Significance of Conductometric Analysis in Sugar Industry

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Simple and rapid methods are needed for the determination of purity of sugar products that may contain electrolytes and non sugars. Using conductometric studies of cane juice and cane sugar systems shows that the conductivity is linear with the electrolytes and non sugar present in both cane juice of 20% v/v as well as in cane sugar over the range of 0 to 20 % w/v. With present method linearity can be approached more nearly by increasing non sugars concentration, but a parallel decrease in sucrose purity. Another observation comes out from acidity measurement of cane juice increases 0.1%, whereas, increase in conductivity value is around 11%, indicating conductivity is more informative, precise, and controlling parameter than conventional acidity parameter. Encouraging results have been obtained in the determination of non sugars and electrolytes part in sugar products. Percent reflectance values of sugar were also taken and compare with conductivity data for quality assurance of cane sugar.

Key words: Conductivity, Electrolytes, Non Sugars, Cane Sugar, Percent Reflectance

INTRODUCTION

The measurement of electrical conductivity of is used to monitor the ionic content of solutions (e.g., fruits, juice, soft drinks, natural waters,) and the purity of water (e.g., drinking water, waste water, process water). Many industries, including sugar industry, pharmaceutical, and health care rely on analysis based on electrical conductivity measurement. An electrical conductivity technique is very useful for investigating the water mobility, presence of impurities such as salt in food products (Gurjeet singh et al., & Tarsikka et al., 2008) 12.

In sugar house product analysis, to begin with cane juice composition which consists of sugar; salts, organic non sugars and insoluble’s like sand, bagasse, wax etc. Out of these the Table 1 shows the detail of inorganic and non sugar components (Walfor d1996) responsible for retarding crystal growth and more molasses formation during sugar manufacturing process is controlled by conductometric method (Vikesh et al. 2009, 2010) 34. A review of literature is available for measurement of conductivity to control the cane juice clarification by studying the calcium carbonate and calcium sulphite precipitation (Prasad et al., 1985, 1989) 67. Determination of conductivity of molar solution of raw and refined sugars, prepared with water of conductivity 1.6-664 µS/cm at 25-30 °brix for syrup and 30° brix for final molasses was observed in the presence of various parameters i.e. pol and moisture (Bures 1971 & Karpenko et al. 1984) 68.

Although, Effect of salts and non sugars as mentioned in Table 1, reduce sugar crystallization. The proposed conductivity method shows delay in sugar crystallization in the presence of salts and non sugars in super cooled systems (Longinoti 2002) W. Further to this, conductometric method proves that the inorganic salts and non sugars may affect the important properties of sugar system, including browning development, and kinetics of sugar crystallization and sucrose hydrolysis (Longinoti 2004) 11.

The assessment of true purity in factory products has previously been discussed by proposed method 12 (Sonad 2009). As discussed, the approach can be considered suitable for both high and low purity stocks, boiling point rise, which along with rheological, refractive index and conductometric measurement are so important for process and quality control purposes (Batterman et al., 1975) 13.

The significance of conductometric analysis of sugar house products are governed by immediate chemical environment of the reactant, defined by the chemical composition of the system (Water content, pH, presence and type of salts, temperature and purity). The application of conductometric measurement is considered a potential tool for addressing the key problems of sugar deterioration or storage time of sugar (Prasad 1999) 14.

Many factories in Asian and African countries produce mill off- white sugars which are directly consumed. In the light of above facts we undertook this study and thereby present our findings regarding the presence of impurity percentage in these sugar grades for its quality control.

MATERIALS AND METHODS

In the present investigation, the conductance of fresh cane juice, carbonated juice, sulphited juice and double sulphited juice was taken at regular interval of time at experimental sugar factory National Sugar Institute, Kanpur. Conductivity and acidity values were taken at different intervals of time. Acidity measurement of sugar samples is done by conventional method.

Conductance of plantation white sugar solutions (PWS) at 22.5% w/v was taken. The sugar samples (PWS) were collected from different sugar factories with different ICUMSA color values and of different sizes. The conductance of above sugar was measured at different temperature and for different sets of readings till reproducible values of the conductance was obtained.

For the conductivity measurements (µS/cm) a glass cell with platinized platinum electrode was employed. The resistance, R, of the solution was measured with an A.C. bridge (Wayne

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Kerr (6425) in the frequency range $\omega = 500 \text{ Hz}$ -5 Hz and true resistance were obtained by extrapolation of $R$ vs. $\omega$-1 at infinite frequency. The volume of the cell was 30 cm$^3$. One set of experiment was performed under isothermal condition at 298.15 K. In second set sugar concentration varied and with an experimental temperature (from 298.15K to 373.15 K). A thermostated ethylene water bath was used to control the temperature of the super cooled solution within ± 0.05K, and a kerosene /oil bath was used to control the temperature for the measurement at 298.15K within ± 0.02K. The cell constant was determined as function of temperature employing the reported electrical conductivity of solution of known concentration, aqueous KCl as temperature above 273.15K and ethanol solution of KI for temperature below 273.15K. The cell constant varied from 0.1002 cm$^{-1}$ at 248K, down to 0.0957 cm$^{-1}$ at 323K, and the value at 298.15K was ±0.006 cm$^{-1}$. Solutions were prepared with demonized water free of CO$_2$ and nitrogen was bubbled into the solution to minimize CO$_2$ solubilization prior to the measurement. In all cases specific conductivity of pure sugar in water was determined to correct the measure electrical conductivity by the contribution of ionic impurities of the discharidze or residual CO$_2$.

The experiment results were given as the mean of three parallel trail and measurement. Analysis of variance and Duncan’s multiple range test were employed to statistically analyze all results. A statistical data analysis software system (Stat Soft, Inc. version 6.2001) was used for analysis. P value, <0.05 were regarded as significant.

**RESULTS**

**Cane juice analysis:** To carrying out experiments the Fig. 1 shows a linear relationship between conductivity in $\mu$s/cm and % dilution (up to 20% v/v only) of normal cane juice. This particular dilution was taken in cane juice for comparing with sugar solution, which is deviate above 20% v/v concentration (Sanyal et al. 2004). Another experiment used for basic conception is shown in Figure 2, where the graph shows its significance for different sugar house products. Figure 2 clearly indicates the higher conductivity values in sulphited syrup than unsulphited and clarified juice. This is due to more impurities is persisted in the form of sulphur in sulphited syrup at 5% v/v dilution of juice and syrup. This clearly indicate that non sugar part of sugar house product responds quickly than sugar part i.e. non electrolytes. In view of the fact that initial rise in conductivity value during clarification, unsulphitation and sulphitation in juice due to increasing concentration of ionic impurity like $\text{Ca}^{++}$, $\text{H}^+$, $\text{OH}^-$, $\text{HSO}_3^-$ and $\text{SO}_4^{2-}$ ions. In addition to other inorganic and organic ions which are usually present in cane juice as mentioned in Table 1. During passage of lime and $\text{SO}_2$ into mixed cane juice, the most predominant chemical reactions like the precipitation of calcium carbonate and calcium sulphite occurs. During the precipitation reaction the conductivity values decreases indicating the completion of precipitation. The detailed mechanisms of above precipitation are given as reported elsewhere (Prasad et al 1985, 1989) 

$$\text{Ca(OH)}_2 = \text{Ca}^{++} + 2\text{OH}^-$$
$$\text{SO}_2 + \text{H}_2\text{O} = \text{H}_2\text{SO}_3 = \text{H}^+ + \text{HSO}_3^-$$
$$\text{HSO}_3^- = \text{H}^+ + \text{SO}_4^{2-}$$
$$2\text{H}^+ + 2\text{OH}^- = 2\text{H}_2\text{O}$$
$$\text{Ca}^{++} + \text{SO}_4^{2-} = \text{CaSO}_4$$

Further observation come out from Fig.3 shows conductivity of cane juice (20% v/v) increases as time elapsed due to decrease in sugar purity (non sugar part increases). It is clearly indicate from Figure 3 that the 10 % rise in conductivity value in just 5 hour. Same particular exercise has also been carried out in case of sugar sample showing non sugar part of sugar product is more indicative than sugar part (Figure 3). Another observation comes out from Figure 4 showing acidity of cane juice increases 0.1%, whereas increased in conductivity value around 11%, indicating conductivity is more informative, precise and controlling parameter than conventional acidity parameter. Estimation of titrable acidity at regular intervals by known volume of (25 ml) cane juice titrated against 0.04 N NaOH. The change in conductivity and quantity of NaOH required was recorded carefully till the solution gave pink color. The results were plotted (Conductivity Vs N/10 NaOH) on a graph (Figure 4) which gave the indication of cane juice and cane sugar purity.

**Table 1:** Composition of cane juice

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Constituents (cationic)</th>
<th>Salts</th>
<th>Concentration(%) Brix</th>
<th>Molar Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>$\text{K}_2\text{O}$</td>
<td>KCl</td>
<td>0.77-1.31</td>
<td>0.5616</td>
</tr>
<tr>
<td>2.</td>
<td>NaCl</td>
<td></td>
<td>0.01-0.04</td>
<td>0.0079</td>
</tr>
<tr>
<td>3.</td>
<td>CaO</td>
<td>CaCl$_2$</td>
<td>0.24-0.48</td>
<td>0.2016</td>
</tr>
<tr>
<td>4.</td>
<td>MgO</td>
<td>MgCl$_2$</td>
<td>0.10-0.39</td>
<td>0.096</td>
</tr>
</tbody>
</table>

**Figure 1:** Conductivity Vs concentration of cane juice

**Figure 2:** Conductivity values of different cane juices and syrups of 5% v/v

**Figure 3:** Change in conductivity value of cane sugar and cane juice with time.

Cane sugar analysis:

1. Production of electrical conductivity: A comparative study of the electrical conductivity producing ability of various sugars is summarized in Table 2. Only L-30 grade of sugar was found to generate higher values of electrical conductivity when dissolved in distilled water. The electrical conductivity generating potential of L-30 grade was comparable to well known conducting sugar likes, L-31, M-31, M-30, S-31, and SS-31.

2. Dose response studies: The generation of electrical conductivity from L-30 grade was found to be concentration dependent. A linear relation was found between the concentration of L-30 (5-20 W/V %) and the value of electrical conductivity produced. The relationship between electrical conductivity and concentration of test compounds was observed in dilute solution only. At higher concentration the linearity was disturbed due to low solubility of L-30 (Figure 5). At concentration higher above 22.5 %, the sugar samples started precipitating and studied were hampered (Sanyal 2004, Gillet 1949). Another experiment showing relationship between electrical conductivity of 20 % w/v of various sugars viz L-31, M-31, M-30, S-31, and SS-31 (Figure 6).

3. Production of percent reflectance: In Indian sugar industry, the quality of sugar samples were checked by color measurement with Photovolt meter. The percent reflectance values were taken for sugar standardization. It has been previously experienced by author that luster is an inverse function of the grain size. The smaller is the grain, more is the luster and lower will be the conductivity as observed in this investigation (Figure 7). It was interesting to know that L-30 and L-31 the two sugar grades which gave a lower values for percent reflectance, were found to produce electrical conductivity in appreciable yields (Table 2, Fig.7). L-30 produced electrical conductivity in almost the same quantity as produced by L-31 and M-31, M-30 produced electrical conductivity comparable to S-31 and SS-31 produced lower amounts of electrical conductivity values in comparison others.

Table 2: A comparision of different grades of sugar tested for electrical conductivity production

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Sugar</th>
<th>Electrical conducting production</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L-30</td>
<td>++++</td>
</tr>
<tr>
<td>2</td>
<td>L-31</td>
<td>++++</td>
</tr>
<tr>
<td>3</td>
<td>M-31</td>
<td>++++</td>
</tr>
<tr>
<td>4</td>
<td>M-30</td>
<td>+++</td>
</tr>
<tr>
<td>5</td>
<td>S-31</td>
<td>+</td>
</tr>
<tr>
<td>6</td>
<td>SS-31</td>
<td>+</td>
</tr>
</tbody>
</table>

20 % w/v concentration of different grades of sugars
++ = very strong, +++ = strong, + = moderate

Figure 6: Conductivity generation of different grades of sugar samples (20% w/v concentration)

Figure 7: Conductivity generation of different grades of sugar (20% w/v concentration) samples Vs percent reflectance
DISCUSSION

Selected sugar, S-31, SS-31 grades most commonly used in sugar industry for their ability to produce electrical conductivity in distilled water under normal condition with a view of investigate the possible water-sugar interaction. Sugars were found to produce electrical conductivity of non sugar depending upon the concentration of the salts, L-31, M-31, M-30 (5-20% sugar concentration by weight). At higher concentration, the linearity was disturbed due to low solubility of sugar and various other unknown factors. Results may be further explained by taking into account for their structural features, solvent-water, and hydrogen bonding capabilities and hydration characteristics of sucrose molecule, and the structural behavior of various ions in aqueous system. Water is known to be highly associated liquid. The presence of non electrolytes in sucrose tend to strengthen the hydrogen bonds between the water molecules near the large solute and a relatively “iceberg’ is effectively formed – them. Structure –making/ -breaking properties of various electrolytes influence model to different extent and that explains the variation in the divergence of straight line for different systems. A final aspect of such a transition concerns the possibility of cooperative in the solvent structure induced by the solute (Fred Vaslow 1969) #2. The physical evidence of changes consists in relatively abrupt changes in the slope or curvature of the various properties. It is evident that both ion solvent and the electrolyte-non-electrolytes are predominant in these systems, and the hydration of ions and the bonding tendency of sucrose and water also play an important role.

Studies shows that there is photonic conduction in sucrose and may be attributed to protons hydrogen bond (HB) = C=H-/O<; network present in sucrose crystal. There are several considerations, which strongly favor proton of hydrogen bond network as charge carriers. The fact that when hydrogen bonded protons can take part in charge transport within ice, proteins, and resins then there is no reason why this system should not be involved in transporting charge in the sucrose crystal which is also a good candidate of hydrogen bonding or where the existence of HB are well understood. A very interesting elucidation can be had from the neutron diffraction structure (Brown 1963)\(^ {18}\) of sucrose, which revealed two strong intra molecular hydrogen bonds (O-2\(^ {\circ}\), HO-1\(^ {\circ}\), O-5\(^ {\circ}\), HO-6\(^ {\circ}\), which serve to hold the molecule in a well-ordered, rigid conformation in which two rings are approximately at right angles. Apart from HO-4, all the OH groups are inter molecularly hydrogen bonded. A comparative study with the conductivity of octa-methyl sucrose where there is no hydrogen bonds has revealed that octa-methyl sucrose crystals have no electrical conductivity, which confirms the participation of hydrogen bonds as charge carrier, which is thought to be responsible for the observed conductivity in sucrose crystal. A comparative study with the sugar alcohols, which have infinite chains of –OH--OH--OH--H-bonds, as an ice would provide an additional evidence of hydrogen bond network as charge carrier in C\(_{12}\)H\(_{22}\)O\(_{11}\)(sucrose).

CONCLUSIONS

The present study reveals that the conductivity parameter can be utilized to measure the impurity in sugar solution in terms of its concentration at around 20\%. W/V. The conductivity value can be assumed as a function of impurity concentration (C impurity) and sucrose concentration (C sucrose) as a similar finding is available in literature.

REFERENCES

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