.15.pdf.

[6] F. Bates, Polarimetry, Saccharimetry and the Sugars. Table 109: Brix, apparent density, apparent specific gravity, and grams of sucrose per 100 ml of sugar solutions. *National Bureau of Standards*, 1942. pp. 614:656. Available: https://archive.org/details/circularofbureau440bate/page/614/mode/2up

[7] T. O. J. McCutcheon, S.C., Martin, J.L, Barnwell, *Water Quality in Maidment*, D.R. (Edit. Handbood of Hydrology, McGraw-Hill, 1993.

[8] M. Shachman, *The Soft Drinks Companion: A Technical Handbook for the Beverage Industry*. CRC Press, 2004, pp. 26:29.

تقييم أداء جهاز البركس الرقمي لقياس البركس لمحاليل السكر الخام

يعد قياس البركس لمحاليل السكر الخام مقاساً هاماً في عمليات تكرير السكر اثناء العملية الصناعية، يمثل البركس كمية محتوى السكروز الموجود في المحاليل السكرية ويقاس بالدرجة بركس (B °). درجة واحدة بركس هي ١ جرام من السكروز ذائبة في ١٠٠ جرام من المحلول. تم تصميم طريقة جديدة مقترحة لقياس البركس لمحاليل السكر الخام. اعتمدت تلك الطريقة على استخدام مستشعرات إلكترونية ذات القدرة على قياس الكتلة ودرجة حرارة المحلول وارسالها قيمتهما الى وحدة معالجة رقمية قادرة على حساب قيمة البركس وإظهار النتيجة على الشاشة. تم مراعاة ان تكون تلك الطريقة منخفضة التكلفة وذات دقة عالية. تم تجربة قياس درجات البركس لمجموعة من العينات عند احجام مختلفة للوقوف على الاحجام المثلى للقياس والتي تحقق عندها أفضل دقة مطلوبة لدرجات للبركس. كما تم دراسة العوامل المؤثرة على دقة القياس. تم تصميم جهاز بركسمتير رقمي تقوم فكرة عمله على الطريقة المقترحة. كما تم مقارنة النتائج درجات البركس المقروءة بواسطة جهاز البركسميتر المقترح بالنتائج المقروءة بواسطة جهاز الانكسار الضوئي ذات الدقة العالية لإثبات مدى دقة جهاز البركسميتر الرقمي المقترح.