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A novel Method for Brix Measuring in raw Sugar Solution

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Abstract

In Sugar Industry, the Brix value is an important factor in extraction processes. Brix is the amount of sucrose contents presents in the raw sugar solution. Degree Brix (symbol °Bx) measures the concentration of dissolved solids in the solution. One-degree Brix is 1 gram of sucrose in 100 grams of solution and represents the strength of the solution as percentage by mass. Based on the brix value in solution, the operators can measure and take decisions in sugar industrial process.

The aim of the present paper is suggesting method to measure the brix value in a raw sugar solution using several electronic sensors that have been installed and connected to microcontroller to perform several calculations to calculate brix. This proposed method is a low price with high accuracy in reading Brix in raw sugar solutions in industrial processes.

This method depends on the physical properties of the sugar solution. Electronic sensors can directly measure the mass, and temperature of the solution to express the brix and give the result on the screen. Also, the results can be sent directly to the central control room. Moreover, it can be used manually on the production line and in various food industries.

The suggested method can be applied directly in the industrial process during extracting sugar such as juice and syrup to determine their

concentration. Whereupon the efficiency of industrial process is improved.

The proposed method for the first-time sheds light on the possibility to make an electronic hydrometer capable of reading the physical properties of liquid solutions using a group of electronics and judging its efficiency, accuracy, scope of work and the factors affecting the results.

Keywords: Brix, Hydrometer, Calculate Specific Density, Temperature Corrections

1- Introduction

Brix and degree of super saturation is a technical term in the sugar industry. The term "Brix" technically means the percent of weight of sugar solids in a pure sucrose solution. Brix sugar solution represents the concentration of sugar. Degrees Brix is the sugar content of an aqueous solution. If the solution contains dissolved solids other than pure sucrose. Then the °Bx only approximates the dissolved solid content. The °Bx is traditionally used in the wine, sugar, carbonated beverage, fruit juice, maple syrup and honey industries [1].

Different types of sugarcane can classify greatly in their sucrose levels, sucrose content can vary from 15% Brix to 23% Brix. Sugarcane with a Brix percentage closer to 23% Brix is considered to produce the highest quality of cane sugar. After harvesting the sugarcane stems, the manufacturing process begins with extraction of the cane juice. The sugarcane stems are crushed in a series of mills which squeeze out the juice and separate the cane fibers. The cane juice is filtered and evaporated to produce a thicker, syrup-like product, to which sulfur is added for coloration and increased shelf life. The thickened cane juice is then boiled to promote the growth of sugar crystals, which are then separated by centrifugation. The pure sugar is finally dried prior to packaging and final storage [2].

Sugars are the most abundant soluble solid in raw sugar solution during extraction sugar. Among the various analytical methods required in cane sugar production, analysis of Brix percentage of sugarcane juice is one of the most important parameters. Brix

values are important because they can be measured objectively, and they relate to a subjective criterion that buyers and manufacturers to assess the quality of the crop [3].
The instruments generally used for Brix measurement are Brix hydrometers and refractometers. Brix hydrometers are widely used for measurement of Brix. They have relatively good accuracy and are available at reasonable prices. One disadvantage of hydrometers is, that due to different operators and the way of working (e.g. put down the hydrometer calmly) the results may differ a lot. The hydrometers are made of glass and therefore highly breakable. Brix refractometers measure the extent of light refraction (as part of a refractive index) of transparent substances in either a liquid or solid state. This is then used in order to identify a liquid sample, analyses the sample's purity and determine the amount or concentration of dissolved substances within the sample. As light passes through the liquid from the air it will slow down and create a ‘bending’ illusion, the severity of the ‘bend’ will depend on the amount of substance dissolved in the liquid [4].

Brix measurement devices in sugar factories in Egypt are divided into two types, the first type is installed on the production line and is expensive and does not give accurate results in most cases and depends on the theory of optical refraction work. The second type is solved by taking a sample and sending it to the central laboratory to measure brix. The central laboratory has a hydrometers device which gives not accurate result. While the refractometers give accurate result, but it need more time plus it is expensive devices.

This paper aims to use new modern electronic sensors to measure brix value in raw sugar solution. This method uses smart microcontroller to collect data which come from these sensors and make mathematical algorithms previously programmed to find accurate brix value. The proposed method is cheap, fast, gives accurate result. The results of the proposed method is compared with accurate refractometer results.

2- Process Analysis

Adolf Ferdinand Wenceslaus Brix was a German mathematician and engineer. The unit for specific gravity of liquids, degree Brix (°Bx), is named after him. Brix made a career as a civil servant in professions related to civil engineering, measurements and manufacture and retired in 1866. He was director of the Royal Prussian Commission for Measurements, member of a technical committee in the Ministry of Trade, and the technical building committee. He was also a teacher of applied mathematics at Gewerbeinstitut zu Berlin. As well as in higher analysis and applied mathematics at the Bauakademie, both of which are forerunners of the Technical University of Berlin. He participated in many public works in Berlin and Potsdam [5].

In the early 1800s, Karl Balling, followed by Adolf Brix, and finally the Normal-Commissions under Fritz Plato, prepared pure sucrose solutions of known strength, measured their specific gravities and prepared tables of percent sucrose by mass vs. measured specific gravity. Balling measured specific gravity to 3 decimal places, Brix to 5, and the Normal-Eichungs Kommission to 6 with the goal of the Commission being to correct errors in the 5th and 6th decimal place in the Brix table [6].

Based on previous studies, Brix is measured with two method. The first method uses specific density to determine the degree of brix. The second method depends on relative index of the sample and both way the sample must be at 20° C. Design and evaluation of a modern method for measuring brix on raw sugar solutions, which have cheap price, accurate, fast measurement data. Using hydrometer theory. All trials and results were conducted under supervision Sugar and Integrated Industries Company, Abu Qurqas, is the largest sugar company in South Minya, Egypt. Central laboratory control and quality, under supervisor of Research and Development Department at the main center in Hawamdiya.

2-1 Measuring Principles

There are two methods to measure brix:

2-1-1 Hydrometers:

As specific gravity was the basis for the Balling, Brix and Plato tables, dissolved sugar content was originally estimated by measurement of specific gravity using a hydrometer or pycnometer. In modern times, hydrometers are still widely used, but where greater accuracy is required, an electronic oscillating U-tube meter may be employed. Whichever means is used, the analyst enters the tables with specific gravity and takes out (using interpolation if necessary) the sugar content in percent by mass. If the analyst uses the Plato tables (maintained by the American Society of Brewing Chemists) he or she reports in °P. If using the Brix table (the current version of which is maintained by NIST and can be found on their website), he or she reports in °Bx. If using the ICUMSA tables, he or she would report in mass fraction (m.f.). It is not, typically, actually necessary to consult tables as the tabulated °Bx or °P value can be printed directly on the hydrometer scale next to the tabulated value of specific gravity or stored in the memory of the electronic U-tube meter or calculated from polynomial fits to the tabulated data. Both ICUMSA and ASBC have published suitable polynomials; in fact, the ICUMSA tables are calculated from the polynomials. The opposite is true with the ASBC polynomial. Also note that the tables in use today are not those published by Brix or Plato. Those workers measured true specific gravity reference to water at 4 °C using, respectively, 17.5 °C and 20 °C, as the temperature at which the density of a sucrose solution was measured. Both NBS and ASBC converted to apparent specific gravity at 20 °C/20 °C. The ICUMSA tables are based on more recent measurements on sucrose, fructose, glucose and invert sugar, and they tabulate true density and weight in air at 20 °C against mass fraction [7]. The hydrometer has advantages such as it is a simple method, gives quick measurements for specific density, and an inexpensive instrument. However, it has disadvantages like, it does not give direct brix value, is a breakable glassware. has limited accuracy. And Large sample volume is required [4].

2-1-2 Refract meter

Dissolution of sucrose and other sugars in water changes not only its specific gravity but its optical properties, in particular its refractive index and the extent to which it rotates the plane of linearly polarized light. The refractive index, nD, for sucrose solutions of various percentage by mass has been measured and tables of nD vs. °Bx published As with the hydrometer, it is possible to use these tables to calibrate a refractometer so that it reads directly in °Bx. Calibration is usually based on the ICUMSA tables [8]. but the user of an electronic refractometer should verify this. The refractometer has advantages such as it gives accurate brix value. gives quick measurements. and it is an inexpensive instrument. While there are some disadvantages such as it does not give direct brix value.it is expensive price., it is a complicated construction. and it needs calibrations [1].

2-1-3: The Suggested Method (Electronic Hydrometer):

The International Commission for Uniform Methods of Sugar Analysis (ICUMSA) is an international standards body, founded in 1897, that publishes detailed laboratory procedures for the analysis of sugar. They are putting brix degree depend on specific gravity at constant temperature degree .In this method, the theory of work of the hydrometer is chosen , which depends on the use of specific density to determine the degree of brix of the solution, because it is the primary method for measuring brix and its efficiency and for the ease of obtaining sensors to deal with it. Accurate values of °Bx can be computed from Equation (1) [9]:

$$°Bx = 182.4601S^3 - 775.6821S^2 + 1262.7794S - 669.5622$$

Where S=specific gravity of the solutionThis equation is derived Bates, Frederick "Polarimetry, Saccharimetry from the brix table, and the Sugars. Table 114: Brix, apparent density, apparent specific gravity, and grams of sucrose per 100 ml of sugar solutions". National Bureau of Standards [7].

2-2 Temperature Correction

The density of water changes predictably with temperature and so it is possible (and important) to correct readings taken at temperatures the hydrometer is not calibrated for. Most hydrometers are calibrated to 20°C [10]. The previous equation calculates brix at 20°C, the brix will change if the temperature is different from standard, so below equation will calculate brix at different temperature [11]. This equation Calculated by values from table 110 (temperature correction to reading of brix hydrometer), Equation 2:

$$\text{Corrected-Reading} = r * ((1.00130346 - (0.000134722124 * t) + (0.00000204052596 * t^2) - (0.00000000232820948 * t^3)) / (1.00130346 - (0.000134722124 * c) + (0.00000204052596 * c^2) - (0.00000000232820948 * c^3))).$$

where: r = reading of brix hydrometer, c = calibration temperature ° F, t= temperature ° F

This equation gets from in this suggested method, the temperature sensor is used to read real sample temperature directly, putting direct brix degree reading vs brix correction reading and it is cared to compare the different between them.

3- Instrument design and operation

The idea of the suggested method in this study is measuring the mass of 100 cm^3 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 or sends it to the central control room. The following Figure (1) shows the block diagram of suggested measuring process

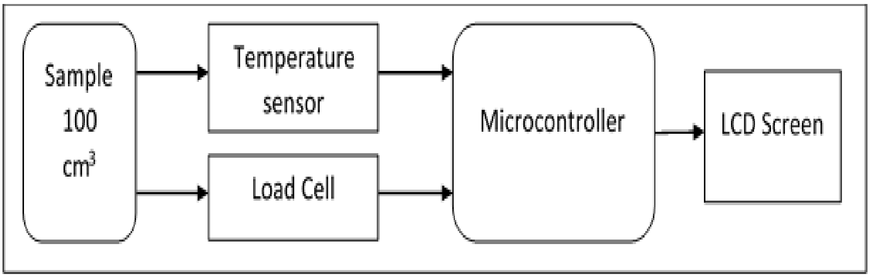

Figure (1): Block Diagram of the Suggested Method

3-1 Steps of Suggested Method to Measuring Brix

The microcontroller was programmed to serval steps as shown in figure (2) as the following: -

1. Preparing 100 cm^3 from pure sample.
2. Get sample mass by load cell (mass sensor).
3. Get sample temperature by temperature sensor.
4. Microcontroller gets the sample density from relation: $\mathbf{q_s = m/v}$
5. Microcontroller gets the water density at measuring temperature from relation

$$\mathbf{q_w = 1000(1 - T+288.9414/(508929.2*T+68.12963)*(T-3.9863)^2)}$$ [12]

where T is temperature.
6. Microcontroller calculated sample specific gravity by relation:

$$\mathbf{q_t = q_s / q_w}$$

7. Microcontroller calculated sample Brix by relation:

$$Brix = 182.4601\, q_t^2 - 775.6821\, q_t^2 + 1262.7794\, q_t^2 - 669.5622$$ [9]

8. Microcontroller send brix value to LCD screen to display.

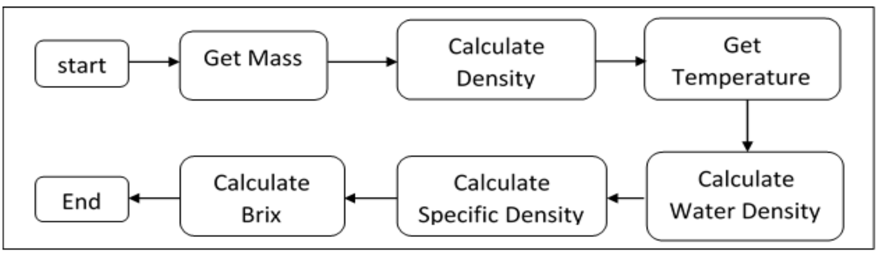

Figure 2: Steps of Suggested Method to Measuring Brix

3-2 Components of The System

3-2-1 Load Cell

A load cell shown in Figure (3) is a physical element that can translate pressure (force) into an electrical signal. By depend on strain measurements relating to weight measurement. A load is applied to a strain gauge, which causes the gauge to strain a certain amount and output a voltage proportional to the applied load. This relationship between strain and voltage is used in many applications where weight measurement is important. Load cells are very common because of their linearity, cost effectiveness, and their ease of implementation. The data sheet of the load cell is, 5 Kg, Output: 1mv / v, Temperature zero drift: 0.1% F.S, Output sensitivity: ± 0.15mv / v, Temperature sensitivity: 0.05% F.S, Insulation resistance: ≥ 2000MΩ, Excitation voltage: 5-10VDC.

3-2-2 Temperature sensor

MAX6675 K-type Thermocouple Module makes use of the Maxim MAX6675 K-Thermocouple to digital converter IC to provide a microcontroller compatible digital serial interface (SPI compatible) to provide accurate temperature compensated measurement of the supplied K-Type thermocouple sensor. It has a 12-bit resolution providing temperature readings from 0^{o}C to

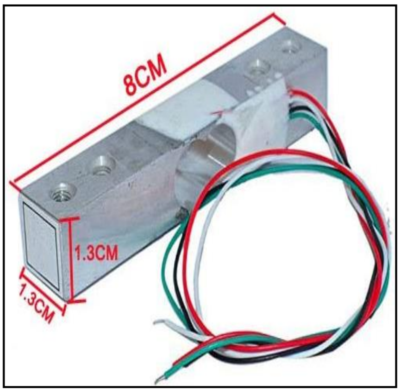

FIGURE (3): LOAD CELL

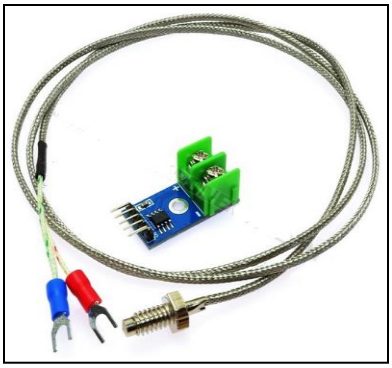

FIGURE (4):MAX6675 K-TYPE THERMOCOUPLE

1024^{o}C (max temperature of supplied sensor is 450^{o}C) with a resolution of 0.25ºC. The temperature sensor is shown in Figure (4) and it has data sheet of ,Working voltage: DC5V,Operating Current: 50mA,The temperature measuring range: -200°C – 1300 °C [Test procedure for 0-1023 °C],The temperature measurement accuracy: ± 1.5 °C, The temperature resolution: 0.25 °C, The output mode: SPI digital signal With a fixed mounting holes for easy fixed installation Storage temperature: -50 ~ 150 °C.

3-2-3 Input Keypad:

Standard Matrix Keypad 4×4 Flat switches and can be stick it on any box – Numerical Shape and it is shown in Figure (5).

3-2-4 LCD Display:

LCD is an electronic display module which uses liquid crystal to produce a visible image. The 16×2 LCD display is a very basic module commonly used in DIYs and circuits. The 16×2 translates o a display 16 characters per line in 2 such lines. In this LCD each character is displayed in a 5×7 pixel matrix and it is depicted in Figure (6).

FIGURE (5): KEYPAD

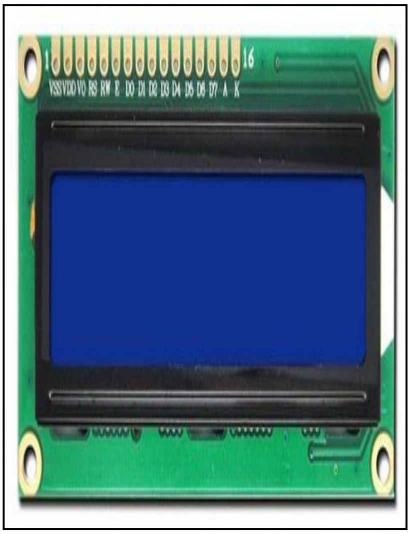

FIGURE (6): CHARACTER LCD 2×16

3-2-5 Microcontroller:

The Arduino Mega 2560 shown in Figure (6) is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins, 16 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller. Its data sheet consists of Operating Voltage:5V, Input Voltage (recommended): 7-12V, Input Voltage (limit): 6-20V,Digital I/O Pins: 54, Analog Input Pins: 16,DC Current per I/O Pin: 20 mA, DC Current for 3.3V Pin: 50 mA, Flash Memory: 256 KB, SRAM: 8 KB, EPROM: 4 KB, Clock Speed: 16 MHz, Length: 101.52 mm, Width: 53.3 mm, Weight: 37 g.

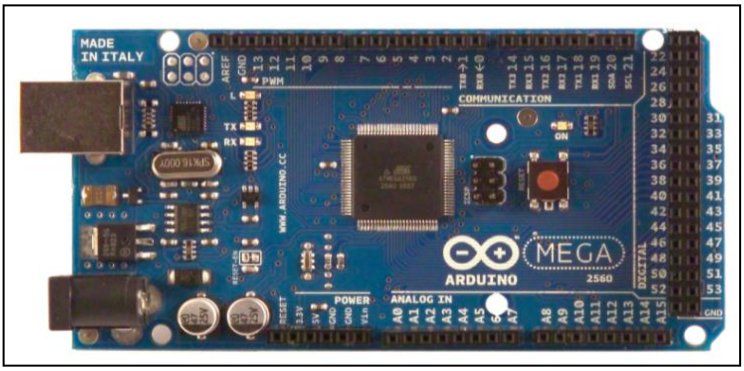

FIGURE (3): ARDUINO MEGA 2560

4- Results and Discussion

The main objective of the experiment is to obtain an accurate value of the sample brix in a small time. While the hydrometer devices do not give direct values to the brix, and their results are inaccurate and need to be corrected. However, the brix value of the refractometer devices is more accurate but needs longer time because the refractometer automatically cools the sample to a temperature of 20° C and shows the result on the screen. It was conducted these experiments and obtained the value of brix from the proposed device, Also the results were compared to reading the brix of the same sample on the refractometer device as type (RTP 46

XP) in Abo-Qurqas, laboratory Sugar & Integrated Industries Company, South Minya. The results are shown in Table 1 and Figure (8).

Table [1]: Comparison of direct brix readings registered by the suggested Brix meter and refractometer Brix

No	Mass	Volume	Sample Density	T° C	Water Density	Specific gravity	T° F	SG correction	Brix Meter	Brix after Correction	Brix Refractometer	Difference
1	102.20	100	1.0240	18.75	0.9985	1.0256	65.75	1.0256	6.46	6.47	6.53	0.06
2	103.10	100	1.0330	18.25	0.9986	1.0345	64.85	1.0345	8.65	8.66	8.45	-0.20
3	104.40	100	1.0460	18.75	0.9985	1.0476	65.75	1.0476	11.81	11.82	11.55	-0.26
4	104.20	100	1.0440	18.00	0.9986	1.0454	64.4	1.0455	11.30	11.31	11.33	0.03
5	105.25	100	1.0545	18.75	0.9985	1.0561	65.75	1.0561	13.83	13.84	13.88	0.05
6	105.05	100	1.0525	19.00	0.9984	1.0542	66.2	1.0542	13.37	13.38	13.65	0.28
7	106.00	100	1.0620	18.75	0.9985	1.0636	65.75	1.0637	15.58	15.59	15.59	0.01
8	105.85	100	1.0605	18.50	0.9985	1.0621	65.3	1.0621	15.22	15.23	15.49	0.27
9	107.84	100	1.0804	18.50	0.9985	1.0820	65.3	1.0820	19.78	19.79	19.97	0.19
10	110.10	100	1.1030	19.00	0.9984	1.1047	66.2	1.1048	24.80	24.81	25.01	0.21

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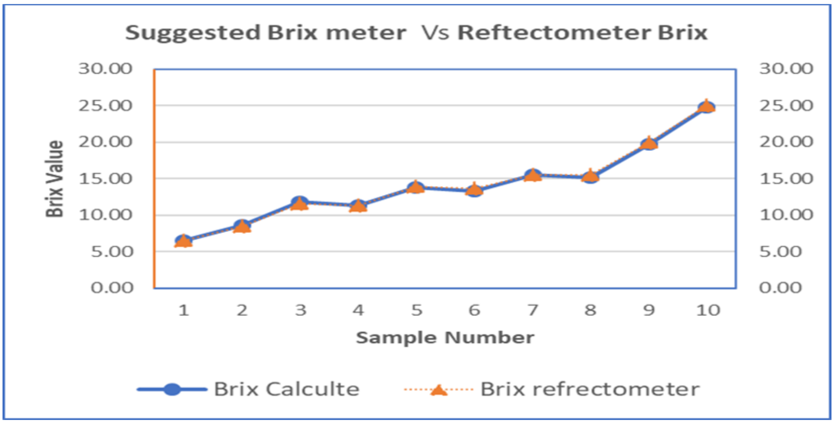

Figure (8): Suggested Brix meter Vs Reflectometer Brix

1 The Discussion of the Results

1- The results indicate that the results of the brix value calculated from the suggested device for measuring brix are approaching with the exact value extracted from the refractometer device, noting that the refractometer device used has a refrigerator to cool the sample to a temperature of 20° 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.

2- The results also indicate that the maximum difference between the brix value between the two devices is 0.28 Brix degree, which is a very acceptable rate in the sugar industry. Therefore, the results also are matched often.

3- Neglecting the correction factor or exposure in the correction equation, due to the extreme convergence between the direct results of brix from the proposed device with the calculated value after compensation in the correction equation. so, it does not need correction.

4- The results confirm that the slight change in weight measurement greatly affects the outcome of brix, while the change in temperature does not strongly affect brix.

5- The results indicate that we can measure the Brix degree of raw sugar solutions in general in the food and sugar industries using inexpensive, fast-measuring electronic devices using sensors to measure mass and temperature.

6- The results also indicate that when using this suggested device there is no need to use equations to correct temperature or specific density to obtain accurate results for brix. Figure (9) shown suggested device and Figure (10) shown the RTP Refractometer in central laboratory in Abo Qurqas sugar factory.

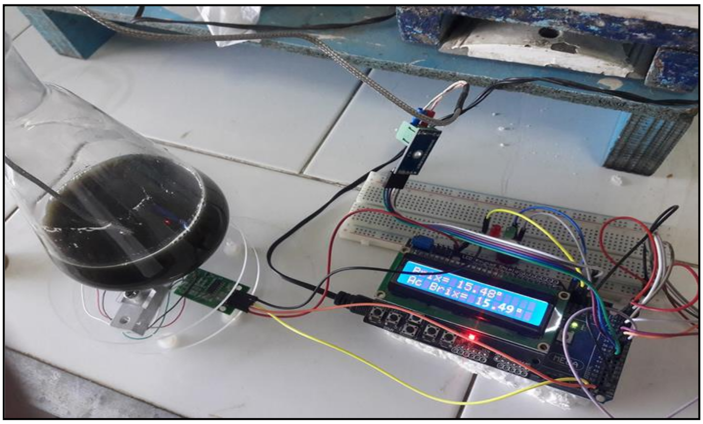

FIGURE (9): SUGGESTED BRIX METER

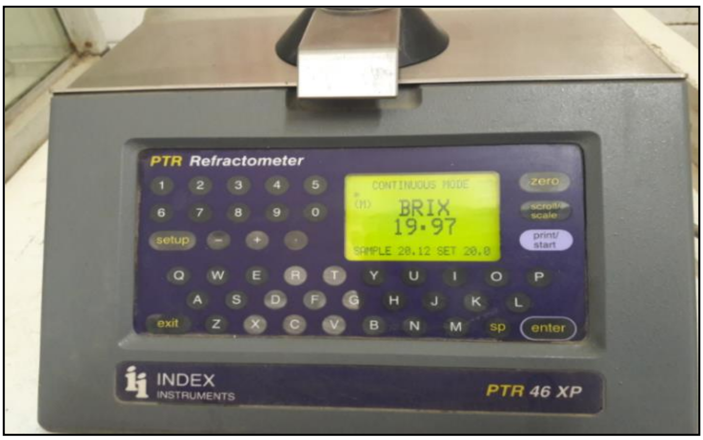

FIGURE (10): THE PTR REFRACTOMETER

7-Based on the previous recommendations from National Bureau of Standards it is necessary that the sample to be measured is clear and free from all suspended substances, therefore all impurities and suspended materials must be removed before measuring the sample brix.
8- 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.
9-The scope of this study exceeds solutions containing other autoimmune substances in the sample other than sugars and non-protective samples that contain impurities.
10-It is necessary to review the sensors used and ensure the correct measurement of them and it must be constantly reviewed.
11-All suspended material must be removed, and the purity of the sample confirmed.
12-The sample size must be a minimum of 100 cm3, the higher the sample size are more likely it is to have an accurate reading of brix.

4.2 The Studied method Summary

1. The results are consistent with previous research that examines brix measurement and is an addition to the types that use the hydrometer working theory to measuring brix.

2. The study is one of the few studies available that measures the relationship between brix readings with hydrometer devices with optical refraction devices, and the study confirms their compatibility.

3. The study also confirms the validity of the brix calculation equations and the correct its results with the brix tables shown from National Bureau of Standards, also validity of the correction temperature equations and its results with the brix tables shown from National Bureau of Standards.

4. This study opens the way for the use of electronic devices in measuring brix and expansion in the study and research and the use of electronic sensors more accurate and efficient to obtain real readings to focus sugar substances in raw sugar solutions.

5. These results should be taken into consideration when explaining the relationship between mass, volume, temperature and their effect on the value of Brix in a raw sugar solution.

5- Conclusions

This paper presents for the first time, an electronic hydrometer. 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 and displays it to the LCD screen. It can develop 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.

The system can be used widely in the sugar industries and food 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 based on these conclusions.

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الملخص العربي

تصميم طريقة مقترحة لقياس البركس في محاليل السكر الخام

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تعد قيمة البركس عاملاً هاماً في عمليات استخراج السكر من محاليل السكر الخام اثناء العملية الصناعية، البركس هو كمية محتوى السكروز الموجود في المحاليل السكرية. درجة بركس(°Bx) تقيس تركيز المواد الصلبة الذائبة في المحلول. درجة واحدة بركس هي 1 جرام من السكروز ذائبة في 100 جرام من المحلول. استنادًا إلى قيمة البركس في المحلول او العينة يمكن للمصنعين قياس واتخاذ القرارات اثناء عمليات صناعة السكر.الهدف من تلك الورقة البحثية هو دراسة طرق ونظريات قياس البركس للمحاليل السكرية وتحليلها وإيجاد مزايا وعيوب كل منها. وكذلك اختبار طريقة مقترحة ابتكرها وطورها الباحث باستخدام عدة مستشعرات الكترونية تم تركيبها وتوصيلها بوحدة تحكم قادرة على استقبال قراءات المستشعرات واجراء عدة عمليات حسابية لحساب البركس. تم اقتراح هذه الطريقة مع الأخذ في الاعتبارأن تكون قليلة التكلفة وذات دقة عالية في قراءة بركس على محاليل السكر الخام في العمليات الصناعية. تعتمد هذه الطريقة على الخصائص الفيزيائية للمحاليل السكرية، يمكن لأجهزة الاستشعار الإلكترونية قياس كتلة ودرجة حرارة المحلول للتعبير عن البركس، وارسال النتيجة على الشاشة ، أو يمكن إرسالها مباشرة إلى غرفة التحكم المركزية. كما يمكن استخدامها يدويًا على خط الإنتاج كما يمكن استخدامها في الصناعات الغذائية المختلفة. هذه الطريقة المقترحة تلقى الضوء لأول مرة على امكانية انتاج الهيدرومترالإلكتروني والقادر على قراءة الخواص الفيزيائية للمحاليل السائلة باستخدام مجموعة من الالكترونيات والحكم على كفاءته ودقته ونطاق عمله والعوامل المؤثرة على النتائج.