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Colorants Behavior during Sugar Processing a Case Study: Assalaya Sugar Factory (Sudan)

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Abstract | **Original Research Article**

The objectives of this research are to study factors contributing in the formation of sugar color, affecting sugar quality and study of chemicals used such as bleaching agents in order to reduce sugar color in Assalaya sugar Factory. International Commission for Uniform Method of Sugar Analysis (ICUMSA) reference method book was used to determine color, RS, ash, pH, Brix, and turbidity. The results of analysis obtained showed that one of the most significant factors affecting color is the pH. However, the state of agglomeration of the precipitate, which directly influences the filterability, depends upon the nature of the impurity. But, as shown, the increase in pH from 7.00 to 8.06 resulted in an increase in color from 55 to 735. Also, the result indicated that when ash increased from 0.10 to 0.17 colors increased from 50 to 727, and this was observed in all examined solutions. It is clear that raw sugar and melt liquor have a quantity of color 727, 641which decreased when ash decreased from 0.17 to 0.14 by ion exchange resins process. The high amount of reducing sugars (RS) could increase the color, when, RS was increased from 0.25 to 0.77 the color increased from 45 to 776 ICUMSA. Thus, detailed studies of colorants removal across refinery processes assist in the understanding of the behavior of individual colorants and potential refinability issues.
Keywords: sugar, color, quality parameters.

INTRODUCTION

Colorants can fall into one of two categories: natural and those formed during production. Plant pigments: Plant pigments are inherent in the structure of the cane plant. They have been described as being primarily flavonoids and phenolics [1,2]. They can comprise as much as two-thirds of color in raw sugar. Flavonoids can be a considerable problem for sugar production, as they may account for 30% of the coloration of raw sugar at pH 7 [3]. Bento [2] reports that, due to their solubility, flavonoids can pass through the sugar production process without being removed. The inclusion of a glycoside in their structure causes an affinity for sugar crystals. Phenolics are generally uncolored until they undergo reactions with compounds such as amines or iron. Both phenolics and flavonoids undergo enzymatic oxidation reactions, which lead to process-formed colorants, described later. Plant pigments tend to have molecular weights of less than 1000 Daltons (Da). They are highly ionized, which gives them a high indicator value (IV, the ratio of the absorbance at 420 nm of a sample at pH 9 to pH 4). They are readily removed during refining, but are also easily incorporated in the sugar crystal [1]. With sulphitation the color increase in one of clarified juice is very negligible; during the complete evaporation the color formation in the first body is also insignificant.

Colour increase in the evaporation process is much lower with clarified Juice from the sulphitation process than the clear juice from defecation. This is due to the processing effect of the sulphites on the colour formation and also due to better elimination of coloring matter in the sulphitation process. Colour content of clear juice and colour of syrup from the sulphitation process are lower than that from defecation by 27.81% and 31.44% respectively [4].

Colour of the final product is a crucial quality measurement in the sugar industry while the nature of coloring substances in sugarcane processing was well studied and documented [5].

Samples of different grade massecuites along with their washings were collected for estimation of Brix, Pol, Purity, and Colour [6].

The data collected for both white and raw sugar massecuites of A, B and C grade as revealed that:

- In white sugar A- massecuites, the washings contain about 93% higher color. In B and C- massecuites the color formation in washes is slightly less than in A-massecuites.
- In raw sugar boilings also the color development is higher in A- strikes than in B or C strikes.
- The color increase during washing is more elevated in white sugar strikes than in raw sugar strikes.
- The wash of A and C- raw sugar massecuites contain more colour by about 10-20% than the washes of respective white sugar strike.

Caramelisation, inversion and Colour formation are proportionally more marked with the higher temperature. It follows that, when making white it will be necessary to utilize a corresponding sugar, lower steam pressure and maintain in the pan a correspondingly higher vacuum when a better color of sugar is required. The most favorable temperature for A and B massecuites are between 130-165°F, color formation and undesirable reactions causing decomposition are then minimal, and the crystallization rate is satisfactory. Melanoidins as Maillard reaction products are formed by the reaction of monosaccharide's and carbonyl as compounds with amino acids and are recognized as acidic and polymeric compounds with a highly complicated structure [7].

Materials and Methods

Materials

Raw sugar**,** melt liquor**,** clarified liquor, filtrate liquor**,** de-colorized liquor, and refined sugar samples were collected during sugar production process at Assalaya Sugar Factory, Sudan.

Refractometer Brix% determination

Before testing the sample, the refractometer was zero adjusted with distilled water to ensure its precision. Prism was dried. Two three drops of the sample were dropped on the prism.

Determination of pH by direct method-official

The principle of the method is the potentiometric measurement of pH. The electrodes were standardized with buffer solutions, rinsed with distilled water and immersed in the sugar solution. The reading is taken after 5 min when the equilibrium potential across the electrodes is judged to have been reached, ICUMSA [8].

Determination of juice color

100 ml of juice was diluted to 5 Brix and filtered through whatt man filter No 5(membrane of 0.45 opening is preferred). pH value was pore adjusted to pH-7.0. The Tale-meter was put on for 30 minutes before testing. SUMA Tale-meter Mw was used. It is a multi-wavelength spectrophotometer zero absorption at 420 nm wavelength was adjusted, water in I cm cell placed at the extreme right end of Tale-meter carriage. The sample was put in the same cell after rinsing and reading in mau at 420-nm wavelength was taken. According to the method the reading was multiplied by Brix factor. The color is in the ICUMSA Unit (IU).

Determination of clarified juice turbidity

First, the spectrophotometer brought to zero reading at 900 nm by filling the 10 cm cell with distilled water and pressing calibration key. Then the cell rinsed and filled with the clear juice sample and absorbance at 900 nm was determined, the turbidity was calculated as follows:
Turbidity index s = AL

Where (A) is the absorbance at 900 nm, (L) is the cell length in cm. Because (s) is a small number, the turbidity is expressed as (S) where
Turbidity s = 100×s

Determination of sugar solution color

The juice sample was diluted by distilled water and filtered under vacuum through 0.45-micrometer membrane into a clean dry conical flask. Refractometer Brix was measured for filtrate, and by ICUMSA using tables. The factor corresponding to the measured Brix was obtained. The zero absorbance point was determined by Spectrophotometer, and suitable wavelength was adjusted using distilled water and 10 cm cell. The cell was rinsed and filled with juice sample, and the spectrophotometer reading was taken. The color was calculated using the following equation.

ICUMSA colour-10 x A (corrected RDS) x p International Unit" where A: absorbency of the sample at a suitable wavelength in mau (milli absorbance unit, corrected RDS is given by factor measured RDS. p Kg m'" is obtained from the table by corrected RDS.

Determination of conductivity ash for A-sugar

The specific conductivity of sugar solution at a concentration of 5g 100ml or less without the addition of sugar is determined [8].

The solution sample was prepared by dissolving 5 g of the sample in distilled water in a 100ml flask at 20°C. Then mixed thoroughly and it was transferred to measuring cell. The reading was taken. The conductivity ash was calculated using the following equation:

Conductivity Ash % = (162 +0,36 D) + 10-4 × C × f…………. (3.7)

Where D is the dry substance concentration of the solution tested in g 100 ml, C C1 is-G, where the measured conductivity is at 20°C and G is the specific conductivity of water, f is the dilution factor of the solution.

Determination of reducing sugars in juice using Lane and Eynon method

The ICUMSA method book was used for this purpose [8].

RESULTS AND DISCUSSION

Factors affecting sugar solution color

pH

The results of analysis obtained in Table (1), showed that the effect of pH on color increased in raw sugar. It may be due to caramelization and chemical degradation which caused thermal mechanism colorants. Alkaline degradation occurs at high pH and forms much darker colorants [9]. The Maillard reactions occur throughout the factory and have many complex pathways [17]. They proceed under almost all conditions, as reducing sugars and amines or amino acids are always present except in the purest solutions. Iron also plays an important role, particularly in plant-derived colorants [10].

Removal of impurities (consisting of both soluble and insoluble non-sugar compounds) from cane sugar juice by clarification is an essential part of the process of raw sugar manufacture. In Assalaya factory, the clarification process is described as pure defecation. This process is based on the addition of lime as lime saccharate (i.e., lime dissolved in sugar syrup) to heated juice at about 76 ^{o}C in order to raise the juice pH to between 7.8-8.0 and prevent inversion of sucrose. This is followed by secondary heating of the limed juice under pressure to approximately 103 ^{o}C and flashing to remove dissolved air. The de-aerated juice then enters the clarifier. At this stage, the juice contains insoluble calcium salts formed from the reaction between free calcium ions supplied by the lime saccharate and inorganic phosphate from the raw cane sugar juice. These precipitated calcium phosphate microfloc particles act as a sweep flocculant in the clarifier, removing suspended matter from the juice and adsorbing dissolved molecules and ions.

Ash

The results of the analysis in Table (2) present color versus ash. When ash increased color increased too in all solutions. It is clear that raw sugar and melt liquor has a quantity of color which decreased when ash decreased by ion exchange resins process. This is matched with Remco Engineering, 1981 who said that the use of ion exchangers in sugar decolorization is documented, and the use of various combinations of resin type has been explored, providing a concise and sufficient explanation of basic ion exchange chemistry.

The ash determined by conductometer, known as conductivity ash", cannot be directly compared with gravimetric ash determined by incineration and weighing of the ash. Conductivity ash has its own individual significance ICUMSA.1986. The conductivity ash was measured for A- sugar and found to be 0.12%, whereas the standard value is 0.10%. The obtained results showed that the ash content lied within the standard range. Affination is the main ash removal process in a phosphatation/ion exchange refinery. The amount of ash removed in affination is dependent on a number of factors; one of the most important being the quantity and composition of the impurities in the adhering molasses film.

Ash components such as potassium and sodium increase the solubility of sucrose thus leading to increased sugar loss in molasses. High sulphate levels can produce increased scaling in evaporators and pans. High levels of sulphate ions can lead to a reduction in decolorization performance of acrylic and styrene resins. Although this effect is often quite small, this result is significantly matched with Donovan, and Williams [11].

Table-1: Relationship between pH and color

Sample Analysis	Color, ICUMSA	pH
Raw sugar	735	8.06
Melt liquor	646	7.60
Clarified liquor	345	7.40
Filtrate liquor	200	7.30
De-colorized liquor	80	7.20
Refined sugar	55	7.00

Reducing sugars (R.S)

From Table (3) it can be seen that R.S has an influence on color. Excessive retention time will invariably produce sugar losses and high color formation. Juices are sometimes challenging to clarify if containing large amounts of low-density materials in suspension in such cases, increasing the capacity of the clarifiers and consequently increasing the retention time, which is not a good solution, and rarely produce good results. In Asslaya sugar factory, the capacity of the clarifier's station should be adjusted to the designed grinding rate, or a new clarifier should be installed to meet the increased crushing rate due to high yield of sugar cane. Otherwise, high retention time will occur and this can result in more reducing sugar formation. The high amount of reducing sugars causes or raise the color.

Table-2: Relationship between color and ash.

Sample Analysis	Color, ICUMSA	Ash
Raw sugar	727	0.17
Melt liquor	641	0.14
Clarified liquor	335	0.13
Filtrate liquor	206	0.12
De-coloized liquor	80	0.11
Refined sugar	50	0.10

This matches with Baikow [12], who reported that there is a danger of destruction of invert sugar, which in the presence of excessive amount of lime forms acids which lower the pH and cause inversion of sucrose. Inversed sucrose will form more organic acids, which produce further inversion. This will increase losses of sucrose to final molasses because sucrose will have a tendency to replace the lost invert sugar and therefore the yield in crystallized sugar will decrease.

The coloration of the juice due to decomposition of its constituents

At high temperature 200°C sucrose and the two reducing sugars glucose and fructose caramelize and assume a dark coloration. The decomposition of fructose takes place first, then comes the turn of glucose and fructose caramelize and assume a dark coloration. In the interest of light colored juices, high temperature should be avoided according to [13].

Colour of the cane juice

Coloring matter in sugarcane juice and syrup is an undesirable impurity due to its adverse effects on crystallization process and on finished sugar products.

The organic non-sugars are coloring matters in sugarcane and raw juice. The color of the cane juice may have two origins [13].

Coloring matters from the cane itself

This may have four origins: (1) Chlorophyll, (2) anthocyanin, (3) saccharetin, and (4) tannins. The rind cells of sugarcane stalks contain a mixture of two coloring matters, the chlorophyll, and the anthocyanine. The fiber of the cane contains saccharetin, and the 'top' and 'cysts' of the plant contain 'tannins' It includes several other coloring matters, but very little is known about them, these pass with the juice on extraction according to [13].

Table-3: Relationship between color and RS

Sample Analysis	Color , ICUMSA	RS
Raw sugar	776	0.77
Clarified liquor	360	0.57
Filtrate liquor	220	0.52
De-colorized liquor	75	0.42
Refined sugar	45	0.25

Brix

As shown in Fig (4) the relationship between color and Brix regarding raw sugar, melt Liquor, clarified liquor, filtrate liquor, de-colorized liquor, and refined sugar there was no influence of color value on Brix. High levels of insoluble solids put extra load on clarification. It also causes reduced purging efficiency of affination fugal by blocking the backing screens. At Assalaya factory there are no continuous affination fugals that may need to clean backing screens on a daily basis where there is a high level of insoluble solids in the feed sugar. The decrease of Brix due to the destruction of laevulose into acids, this also increases apparent purity according to [14]. Fort and others have shown that a large part of the purity increase is due to the removal of suspended matter. In Assalaya factory there should be an attempt to capture differences in the incoming raw sugars, as well as the service life of particular decolorizing systems, in order to gain a representative picture.

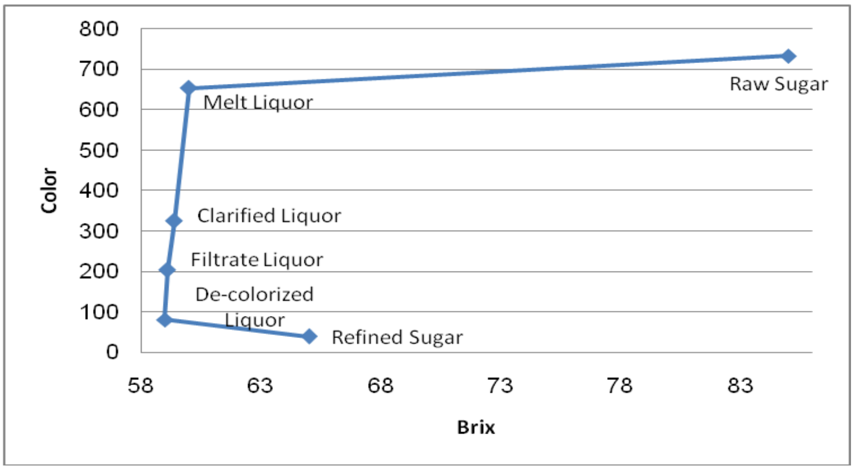

Fig-4: Relationship between color and Brix

Turbidity

Fig (5) illustrate the relationship between color and turbidity during processing from raw sugar to refined sugar at Asslaya factory. The turbidity was decreasing from melt liquor to filtered liquor. The drop in turbidity was 50%. Fig. (5) showed that the decrease in turbidity from raw sugar to refined sugar is due to the clarification process. Dextran plays a major role in turbidity increase during sugar processing. Dextran is a product of a micro-activity of Leuconostoc Mesenteroides bacteria. Turbidity effected by pH, RS, Ash, and Bix when pH above 7. RS form colorants then lead to an increase in turbidity, but Brix has no influence, but in general impurities in sugar solution increase turbidity. Rapid flocculation and sedimentation of suspended particles in primary cane sugar juice are achieved using a high molecular weight anionic polymer flocculant. This work reports on efforts to enhance the performance of an anionic flocculant by the addition of cationic polymers. Homopolymers of poly (trimethylammonium ethyl methacrylate chloride) [TMAEMAC] and cationic copolymers of poly (trimethylammonium ethyl acrylate chloride) [TMAEAC] and acrylamide were synthesized and their performance to enhance the flocculation and sedimentation of cane sugar juice particles evaluated by turbidity and settling rate measurements as observed at Assalaya factory. The obtained results were confirmed by [15].

The reduction in turbidity observed with increasing cationic content is probably related to stronger binding between the polymer and the particles due to the increasing positive charge of the polymer.

Finally, it should be noted that simply adding increasing amounts of commercial anionic flocculant to the cane sugar juice as at Assalaya factory gave little improvement in either turbidity or settling rate, suggesting that the improvement seen is not simply a matter of the amount of bridging flocculant present, but that the cationic flocculants are targeting a different population of suspended material, may be due to dextran formation, which greatly influences turbidity increase.

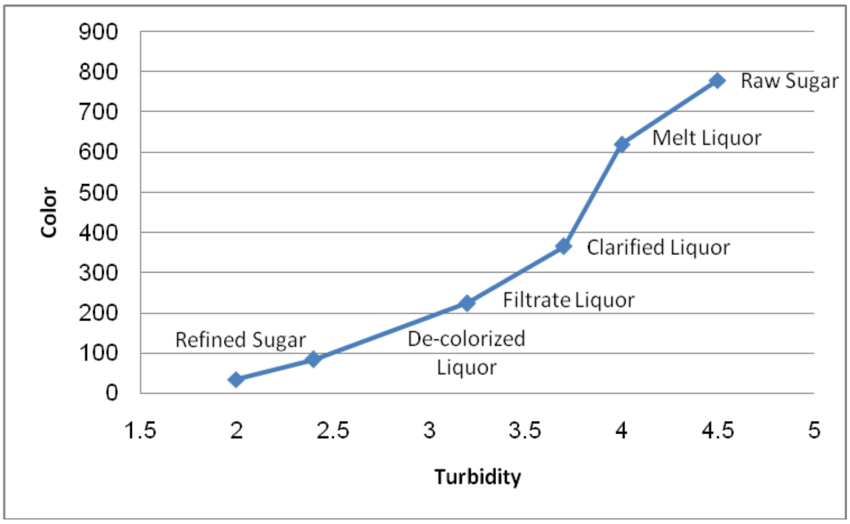

Fig-5: Relationship between color and turbidity

The relationship between RS and ash

Fig. (6) Showed results of samples analysis obtained from Assalaya Factory, when RS increased ash increased too. But ash has a lot of resources for increasing. It is not only due to reducing sugar. Detailed studies of colorant removal across refinery processes assist in developing a complete understanding of the behavior of individual colorants and potential refinability issues. Combinations of available unit refining processes are capable of removing colorants to differing degrees. The best quality refined sugar able to be produced by a given refinery is, therefore, a function of the types of colorants present in the raw sugar, and the processes employed to remove them. Optimum process combinations have been previously assessed by [1], and this work sought to apply this concept. During this study, colorants were monitored through the factory, that, employ a clarification and decolorizing techniques, thereby allowing the relative efficiency of removal of particular colorants to be evaluated. Where possible, a sampling of refinery streams was performed in order to maximize variability by reflecting the age and color load of incoming raw sugars, as well as the service life of particular decolorizing systems employed.

Invert degradation products

The colorants are referred to as hexose alkaline degradation products [3] and alkaline degradation products of fructose [1]. They are produced by the decomposition of monosaccharides in alkaline media. They tend to be brown in color, acidic (which can cause inversion), and, therefore, form more degradation color products. Since they are produced by high temperatures, their production is continuous throughout the sugar process, particularly on heated surfaces and as can be seen from Fig. (6), the increase in ash content leads to an increase in RS. But RS influence the color of the sugar solution, so it can be said that high ash content plays a role in the color formation, so it is advisable to maintain ash level at a minimum.

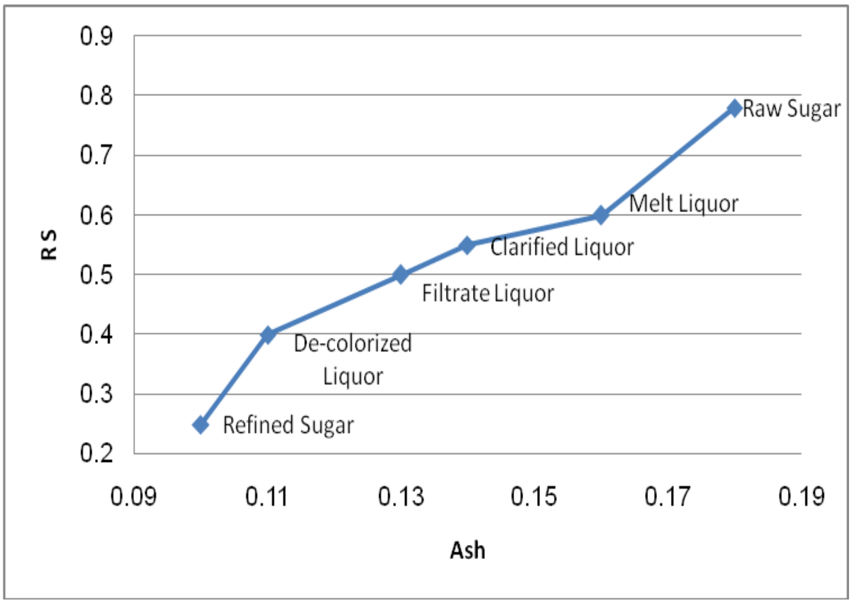

Fig-6: Relationship between RS and ash

Color drop during processing

The results of analysis that obtained from Assalaya Factory in Table (7) mention that, there is a color drop during processing: (Raw Sugar, Melt, Liquor, Clarified Liquor, Filtrate Liquor, De-colorized Liquor, and Refined sugar) this drop cleared the degree of color from stage to another and was decreasing till being 20 ICUMSA. This showed the effect of treatment of syrup during the process, the absorbency of filtered samples was measured by spectrophotometer at a wavelength as shown in the method (3-6). And the colour was calculated according to [8]. The increase in color of mixed juice in Asslaya factory may be attributed to the overdosing of lime milk. The destruction of monosaccharides occurs in the alkaline media, and the amino acids produced react with invert sugar to yield the coloring substances which lead to melanoidin formation. The nature and amount of color formation in evaporators is mainly related with an iron content of the clear juice [16]. Therefore, it is necessary to check the iron content of the clear juice when color is abnormal during evaporation at Assalay sugar factory.

Conclusions

Excessive pH and temperature can form highly colored decomposition products as a result of the destruction of reducing sugars. It should be noted that simply adding increasing amounts of commercial anionic flocculant to the cane sugar juice as at Assalaya sugar factory gave little improvement in either turbidity or settling rate.

The increase in color of mixed juice in Asslaya sugar factory may be attributed to the overdosing of lime milk. It is necessary to check the iron content of the clear juice when color is abnormal during evaporation at Assalaya sugar factory. Caramels form as thermal degradation products of sucrose, with a high molecular weight that increases with time and temperature as a result of growing polymerization. Sugar refining can be used to produce refined sugar from raw sugar obtained without sulfitation process.

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