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The Use of Locally Produced Lime for Clarification of Juice in the Cane Sugar Industry

A Thesis Submitted in Fulfillment of the Requirements For M. Sc.
Degree in Chemical Engineering

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O

قال تعالى:

(وقل ربي
زدني
علماً)

صدق الله
العظيم

Dedication

To my home Syria

To my dear father

and mother

To my love Adnan

To my family

To my daughter

Laila

Mona

Acknowledgement

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Abstract

Juice purification using lime is a standard established practice in the sugar industry allover the world.

In order to remove impurities from juice, the juice is treated mechanically, thermally and chemically. The main compound for chemical treatment is CaO in Association with flocculants (polymers), which precipitate the soluble salts and colloids in the juice as insoluble ones.

In Sudan lime is imported to meet the demand of the growing sugar industry. So, the purpose of this study could be summarized in the following:

1) To assess the suitability of local lime for juice clarification.
2) To determine the effectiveness of the local lime mixed with polymers (PDADMAC, PAC) for juice clarification.
3) To identify and assess the factors affecting juice clarification.
4) To determine the optimum concentrations and conditions for juice clarification.

In order to achieve the above objectives Elgunied Sugar Factory has been chosen to represent the sugar factories in Sudan.

After comprehensive comparative study and laboratory research, it was found that the local lime is suitable for clarification process with and without polymers economically and practically. Since the removed turbidity reached 93.5%, the removed colour reached 2.7% when only the local lime is used in juice clarification, comparatively the imported lime removed 92.3% of the turbidity and 16.4% of the colour.

الملخص

تعد تنقية العصير باستخدام الكلس (الجير) طريقة معيارية معتمدة في صناعة السكر عالمياً. حيث أنه لإزالة الشوائب من العصير تتم معالجة العصير ميكانيكياً، حرارياً، كيميائياً. والمركب الأساسي المستخدم عند المعالجة الكيميائية هو CaO (أوكسيد الكالسيوم) مترافقاً بإضافة البوليميرات كمواد مندفة لترسيب الأملاح والغرويات المنحلة الموجودة في العصير.

في السودان يتم استيراد الجير لتلبية متطلبات صناعة السكر، لذلك فإن الغرض الأساسي من هذه الدراسة يتلخص في الآتي:

1) بحث إمكانية استخدام الجير المحلي في تنقية العصير.
2) تحديد فعالية الجير المحلي مع البوليميرات (PAC, PDADMAC) في عملية تنقية العصير.
3) تحديد العوامل المؤثرة في عملية تنقية العصير.
4) تعيين التراكيز والظروف المثلى لعملية تنقية العصير.

ولتحقيق هذا الغرض فقد تم اختيار مصنع سكر الجنيد كمثال عن مصانع السكر في السودان.

وبعد الدراسة الشاملة والتجارب المعملية اتضحت ملائمة الجير المحلي اقتصادياً وتجريبياً لعملية تنقية العصير مع البوليميرات وبدونها. حيث أنه عند استخدام الجير المحلي لوحده في تنقية العصير خفض عكارة العصير بنسبة 93.5%، وخفض لون العصير بنسبة 2.7%.

مقارنة بتخفيض للعكارة بنسبة 92.5% وللون بنسبة 16.4% عند استخدام الجير المستورد لوحده في تنقية العصير.

List of Abbreviations

AAS	Atomic Absorption Spectrophotometry.
Bx	Brix.
DS	Dry Solids.
ICUMSA	International Commission for Uniform Methods of Sugar Analysis.
ICU	ICUMSA Unit.
L	Local Lime.
M	Imported Lime.
PAA	Polyacrylamide.
PAC	Polyaluminium Chloride.
PDADMAC	Polydiallydimethylammonium Chloride.
pH	Concentration of Hydrogen Ions.
pol	Polarization.
ppm	Part Per Million.
Py	Purity.
ZP	Zeta Potential.

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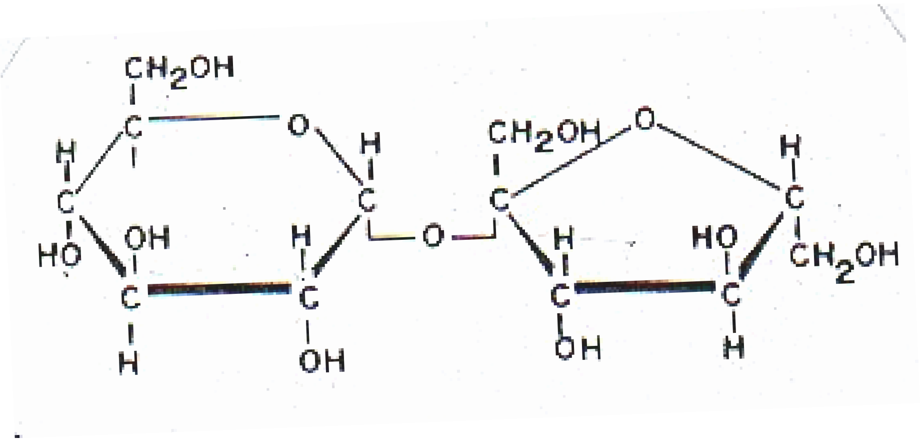
Chapter One

Introduction

1-1- General:

Sucrose is α-D-glucopyranosyl-β-D-fructofuranoside. It is a disaccharide with one molecule of α-D-glucose in the pyranose or 6-membered ring and is condensed with one molecule of β-D-fructose in the furanose or 5-membering form.

It is represented by the following structural formula:



Sucrose (α-D-glucopyranosyl-β-D-fructofuranoside)(8)

Sucrose is obtained from sugar cane and sugar beets. In commercial usage, the term "sugar" usually refers to sucrose without reference to its origin.

In terms of commercial production, sucrose is by far the greatest in volume on a world-wide basis(8).

1-2 Manufacturing of Sugar in Sudan:

There are 5 sugar factories in Sudan, (Elgunied, Sinnar, Asalaia, Halfa Elgadida and Kenana). Their function is to extract the sweet juice from the sugar cane and crystallize it into sugar as following:

1-2-1 General Process for Manufacturing of Cane Sugar:

The production season in Sudan extends from November to May. The production of sugar is a separation process in general which contains mechanical separation, extraction, clarification, evaporation, crystallization, centrifuging, drying, …etc.

At first the cane is burned in the field after thrust for about 2-3 weeks to release the leaves, then it is cut manually or mechanically. Cane is then transported to the sugar factory. When the cane is cut, rapid deterioration of the cane begins.

Therefore, sugar cane cannot be stored for later processing without excessive deterioration of the sucrose content.

1-2-1-1 Cane Preparation:

The cane is received at the factory and prepared for juice extraction. At first the cane is weighed, then it is mechanically unloaded on a large table, and washed by water. From there the cane continuously travels through a system of conveyors to the cane preparation units.

Rotating knives chop the cane into small pieces before being fed into the shredder which shreds all the fibers and opens the inner part of the cane for the extraction process(20).

1-2-1-2 Juice Extraction:

Two methods employed for juice extraction from the prepared cane: Diffiosion process or milling process (20).

- **Diffusion:** The prepared cane passes through a huge vessel called a diffuser. Hot water is continuously sprayed on the moving bed of finally prepared cane, thereby leaching out the sucrose from the cane (20).

- **Milling:** (This is the applied method in Sudan), the prepared cane passes successively through a series of large heavy roller mills, which squeeze out the juice (20).

  To aid in the extraction of the juice (by imbibitions process), sprays of water are directed on the cruched cane in the last mill and transferred from mill to mill towards the first two mills, while the cruched cane travels from the first to the last mill. The cruched cane exiting from the last mill is called bagasse. The juice from the first and second mill is mixed to form mixed juice (18).

1-2-1-3 Clarification:

The dark-green juice from the mills acidic and turbid. The clarification process, designed to remove both soluble and insoluble impurities, universally employs lime and heat, small quantities of phosphate also maybe added.

The lime is added to neutralize the natural acidity of the juice, forming insoluble lime salts, mostly calcium phosphate. And the limed juice is heated to boiling or slightly above to coagulate the albumine and some of the fats, waxes and gums. The mud separate from the clear juice by sedimentation in the clarifier.

The muds are filtered on rotary drum vacuum filters. The filtered juice returns to the process or goes directly to the clarified juice, and the press cake is discarded or returned to the fields as fertilizer. The clear brownish clarified juice goes to the evaporators without further treatment(9).

1-2-1-4 Evaporation:

The clarified juice contains about 85% water, two-thirds of this water is evaporated in vacuum multiple-effects system consisting of succession (generally four) of vacuum-boiling bodies arranged in series so that each succeeding body has a higher vacuum, and therefore, boils at a lower temperature. The vapors from one body can thus boil the juice in the next one.

By this system the steam introduced into the first body does multiple-effect evaporation. The vapor from the final body goes into a condenser. Steam from the boilers is used to heat the first body. The syrup leaves the last body with about 65% solids and 35% water(9).

1-2-1-5 Clarification of Raw Syrup:

The syrup is clarified by adding lime, phosphoric acid, and polymer flocculant, aerated, then the syrup is passed directly to a clarifier. From the clarifier the syrup goes to the vacuum pans for crystallization(9).

1-2-1-6 Crystallization:

Crystallization takes place in vacuum pans, where the syrup is evaporated until saturated with sugar. At this point seed grain is added to serve as nuclei for sugar crystals, and more syrup is added as the water evaporated. The growth of the crystals continues until the pan is full, the crystals and syrup from a dense mass known as massecuite. The strike (or contents of the pan) is then discharged to the mixer or crystallizers(9), which are large open vessels with slow moving stirrers, where the action of stirring and coaling is to maximize the sugar crystal removal from the massecuite(20).

1-2-1-7 Centrifuging and Reboiling of Molasses:

The massecuite from the mixer is fed into revolving machines called centrifuges, where the crystals are retained on wire cloth and the mother liquor (molasses) is removed from the mass.

In the three-boiling system the first boiling of raw syrup yields A sugar and A molasses, which returned to vacuum pan and reboiled to yield massecuite B that yields B sugar. And the B molasses is of much lower purity and in turn is reboiled to form C massecuite which remains in crystallizers for several days, where they cool while being kept in motion with stirring arms. The C sugar is mingled with syrup and used for A and B massicuite seed.

The C molasses used primarily as a supplement in cattle feed (9).

A sugar and B sugar are mixed then dried and cooled for storage and shipment.

Figure (1-1) shows flow diagram of the cane sugar factory(8).

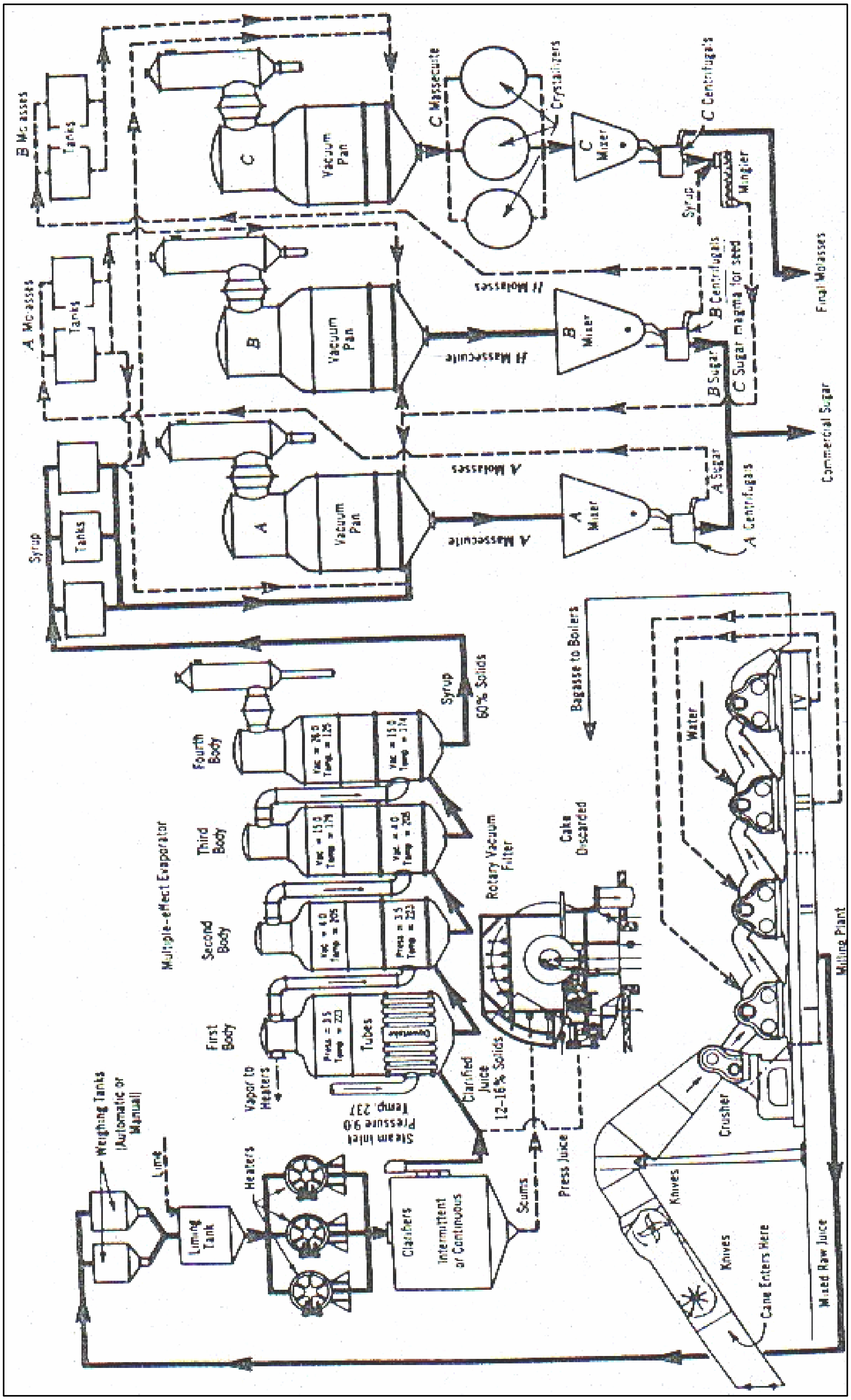


Figure (1-1) Flow diagram of cane sugar factory(8)

1-3 Objectives of the Study:

- **General Objective:**

To investigate the suitability of locally produced lime for clarification of juice in the cane sugar industry, so that we can reduce the production cost of sugar by getting ride of imported lime bill.

- **Specific Objectives:**

1. To assess the suitability of locally produced lime for juice clarification.
2. To determine the effectiveness of the locally produced lime mixed with polymers (poly DADMAC, polyaluminum chloride) for juice clarification.
3. To identify and assess the factors affecting juice clarification such as (pH value, lime and polymer doses, juice clarity … etc.).
4. To determine the optimum concentrations and conditions for juice clarification.

Chapter Two
Literature Review

Literature Review

2- Clarification of Juices:

2-1 Cane Juice:

Mixed juice reaches the clarification station as a complex mixture of the integral components of the cane plant. Extraction by crushing and washing operations contributes the wide variability in composition of the juice. Juice composition depends not only upon the geographical location, cane variety, season, cultural practice, and maturity at harvest, but also upon the mechanical treatment given to cane during harvesting, transporting, cleaning, and milling(12).

The principal constituents of cane juice are shown in table (2-1) (13)

Table (2-1) Cane Juice Composition on Soluble Dry Substances

Juice constituent	**g/100g soluble dry substance**
Sugars	75.0-94.0
Sucrose	70.0-90.0
Glucose	2.0-4.0
Fructose	2.0-4.0
Oligosaccharides	0.001-0.05
Salts	3.0-4.5
of inorganic acids	1.5-4.5
of organic acids	1.0-3.0
Organic acids	1.5-5.5
Carboxylic acids	1.1-3.0
Amino acids	0.5-2.5
Other organic non-sugars	
Protein	0.5-0.6
Starch	0.001-0.18
Soluble polysaccharides	0.03-0.50
Waxes, fats, phosphatides	0.04-0.15

2-2 Purpose of Clarification:

Clarification as used in sugar industry refers to the precipitation and removal of all possible non-sugars, organic and inorganic, and the preservation of the maximum sucrose and reducing sugars possible in clarified juice (1).

There are many methods applied to juice clarification these include(5):

- Defecation (the treatment with lime and heat).
- Sulphitation (with SO_2).
- Carbonation (with CO_2).
- Magnesia (with MgO).

The over all objectives of these methods are to produce rapid settling of suspended particles in the clarifiers, raise juice pH while lowering the percent volume of sediments or "mud" and producing a clear liquid. In addition, clarification should also produce juice of high clarity with minimum unfavorable effects on the subsequent recovery of sucrose from the clarified juice through maximum removal of non-sugars at the earliest possible stage in the process.

The degree of clarification has great bearing on the subsequent stations of the factory, effecting the pan boiling, the centrifuging, the quality of products, and most important of all the yield of sugar(9).

Lime and heat are the agents mostly used for juice clarification, although a small amount of soluble phosphate is generally added, and the more recent innovation of polymers as flocculating agents, have further complicated defecation processes(9).

2-3 Defecation Process:

Clarification by heat and lime, known as the simple defecation process, is the oldest and in many ways the most effective and cheap means of purifying the juice(9).

Milk of lime ($Ca(OH)_2$) or lime saccharates is added to mixed juice to raise juice pH from approximately 5.2 to around 7.5-7.8; lime reacts with inorganic phosphates present in juice to from calcium phosphate floc which sweep insoluble impurities from the juice mixture. Lime may be added batch wise or as a continuous mixture to juice. The lime addition may be to cold juice (35-40ºC), intermediate juice (72-76ºC) or to hot juice (100ºC)(9).

The overall chemical reactions of defecation involve (3):

- The precipitation of amorphous calcium phosphate.
- Denaturing of proteins (and other organics, such as gums and waxes).
- Inversion of sucrose due to the combined effect of pH and temperature.
- Degradation reducing sugars to organic acids due to high pH and temperature.
- Precipitation of organic and inorganic salts.
- Formation of color bodies due to the polymerization of flavonoids and phenolic compounds.

2-3-1 Quality of Lime:

Lime to be used in sugar industry must be first class lime (food-grade).

Table (2-2) shows the typical specifications of hydrated lime (food - grade).

Table (2-2) The Typical Specifications of Hydrated Lime (food-grade) (17)

Compound	**Amount %**
Available calcium hydroxide	95% min
Available calcium oxide (CaO)	72.6% min
Total calcium oxide	73% min
As calcium carbonate ($CaCO_3$)	2.4% max
Magnesium oxide (MgO)	0.8% max
R_2O_3 ($Al_2O_3 + Fe_2O_3$)	0.3%max
Silicon dioxide (SiO_2)	0.5% max
Acid in-soluble	0.5% max
Loss on ignition (LOI)	24% max

* (Analysis method: ASTM C-25/96a).

2-3-2 Quantity of Lime:

The amount of lime to be added to the juice varies, with differing conditions and different practices. It varies from 1lb to 1.5 lb CaO per ton of cane(9).

2-3-3 The preparation of milk of lime:

- lime can be used in the clarification process as unslaked lump lime, powdered hydrated lime, or powdered quicklime, whichever is most feasible economically(9).

- The addition of lime in solid (powdered) form is still practiced, but it is not recommended because of slow solubility and certainly of local over liming. So milk of lime is used(9).

- Milk of lime is prepared by mixing the lime with water to the desired density, usually, 15 Baume′, (148g CaO per liter, 1.116 weight in Kg of one liter milk of lime, 13.26% CaO).

  The density 15 Baume′ produces great ash elimination and low residual calcium in clarified juice (12).

- A considerable quantity of soluble impurities can enter the juice if the water contains any hardness or any soluble impurities, so condensed water from the third and fourth evaporators should be used for slaking and diluting(12).

2-3-4 Sequence of Liming and Heating:

- **Cold Liming**: All the lime is added to the cold juice, the limed juice is rapidly heated to the final temperature (almost always to the boiling point or just above) (9). The precipitate consists mainly of calcium phosphate, iron and aluminium hydroxides(12).

  The advantages of this process are the simplicity and ease of control of the method(12).

- **Hot Liming:** The raw juice is heated and the lime is added after the juice has reached the final temperature. Certain colloids (albumin and hydrous silica) are precipitated with heat and the pH of raw juice. (9).

- **Intermittent Liming:** In this process part of the lime is added to the cold juice to increase the pH to 6.1-6.4 and then heated to the boiling point or slightly above with further liming to increase the pH to 7.4-7.8, the purpose of these modifications to gain the advantages of heating acid juice (colloid precipitation), while avoiding the possible disadvantages of hot liming (inversion and destruction)(9).

- **Fractional Liming and Double Heating (FL and DH):** this process is the most successful of all the intermittent liming practices. It consists of liming the juice to pH 6.4, boiling, liming to pH 7.6, and again boiling and settling; the essential feature is the second heating after the second liming. The advantages found are much greater rapidity of settling, 35% less lime used than for cold liming, greater elimination of non-sugars, reduction in mud volume, and greater clarity of juice.

  FL and DL had no commercial backing, and have generally been supplanted by the use of polymers (9).

2-4 Effects of pH on Juice Clarification:

- The juice should be neutralized with lime to pH> 7 to avoid losses by inversion of sucrose during settling and concentration of the juice(12).

- Excessive liming to pH > 8.5 has to be avoided, because this causes destruction of reducing sugars with attendant colour increase, the formation of acid decomposition products (drop in pH), re-solution of some nitrogenous bodies, and the formation of soluble lime salts, which causes sucrose losses and hinders sugar crystallization(12).

- The optimum pH to which juice should be limed is dependent on many conditions and varies with the location of the factory, the variety and maturity of the cane, and other local conditions(9). Generally, the minimum of lime that will give clear juice with a final reaction close to pH 7 is most desirable, to neutralize the charge on the fine suspended particles in the juice to facilitate coagulation and settling. In addition, pH is important to the rate at which certain reaction occurs especially the precipitation of calcium phosphate. The juice pH was shown to have implications on the inversion losses, colour formation, loss of sugar, sugar quality, and scaling in subsequent process(14). Also some studies have indicated that sucrose loss as a percentage of total sucrose per hour in clarifiers decreases as the pH increases, and ranges from 3% at a pH of 5 to 0.1% at a pH of 6.5(15).

2-5 Effects of Time on Juice Clarification:

The retention time of juice in the clarifiers has great effect on the juice and its components. Retention of juice at an elevated temperature leads to inversion and reducing sugars degradation to from organic acids, resulting in purity and pH drop(9).

If the juice is refractory or contains large proportion of suspended matter it may be logical to hold the juice in the clarifier for longer periods. However excessive capacity clarifiers that hold juice for long periods result in higher level of inversion(1). The minimum retention time recommended for the Rapi Dorr444 clarifier is 2 hours and maximum of 3 hours. The retention time may vary according to the type of liming technique utilized as some methods may result in a slower settling rate or the reactions of the defecant in the juice may be slower and require more time than other methods.

2-6 Effects of Temperature on Juice Clarification:

- Temperatures just above the boiling point, say (103-105ºC), are the maximum for good practice and if temperature drops below 75ºC there is a chance of loss due to micro-activity (drop in pH)(9).

- The effect of temperature in juice clarification is to accelerate the rate at which chemical reactions occur in the juice.

- The effect of temperature in juice clarification is best described as a comparison between hot and cold liming. Investigations carried out into the effects of cold versus hot liming indicated that hot liming was more favorable as it removed more colour, dextran, oligosaccharides, and produced clarified juice with lower calcium levels, but results in higher mud levels and a slower floc settling rate(4). But the main advantage of hot liming is the reduction of scale formation in juice heaters and evaporators as a result of increased calcium removal(3).

2-7 Chemical Reactions of Clarification:

- In a complex system as represented by cane juice the chemical reactions that occur during clarification are not fully understood.

  It is fundamental that reactions will take place preferentially which will result in a system of lower free energy content.

- Defecation as out lined earlier is the mostly used method for clarification, therefore in looking at the reactions in clarification, defecation will be the clarification method of choice.

- The solubility of calcium oxide in water is about 0.12% at 25ºc, but it is greatly increased in a solution of sucrose. The solubility decreases with increase in temperature. Calcium hydroxide is a relatively strong base of a divalent metal ionizes in solution in two steps:

  $$\mathrm{Ca(OH)_2} \leftrightarrow \mathrm{CaOH^+} + \mathrm{OH^-}$$
  $$\mathrm{CaOH^+} \leftrightarrow \mathrm{Ca^{+2}} + \mathrm{OH^-}$$

  Chemical activity of compound depends principally upon the activity of the Ca^{+2} and the OH^- ions, although the $CaOH^+$ ions may take part in the reaction also. Because the secondary ionization is small the concentration of Ca^{+2} is low, with less than 10% of calcium as Ca^{+2} in sucrose solution containing 0.3-0.5% calcium oxide(12).
- The most important factor in efficient clarification is phosphate content of the juice. In mixed juice the phosphates are inorganic as will as organic. The inorganic phosphates exit as free phosphate ions, whereas the organics exist in the form of phospholipids, phosphoproteins, nucleotide phosphates, and hexose phosphates. It is understandable that only the free phosphate ions take part in juice clarification (9). If the inorganic phosphate level in raw juice is less than 300 ppm, the juice cannot be properly clarified, and addition of phosphate is required (9).

  In addition, the amount of inorganic phosphate left in clarified juice should not be less than 10 ppm; otherwise there exists a considerable danger that the juice has been over limed, a condition accompanied by higher nonsugar content of clarified juice, increased lime salts, and poor resulting sugars(12).

The reaction of lime and phosphate in juice leads to precipitation of calcium phosphate. This reaction is rather complex due to the reactions of phosphoric acid, calcium hydroxide, and the presence of other organic and inorganic compounds. Calcium phosphate reaction rate is very slow and the precipitate is formed in two forms, tri-calcium phosphate $Ca_3(PO_4)_2$, and calcium hydrogen phosphate $CaHPO_4$, as shown by the following reactions:

$$\mathrm{Ca}^{+2} + \mathrm{HPO_4}^{-2} \rightarrow \mathrm{CaHPO}_{4\downarrow}$$
$$3\mathrm{Ca}^{+2} + 2\mathrm{PO_4}^{-3} \rightarrow \mathrm{Ca_3(PO_4)}_{2\downarrow}$$

The formation of calcium hydrogen phosphate have a faster reaction rate, and as it approaches completion the rate of the formation of tri-calcium phosphate increases.

The rate of both reactions are greatly increased at high temperatures and result in an increase in the hydrogen ion (H^+) concentration, which has been suggested as a contributor to the drop in the pH observed when juice is heated.

Approximately 80-90% of the phosphate present in juice is precipitated with lime. It was shown that at a pH of about 8.5, about 99% of inorganic phosphate added to juice is precipitated, but only 90% of phosphorus occurring in the cane plant is precipitated (12).

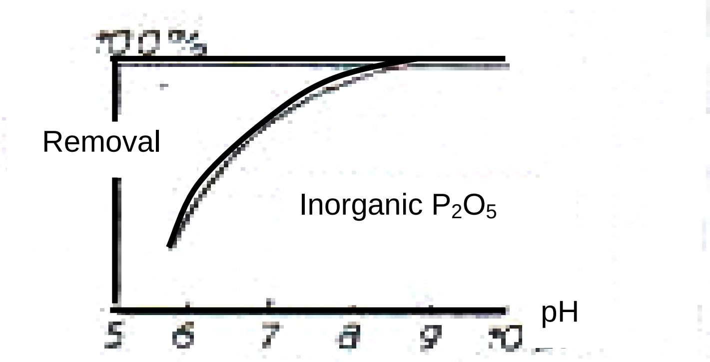


Figure (2-1) Effect of Clarification on the Removal of P_2O_5(12)

- Other calcium salts are precipitated in clarification, these may include sulfate, aconitate, oxalate, tartrate, and citrate salts. These salts are normally precipitated in small quantities, but variations do occur depending on the quality of the juice (12).

  The organic acids in juice are responsible for the natural pH of the juice (5.2-5.4) as well as the buffering capacity of the juice, which is mainly due to the juice aconitic acid content. The aconitate concentration of raw juice range from 0.6 to 2% on dry solids (Ds) with an average of 1.1% Ds, less than 10% aconitate is removed during clarification (15).

  The sulfate content of cane juice is highly variable and approximately 20% is removed by liming to pH in the range of 7-8(12).

- Another component of cane juice is silica. Silica is present in the juice in the form of dissolved silica, colloidal or suspended silica or as silicates. On average it is 0.42% of solids in mixed juice. Most of the suspended silica is removed by liming(7).

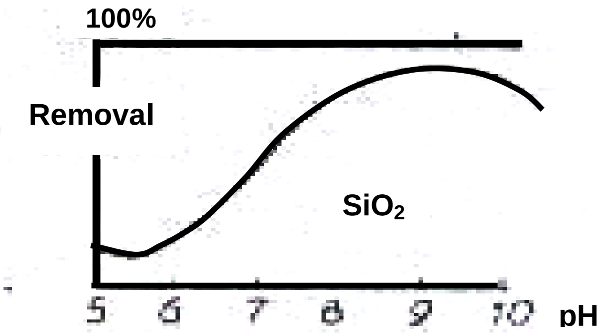


Figure (2-2): Effect of clarification on the removal of SiO_2(12)

- Magnesium, iron and aluminum occur in juice to alesser extent. During clarification magnesium is not precipitated totally; results show that magnesium precipitation is only about 21%(7).

- It was shown that at pH between 7.5 and 8.5 the increase in calcium ion concentration is paralleled by the decrease in magnesium ion, indicating that the magnesium precipitated is replaced by calcium(12).

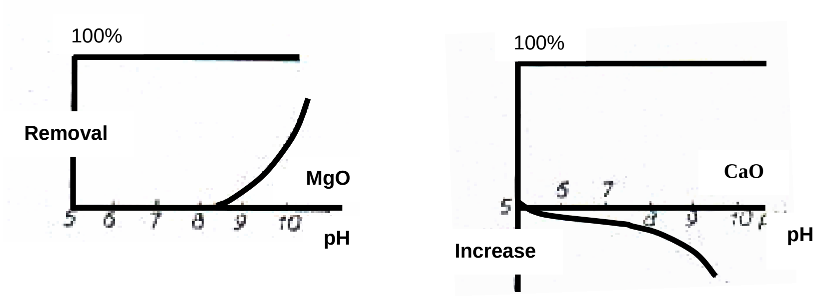


Figure (2-3): Effect of clarification on the removal of MgO and the increase of CaO(12)

Iron and aluminum are almost practically completely removed by liming to pH 8 (12).

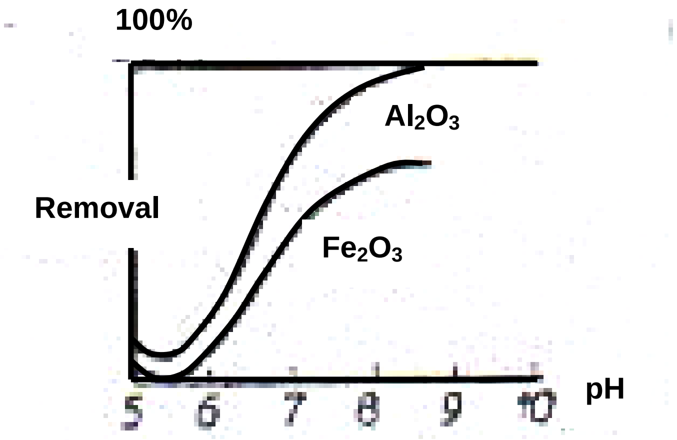


Figure (2-4) The Effect of Clarification on the removal of Al_2O_3 and Fe_2O_3(12)

- Other inorganic elements present in the juice are potassium, sodium and chlorine. These are found in ionic forms and unchanged by the process of clarification with lime(12).

- Reactions of sucrose and reducing sugars are undesirable in the clarification process. Reaction of sucrose that may occur includes the hydrolysis of sucrose to reducing sugars (D-Fructose and D-glucose) as follows:

$$C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6$$

Sucrose D-glucose D-fructose

The reaction is irreversible and is accelerated at low pH and high temperature.

However, this reaction is negligible at pH above 7.2

The sucrose loss during hydrolysis is irreversible and hence it is important that this reaction be kept to a minimum during clarification (12).

Reducing sugars on the other hand are naturally occurring in cane juice as glucose, fructose and mannose. Mannose is found only in minute quantities, but together the reducing sugars are the second most abundant component in juice calculated on dissolved solids. Unlike sucrose, reducing sugars are very stable at low pH, but are readily oxidized under alkaline conditions of pH above 8. The oxidation of reducing sugars is undesirable since the products of the oxidation are acids and brown colour compounds that import colour to crystals(12).

Reducing sugars combine with amino acids to from undesirable highly coloured products(12).

Table (2-3): Influence of pH, temperature, and time, on the destruction of reducing sugars and sucrose(12)

Influence of ↓ On	PH		Temperature	Time
	<7, acid	> 7, alkaline		
Reducing Sugars	No destruction	*Destruction moderate*, if temperature < 55° C; decomposition products uncolored *Destruction considerable*, if temperature > 55° C; formation of many organic acids and coloured compounds	Generally rising temperatures accelerate the rates of the reactions	The quantity of formed decomposition products depends on the length of time exposure
Sucrose	*Destruction* by inversion; formation of invert sugar	No destruction		

- The remaining compounds existing in juice are mainly nitrogenous in nature. Amino acids are stable under condition of clarification and remain unprecipitated; amino acids undergo the browning reaction with reducing sugars which results in the formation of complex coloured products(12).

Of the amino amids, asparagine is relatively stable.

Glutamine is rapidly hydrolyzed at 100ºC in alkaline solutions, losing ammonia and water, to form phyrrolidone carboxylic acid.This decomposition results in the development of acidity and increase the amount of lime going into solution(12).

Proteins are almost completely precipitated by clarification(12).

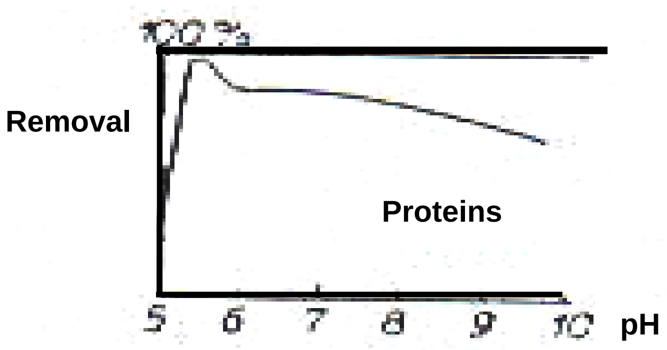


Figure (2-5) Effect of Clarification on the Removal of Proteins(12)

- Other components include gums, waxes, resins and fats are generally present in very small proportions.

Gums (polysaccharide materials, pentosans, hemicellulose, glucans, and other hexosans) may or may not be partly removed by clarification, but some of their soluble fraction carries through to the raw sugar(9).

Waxes, resins, and fats are found in the cane juice in suspension, and may rise to the surface of the juice as scum while a part may be precipitated during clarification(12) .

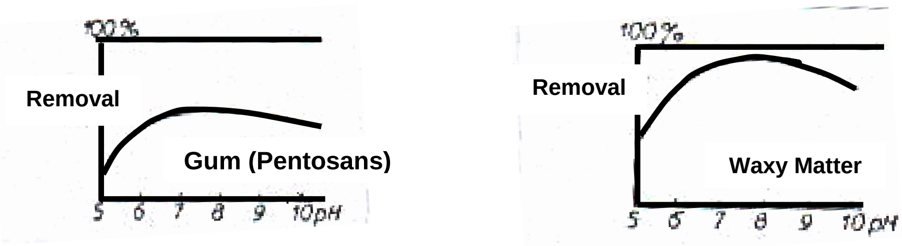


Figure (2-6) Effect of clarification on the removal of gums and waxes (12)

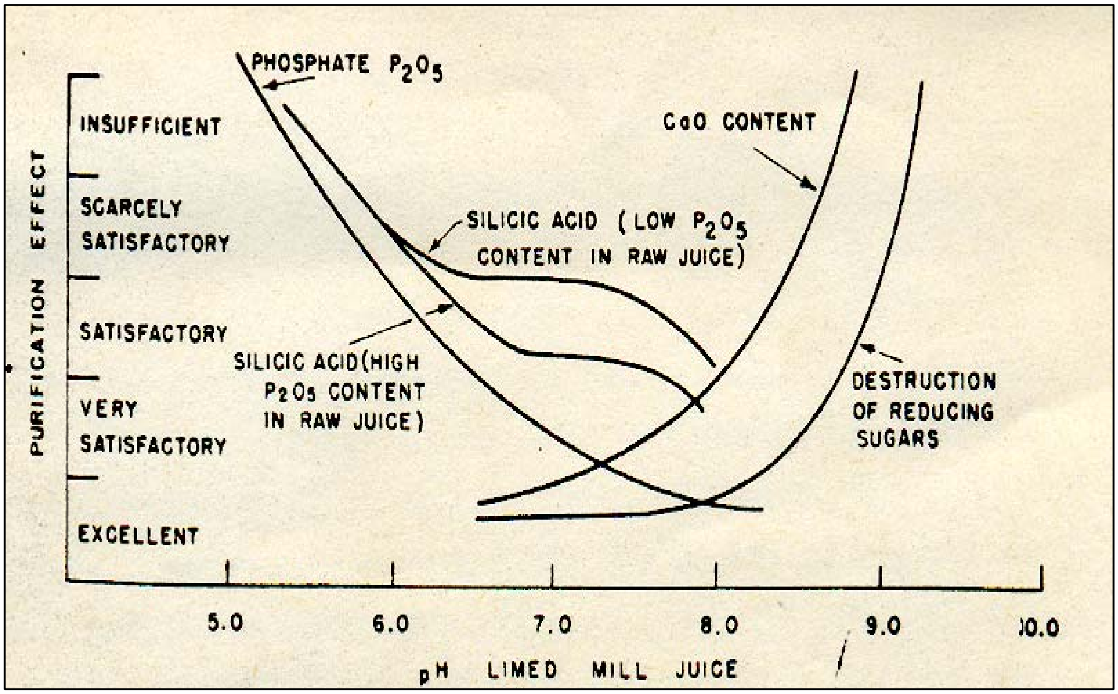


Figure (2-7) Scheme of obtainable clarification effect in liming(12)

Table (2-4) The behaviour of the removable nonsugars in the clarification (12)

			Effect of liming		
Type of non-sugars present in mill juice	**Effect of straining**	**Effect of heating**	**To pH = 6.8 – 7.2 in clarified juice**	**To pH = 7.6 – 7.8 in clarified juice**	**To pH over 8.0 in clarified juice**
Bagacillo	Removable to a great extent	None, except that air is removed, which prevents the settling of bagacillo	None	None	None
Sand	Removable	None	None	None	None
Clay	Partly removable	None	None	None	Sometimes becomes peptized
Waxy matter					
Cane wax	Partly removable attached to bagacillo	May be emulsified	Are absorbed with the precipitated inorganic nonsugars	Same as pH 6.8-7.2	Same as pH 6.8-7.2
Phosphatides	A small amount removable	May be emulsified		Same as pH 6.8-7.2	May be partly emulsified
Proteinic nonsugars	A small amount removable	Coagulates and becomes removable	Precipitated and removable with the precipitated inorganic nonsugars	Same as pH 6.8-7.2, may be a slight peptization	May be partly hydrolyzed and redissolved
Pentosans	None	Partly coagulated	Precipitated and removable with the precipitated inorganic Nonsugars	Partly coagulated and removed	Same as pH 6.8-7.2
Cao	None	None	Increased by the added milk of lime combined with the organic acids in the mill juice	Increases	Increases to a great extent by the formation of organic decomposition products
MgO	None	None	Partly precipitated with P_2O_5	Same as pH 6.8-7.2	Is partly precipitated as $Mg(OH)_2$
$Fe_2O_3 \div AL_2O_3$	None	Partly precipitated with SiO_2	Partly precipitated	Precipitated	Precipitated as $Fe(OH)_3$ and $Al(OH)_3$ Ca-ferrate
P_2O_5	None	None	Partly precipitated as Ca-Mg-phosphate	Practically as inorganic-Ca phosphate	Precipitated as Ca-phosphate
SiO_2	None	Partly precipitated in combination with sesquioxides	Absorbed by Ca-Mg-phosphate and sesquioxides	The same as pH 6.8-7.2 only to a greater extent	Precipitated and absorbed by the other precipitates

2-8 Physical Chemistry of Clarification:

- From a practical stand point the followings are desirable for good clarification (12):

  (1) Precipitation and coagulation as complete as possible.
  (2) Rapid rate of settling.
  (3) Minimum volume of settlings.
  (4) Dense settlings.
  (5) Clear juice.

Temperature, pH, quantity of lime, mechanism of the process, coagulants and any other expendients added determine the final physical characteristic of the resulting solid-liquid system. Unsatisfactory results in clarification involve some of the following factors(12):

1. In complete settling may be due to:
   a. Small size of particles
   b. Protective colloid action.
   c. Density of some particles not greater than that of liquid.
2. Slow settling may be due to:
   a. Viscosity of liquid
   b. Large surface area of particles.
   c. Small density difference between particles and liquid.
3. Large volume of settlings may be due to:
   a. Large amount of percipitable material, particularly phosphate.
   b. Low density of settlings.

4. Low density of settlings may be due to:

   a. Shape and size of particles.
   b. Hydration of particles.

- Since the clarification of cane juice is to change soluble non-sugars into insoluble solids and then to separate the suspended matter by sedimentation, the parameters commonly controlling the rate of settling of a particle are governed by stoke's law for laminar process as:

$$V = \frac{D_P^{\,2}(\rho_s - \rho_l)g}{18\mu}$$

Where;

V ≡ velocity of settling (m/s)

D_p ≡ diameter of the particle (m)

g ≡ gravity constant (m/s^2)

ρ_s ≡ density of the solid (Kg/m^3)

ρ_l ≡ density of the liquid (Kg/m^3)

μ ≡ viscosity of the liquid (N.s/m^2)

The settling rate of the coarse suspended particle will depend on the effective diameter of the particle, the difference between the density of the particle and the density of the liquid it is suspended in, and the viscosity of the liquid.

In juice the density of the liquid ρ_l is usually between 1.05 and 1.10, whereas the density of inorganic matter such as calcium phosphate and soil particles is in the range of 2.2 to over 3.0, the organic matter will have a density close to that of juice, 1.1 or less, and may be even less than 1.0 in the case of fats and waxes. On the whole, the density of the particles will average greater than 1.5 so that the difference ρ_s-ρ_l will be large enough to produce relatively rapid settling (12).

The important factors in rate of settling, therefore, become size and shape of the particles. Heating the juice hastens the formation of larger and more dense particles both by increasing the speed of movement, and thus increasing the opportunity for contact, also by dehydrating the flocculent particles, and decreasing viscosity and density of the juice(12).

Lyophylic colloids in the juice will tend to prevent coalescence of the particles both by increasing the hydration of the particles and by increasing the electrical charge on the surface. The suspended particles in the juice all bear a negative charge. The repulsion force of the charges must be overcome before the particles coalesce. The smaller the surface the less will be the charge, but smaller particles may have relatively high charge per unit area. Therefore, large particles with a minimum surface area will precipitate most readily(12).

But only larger particles follow stock's law; the smaller particles defy it. Every particle in suspension acquires an electric charge, which has an enormous bearing on the stability of the dispersion if the particle is small. This charge causes what is called zeta potential which is an electro kinetic potential. The neutralization of zeta potential (ZP) is considered as the removal of one resistance to agglomeration, figure (2-8) shows the concept of the ZP (9).

- Colloids present in cane juice may be lyophylic (colloids having strong affinity for the liquid in which it is dispersed) and lyophobic (colloids lacking affinity for the liquid in which it is dispersed). Their presence in cane juice is highly unfavorable as they may prevent coalescence of suspended particles during clarification. Lyophylic types are mainly organic compounds that may be pentosans and proteins, and are characterized by their strong affinity for the liquid, this results in a high degree of hydration, swelling and viscosity.

Lyophobic colloids on the other hand are less hydrated and more unstable dispersions which have little effect on the viscosity. The main lyophobic colloids present in the cane juice are fats and waxes, soil particles, and extaneous materials from the milling operations(12).

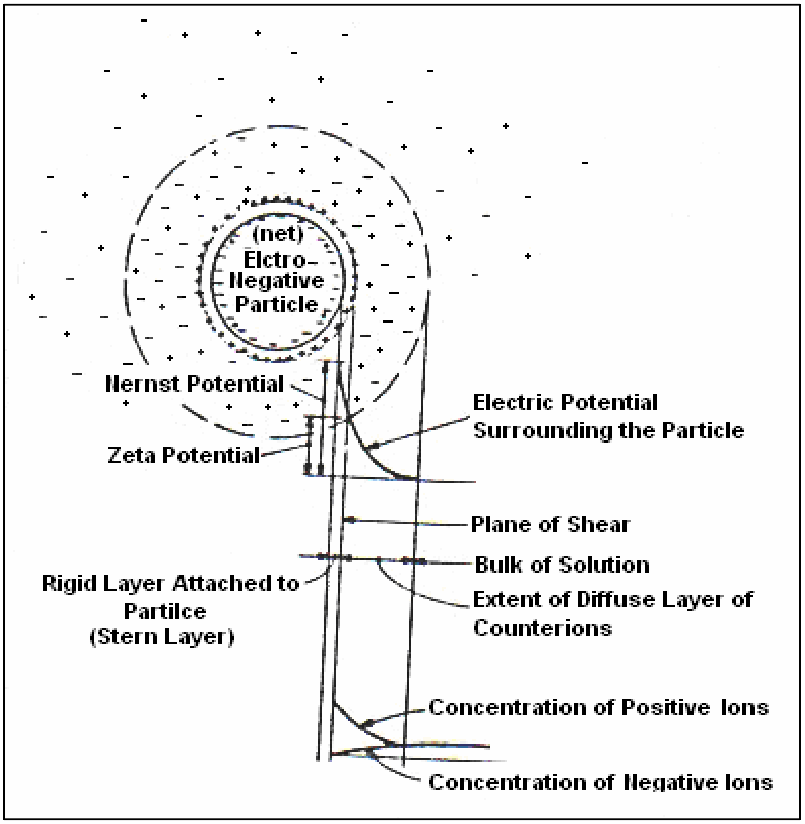


Figure (2-8) Concept of the zeta Potential(9)

Colloidal particles in sugar cane juice normally carry negative charge, these charges stabilize the colloidal system and cause particles to repel each other and prevent their coalescence(12).

The relationship of colloid stability to ZP is given in table (2-5).

Table (2-5) relationship of practical colloid stability to zeta potential(9)

Stability Characteristics	**Average ZP (mV)**
Maximum agglomeration and precipitation	+3 to zero
Excellent agglomeration and precipitation	-1 to -4
Fair agglomeration and precipitation	-5 to -10
Threshold of agglomeration (agglomerates of 20-10 colloids)	-11 to -20
Plateau of slight stability (few agglomerates)	-21 to -30
Moderate stability (no agglomerates)	-31 to -40
Good stability	-41 to -50
Very good stability	-51 to -60
Excellent stability	-61 to -80
Maximum stability	-81 to -100

Through out ordinary lime clarification albumins are coagulated by heat alone and are precipitated out. Other proteins are coagulated and precipitated by the change in pH(12).

- The stability of the mixed juice suspension is due to the facts that:
    1. All particles carry negative charge and therefore tend to repel each other.
    2. The particles all carry a layer of adsorbed proteinaceous/polysaccharide material which is strongly hydrated and therefore, provides a cushion of bound water molecules. Adjacent particles are therefore prevented sterically from close approach(2).

For proper juice clarification, destabilization and rapid settling with minimum sucrose losses are required.

Destabilization and clarification may be brought about by three stages(2):

1. The ZP (electrokinetic potential) of the dispersed particles must be reduced to a value close to zero. It can be neutralized by the addition of organic surface-active cationics or of polyvalent inorganic cations.
2. Reduction of degree of hydration, when the juice is heated to the boiling point a dehydration of colloidal particles and denaturing of proteinaceous matter occurs. This proteinaceous matter coagulates and deposits on colloidal particles. The addition of organic surface-active cationics may also reduce the degree of hydration.
3. The introduction of bridging mechanism. Such as a synthetic polymer may aid precipitation as each site on the polymer chain can attach a cluster of particles. Upon liming inorganic phosphate content of the juice is precipitated as various species of calcium phosphate, the first flocculation mechanism shown diagrammatically in figure (2-9) is known to proceed with no appreciable change in the electrical charge carried by the particles. This is primary flocculation.

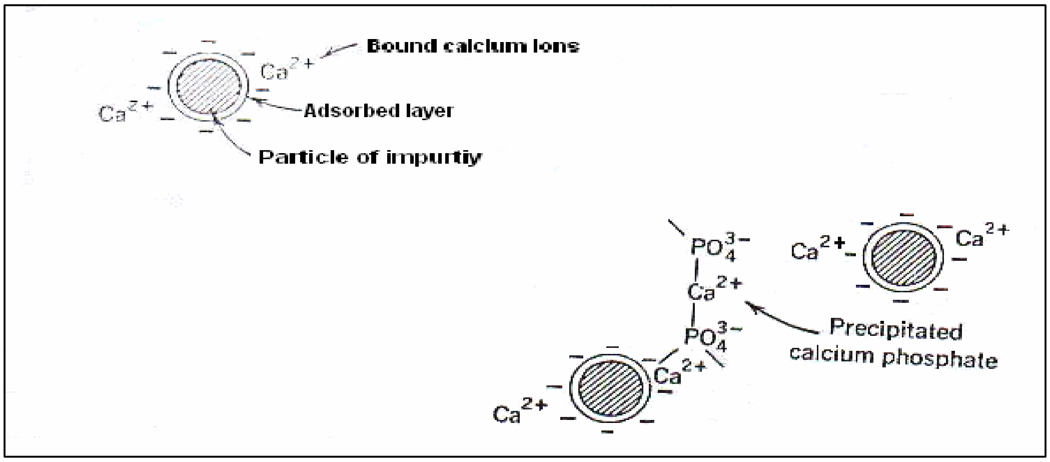


Figure (2-9) Primary flocculation (9)

Secondary flocculation occurs when high molecular weight synthetic polymer is added. See figures (2-10) and (2-11).

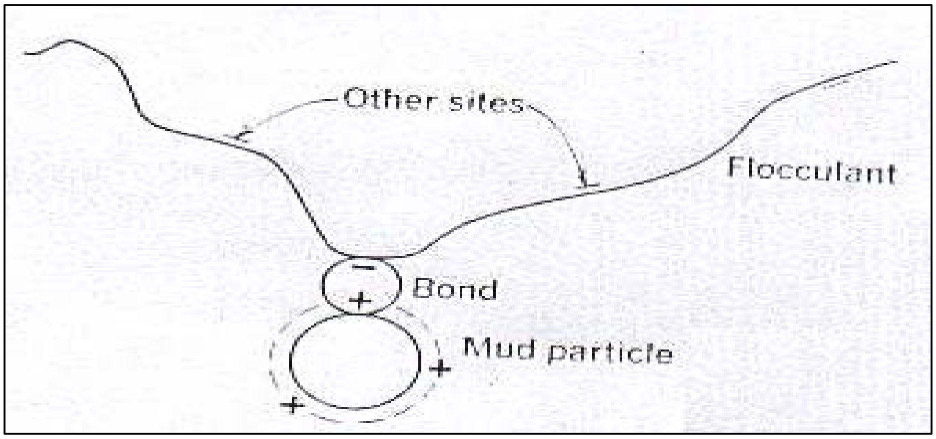


Figure (2-10) Attachment of Impurity to Polymer (9).

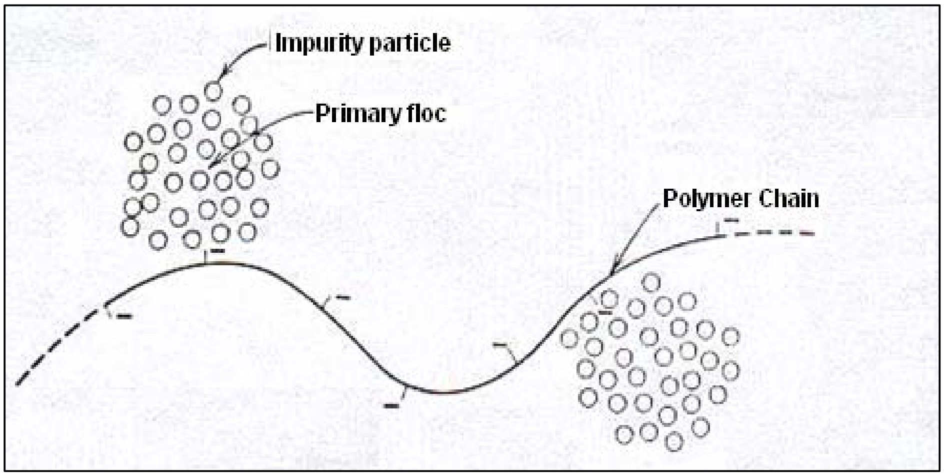


Figure (2-11) Attachment of primary flocs to polymer chain: secondary flocculation(9)

2-9 Polymer Flocculants:

- A number of synthetic water-soluble polymers are used to produce secondary flocculation. Generally, a good flocculants improves flocculation, increases the clarity of the clarified juice, increases settling rate, reduce mud volume, and decreases pol in cake(9).
- Polymers which are used in sugar industry must be food-grade as polyacrylamide, polydadmac, and polyaluminium chloride, which are used in this work.
- Factors that affect the performance of polymers in juice clarification are: time of agitation of stock solution, polymer solution concentration and solution pH, polymer dose, influence of P_2O_5 precipitate, and concentration of calcium in clear juice(9).
- The polymers adopted so far by sugar industry are mainly anionic, which carry the same charge as the particles of the suspension in juice, (it must be noted that charge neutralization is not the sole mechanism of flocculation), that the chain molecules of polymer adsorbed on two or more of the suspended particles and thus polymer "bridges" are formed which tend to draw the particles together, to distances sufficiently close for the van der waals attraction between them to be come dominating(11).

  The settling rate increases with increasing the molecular weight of polymers. Molecular weights below 10^6 are not large enough for bridging and should be on the order of 10^7 for good clarification (9).
- The normal dosage of polymer in juice clarification is 2-4 ppm on weight of juice. The polymer is prepared first as a stock solution of 0.5-0.1% concentration (9).

Over dosage have adverse effect that each individual particle becomes covered with polymer chains, and the resultant coatings prevent mutual approach to sufficiently small distances for coagulation to occur (11).

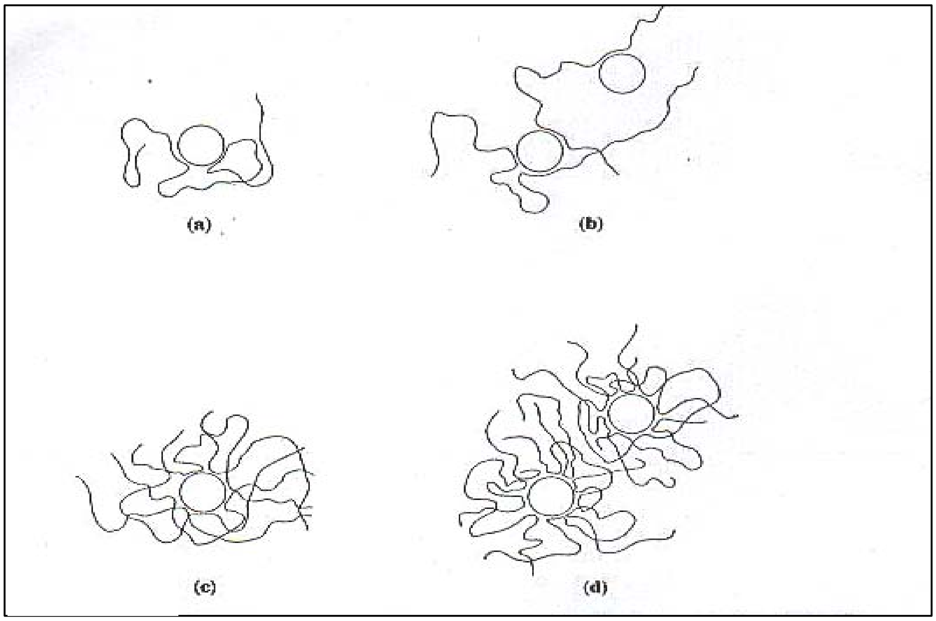


Figure (2-12) Illustration of polymers protective action (high concentrations) and sensitization (low concentrations) (11)

Note: (a) and (b) show the situation at low concentration, where the low coverage of the surfaces of the colloidal particles permits polymer chains to form bridges between them; (c) and (d) show the situation at higher concentrations, where the high surface coverage prohibits a polymer chain from having simultaneous attachments to two or more particles.

- Because of the variations of local conditions and cane varieties, there is no universal polymer that will suit all diversified conditions, but for a particular factory, there may be one polymer that will give consistent performance(9).

Chapter Three

Materials and Methods

3-1 Preparation of the Materials:

3-1-1 Preparation of the Lime:

- First lime sample was obtained from Elgunied sugar factory. The lime was imported from U.A.E. (Hydrated lime).

- Second lime sample was prepared by calcining the local limestone, which was taken from Wadi Kurmut-Atbara region, shown in figure (3-1), at 1000°C to constant weight in an electric muffle(12) (quicklime).

Figure (3-1) Sudan – Atbara region (19)

- The two lime samples were then analyzed by AAS spectrometer in the chemical laboratory of Geological Research Authority of Sudan.

- The milk of lime then was prepared for the two samples by mixing the lime with condensed water to the density of 15 Baume′ (148gCaO Per liter) (12).

3-1-2 Preparation of Polymers:

- Polyacrylamide (Separan Ap 30) polymer was obtained from Elgunied sugar factory. The polymer was imported from Germany for cane juice clarification.

- Polydadmac (zeta floc 226) and polyaluminium chloride (PAC) (sumal chlor 50^{TM}) were obtained from Almoqran station for water treatment. Both of the two polymers were imported for potable water treatment. Polydadmac was imported from South Africa and PAC was imported from U.S.A.

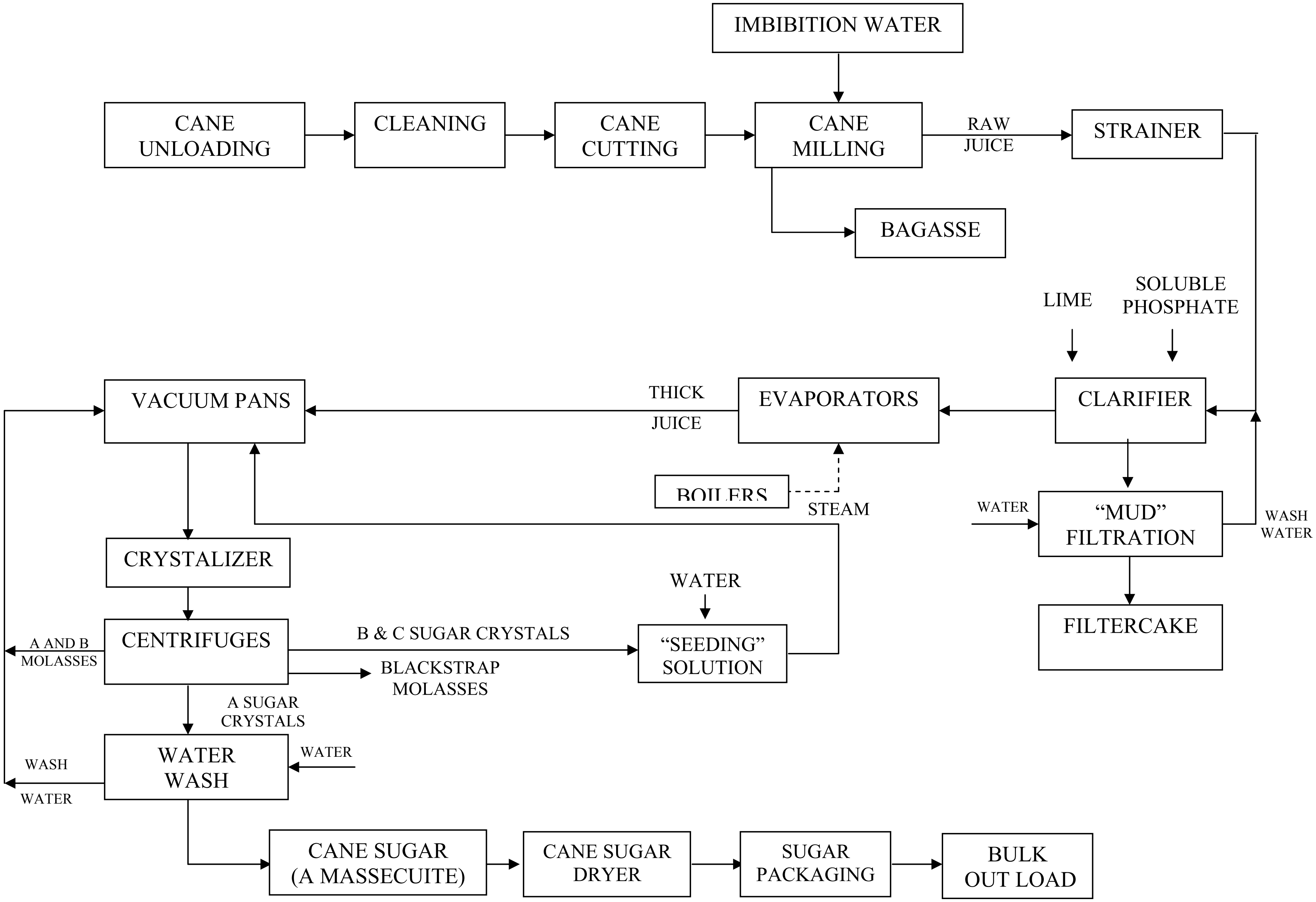
- Stock solutions of the polymers were then prepared to concentration of 0.1%(9).

3-1-3 Preparation of Mixed Juice:

The experimental work was carried out at Elgunied sugar factory. Figure (3-2) shows the simplified process flow diagram for Elgunied sugar factory.

Mixed juice samples were collected from Elgunied sugar mill during the 2003 to 2004 milling season.

Figure (3-2) The simplified process flow diagram for ElGunied sugar facto


IMBIBITION WATER
CANE UNLOADING
CLEANING
CANE CUTTING
CANE MILLING
RAW JUICE
STRAINER
BAGASSE
LIME
SOLUBLE PHOSPHATE
VACUUM PANS
THICK JUICE
EVAPORATORS
CLARIFIER
BOILERS
STEAM
WATER
"MUD" FILTRATION
WASH WATER
CRYSTALIZER
WATER
FILTERCAKE
CENTRIFUGES
B & C SUGAR CRYSTALS
"SEEDING" SOLUTION
A AND B MOLASSES
BLACKSTRAP MOLASSES
A SUGAR CRYSTALS
WATER WASH
WATER
WASH WATER
CANE SUGAR (A MASSECUITE)
CANE SUGAR DRYER
SUGAR PACKAGING
BULK OUT LOAD

3-1-4 Preparation of Standard Solutions for P_2O_5 Determination(16):

3-1-4-1 Preparation of Ammonium Molybdate Solution(1.5%):

15g powdered ammonium molybdate ($(NH_4)_6Mo_7O_{24}.4H_2O$) were dissolved in 300 ml distilled water at 50°C and cooled. 310 ml concentrated hydrochloric acid were added to the solution, then cooled and diluted to 1000 ml.

3-1-4-2 Preparation of Phosphate Standard Solution:

0.7668g potassium dihydrogen orthophosphate (KH_2PO_4) was dissolved in distilled water in 1000ml – volumetric flask. 10 ml of concentrated sulphuric acid were added. It was diluted to 1000 ml.

So 1 ml $\equiv$ 0.4 mg P_2O_5.

25 ml of the above standard solution were diluted to 1000 ml.

So 1 ml $\equiv$ 0.01 mg P_2O_5.

3-1-4-3 Preparation of Reducing Solution:

180g of sodium metabisulphite ($Na_2S_2O_5$) were dissolved in 1400ml distilled water. 114g anhydrous sodium sulphite (Na_2SO_3) and 3g 1-amino-2-naphthol-4-sulphonic acid ($(C_6H_4).(C_4H.NH_2.OH.SO_3H)$) were dissolved in 200 ml distilled water.

These two solutions were mixed and diluted to 2000 ml. after waiting overnight the solution was filtered.

3-2 Methods:

3-2-1 Juice Analysis:

3-2-1-1 Dry Substance (Solids Content) Bx(10):

Bx was measured by refractometer, which is shown in plate (3-1), after the filtration of the sample with kieslguhr (1% on solids) through filter paper, as shown in plate (3-2).

Plate (3-1) Refractometer

Plate (3-2) Sample filtration for Bx and colour determination

3-2-1-2 pH(10):

pH meter with glass electrode was used for pH measurement. Plate (3-3) shows the used pH meter.

Plate (3-3) pH meter

3-2-1-3 Pol(10):

Firstly the samples were treated with adding basic lead acetate and then filtered through filter paper as shown in plate (3-4).

Plate (3-4) Samples filtration for pol determination

Pol was determined using saccharimeter which is shown in plate (3-5).

Plate (3-5) Saccharimeter

3-2-1-4 Colour(6):

The samples were filtered with kieslguhr (1% on solids) through filter papers as shown in plate (3-2), and the pH was adjusted to 7±0.2 with diluted hydrochloric acid or sodium hydroxide. Then the absorbency of the solution was determined at 560 nm , using filtered distilled water as the reference standard for zero colour, by the spectrophotometer which is shown in plate (3-6).

Plate (3-6) Spectrophotometer

The absorbency index a_s of the solutions calculated as follows:

$$a_s = \frac{-\log T_s}{bc} = \frac{A_s}{bc}$$

Where: T_s ≡ transmitancy.

A_s ≡ absorbency.

b ≡ cell length (cm).

c ≡ concentration of total solids (g/cm^3) determined refractometerically and calculated from density.

The value (a_s) multiplied by 1000 is reported as ICUMSA units ($I.U._X$) where x = wave length used (in nm).

3-2-1-5 Turbidity(6):

The absorbency was measured at 560 nm (for unfiltered sample) after the pH was adjusted to 7±0.2. Then absorbency was measured at 560 nm, by filtering the sample solution with kieslguhr (1% on solids) through filter paper, and the pH was adjusted to 7±0.2 with diluted hydrochloric acid or sodium hydroxide, before absorbency reading, the effect of absorption of light scattering by particles contributing to turbidity is eliminated.

So the difference between absorbency readings before (A_1) and after (A_2) filtration $A_1 - A_2$ is the turbidity of the juice (9).

3-2-1-6 Clarification Tests(10):

- Clarification tests were conducted on mixed juice to evaluate clarification procedures.
- 250 ml of sample was measured in a graduated cylinder and transferred to 400 ml beaker.
- Electrodes of pH meter were immersed in the sample and stirrer run was at medium speed.

- Alkaline clarification agent (local and imported lime 15Be′) was added drop by drop from a 5 ml pipette to the desired (cold limed) pH.
- Then the sample was placed on a hot plate and heated rapidly to boiling, stirring often, and boiled gently for 2 minutes while stirring.
- Chemical additives (polymers) were added. (when the polymer is evaluated). With stirring for one minute.
- Then the sample was at once transferred to imhoff cone, stoppered, and the mud volume was recorded at 5, 10, 15, 20, 30 and 60 minute intervals. Plate (3-7) shows the setting process during clarification test.

Plate (3-7) Settling process during clarification test – Imhoff cones

- After 60 minutes 100 ml of clarification juice were withdrawn with 100 ml pipette, transferred to a beaker to determine turbidity, pH, colour, and purity.

3-2-1-7 P_2O_5 Determination in Mixed Juice(16):

- Preparation of Standard Graph:

A. The following amounts of diluted phosphate standard solution (1ml ≡ 0.01 mg P_2O_5) were taken by pipette into 100 ml volumetric flask: 5, 10, 15, 20, 25, 30, 35, 45 and 50 ml.

B. 10 ml of ammonium molybdate solution, and sufficient distilled water to bring the total volume in the flask to about 85 ml, were added to each flask.

C. 10 ml reducing solution were added to the first flask and the stop watch was started. The volume was quickly made to the mark with distilled water with mixing.

D. The absorbency was exactly measured 10 minutes after adding the reducing solution at 700 nm in 10 mm cell using distilled water as the reference.

E. Steps (C) and (D) were repeated for all other flasks.

F. The graph of absorbency against mg P_2O_5 in solution was plotted.

-Procedure:

- The sample was filtered.
- 10 ml of filtered sample was placed into a 200 ml volumetric flask, and diluted to mark with distilled water and mixed thoroughly.

- 20 ml of diluted solution was placed into each of two 100 ml volumetric flasks. One is diluted to about 60 ml with distilled water and the other to the mark with distilled water for use as a blank.
- 10 ml of ammonium molybdate solution (1.5%) were added to the first flask and mixed by swirling.
- 10 ml of reducing solution were added, made to the mark with distilled water and mixed by shaking. The time at which the reducing solution added was noted.
- The absorbency of the blue colour was measured using the spectrophotometer exactly 10 minutes after the addition of reducing solution. And using a 10 mm cell and measured at 700 nm on the spectrophotometer. The reference is a 10 mm cell containing distilled water.
- The blank sample also was measured against distilled water.
- From the calibration graph the quantity of P_2O_5 corresponding to the absorbency was obtained.

  If P_2O_5 ppm in the solution is a, P_2O_5 ppm in the blank is b, then, P_2O_5 ppm in mixed juice = $(a-b) \times 100$.

Chapter Four

Results and Discussion

4-1 Lime Analysis:

Results obtained from the analysis of lime samples by AAS are shown in table (4-1).

Table (4-1) Lime samples composition

contents % Sample	CaO	MgO	Fe_2O_3	SiO_2	Al_2O_3	L.O.I.
Imported lime (hydrated lime)	58.02	1.44	0.04	N.D.	N.D.	24.70
Local lime (quick lime)	82.88	1.55	0.14	0.62	N.D.	0.00

(N.D. = Not detected.)

Imported lime is food grade, according to typical specifications of hydrated lime (by Sudanese Sugar Co. Ltd.) which are shown in table (2-2).

To compare local lime (quick lime) with imported lime (hydrated lime) the following calculations were carried:

The slaking process of the quick lime is expressed as following:

$$CaO + H_2O \rightarrow Ca(OH)_2$$

74 56

x → 100g local lime contain 82.88g

$$x = \frac{74 \times 82.88}{56} = 109.4016\text{g } Ca(OH)_2$$ So,

109.4016 + (100 – 82.88) = 126.5216g hydrated lime.

impurities

82.88g CaO. So 126.5216g of locally hydrated lime contain

yg CaO. And 100g of locally hydrated lime contain

$$y = \frac{82.88 \times 100}{126.5216} = 65.5\%$$ Then,

While in imported lime the percentage was 58.02% CaO (table (4-1)). Similarly, the following results were calculated:

Table (4-2) The difference between local and imported limes

contents % **Sample**	**CaO**	**MgO**	**Fe_2O_3**	**SiO_2**	**Al_2O_3**
Locally hydrated lime	65.5066	1.2251	0.1106	0.4900	N.D
Imported lime	58.0200	1.4400	0.0400	N.D	N.D

From the previous results it was noticed that CaO%, Fe_2O_3% and SiO_2 in the local lime are more than its percentage in the imported lime.

Whereas MgO% in the local lime is less.

The effect of these results on the clarification process were determined through the next experimental results.

4-2 P_2O_5 in Mixed Juice:

During the determination of P_2O_5 in mixed juice the following results were obtained for the preparation of the standard graph:

Table (4-3) Absorbency (ABS) of P_2O_5 standard solutions

P_2O_5 (mg/L)	**Absorbency**
0	0
0.5	0.053
1	0.097
1.5	0.133
2	0.167
2.5	0.216
3	0.263
3.5	0.298
4	0.330
4.5	0.364
5	0.407

And the graph of absorbency against mg/l P_2O_5 was plotted as shown in figure (4-1).

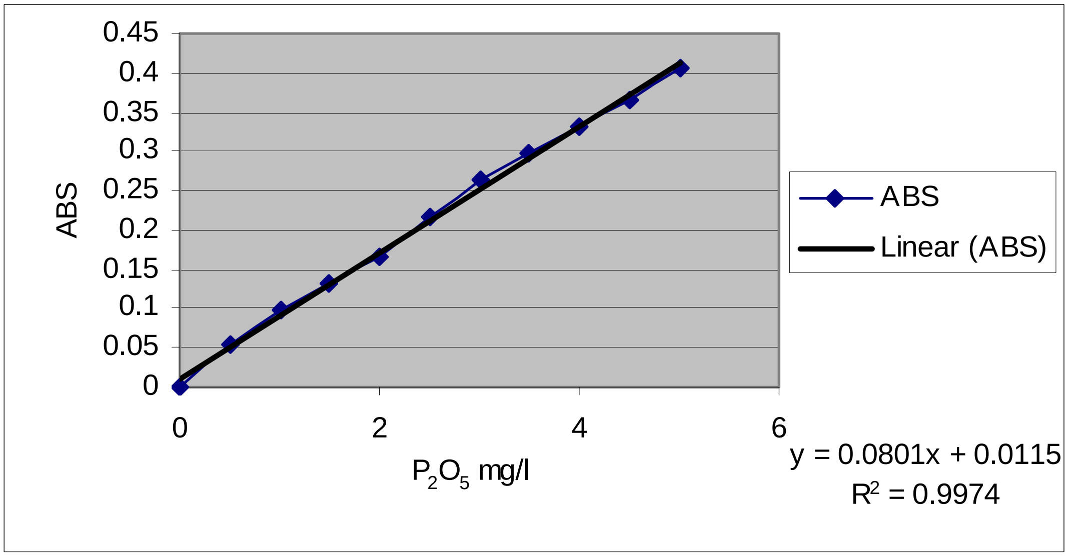


Figure (4-1) Standard graph for P_2O_5 determination in the mixed juice

Then the P_2O_5 content in the mixed juice was determined from the previous table and figure. Where the absorbency of the sample was 0.16 and the absorbency of the blank was 0.012.

From the calibration graph the quantity of P_2O_5 corresponding to the determined absorbency was obtained as:

$a = 1.8539$

$b = 0.0062$

$100\times = (1.8539 - 0.0062) \quad \Rightarrow P_2O_5$ ppm in mixed juice

$= 184.7688 \approx 185$ ppm

According to Chapter Two of this thesis (Literature Review) the required content of P_2O_5 in mixed juice for efficient clarification is about 350 ppm (12). So the quantity of P_2O_5 that must be added to the mixed juice for the clarification process is:

$= 165$ mg/L $\quad 350 - 185$

P_2O_5 is added to the mixed juice as commercial phosphoric acid (85% H_3PO_4 as in Elgunied factory).

$$2H_3PO_4 \rightarrow P_2O_5 + 3H_2O$$

$142 \quad 98\times2$

$\leftarrow$ 165mg $\quad$ x

$$x = \frac{165\times2\times98}{142} = 227.74 \text{ mg } H_3PO_4$$ So,

But 100g commercial phosphoric acid contain 85g H_3PO_4

227.74mg $\quad \leftarrow$---------- $\quad$ So: y

mg commercial phosphoric acid must be $y = \frac{227.74\times100}{85} = 267.9$

added to one liter of the mixed juice for efficient clarification.

4-3 Clarification Test:

To determine the optimum dosage of imported and local limes in the clarification process, the clarification tests were carried applying different doses of the lime to adjust PH to 7, 7.5, 8 and 8.5. The mud volumes were recorded against time, and the clarified juice was analyzed for Pol, Bx, Py, turbidity and colour.

4-3-1 Clarification Tests with Imported Lime:

Table (4-4) Change of Py of the clarified juice with imported lime dose (pH)

pH	Py %
7	81.6725
7.5	83.8816
8	84.2717
8.5	85.5856

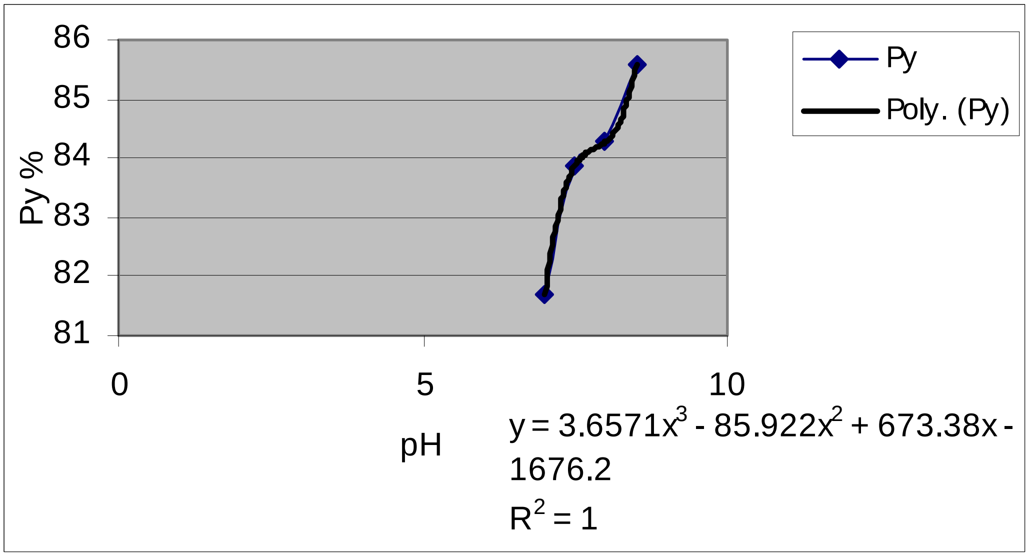


Figure (4-2) Effect of imported lime dose (pH) on Py of the clarified juice

Table (4-4) and figure (4-2) indicates clearly that Py of the clarified juice increased when increasing the dose of imported lime at PH=8.5.

No great reliance can be placed on purity increase as a criterion for good clarification.

A significant part of the supposed purity increase is mostly due to the removal of suspended matter. And the rise of apparent purity maybe due to destruction of levulose, which causes a more dextrorotatory effect to the pol reading. The destruction also brings down the Brix of juice, thus increasing the purity quotient(9).

Table (4-5) Change of turbidity of the clarified juice with imported lime dose (pH)

pH	Turbidity (ICU)
7	6473
7.5	1517
8	2197
8.5	3200

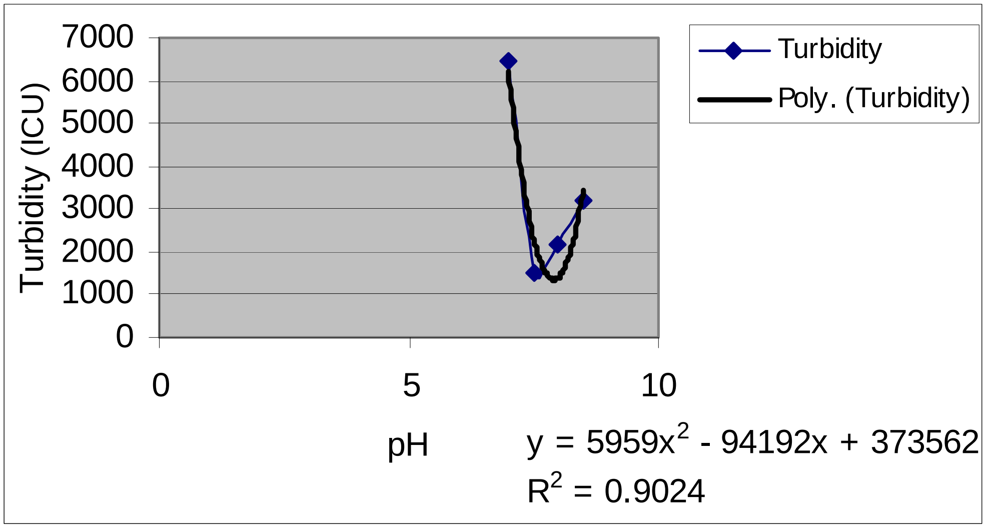


Figure (4-3) Effect of imported lime dose (pH) on turbidity of the clarified juice

Observation of the obtained results show that clarity of the clarified juice increased with the increase of the imported lime dose to pH = 7.5, and then decreased up to pH = 8.5.

It is expected that the increase in the imported lime dose to pH above 7.5 would cause an excess of calcium ions with positive electrokinetic charge in the precipitated flocs, which would lead the flocs to repel each other and thus causing an increase in juice turbidity.

No doubt the CaO content of clarified juice should be kept at the lowest possible limit proportionate with clarity (9).

Table (4-6) Change of colour of the clarified juice with imported lime dose (pH)

pH	Colour(ICU)
7	2991
7.5	2630
8	1933
8.5	1510

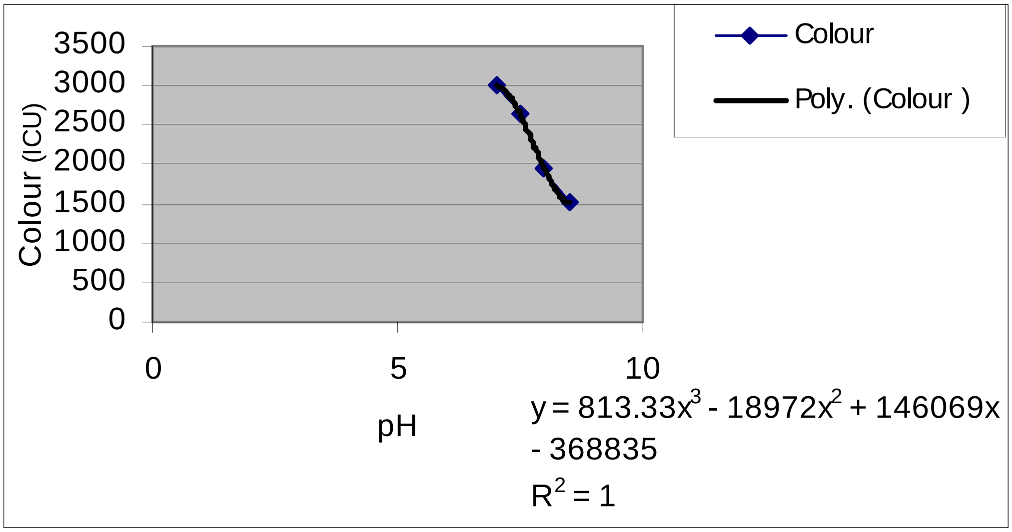


Figure (4-4) Effect of imported lime dose (pH) on colour of the clarified juice

It was apparent from table (4-6) and figure (4-4) that the increase of imported lime dose caused decrease in colour of the clarified juice.

The mechanism of colour removal is attributed to the fact that the precipitate of calcium phosphate formed in liming absorbs colour(12).

It has been reported that most of the colouring matter developed from reducing sugars is absorbed in the precipitates (12).

According to references the increase of the colour is due to polyphenol-iron compounds (12).

So it is concluded that the increase of the alkanility increased the precipitation of removable inorganic nonsugars (sesquioxides as Fe_2O_3), which in turn caused decrease in the colour of the clarified juice (polyphenol-iron compounds).

Table (4-7) Mud volume at different doses of imported lime (pH)

Time(min)	**Mud volume (ml) with pH**			
	pH=7	**pH=7.5**	**pH=8**	**pH=8.5**
5	50	100	120	120
10	42	90	100	90
15	41	75	80	74
20	40	64	66	66
30	38	60	61	60
60	35	52	54	52

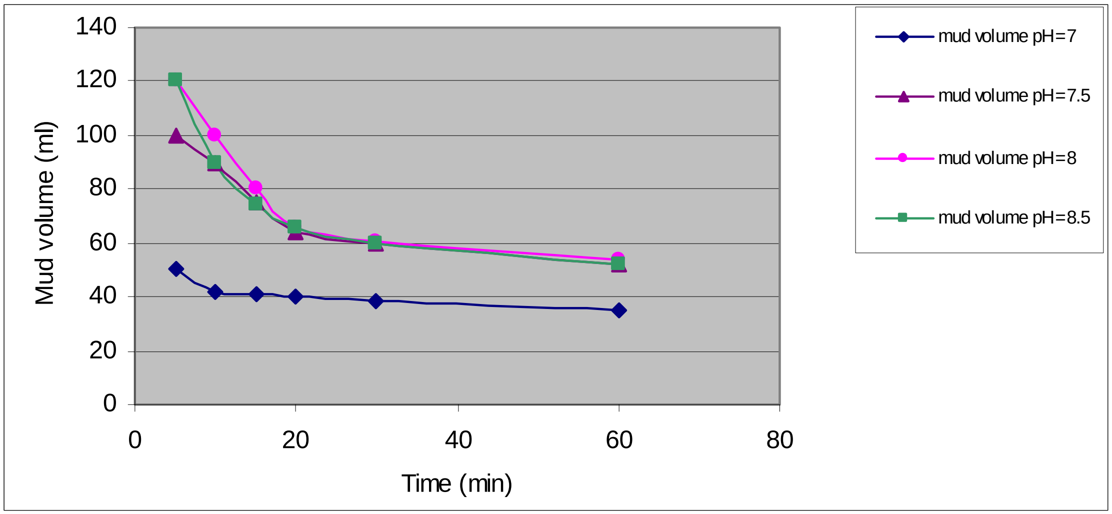


Figure (4-5) Mud volume with different doses of imported lime (pH) against time

From the plot of mud volume against time settling rates were determined as in table (4-8) and figure (4-6) which illustrate the influence of imported lime dose on settling rate.

Table (4-8) Change of settling rates with imported lime dose (pH)

pH	Settling rate (ml.min^{-1})
7	0.2092
7.5	0.7891
8	2.3838
8.5	0.9731

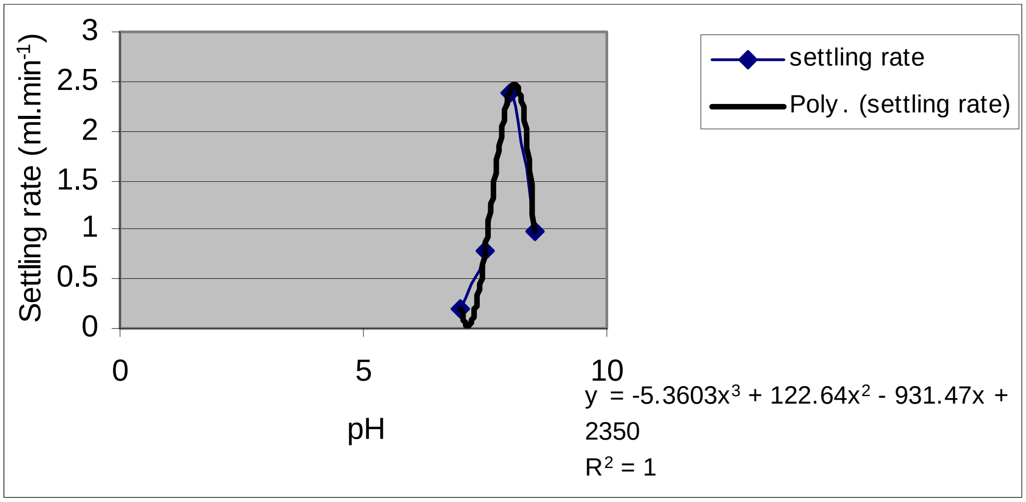


Figure (4-6) Effect of imported lime dose (pH) on the settling rate

So, it is concluded the results that optimum dose of imported lime for clarification process is at pH = 7.5, because this dose gave the best juice clarity.

But the clarity peak (at pH = 7.5) was offset (to pH = 8) from the settling rate peak. This may be due to the large surface area of settling flocs, their low density or their hydration (2), at imported lime dose of pH = 7.5. However the settling rate increased at pH = 8 due to the increase in settlings volume, increase in the density of settlings as a result of dehydration of settlings due to the increase in the pH more than 7.5.

4-3-2 Clarification Tests with Local Lime:

Table(4-9) Change of Py of the clarified juice with local lime dose (pH)

pH	Py %
7	82.4864
7.5	83.5032
8	84.4613
8.5	84.8509

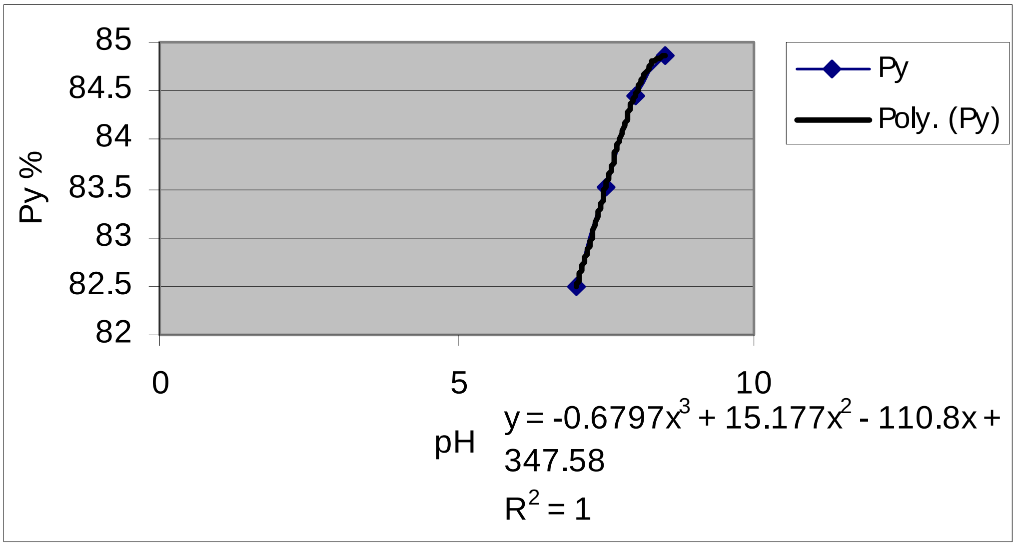


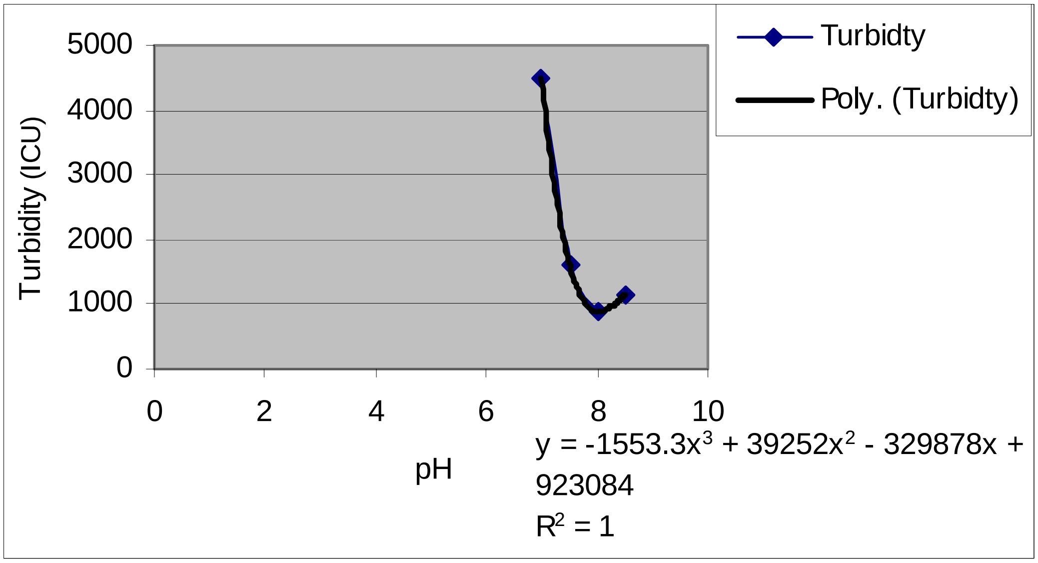
Figure (4-7) Effect of local lime dose (pH) on Py of the clarified juice

As shown by the previous table (4-9) and figure (4-7), increase the dose of local lime caused increase in Py of the clarified juice.

Table (4-10) Change of Turbidity of the clarified juice with local lime dose (pH)

pH	Turbidity (ICU)

7	4495
7.5	1614
8	884
8.5	1140



Figure(4-8) Effect of local lime dose (pH) on turbidity of the clarified juice

It was shown that clarity of the clarified juice increased with the increasing of local lime dose up to a pH of 8 , and then decreased until pH = 8.5.

The increase in local lime dose up to pH > 8 caused increasing in CaO content in the clarified juice which increased zeta potential (resuspension) and caused juice turbidity.

Table (4-11) Change of Colour of the clarified juice with local lime dose (pH)

pH	**Colour(ICU)**
7	2248

7.5	2952
8	3061
8.5	2873

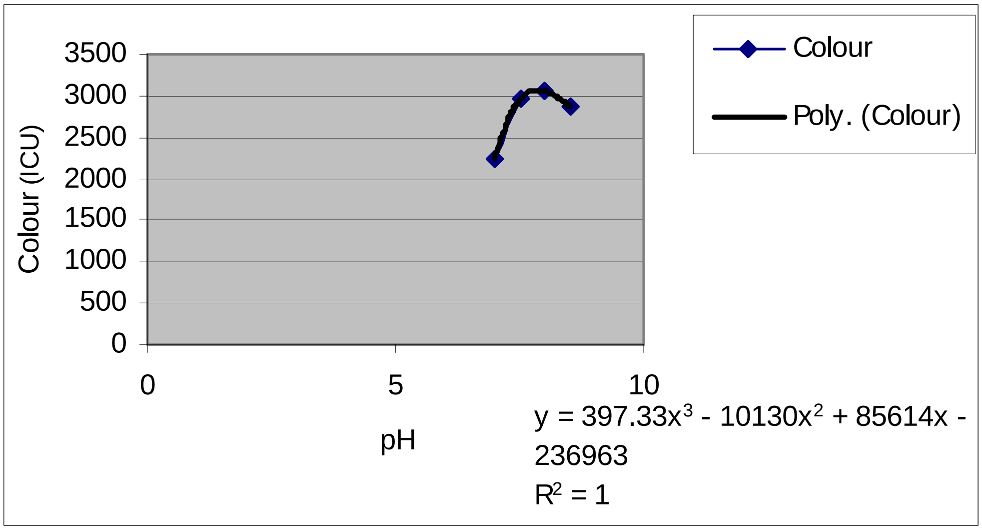


Figure (4-9) Effect of local lime dose (pH) on Colour of the clarified juice

It was noticed that when increasing the dose of the local lime to pH=8 colour of the clarified juice increased, there after it decreased until pH=8.5.

It was shown from table (4-1) that Fe_2O_3 content in the local lime is 3.5 times more than its content in the imported lime .And the increase in colour was a result of the increase in Fe_2O_3 content from local lime in the juice (polyphenol-iron compounds), then at pH>8 the alkalinity decreased Fe_2O_3 content in the juice, so caused colour decrease.

Table (4-12) Mud volume with local lime dose (pH)

Time(min)	**Mud volume (ml) with pH**			
	pH=7	**pH=7.5**	**pH=8**	**pH=8.5**
5	70	94	100	100

10	62	82	92	90
15	60	78	86	82
20	58	72	80	80
30	55	68	75	76
60	50	63	68	70

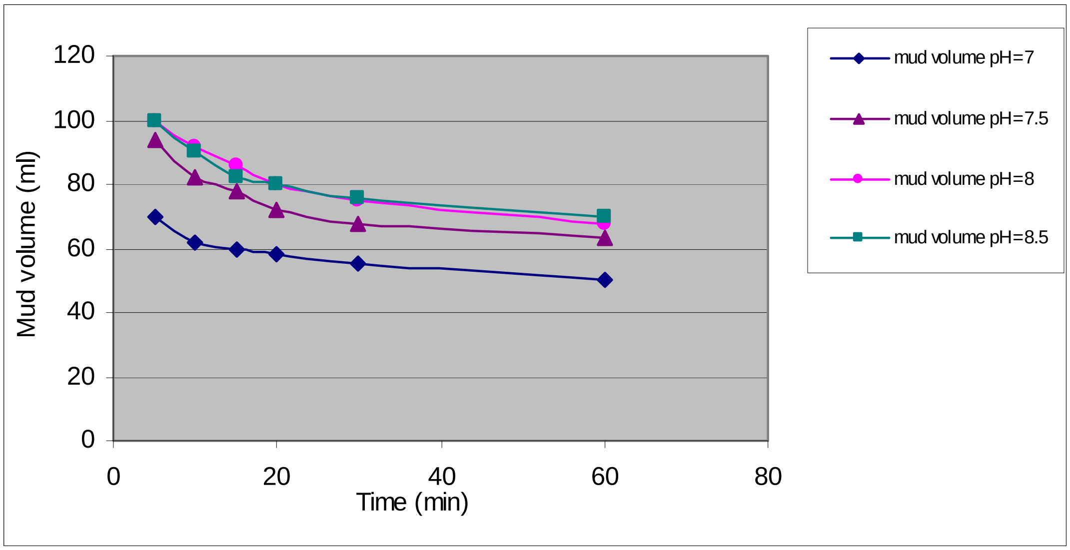


Figure (4-10) Mud volume with local lime dose (pH) against time

Settling rates were determined from the previous figure (4-10).

Table (4-13) Change of settling rates with local lime dose (pH)

pH	**Settling Rate(ml.min^{-1})**
7	0.3042
7.5	0.4756
8	0.5294
8.5	0.4588

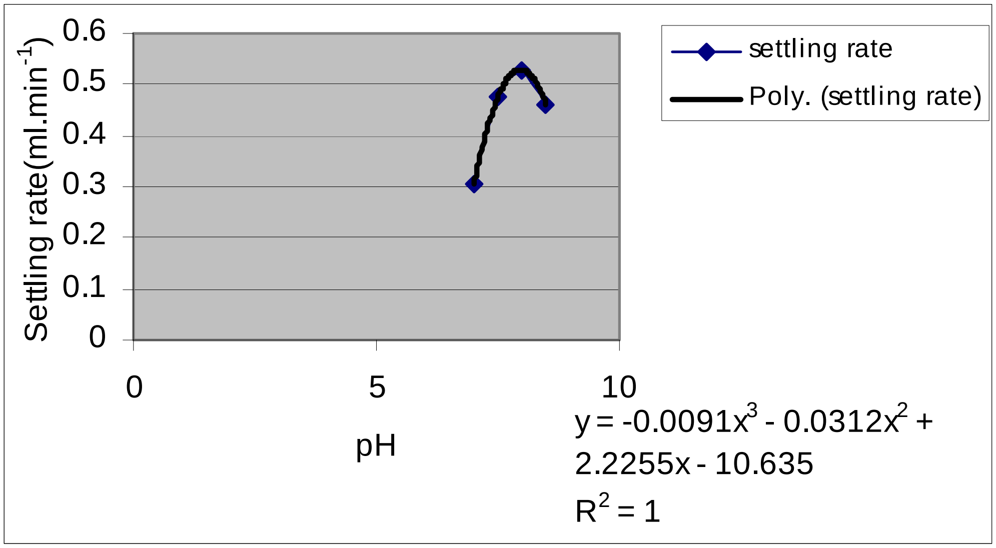


Figure (4-11) Effect of local lime dose (pH) on settling rates

Previous results indicated that the optimum dose of local lime for clarification process is at pH=8.

This dose gave the best juice clarity and the best settling rate.

4-3-3 Clarification Tests with Polymers:

Clarification tests were carried with different types and doses of polymers for both of the local and imported limes.

4-3-3-1 Clarification Tests with PAA and imported lime at (pH=7.5):

Table (4-14) Change of Py of the clarified juice with PAA dose (imported lime)

PAA dose	Py %
0	84.5689
1	84.8826
2	86.1680

3	86.6918
4	86.5791
5	85.8996

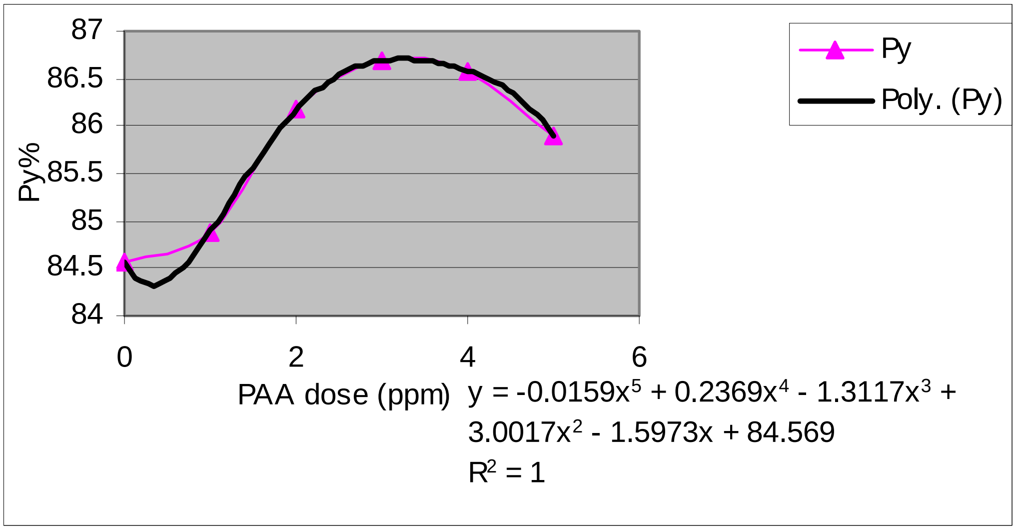


Figure (4-12) Effect of PAA doe on Py of the clarified juice (imported lime)

It was shown that increase PAA dose to 3ppm caused Py increase. Then at doses > 3ppm Py decreased with PAA dose increase.

Table (4-15) Change of turbidity of the clarified juice with PAA dose (imported lime)

PAA dose	Turbidity(ICU)
0	5549
1	1640
2	220
3	126
4	218
5	1897

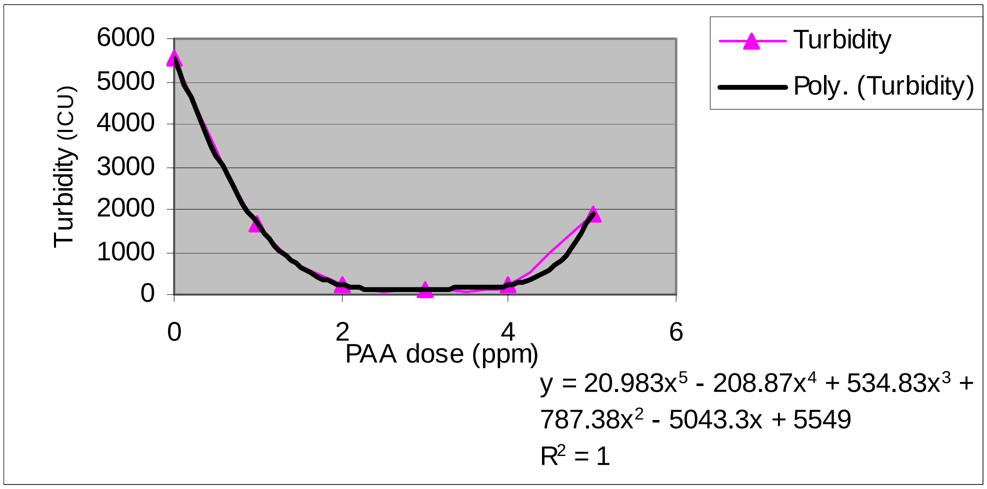


Figure (4-13) Effect PAA dose on turbidity of the clarified juice (imported lime)

The best clarity of the clarified juice was at PAA dose =3 ppm.

Table (4-16) Change of colour of the clarified juice with PAA dose (imported lime)

PAA dose	Colour(ICU)
0	2965
1	3735
2	3492
3	3209
4	3079
5	1555

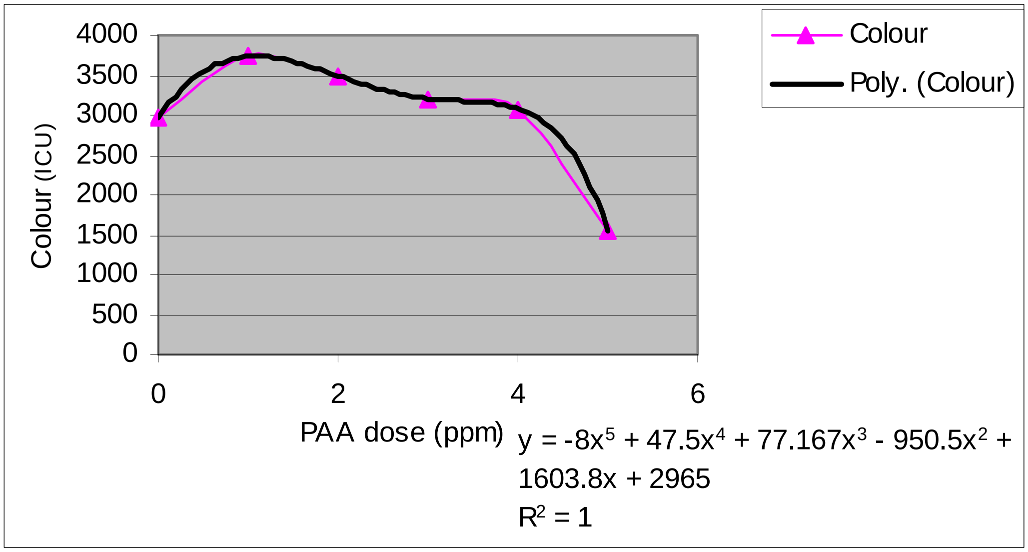


Figure (4-14) Effect of PAA dose on colour of the clarified juice (imported lime)

The increase in PAA dose cause decrease in colour of the clarified juice.

Table (4-17) Mud volume with PAA doses (imported lime)

Time (min)	**Mud volume with PAA Doses (d)**					
	d = 0 ppm	**d = 1 ppm**	**d = 2 ppm**	**d = 3 ppm**	**d = 4 ppm**	**d = 5 ppm**
5	77	82	60	53	54	52
10	60	69	50	49	51	50
15	55	64	46	48	51	50
20	52	60	44	47	51	50
30	48	54	42	47	51	50
60	43	47	40	46	50	50

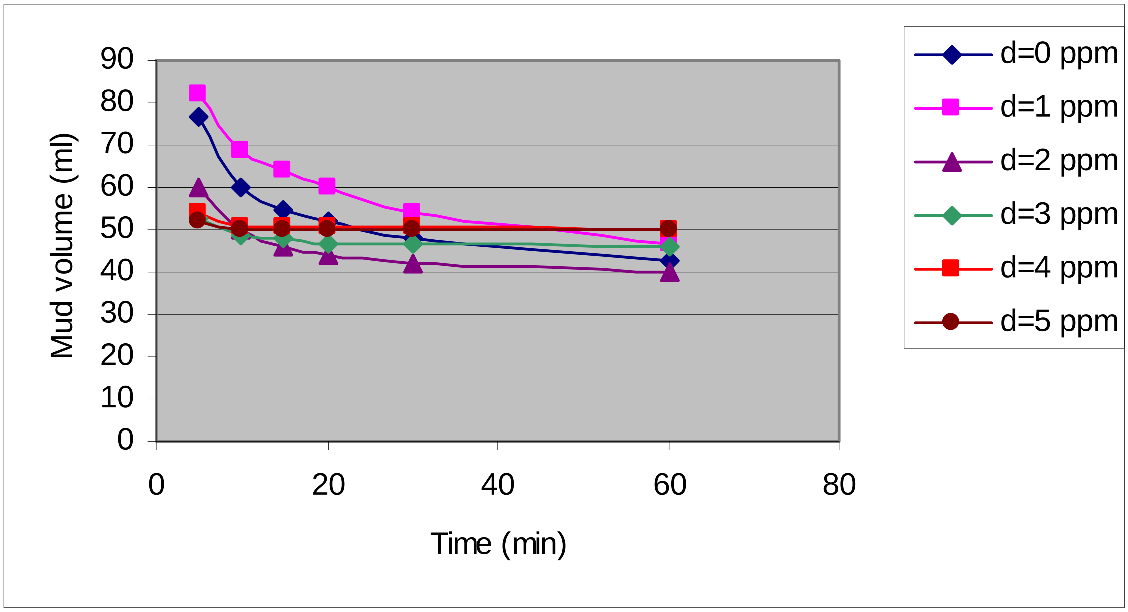


Figure (4-15) Mud volume against time with different doses of PAA (imported lime)

It was noticed that PAA (negatively charged polyelectrolyte) was effective in flocculating negatively charged colloids which could be due to proposed bridging mechanism(11). And the flocculation efficiency was optimum at PAA dose = 3 ppm, below this concentration there was insufficient polymer to form bridges, whereas above it the polymer chains coated the particles protectively and floc formation was inhibited (11).

4-3-3-2 Clarification Tests with PAA and local lime (at PH = 8):

Table (4-18) Change of Py of the clarified juice with PAA dose (local lime)

PAA dose	Py %
0	84.0671
1	84.4481
2	86.0572
3	86.3546
4	86.1830
5	85.8481

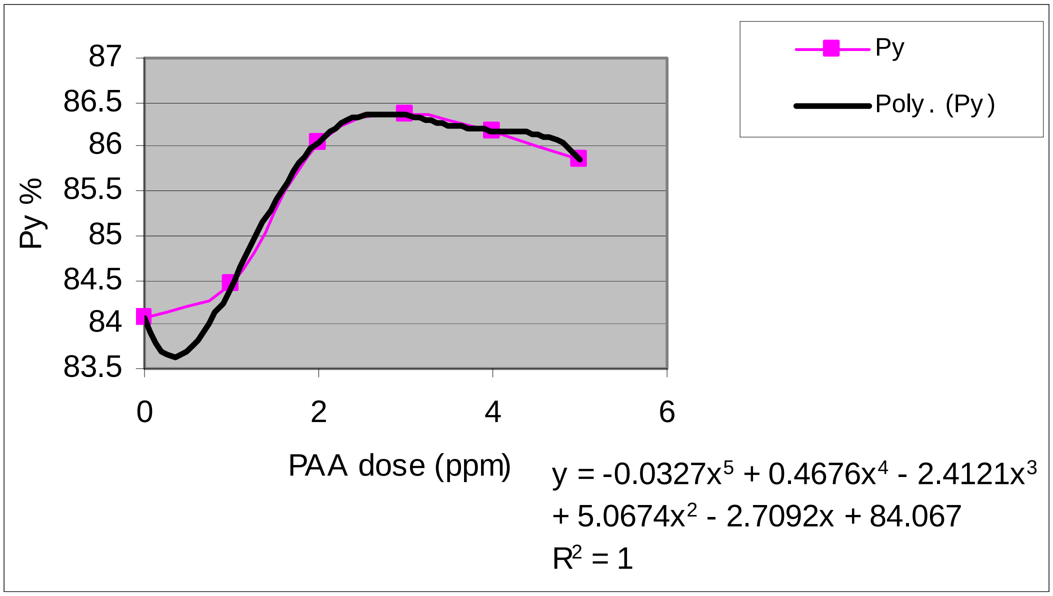


Figure (4-16) Effect of PAA dose on Py of the clarified juice (local lime)

Py of the clarified juice increased with the increase in PAA dose up to 3 ppm, then when PAA dose increased above 3 ppm the Py of clarified juice decreased (because of the remained polymer in the clarified juice – over dosage).

Table (4-19) Change of turbidity of the Clarified juice with PAA dose (local lime)

PAA dose	Turbidity(ICU)
0	3683
1	1119
2	179
3	96
4	284
5	296

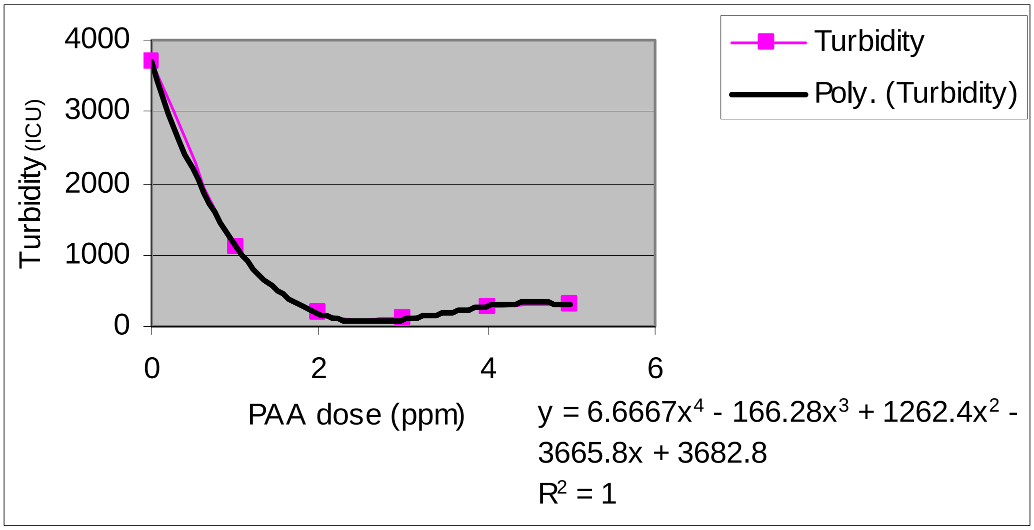


Figure (4-17) Effect of PAA dose on turbidity of the clarified juice (local lime)

The obtained results demonstrates that at 3 ppm PAA dose the best clarifty of clarified juice was obtained, above and below this concentration the turbidity increased.

Table (4-20) Change of colour of the clarified juice with PAA dose

(local lime)

PAA dose	Colour(ICU)
0	3583
1	3889
2	3628
3	3500
4	3485
5	3416

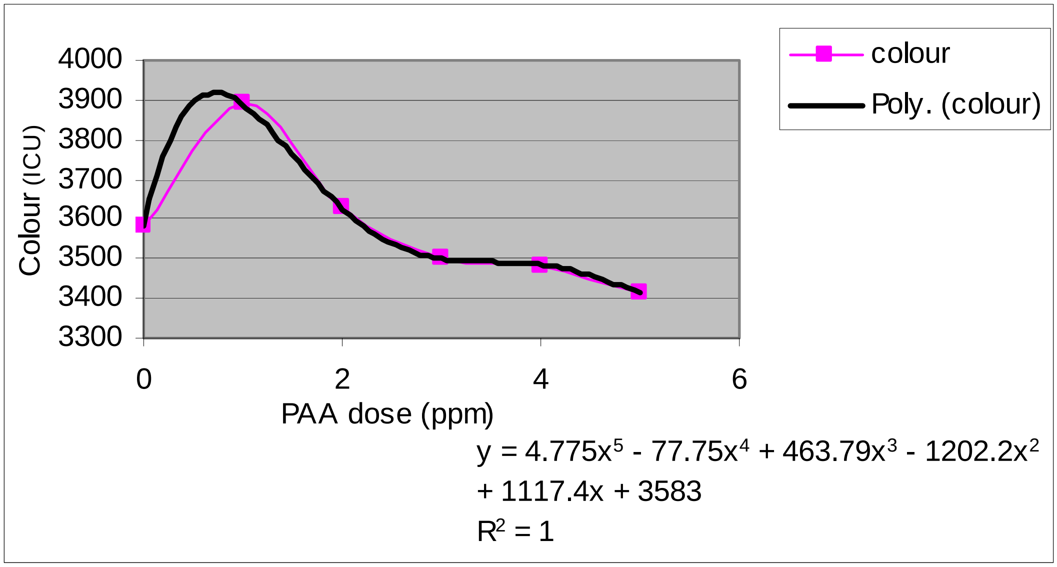


Figure (4-18) Effect of PAA dose on colour of the clarified juice (local lime)

It was noticeable that the increase in PAA dose caused colour decrease.

Table (4-21) Mud volume with PAA dose (local lime)

Time (min)	Mud volume with PAA dose (d)					
	d = 0 pmm	**d = 1ppm**	**d = 2 ppm**	**d = 3 pmm**	**d = 4 ppm**	**d = 5 ppm**
5	84	77	63	54	48	49
10	74	70	57	49	48	48

15	69	66	53	46	48	48
20	64	62	50	45	48	48
30	60	58	46	44	48	48
60	55	52	42	43	47	47

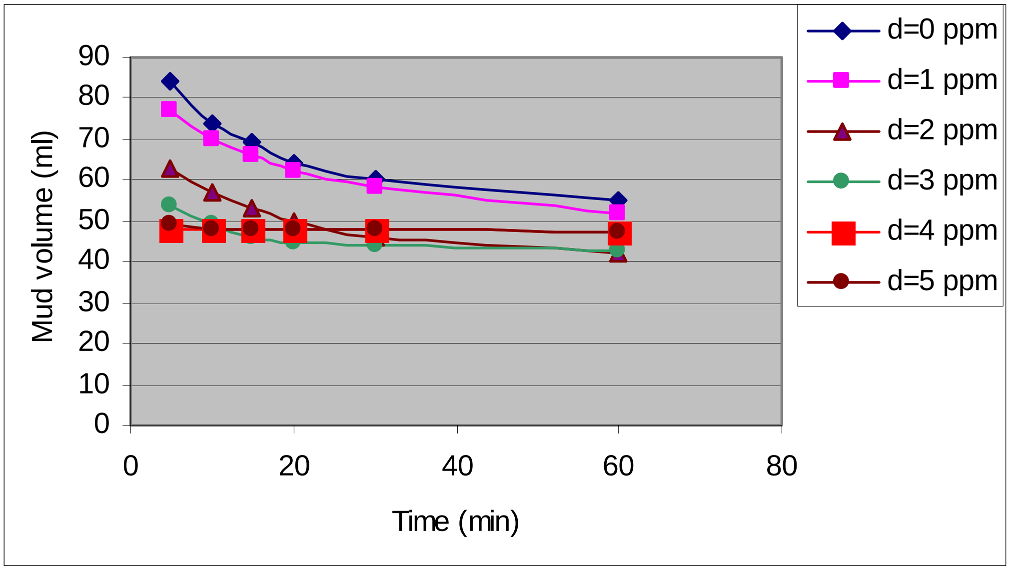


Figure (4-19) Mud volume against time with different dose of PAA (local lime)

Obtained results showed that the optimum PAA dose with local lime (to pH = 8) was at 3 ppm, above and below this concentration the clarification efficiency decreased.

4-3-3-3 Clarification Tests with Polydadmac and imported lime:

Table (4-22) Change of Py of the clarified juice with polydadmac dose (imported lime)

PDADMAC dose	Py o%
0	84.124
1	84.3668
2	84.6195

3	85.4999
4	85.1176
5	84.2605

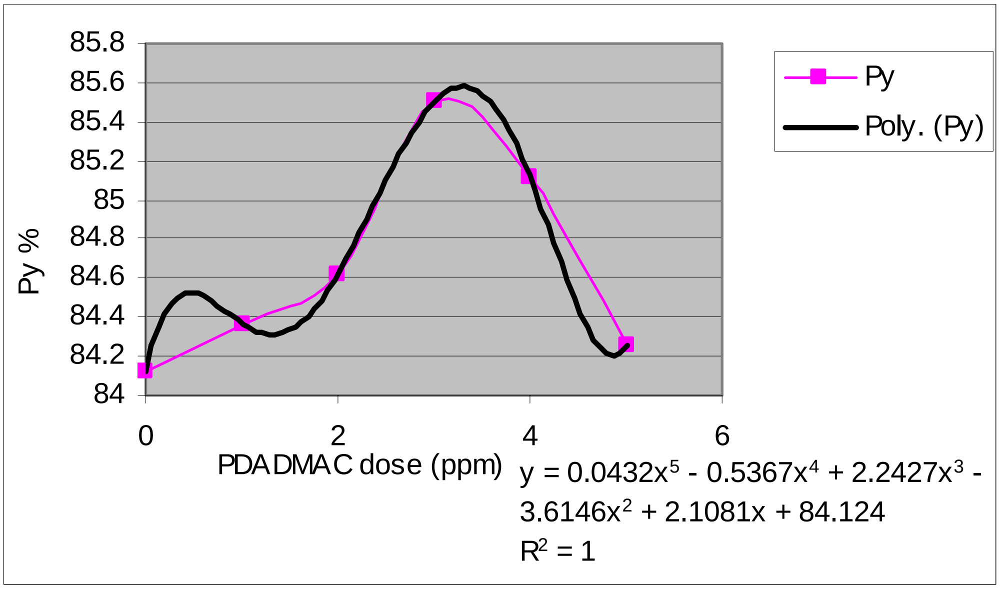


Figure (4-20) Effect of polydadmac dose on Py of the clarified juice (imported lime)

Py of the clarified juice increased with the increase in polydadmac dose up to 3 ppm, then above 3 ppm the Py of the clarified juice decreased (because of the excess remained polymer in the clarified juice as a result of over dosage).

Table (4-23) Change of turbidity of the clarified juice with polydadmac dose (imported lime)

PDADMAC dose	Turbidity(ICU)
0	4534
1	3805
2	3470
3	457
4	924
5	1217

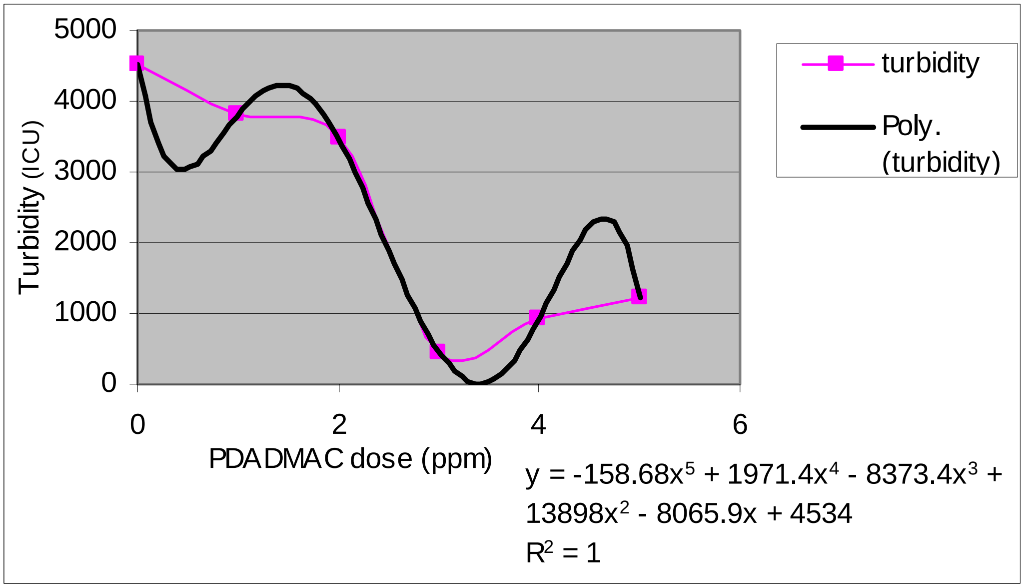


Figure (4-21) Effect of polydadmac dose on turbidity of the clarified juice (imported lime)

The best clarity of the clarified juice was at polydadmac dose of 3ppm, above and below this concentration the turbidity increased.

Table (4-24) Change of colour of the clarified juice with polydadmac dose (imported lime)

PDADMAC dose	Colour(ICU)
0	2544
1	649
2	454
3	1999
4	2829
5	3254

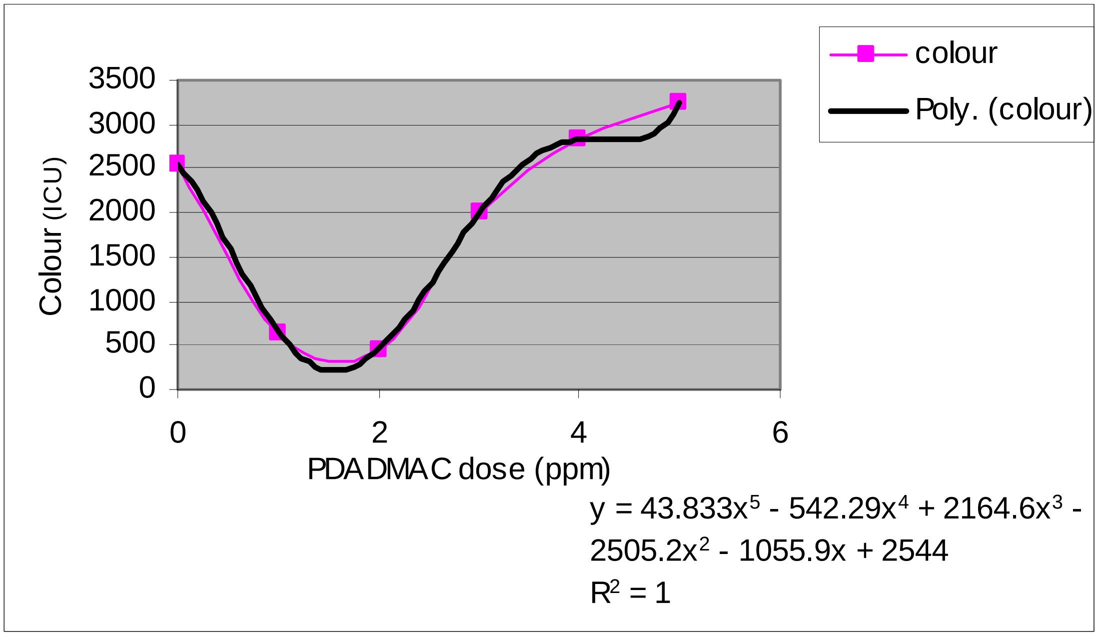


Figure (4-22) Effect of polydadmac dose on colour of the clarified juice (imported lime)

It was shown that the increase in polydadmac dose up to 2 ppm caused high decrease in colour of the clarified juice (colour removal was

82%), and then when polydadmac dose increased above 2 ppm the colour increased.

Table (4-25) Mud volume with Polydadmac dose (imported lime)

Time (min)	Mud volume with PDADMAC dose (d)					
	d = 0 pmm	d = 1ppm	d = 2 ppm	d = 3 pmm	d = 4 ppm	d = 5 ppm
5	105	110	97	110	120	120
10	85	98	84	91	95	92
15	77	90	78	84	85	82
20	73	84	74	78	79	77
30	68	76	68	72	71	71
60	62	68	61	64	62	63

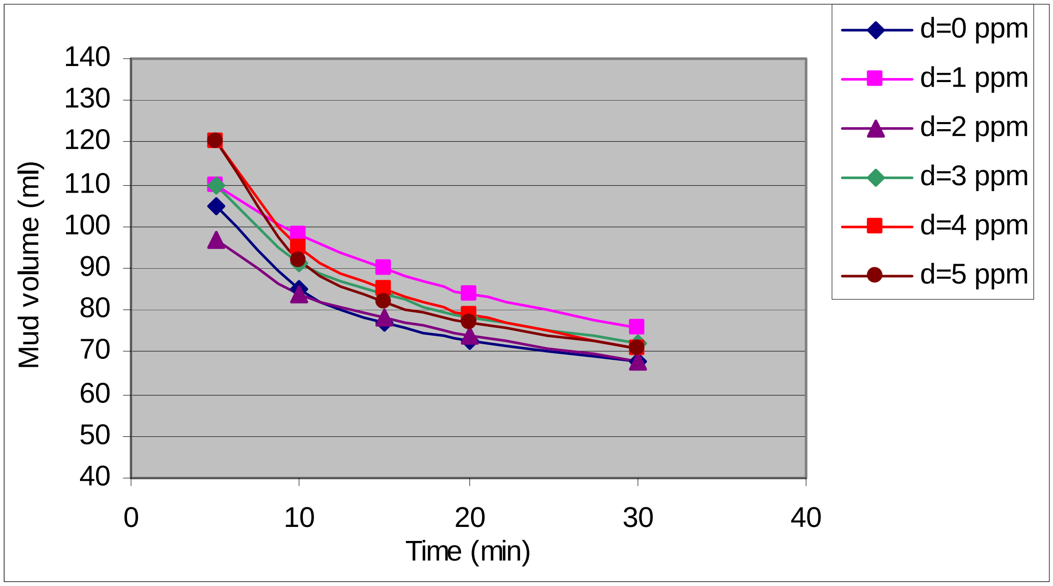


Figure (4-23) Mud volume with polydadmac dose against time (imported lime)

Table (4-26) Change of settling rate with polydadmac dose (imported lime)

PDADMAC dose	Settling rate(ml.min^{-1})
1	0.6824
2	0.5571
3	0.6874
4	0.8529
5	0.7983

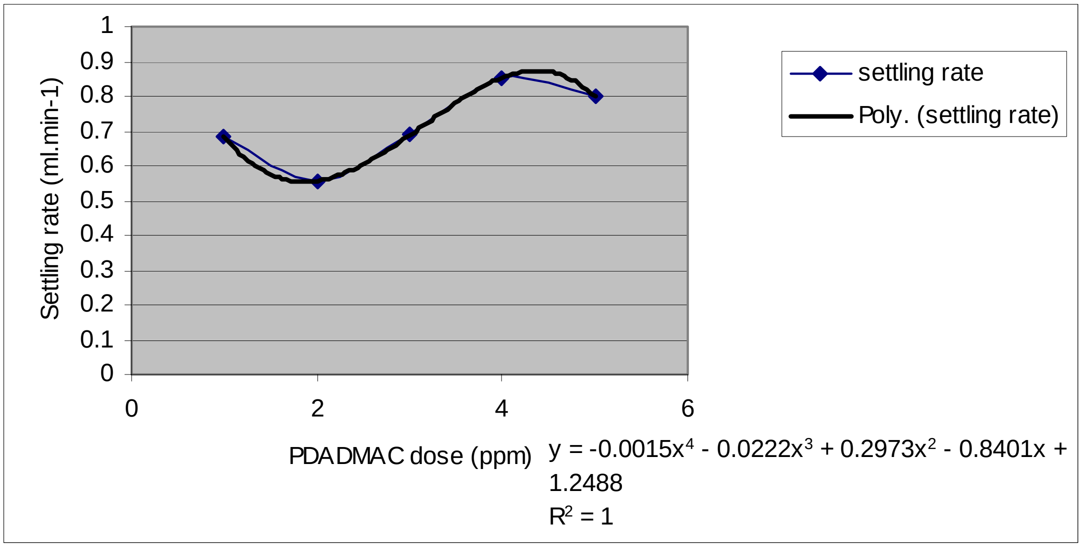


Figure (4-24) Effect of polydadmac dose on the settling rate (imported lime)

At Polydadmac concentration of 2 ppm it seemed clearly that the surface area of the settlings was large, which caused a slow settling and turbid juice at this dose.

That can be overcome by increasing the agitation time and the rate of mixing, when Polydadmac was added to the juice.

From the previous results it can be concluded that the optimum dose of polydadmac with imported lime was 2 ppm (according to economical and experimental analysis and observations).

4-3-3-4 Clarification Tests with Polydadmac and Local Lime:

Table (4-27) Change of Py of the clarified juice with Polydadmac dose (local lime)

PDAMAC dose	Py %
0	85.758
1	86.5918
2	87.1742
3	87.0682
4	86.8807
5	85.7577

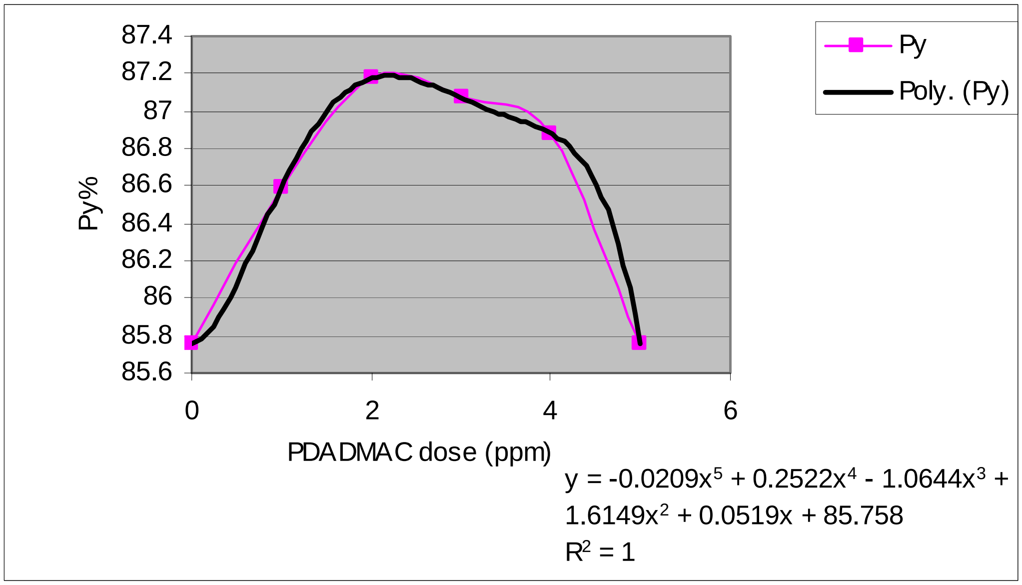


Figure (4-25) Effect of Polydadmac dose on Py of the clarified juice (local lime)

The best Py of the clarified juice was obtained at polydadmac dose of 2 ppm.

Table (4-28) Change of turbidity of the clarified juice with polydadmac dose (local lime)

PDADMAC dose	Turbidity(ICU)
0	7146
1	1863
2	848
3	824
4	1208
5	3652

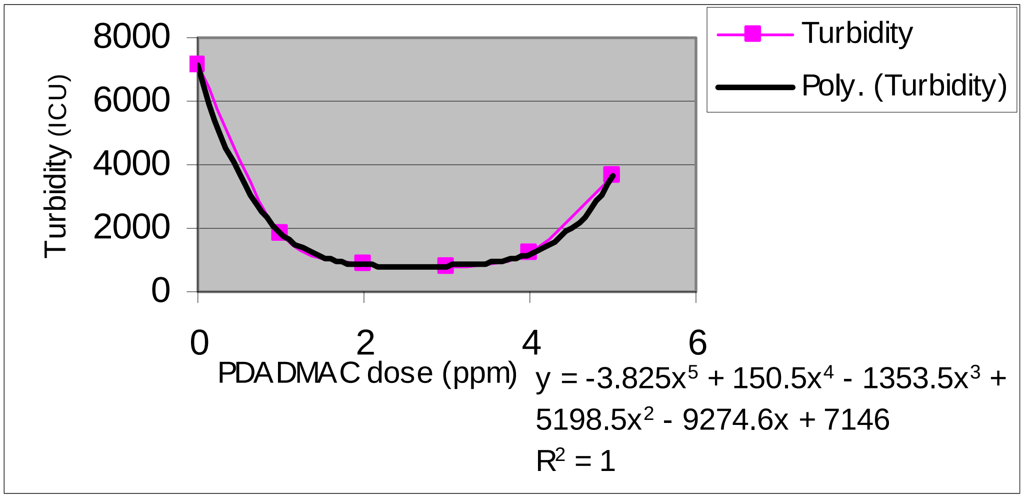


Figure (4-26) Effect of polydadmac dose on turbidity of the clarified juice (local lime)

So, from the above results, it is clear that the most clear juice was obtained at polydadmac dose of 3 ppm.

Table (4-29) Change of colour of the clarified juice with polydadmac dose (local lime)

PDADMAC dose	Colour(ICU)
0	3166
1	1249
2	692
3	2048
4	3648
5	4148

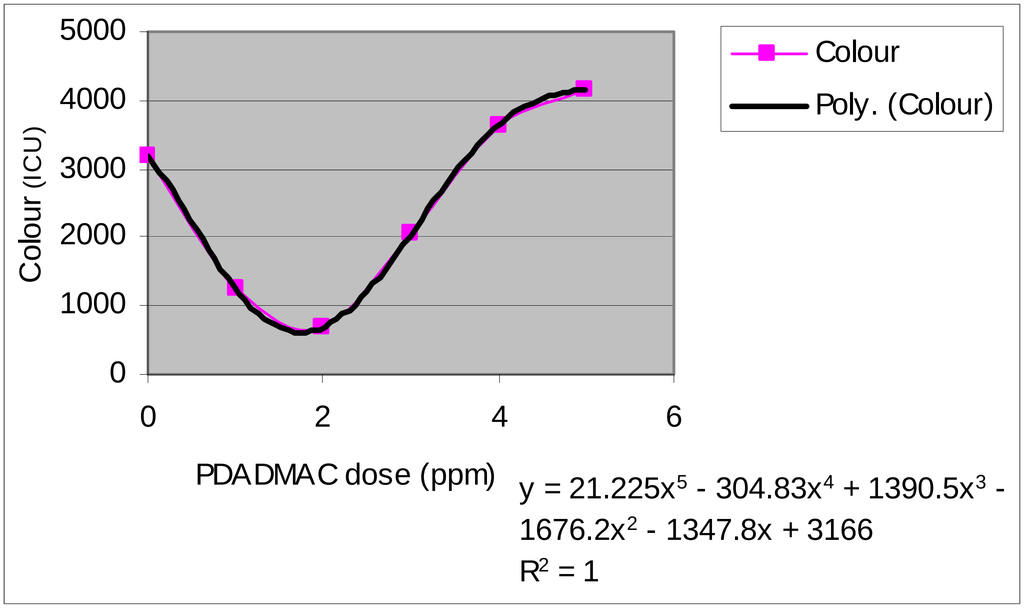


Figure (4-27) Effect of polydadmac dose on colour of the clarified juice (local juice)

The results indicate that the best colour removal was obtained at polydadmac dose of 2 ppm (78%).

Table (4-30) Mud volume with polydadmac dose (local lime)

Time (min)	Mud volume with PDADMAC dose (d)					
	d = 0 pmm	d = 1 ppm	d = 2 ppm	d = 3 pmm	d = 4 ppm	d = 5 ppm
5	58	110	98	100	108	105
10	49	94	88	90	88	85

15	46	88	84	86	83	80
20	44	84	80	81	79	75
30	42	78	76	76	74	70
60	38	68	69	68	66	60

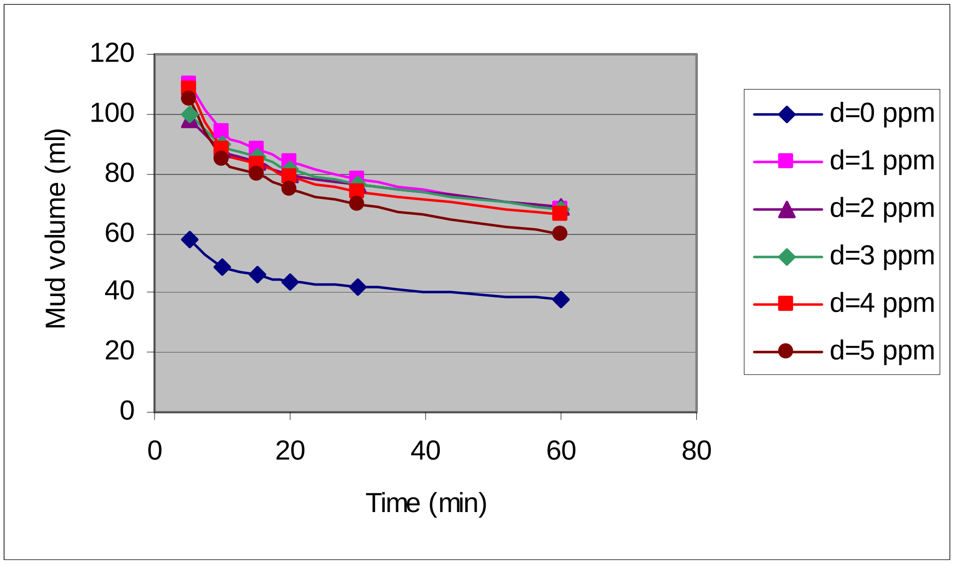


Figure (4-28) Mud volume against time with polydadmac dose (local lime)

Table (4-31) Change of settling rate with polydadmac dose (local lime)

PDADMAC dose	Settling Rate(ml.min^{-1})
1	0.6403
2	0.4538
3	0.5143
4	0.6025
5	0.6597

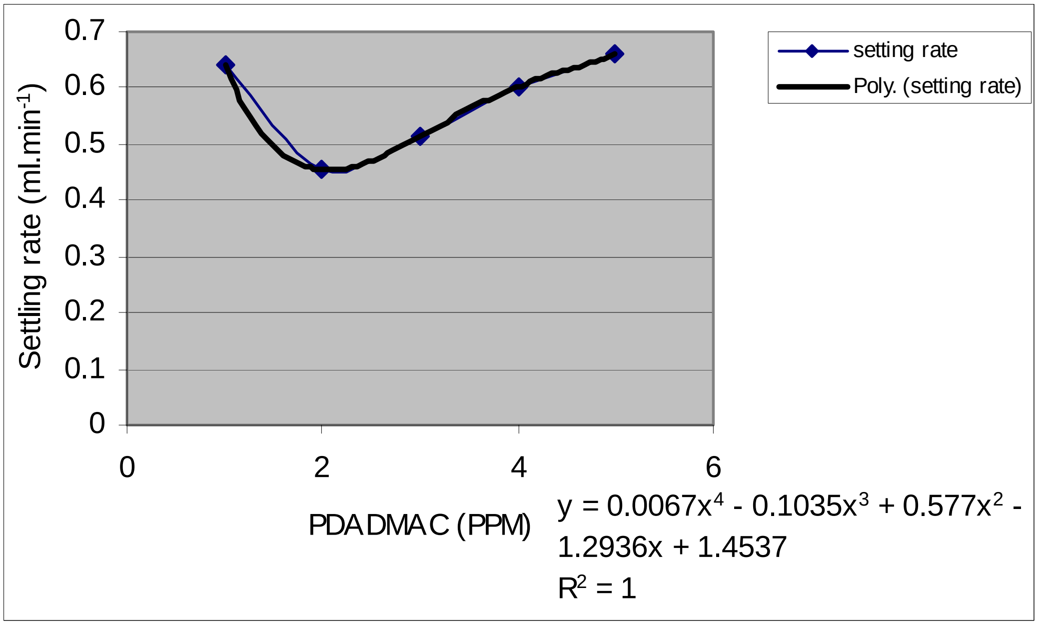


Figure (4-29) Effect of polydadmac dose on the settling rate (local lime)

It was noticed that at 2 ppm dose the suspended settlings can be precipitated by increasing the agitation time and the rate of mixing of polydadmac with the juice (when added to obtain more dense settlings and increasing the settling rate).

So, from the practical and economical analysis and observations it was deduced that the optimum dose of polydadmac with local lime was 2 ppm.

It must be noted that polydadmac is a cationic polymer, the flocculating mechanisms of this polymer are both charge neutralization and bridging mechanisms.

4-3-3-5 Clarification Tests with PAC and Imported Lime:

Table (4-32) Change of Py of the clarified juice with PAC dose (imported lime)

PAC dose	Py %
0	83.9457
1	85.0282
2	85.6247
3	86.1164
4	86.9860
5	87.1506

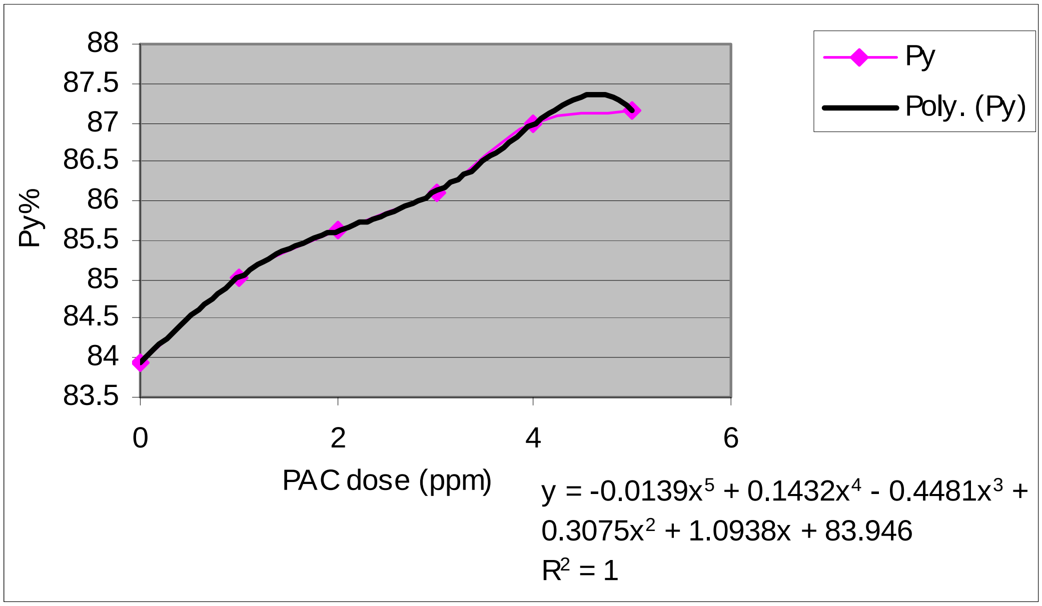


Figure (4-30) Effect of PAC dose on Py of the clarified juice (imported lime)

Table (4-33) Change of turbidity of the clarified with PAC dose (imported lime)

PAC dose	Turbidity(ICU)
0	7477
1	4298
2	1507
3	768
4	202
5	647

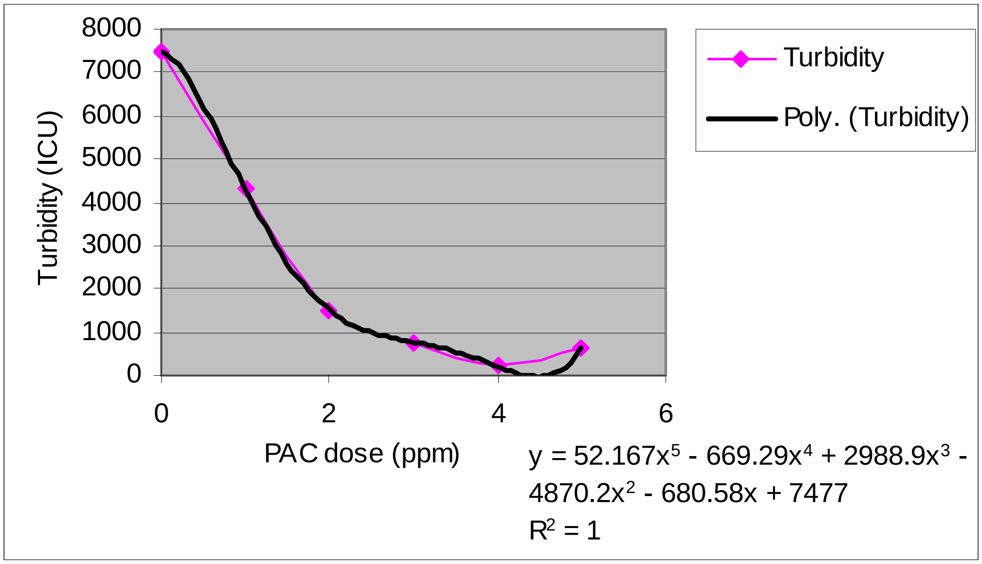


Figure (4-31) Effect of PAC dose on turbidity of the clarified juice (imported lime)

Table (4-34) Change of colour of the clarified juice with PAC dose (imported lime)

PAC dose	Colour(ICU)
0	3605
1	2921
2	2650
3	2551
4	2173
5	2066

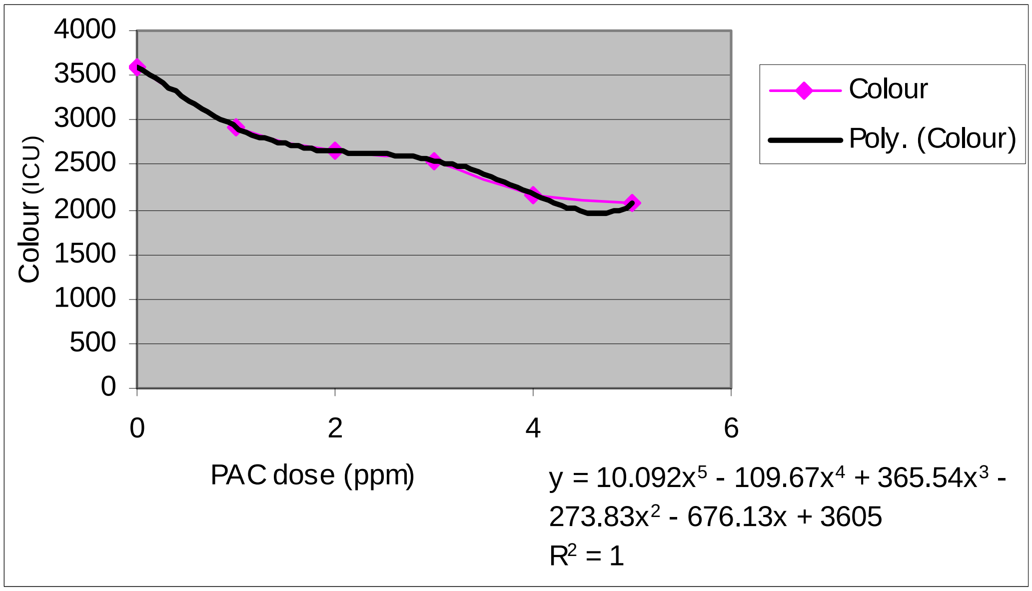


Figure (4-32) Effect of PAC dose on colour of the clarified juice (imported lime)

Table (4-35) Mud volume with PAC doses (imported lime)

Time (min)	**Mud volume (ml) with PAA dose (d)**					
	d = 0 pmm	**d = 1ppm**	**d = 2 ppm**	**d = 3 pmm**	**d= 4 ppm**	**d = 5 ppm**
5	81	145	155	160	180	200
10	67	110	130	145	150	170
15	60	100	125	140	145	165
20	60	94	120	135	140	160
30	56	90	110	120	135	150
60	50	80	97	110	125	145

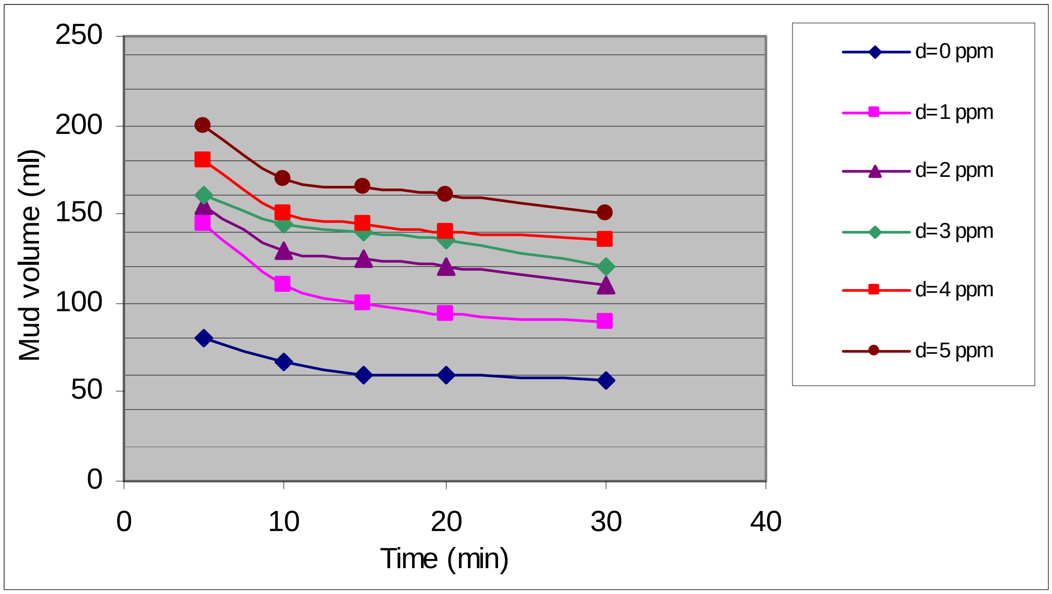


Figure (4-33) Mud volume against time for different doses of PAC (imported lime)

4-3-3-6 Clarification Tests with PAC and Local Lime:

Table (4-36) Change of Py of the clarified juice with PAC dose (local lime)

PAC dose	Py %
0	83.4889
1	84.0833
2	84.4411
3	84.8700
4	85.9948
5	87.0607

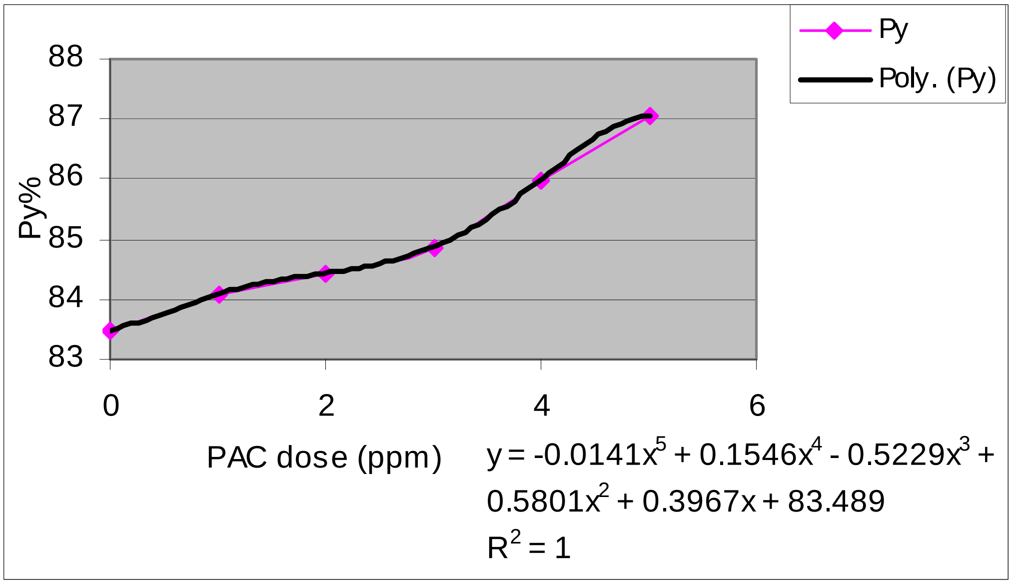


Figure (4-34) Effected of PAC on Py of the clarified juice (local lime)

Table (4-37) Change of turbidity of the clarified juice with PAC dose (local lime)

PAC dose	Turbidity(ICU)
0	2754
1	2075
2	543
3	100
4	96
5	334

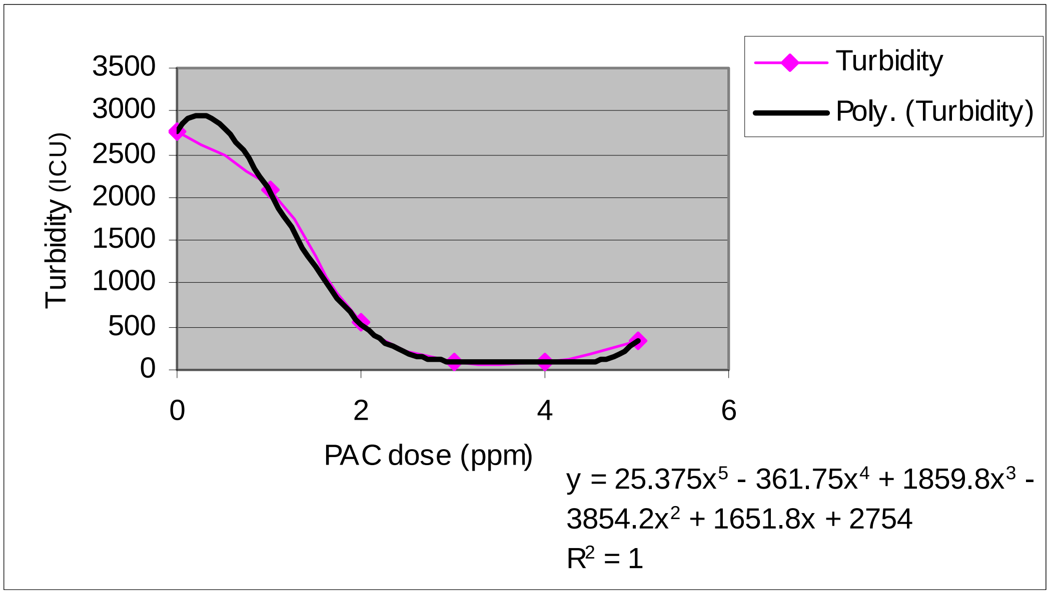


Figure (4-35) Effect of PAC dose on turbidity of the clarified juice (local lime)

Table (4-38) Change of colour of the clarified juice with PAC dose (local lime)

PAC dose	Colour
0	3114
1	2022
2	1913
3	1777
4	1619
5	1251

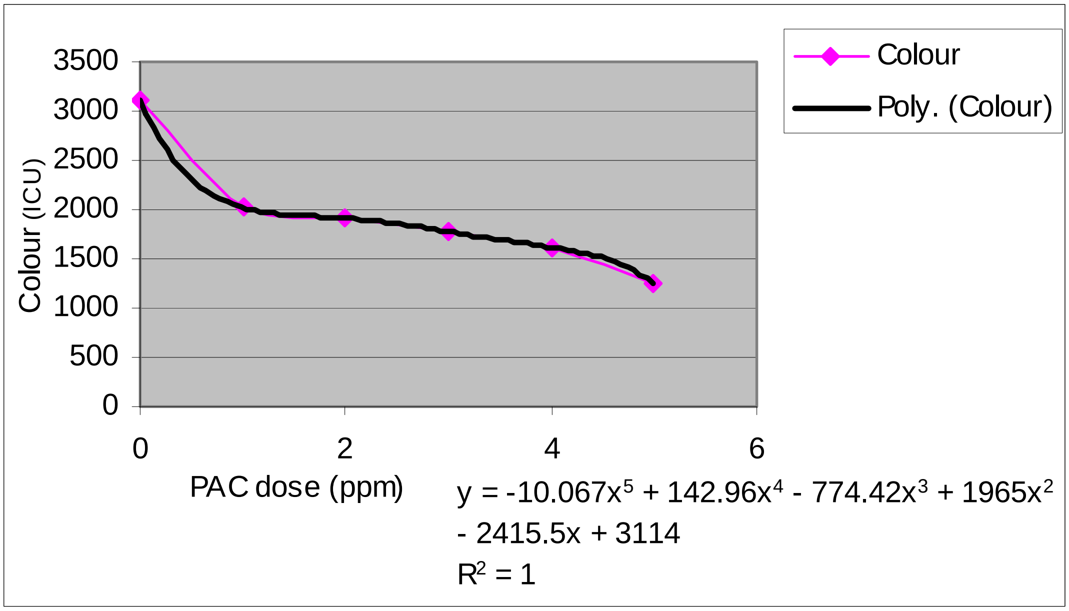


Figure (4-36) Effect of PAC dose on colour of the clarified juice (local lime)

Table (4-39) Mud volume with PAC dose (local lime)

Time (min)	Mud volume (ml) with PAA dose (d)					
	d = 0 pmm	**d = 1ppm**	**d = 2 ppm**	**d = 3 pmm**	**d = 4 ppm**	**d = 5 ppm**
5	86	140	145	150	180	190
10	75	115	130	140	150	175
15	70	105	125	135	145	170
20	67	98	120	130	140	160
30	62	90	105	125	135	150
60	56	80	96	110	130	145

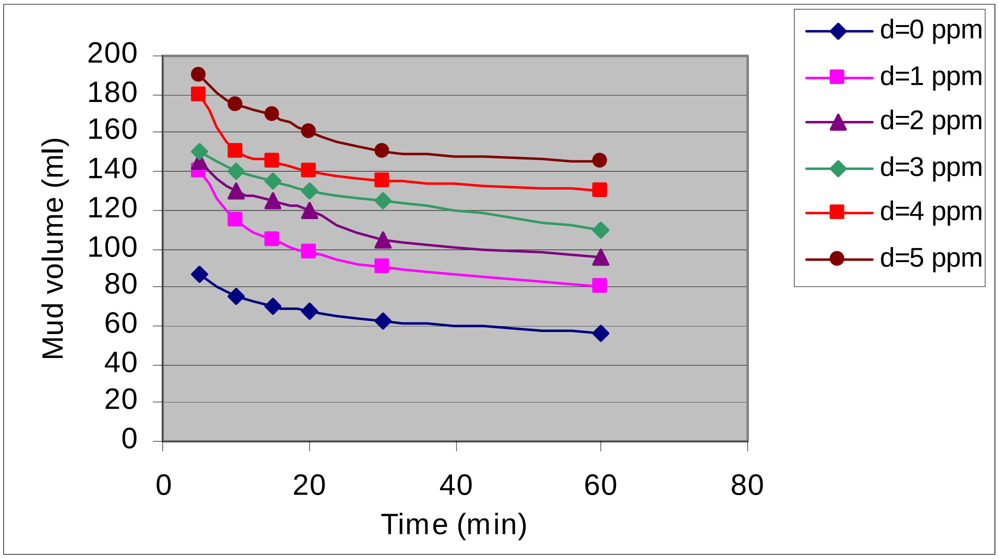


Figure (4-37) Mud volume against time for different doses of PAC (local lime)

The previous figures and tables (figure (4-30) to (4-37), table (4-32) to (4-39) showed clearly that there were incomplete settling due to the small size and density of the settlings, causing very large mud volumes.

This may be due to temperature, pH, agitation rate, or the mechanism of the process.

The addition of aid agent, and the changing of the clarification conditions may improve PAC efficiency.

4-3-4 Comparison of Results:

To compare the efficiency of the imported lime versus the local lime, with and without polymers, clarification tests were carried with the optimum doses of lime and polymers and the following results were obtained:

Table (4-40) Py of the juice samples

Juice Sample	Py %
Mixed juice	82.1911
Clarified Juice with:	
PAA +L	84.5495
PDADMAC +L	85.0548
PAC +L	84.7338
L	83.5699
PAA+M	85.0664
PDADMAC +M	85.5733
PAC +M	85.2051
M	83.3973

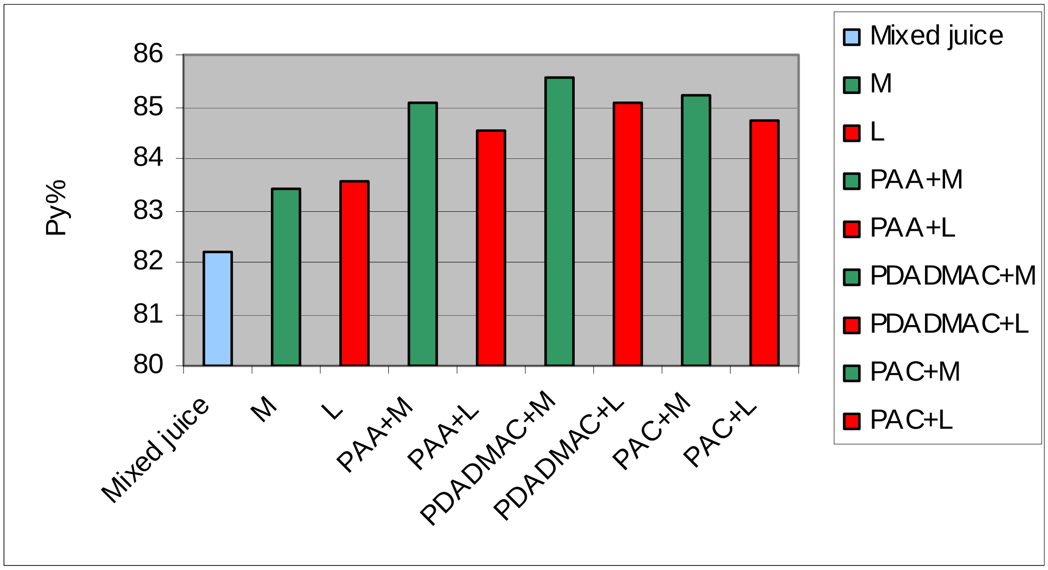


Figure (4-38) Variations of juice Py with various used flocculants

Table (4-41) Turbidity of juice samples

Juice Sample	Turbidity (ICU)
Mixed juice	40443
Clarified juice with:	
PAA +L	317
PDADMAC +L	471
PAC +L	145
L	2640
PAA +M	223
PDADMAC +M	588
PAC +M	125
M	3126

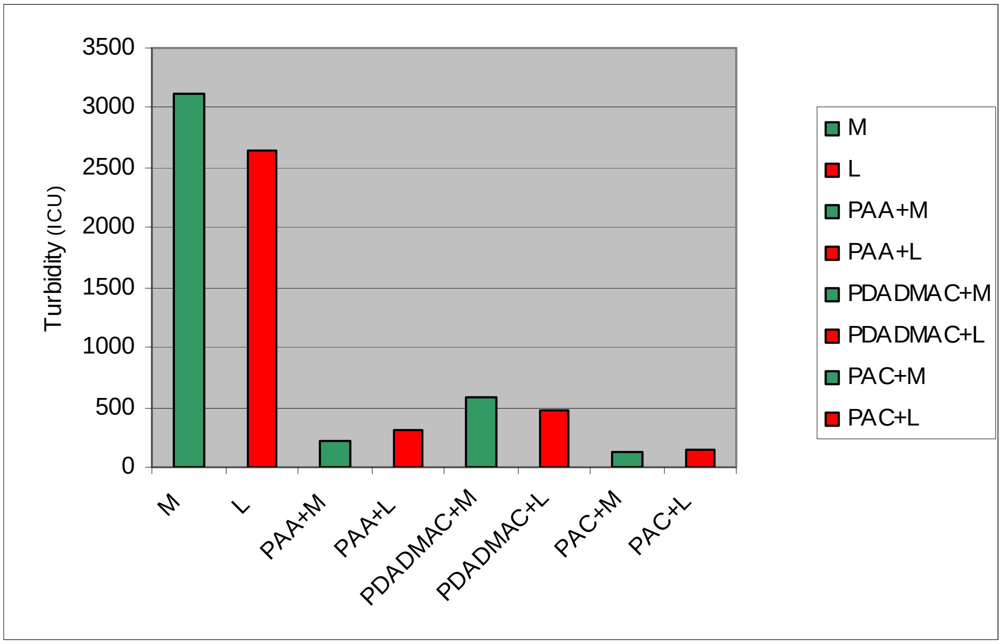


Figure (4-39) Variation of juice turbidity with various used flocculants

Table (4-42) The colour of juice samples

Juice Sample	Colour (ICU)
Mixed juice	2739
Clarified juice with:	
PAA +L	2391
DAD +L	244
PAC +L	1111
L	2665
PAA +M	2745
DAD +M	295
PAC +M	1076
M	2289

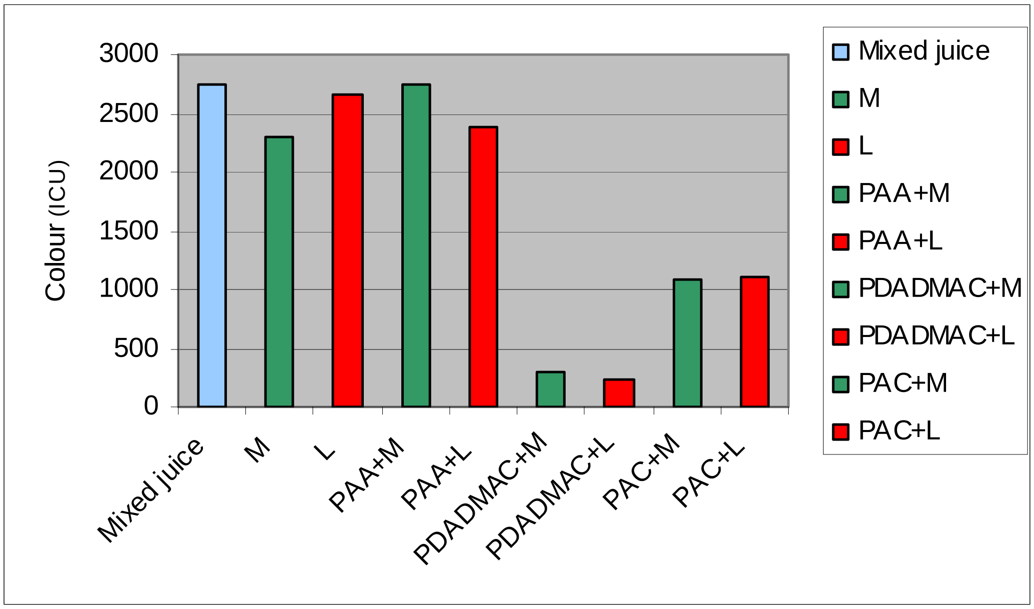


Figure (4-40) Variation of juice colour with various used flocculants

Table (4-43) Mud volume of juice samples with time

Time (min)	**Mud volume (ml)**							
	PAA+ L	**DAD+ L**	**PAC+ L**	**L**	**PAA+ M**	**PDADMAC+ M**	**PAC+ M**	**M**
5	66	120	220	77	60	100	220	85
10	62	94	175	65	60	80	180	70
15	60	87	160	60	58	76	170	65
20	60	84	155	55	60	73	160	60
30	60	80	150	53	58	70	150	57
60	60	72	145	47	56	64	145	53

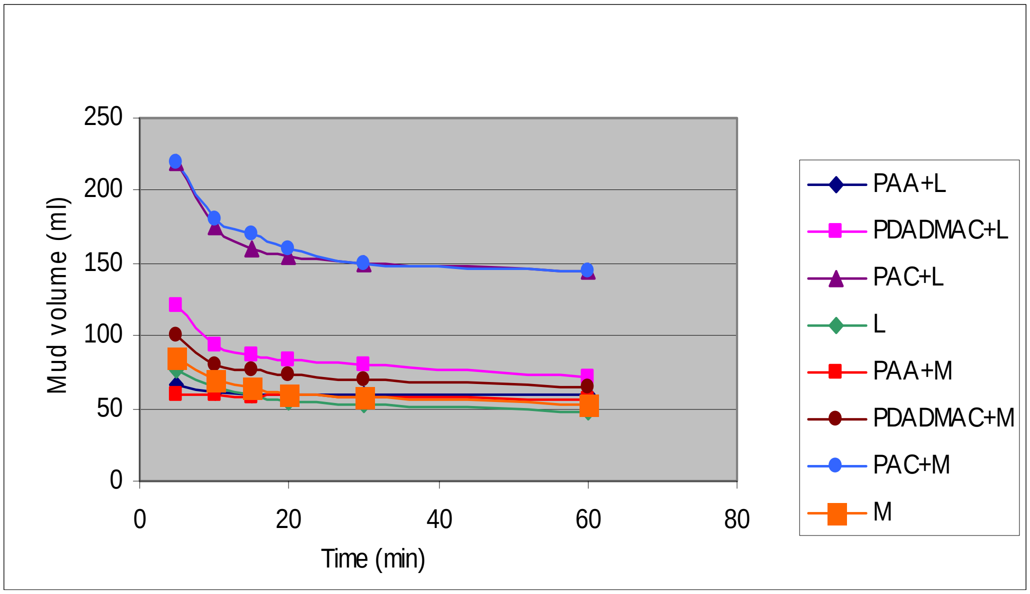


Figure (4-41) Mud volume against time with juice samples

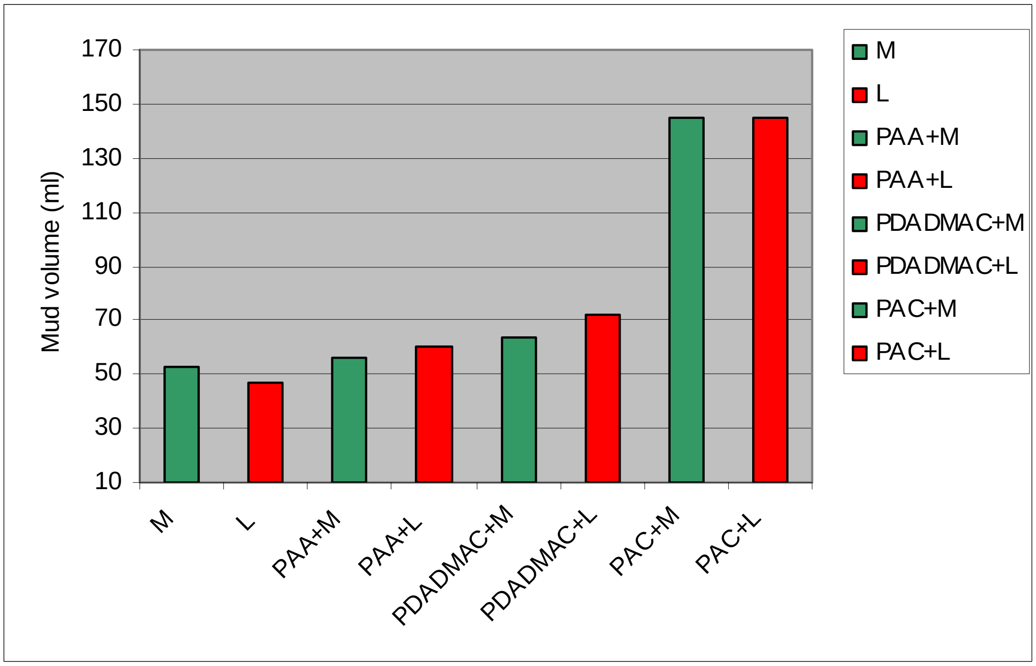


Figure (4-42) Variations of mud volumes with various used flocculants (at 60 min)

4-4 - The Cost of Polymer and Lime Usage:

In the calculation of the cost of adding polymers and limes to the clarification process the following operating conditions are considered:

1- CaO usage is at the rate of 0.567 kg/ton cane (9).
2- PAA addition is at the rate of 3 ppm on cane (a result of this thesis).
3- Polydadmac addition is at the rate of 2 ppm on cane (a result of this thesis).
4- One ton of cane produces one ton of mixed juice (9).
5- Mill crushing capacity is 966000 tons cane annually (as in Elgunied Sugar Factory).

Assuming the prices of the added polymers and limes are as following:

- Local price is U$115/ton (consultations with concerned personnel).
- Imported lime price is U$160/ton (Sudanese Sugar Co. Ltd).
- PAA price is U$2588/ton (Sudanese Sugar Co. Ltd).
- PDADAMAC price is U$2000/ton (Khartoum State Water Authority).

a- Imported Lime Cost:

As shown in table (4-1) CaO content in the imported lime sample is 58.02%. So, the imported lime required for one ton of cane will approximately be:

$$\text{imported lime/ton cane} \quad \text{kg}\, 0.567 \times \frac{100}{58.02} = 0.9772$$

imported lime/year ton $\frac{0.9772 \times 966000}{1000} = 944$

And the total cost of imported lime to be used over the season

160 = U$151040/year×= 944

b- Local Lime Cost:

CaO content in local lime is 82.88% (table (4-1)). So, the local lime required for one ton of cane will approximately be :

kg local lime/ton cane $0.567 \times \frac{100}{82.88} = 0.6841$

ton local lime/year $\frac{0.6841 \times 966000}{1000} = 661$

The total cost of local lime to be used over the season

115 = U$76000/year×= 661

c- PAA Cost:

Assuming PAA is added at a rate of 3 ppm on cane. The total PAA required will be:

10^{-6} = 2.898 ton/year× 966000 ×3

So, the total cost of PAA for the season

2588 = U$7500/year×= 2.898

d- Polydadmac Cost:

Assuming PDADMAC is added at a rate of 2 ppm on cane, the total PDADMAC required will be:

10^{-6} = 1.932 ton/year× 966000 ×2

So, the total cost of PDADMAC for the season

2000 = U$3864/year×= 1.932

The results of these calculations are summarized in table (4-44):

Table (4-44) Costs and savings associated with lime and polymer addition to the clarification process

	Operating Conditions					
	Lime Only		**Lime Plus Polymer**			
	M	**L**	**M+PAA**	**M+PDADMAC**	**L+PAA**	**L+PDADMAC**
Cost of additives	U$151040	U$76000	U$158540	U$154904	U$83500	U$79864
Saving	-	U$75040	-	U$3636	U$75040	U$78676

The table (4-44) indicates that when only lime is used in the clarification process the local lime saves U$75040/year.

Whereas, if lime is used in combination with a polymer, the maximum savings are obtained when local lime is used in combination with PDADMAC.

Chapter Five

Conclusions and Recommendations

5-1 Conclusions:

The experimental and economical results of this research have clearly shown that:

1- Using local lime in juice clarification process (to pH = 7.5) removed 93.5% of juice turbidity, and 2.7% of juice colour; whereas, comparatively the imported lime removed 92.3% of turbidity, and 16.4% of colour when used in juice clarification process (to pH=8).

2- When PAA is added (3 ppm), the performance of local lime has improved, the removed turbidity reached 99.2% and the removed colour reached 12.7%. Whereas when using PAA with imported lime (3 ppm) the removed juice turbidity reached 99.4%, and for colour the removal reached 21.7%. (The applied method of clarification in Sudanese Sugar Factories).

3- When Polydadmac was added (2 ppm) to improve the performance of local lime, the removed turbidity reached 98.8%, and the removed colour became 91.1%.

However, It must be noted, based on experimental observations, that the clarity of the juice is increased when increasing the density of the settling flocs, and that the density of the formed flocs increases directly proportional to the increase of the mixing rate when adding PDADMAC to the juice.

4- The use of PAC in the Clarification process need more investigations in the future to improve its performance, by manipulating the conditions of the clarification process to determine the optimum.

5- The suitability of the local lime for cane juice clarification (it is suitable economically and practically).

6- PDADMAC addition improved the local lime performance appreciably, that the best obtained results in the clarification process, according to economical and experimental analysis and observations, are when local lime is used in combination with PDADMAC.

5-2 Recommendations:

1- It is recommended to introduce the use of local lime for juice clarification.

2- Lime purity, and process conditions need to additional work for optimization.

3- The use of polymers as coagulants/flocculants in sugar industry need to be addressed critically both from economical and health points of views.

4- PAC usage in the juice clarification process requires more future investigations to improve and optimize its performance.

5- Researchers should be encouraged to indulge in juice clarification to determine:

   - Most efficient coagulants/flocculants (cost/benefit).
   - Optimum conditions for the process.

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Figure (3-2) The simplified process flow diagram for ElGunied sugar factory