

A Comparative Evaluation of Lime Clarification Methods in Sugar Beet and Sugarcane Juice Processing

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Abstract

Original Research Article

Sugar beet and sugarcane serve as the primary raw materials for global sugar production, with juice clarification playing a vital role in determining sugar quality and recovery rates. This study focuses on a comparative evaluation of lime clarification methods applied to sugarcane mixed juice and raw beet juice, using varying concentrations of milk of lime. Juice samples obtained from Elguneid Sugar Factory, Sudan, were treated with milk of lime at concentrations of 1, 2, 3, and 5° Baume. Key parameters, including pH, Brix, Pol%, purity%, reducing sugars, color, and phosphate content, were analyzed following ICUMSA standard methods. The study revealed that beet juice was clarified at a higher pH range (9.27–11.84) compared to cane juice (6.02–6.26). Beet juice also displayed higher values for Brix (18.02–22.92%), Pol% (17.33–21.05%), and purity (89.12–92.45%), while cane juice showed increased levels of reducing sugars (0.43–0.73% vs. 0.0050–0.0064%) and color intensity (8052–11808 vs. 2003–10500 ICUMSA units). The optimal lime concentrations identified were 5° Baume for cane juice (achieving 90.00% purity) and 3–5° Baume for beet juice (resulting in 91.94–92.45% purity). Overall, beet juice demonstrated superior clarification performance. The findings indicate that the higher reducing sugar content in cane juice contributes to lower purity levels and more intense coloration compared to beet juice. These results underline the importance of feedstock-specific optimization in the clarification process to enhance sugar production efficiency and quality.

Keywords: Sugar cane, sugar beet, lime clarification, purity, reducing sugars, ICUMSA.

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INTRODUCTION

Sugar cane and sugar beets are the two primary plant sources of sugar. Produced in more than 120 nations, sugar is one of the world's oldest commodities. Sugarcane provides over 80% of sugar, with sugar beets making up the remaining portion. (Babu, & Adeyeye, 2024). One of the goods most often traded on the global market is sugar. Sugar, also known as sucrose, is a naturally occurring carbohydrate found in the majority of fruits and vegetables. It is a key byproduct of photosynthesis, the process by which plants convert solar energy into edible substances like sugar. (Duraisam, *et al.*, 2017). The sugarcane industry is considered a well-structured sector and stands as one of the leading economic contributors in the country. Sugarcane and sugar beet serve as the main raw materials for sugar production. Research indicates that throughout the various stages of raw material handling and sugar mill

processing, approximately 20–30% of the sucrose generated by sugarcane plants goes to waste. Among the most pressing challenges faced by the sugar industry is the significant post-harvest sugar loss, a concern that has increasingly drawn attention in recent years. (Widatallaa, *et al.*, 2025). Sugar beets are grown in regions with moderate temperatures. Sugar beets are composed of 90–95% sap, 4–5% cellular tissue, and 4–5% water with chemical bonds. Beet sap contains the following compound: 1.0 to 1.5% additional organic materials besides sugar, 0.8% inorganic salt, and 15–18% sugar (saccharose). (Barruel, 1811). The majority of sugarcane juice is utilized by other nations to produce raw and plantation white sugar. To achieve high sugar production and optimum sugar quality, a good juice clearing process is therefore essential in the sugar manufacturing process. Nowadays, cane juice is clarified by carbonation, sulfitation, and defecation. However, technical problems with clarity, particularly with low-quality juice, and food

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safety difficulties when the sulfitation process is utilized have brought attention back to membrane filtering as a substitute clarification technology. (Shi, *et al.*, 2021). In the sugar industry, the term "clarification" refers to the process of precipitating out all potential organic and inorganic non-sugars while maintaining the highest amount of sucrose in the clarified juice. (Baikow, 1982). In a well-executed clarification process, the pol (sucrose and reducing sugars) is expected to remain unchanged. However, the Brix of the juice is anticipated to decrease as some of the dissolved impurities are removed during settling. Consequently, an efficient clarification procedure results in an increase in purity (the ratio of pol to Brix) in the clear juice by 1 to 2 units compared to the mixed juice. This improvement is referred to as the rise in purity between the mixed juice and the clear juice. (Mathur, 1981; Asfaw, 2015). In order to produce sugar from sugar cane and sugar beets, hydrated lime is necessary. Although they are generated in far lesser amounts, it is also used to purify sugar from other sources, such as sorghum or maple. Raw juice, which has a low pH and contains dissolved contaminants, is made by harvesting and processing sugar cane and sugar beets with water. In order to increase the pH and create insoluble calcium organic compounds that can be eliminated, hydrated lime is added to the juice. Carbonation or the addition of phosphoric acid is two methods for getting rid of extra lime. Depending on how pure the final product needs to be, this process could be performed multiple times. (Godshall, 1996). The production of sugar from beet and cane is affected by impurities in the raw juice, which reduce quality and yield. Therefore, it is essential to evaluate and optimize lime addition methods to achieve maximum purity and production efficiency while considering technical challenges and food safety. The Objectives of the Study to compare different methods of adding lime in both beet and cane juice clarification and to investigate the limed juice of both beet and cane by determining the parameters.

MATERIAL AND METHODS

Materials: The following materials which were used in this study were collected from Elguneid Sugar Factory (G.S.F).

Cane Juice: The mixed juice was collected before the scales of Elguneid factory.

Beet Juice: The beet roots were washed mechanically sliced into thin chip called cassettes to extract the sugar contenting to a water solution. The flow rates of cassettes and water are in the ratio one to two.

Chemicals and Reagents:

Chemicals:

- Anionic polymer of polyacrylamide bearing the trade name Separan.
- Ammonium solution.
- Ammonia chloride NH_4Cl .

- Calcium hydroxide solution $\text{Ca}(\text{OH})_2$.
- Phosphoric acid (H_3PO_4).
- Acetic acid.

Reagents:

- Lead sub-acetate, used as filter aid, 1gm per 100cm is usually sufficient.
- Fehling's solution A; 69.278g of copper sulphate pentahydrate (AR) was dissolved in 1000 ml volumetric flask by distilled water and made up to 1000 ml.
- Fehling's solution B; 346g of sodium tartrate dissolved in 500 ml of distilled water, 100g of sodium hydroxide dissolved in 200 ml of distilled water and cooled to room temperature, transferred both solutions quantitatively into a 100ml volumetric flask, then mixed thoroughly and made up to the mark with dissolved water, filtered through filter paper.
- Methylene blue indicator; 1g of pure methylene blue was dissolved in 100ml volumetric flask by distilled water and made up to the mark.
- Potassium hexacyanoferrate.
- Hydrochloric acid (0.05M): 89ml of concentrated hydrochloric acid (HCL) (AR) was diluted to 1000 ml by distilled water; 10 ml of it poured into a 200 ml volumetric flask and made up to 200ml with distilled water.
- Methyl blue.
- Sodium hydroxide (0.05M): 40g of sodium hydroxide (NaOH) (AR) pellets was dissolved in distilled water, then cooled and diluted to 1000 ml, 10ml of it poured into a 200ml volumetric flask and made up to the mark with distilled water.

Equipment and Instruments:

Equipment:

Most of standard laboratory equipment was used in the experiments. Such as beakers (100-250ml), volumetric flask (50 -250ml), cylinders (10-1000ml), pipette (5-25ml), burette (50ml), hot plate, stirring rod, filter paper.

Instruments:

- Orion Digital pH-meter with glass electrode assembly.
- RHB 18ATC Refractometer: Belling and Stainly Ltd, England.
- A A-10 R Automatic Polarimeter: Optical Activity Ltd, England, with pol Tube 200mm
- Talameter. (Spectrum 22B7).
- Thermometer.

Methods of Analysis:

pH Measurement:

The electrometric method, utilizing a pH meter equipped with a glass electrode assembly, was employed to measure pH levels.

The pH meter was calibrated using a standard buffer solution, and the electrode was rinsed with a portion of the sample before measurement. A 100 ml beaker was filled with the sample to a depth sufficient to submerge the bulb of the glass electrode. The setup was then allowed to reach equilibrium before recording the pH value.

Determination of Brix:

The term Brix, widely used in the sugar industry, represents the dry substance content as a percentage by mass (%m/m). Despite ICUMSA's recommendation to discontinue its use, Brix remains commonly employed in various segments of the sugar and molasses industries.

Procedure:

The lime juice sample was discarded. A funnel was covered using a watch glass. The Brix level of the extract was measured with a precision refractometer, ensuring the instrument's zero point was calibrated beforehand using distilled water.

Determination of Pol%:

Horne's dry lead method, as outlined by the (South African Sugar Technologist's Association 1985), was employed. Around 150 ml of the sample was placed in a bottle with a stopper. Approximately 1.5 g of lead subacetate powder was added for clarification. The contents were shaken vigorously to ensure complete dispersion of the lead subacetate, then left to stand before being filtered through a fluted filter paper held in a funnel. A portion of the filtrate was used to rinse the Pol tube and subsequently fill it completely. The polarization, or polarimeter reading, was then recorded. The Pol% was determined using Schmitz's table, based on the sample's Brix value and the polarimeter reading.

Determination of Purity %:

$$\text{The purity \%} = (\text{Pol/Brix}) \cdot 100 \quad (3.1)$$

Determination of Reducing Sugar:

This method to measure the reducing power of a solution of sugar products containing reducing substance e.g. invert sugar in a weak alkaline solution of Cu^{++} complex with tartaric.

Eynon and lane method (South African Sugar Technologist's Association, 1985) was used. The lime

juice sample was filtered then taken 50ml and completed with distilled water in a flask 250ml .5ml from Fehling solution A and 5ml of Fehling solution B was pipetted into the boiling flask. 15ml of the diluted juice from the burette was added. The flask was placed on a fast hot plate, and then allowed to boil for 2 minutes. Three or four drops of methylene blue were added and the addition of the solution from the burette was continued until the color converted from blue to red.

$$\text{Reducing sugar} = 19.2 / \text{Burette reading} \quad (3.2)$$

Determination of Color:

The official method is designed for sugar having color more than 250 ICUMSA units at pH 7(IC).

Procedure: -

According to (ICUMSA, 1994) method (South African Sugar Technologist's Association (1985)), the juice sample was filtered; the pH of the filtrate was adjusted to 7 by using hydrochloric acid or sodium hydroxide. The absorbency of the filtered solution was measured at wave length 420nm in Talameter and solution color is calculated.

The color was calculated using the following equation

$$\text{ICUMSA color} = (A \cdot F) / L \quad (3.3)$$

A: absorbency of the sample at 420nm in MAU (milli absorbance unit).

F: brix factor obtained from tables.

L=cell length in centimeter.

Determination of Phosphate Content:

The lime juice sample was filtered, and then taken 100ml of the juice in beaker. Five drops of ammonia were added and also added 1g of ammonium chloride (NH_4Cl) and 1ml of acid. The addition of 1ml of the solution from burette (uraniul acetate). Put the beaker in the heater until the boiling of contents, the addition also 1ml of uraniul acetate from burette was continued until appear black precipitate.

$$\text{P}_2\text{O}_5 = (\text{BR} \cdot 0.005) / (\text{Density} \cdot 10000) \quad (3.4)$$

BR=Burette reading

Density obtained from tables.

RESULTS AND DISCUSSION

Results:

Table 1: Treatment of Cane Mixed Juice with Lime Milk of Different Concentrations.

Parameter	Lime Milk Concentration (Baume)				
	1	2	3	5	7
pH	6.02	6.03	6.24	6.26	6.25
Brix%	19.15	19.23	19.66	19.56	19.48
Pol%	16.64	16.73	17.25	17.66	17.33
Purity%	86.89	87.00	87.74	90.00	88.96
RS%	0.73	0.43	0.66	0.66	0.47
Color	8052	8622	8749	11808	10800
P ₂ O ₅ (ppm)	231	278	324	231	278

Table (2): Treatment of Beet Raw Juice with Lime Milk of Different Concentrations.

Parameter	Lime Milk Concentration (Baume)				
	1	2	3	5	7
pH	9.27	11.04	10.80	11.96	11.84
Brix%	22.92	22.21	20.10	19.20	18.02
Pol%	21.05	20.00	18.48	17.75	17.33
Purity%	91.84	90.05	91.94	92.45	89.12
RS%	0.0064	0.0060	0.0055	0.0050	0.0050
Color	2003	2700	3868	9679	10500
P₂O₅(ppm)	195	146	196	196	196

DISCUSSION

pH Measurement:

It is fortuitous that adjustment of pH to the optimum level with cheapest alkalizing agent, lime, gives satisfactory removal of much of the undesirable material in the juice and provides as a suitable base for sugar recovery (Payne, 1982).

From figure (4.1) and tables (1) and (2) the pH of the beet juice was higher than in the cane mixed juice. This is natural because the pH in the original components of beet juice is higher than the pH of cane raw juice. Also, in beet juice purification the removal of impurities take place at high pH.

In beet liming the treatment of juice occurs in two stages preliming and main liming. In this research

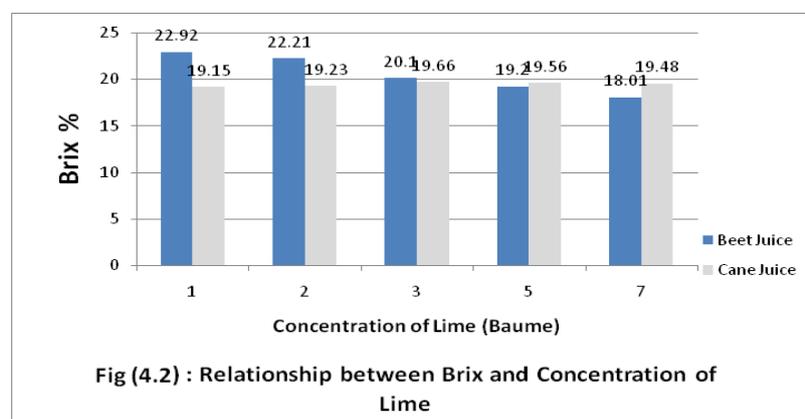
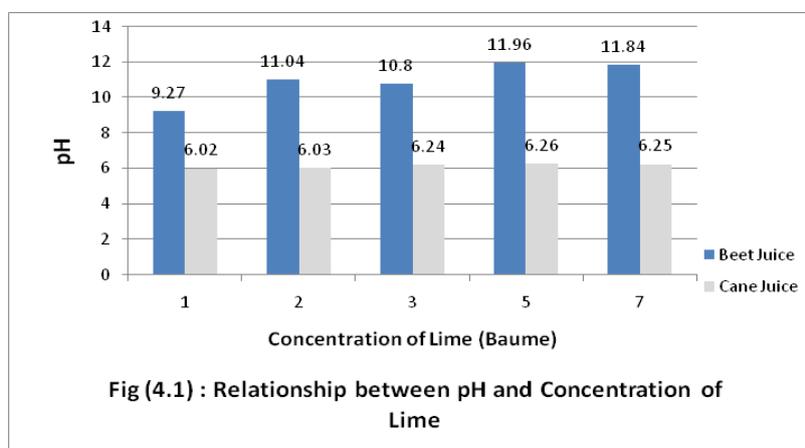
the pH of the beet juice was in the range (9.27-11.84) and this agreed with (Shariff 1994) who stated that the beet juice pH should be in the range (10.8-11.6).

Brix:

It was expressed as (%) of sucrose. The brix considered as the percentage by weight of dissolved solids in a solution.

From figure (4.2) the brix of beet juice at lime concentrations (1, 2, 3)^o Baume, was higher than the brix of cane at the same range of lime concentrations.

According to (Baikow, 1985) destruction of laevulose and formation of acids during clarification causes a decrease in Brix in cane juice purification.



Polarization:

Polarization was measured by an automatic Polarimeter. The Polarimeter reading (Pol) refers to sucrose content and defined as apparent sucrose content (Kelly, 1982).

Figure (4.3) shows that the pol% of the beet raw juice was higher than the pol % of the cane juice.

(Dubourg, 1952) stated that the increase of pol in clarified juice is due to the destruction of laevulose, during clarification which is levorotatory leaving

dextrose which is more stable and dextrorotary and therefore adds to the polarization.

Purity:

True purity refers to percent sucrose in total soluble solids. Figure (4.4) shows that the purity of beet juice was higher than the cane mixed juice at all concentrations of milk of lime. A large part of the purity increase is due to removal of suspended matter, and varies with different juices (Fort, 1939). An increase may also indicate a reduction of solids through the destruction of reducing sugar (Davies, 1942).

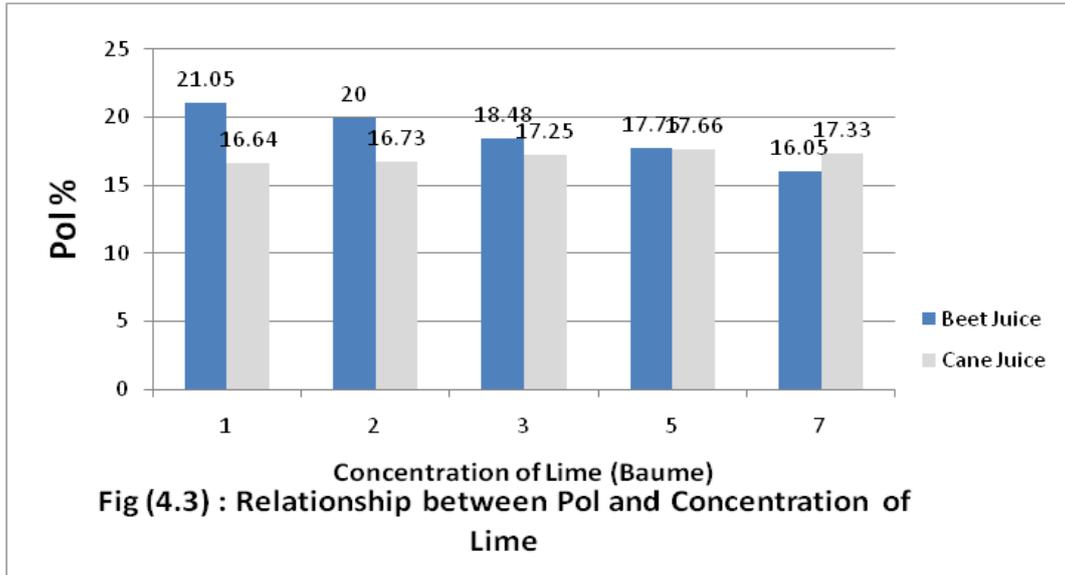


Fig (4.3) : Relationship between Pol and Concentration of Lime

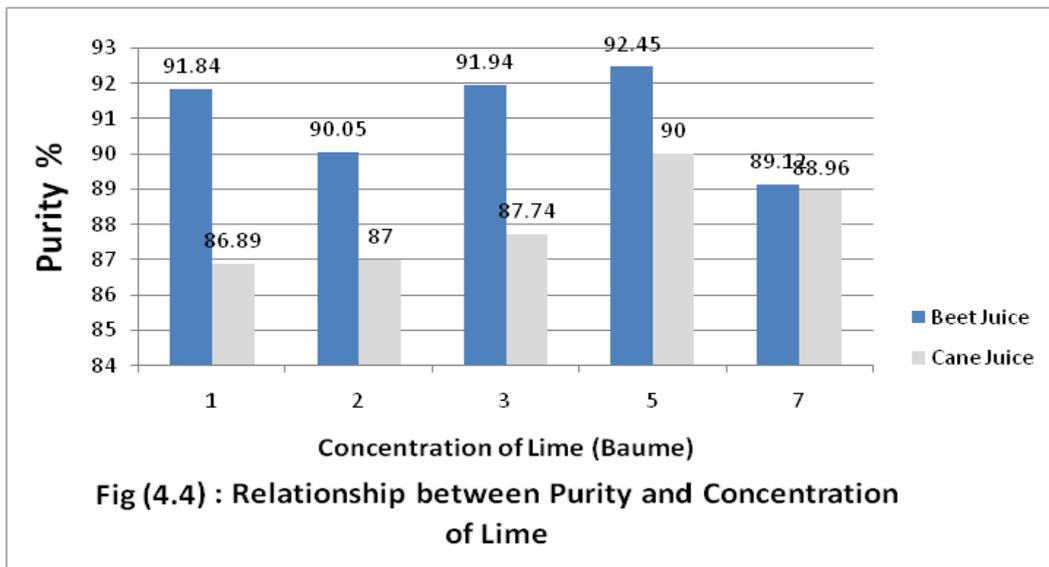


Fig (4.4) : Relationship between Purity and Concentration of Lime

Reducing Sugar:

Mostly consists of hexoses, glucose and fructose. These are quite stable in acid solution but decompose rapidly at high alkalinities, particularly at high temperatures. The decomposition of reducing sugars result in formation of acid with corresponding drop in pH and formation of soluble calcium salts of

these acids (Jenkins, 1966). It is of great importance to keep inversion to a minimum in order to avoid loss of sucrose (Honig, 1970). From figure (4.5) the reducing sugar of cane mixed juice was higher than beet juice. This is because the original cane juice has higher RS% than the beet original juice. In this study the RS% of the beet juice was in the range of (0.5-0.64) % and this is

comparable with the standard value (0.4-0.7) % according to (Vane, 1981). According to (Meade and Chen 1985) the pol% to a great extent is affected by sucrose stability during the clarification. From data obtained the low Pol% and Purity% were found at highest RS% values. That means Pol% and Purity% are in reverse relationship with RS%.

Color:

Color was calculated according to ICUMSA method. From figure (4.6) the color in cane mixed juice

was higher than the color in the beet juice. Color increase in cane juice is caused by the destruction of invert sugar which lead to formation of melanoidins (Mailardreaction) and may also due to high mud volume and to insufficient amount of phosphates of the juice as mentioned by (Fort, 1939), who stated that, the amount of color absorbed increases with the phosphate content of the juice to a certain limit then a gradual rise of color occurs due to the increase of reducing sugar (as a result of lowering pH), which react with amino acid causing the browning color.

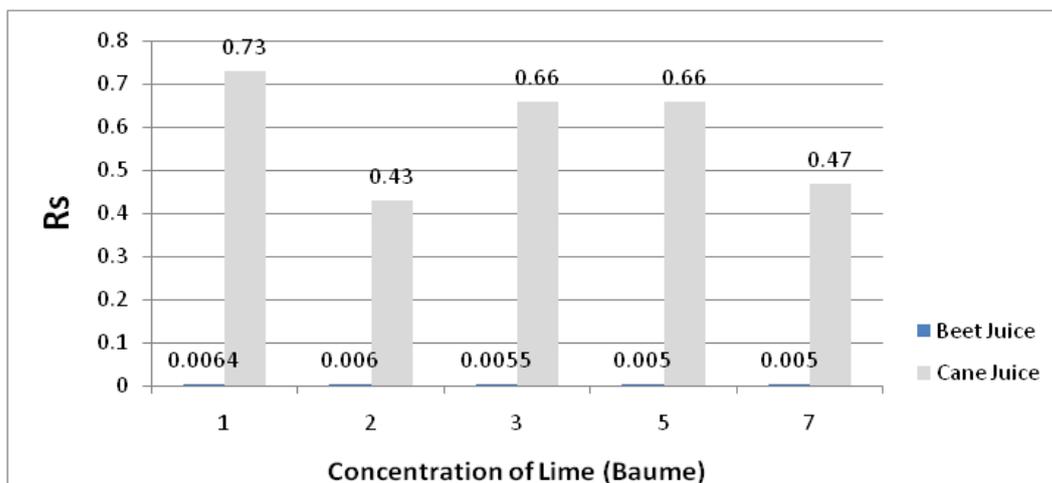


Fig (4.5) : Relationship between Rs and Concentration of Lime

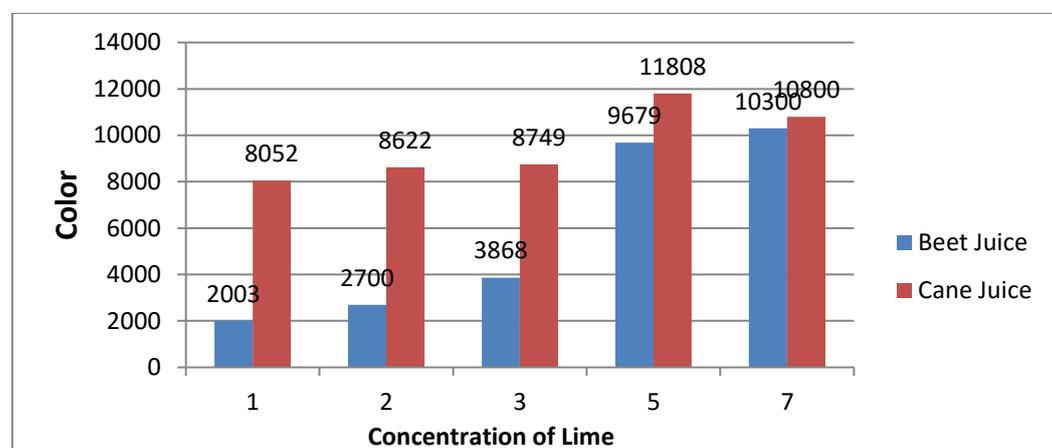
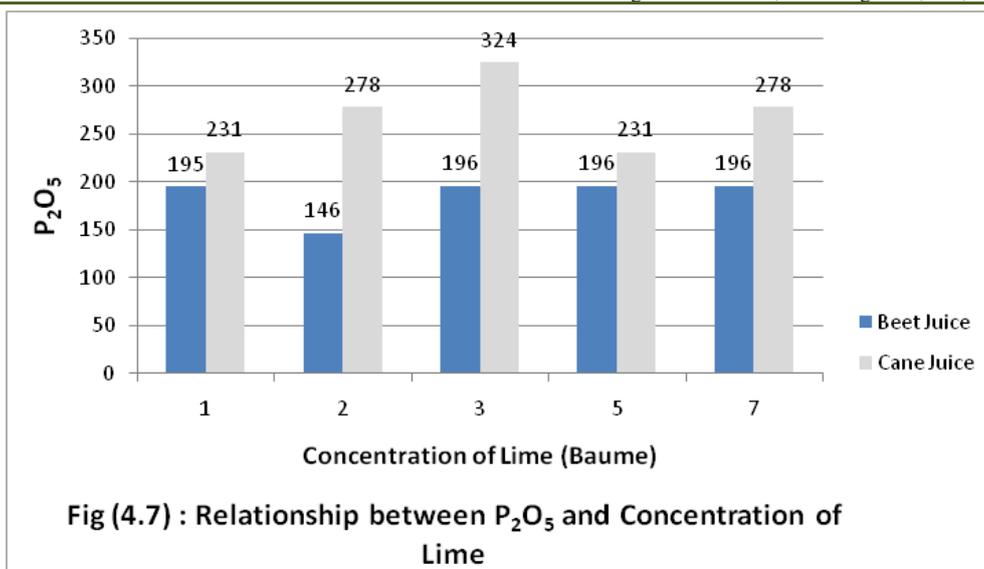


fig (4.6) : Relationship between Color and Concentration of Lime

Phosphate Content:

The use of phosphoric acid improves the clarification of refractory juice by its action in the precipitate formed with lime is mainly tricalcium phosphate. (Gillian and Margaret, 1998). From figure (4.7): shows that the phosphate content in cane mixed

juice was higher than beet juice. The increase in P₂O₅ in cane juice was due to addition of phosphoric acid to mixed cane juice in the range of (250-300) ppm. The addition of P₂O₅ lead to formation of tricalcium phosphate precipitate, which is the major reaction in cane juice purification.



CONCLUSION

This study evaluated lime clarification in the processing of sugar beet and sugarcane juices. Sugar beet juice, clarified at a higher pH, demonstrated superior results with increased Brix, Pol%, and purity levels reaching up to 92.45%. In contrast, sugarcane juice contained significantly higher levels of reducing sugars, which contributed to elevated coloration and reduced purity. An inverse correlation between reducing sugars and purity was identified. The optimal lime concentration was determined to be 5° Baume for sugarcane juice and 3–5° Baume for sugar beet juice. Overall, sugar beet juice exhibited more efficient clarification performance, while high levels of reducing sugars posed a primary challenge in sugarcane juice processing

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