ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)

SCHOOL OF CHEMICAL AND BIO- ENGINEERING

Performance Evaluation of Sugar Cane Milling Plant and Optimization of Process Parameters: A Case of Wonji-Shoa Sugar Factory.

By

Mesele Bocha

A Thesis Submitted to Addis Ababa Institute of Technology School of Chemical & Bio - Engineering, in Partial Fulfillment of the Requirements for the Degree of Master of Science in Chemical Engineering (Process Engineering Stream)

Advisor: Dr. Eng. Hundessa Dessalegn

June 2019

Addis Ababa, Ethiopia

DECLARATION

I declare that this thesis **'Performance Evaluation of Sugar Cane Milling Plant and Optimization of Process Parameters: A case of Wonji Shoa Sugar Factory:'** is my own work and that it has not been submitted in any form for another degree at any university or other institute. Information derived from the work has been fully acknowledged in the text and a list of reference is given.

Signature ___________________

Date______________________

ABSTRACT

Performance assessment of WSSF and setting targets for the relatively inefficient mills to improve the efficiency and productivity is crucial. This study, focus on performance evaluation of milling plant and optimization of its process parameters. The milling plant (WSSF) performances have been evaluated in terms of its Brix juice extracted at all mill sets (5 sets). The performance of each mill was monitored by drawing juice Brix curves. From the Brix curve, the second mill front roller Brix curve overlays the back roller Brix curve this was not appropriate hence, improvement for delivery mill setting was desired. However, the reverse curve showed acceptable result. The juice and bagasse sample analysis for each mill set were analyzed then maximum loss areas were identified and the process optimization were done. The Brix free water for WSSF were done and found to be averagely 30.63 % on cane fiber. The statistical analysis were done by design expert software (6.08, version) of central composite design. The study were done by varying the effect of hydraulic pressure and imbibition water flow on the last mill for the response variables of pol and moisture % of final bagasse. The experimental design combination were held by inserting the lowest and highest values of hydraulic pressure and quantity of imbibition water flow rate for the last mill. The optimal results of pol and moisture % of bagasse were between 1.63 - 1.88% and 50.47 - 51.31% respectively, with the respective hydraulic pressure and quantity of imbibition water application of 195 - 200 kg/cm^2 and 71.3 - 72 m^3/hr. The pol and Brix extraction trends were done for how each and individual mills can perform well for a given milling season. The existing milling plant flow diagram were modified by recycling the primary juice Cush-Cush prior to the first mill and secondary juice Cush-Cush to the second mill. Using the optimum values of application of hydraulic pressure and quantity of imbibition water flow rate on the last mill, drawing juice Brix curve, Brix free water on cane fiber and recycling of respective Cush – Cush to recommended point and the optimum output of pol and moisture content of last mill bagasse which can be taken as a positive outcome to bring efficiency improvement, product maximization, for energy saving, cost reduction and increased profitability to WSSF in particular and all other sugar factories as general.

Keywords: Extraction, Imbibition, Hydraulic Pressure, Moisture, Pol, Optimization, Bagasse, Milling Loss, Milling Efficiency.

ACKNOWLEDGMENTS

First of all I want to praise my “GOD” who never been away all the time throughout my life and work life. Next I want to express my sincere gratitude to my advisor Dr. Eng. Hundessa Dessalegn for his advice, support and guidance during this thesis work. I also like to forward my great thanks to the Ethiopian Sugar Corporation Research and Development Main Center sugar technology and Engineering program manager Mist Grum Asfaw and senior researcher Mist Kassa Hundito for their interest in my thesis and unreserved assistance starting from topic selection till the completion of this project.

The School of Chemical and Bio- Engineering Department group members are greatly acknowledged for giving me fruitful comments for improvements of my project work starting from proposal write up to progress reports. I also appreciate Dr. Eng. Shimelis Admassu for his giving brain storming and highlighting the proposal development and presentation in the beginning and also all staffs of Chemical Engineering Department for their unreserved assistance and sharing of knowledge during my post graduate study; I learned much from them during my study at the Addis Ababa Institute of Technology.

I also would like to thank my sponsored company, Ethiopian Sugar Corporation Research and Development Main Center for giving me the chance to attend my MSc. Program and financial support and any other facilities. It is my greatest pleasure to thank all laboratory members of research and development main center: Mist Tilahun Zeleke Laboratory head, Mist fissaha T. Laboratory chemist I, Miss Emebet F. Laboratory chemist (analyzer), Miss Gadisse Laboratory technician, Miss shitaye Laboratory technician, Mist Habtamu Laboratory chemist II, Mist Dulla Debela senior Laboratory chemist, Mist Mesifin Laboratory chemist. Her special thanks go to my staff members of Sugar Technology and Engineering Research Program members; Mist Minal Getachew senior researcher (Mechanical Engineer), Mist Ayele Alemu senior research coordinator (Chemical Engineer), Mist Efframe Beyene senior researcher (Mechanical Engineer), Mist Biru Hunde senior researcher (Chemical Engineer) and Mist Endale Senior researcher (Mechanical Engineer) for their assistance in facilitating all necessary conditions for the laboratory analysis and for his great material and moral support during all the research time.

TABLE OF CONTENTS

Contents **Pages**

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Appendix – A

Appendix – B

Appendix – C

Appendix – D

Appendix – E

Appendix – F

Appendix – G

Appendix – H

LIST OF SYMBOLS AND ACRONYMS

ANNOVA	Analysis of variance
Brix	Percent by weight of soluble solid in sugar solution
Cush – Cush	Fine bagasse return from the juice
H.V.A	Handlers-Vereeniging Amsterdam
HP	Hydraulic pressure
ICUMSA	International Commission for Uniform Methods of Sugar Analysis
IMB	Imbibition water
PE	Primary Extraction
PI	Preparation Index
POL	Polarization
Qts	Quintals
RME	Reduced Mill Extraction
RSM	Response Surface Methodology
SOP	Standard operational parameters.
TCD	Tons of cane crashed per day
TCH	Tons of cane crashed per hour
WSSF	Wonji-Shoa Sugar Factory
^{0}Z	Degree Zucker

CHAPTER ONE

1. INTRODUCTION

1.1 Background

The sugar industry is one of the largest agro based industries in Ethiopia and plays an important role in the development of the country. Now days there are a number of projects undertaking in Ethiopia to expand the existing, to install new sugar factories and for country sugar consumption as well as building competitive sugar industry to top ten sugars producing countries around the world. The Primary objective of the sugar industry is to promote the welfare of the member or employees of the sugar industry. The country has suitable weather conditions in different areas for cane plantation and sugar production. The main goal of the sugar cane factory is to have an efficient and profitable operation with the required sugar quality and maximum sugar recovery.

A sugarcane plant is basically made up of juice and fiber. The juice includes a sucrose solution and other soluble inorganic and organic substances, whilst fiber constitute all the insoluble substances in the cane (Rein, 2007). Juice extracted from the cane is sent for further processing whilst the fiber (now termed bagasse) is used for electricity generation in the boiler house. The quality and chemical composition of sugarcane juice varies depending on the age of sugar cane, the growing conditions, the harvesting time as well as the cane cultivar grown by the farmer (Meyer et al., 2013).

The amount of sugar extracted from sugar cane and the quality of the juice produced is influenced by the quality of sugarcane delivered at the mill. The efficiency of sucrose extraction from cane is largely affected by the percentage cane fiber content (Meyer et al., 2013). As fiber naturally retains some sucrose, the higher the cane fiber content, the more the sucrose that is lost in the bagasse. On the other hand, the efficiency of sucrose extracted from the juice is determined by the purity of the juice (Rein, 2007; Meyers et al., 2013). The higher the amount of non-sucrose matter in the juice, the higher the amount of sucrose lost with it in the form of molasses. Thus, it is evident that the quality of sugarcane received from the mill affects sucrose extraction and cane juice processing. It is natural for the sugar industry to think and speak in terms of sucrose: we purchase cane and sell sugar on the basis of sucrose content; through the different phases of the process, whether milling or boiling; we follow analyses and check the sucrose to minimize losses as much as possible. All the sucrose of the cane is not available for crystallization as there are two factors governing extraction and recovery of sucrose: first, the fiber content of the cane. Secondly, the purity of the juice; However efficient our milling and boiling techniques may be, some sucrose will be immobilized and retained by the fiber of the cane and by the impurities of the juice. Bearing in mind that the aim of the milling process is to separate the sucrose from the fiber and that of the boiling process is to separate and crystallize the sucrose from the non-sucrose of the juice, sugar technologists have formulated yardsticks to measure and express efficiencies so that guidance is provided to all concerned. Such yardsticks are based on practical results. The choice of yardsticks should be based on their merits which mean that they should measure and express efficiency, accuracy and correctly, hence providing guidance clearly to all concerned.

The efficiency of the factory is based on the efficiency of the milling plant. The efficiency of the milling plant is measured by the performance of each and individual equipment's of the milling plant. Measuring the potential or performance evaluation of individual equipment's will make to know how much the potential or capacity of the plant do have, which results to increase the overall efficiency of the factory.

The juice extraction process of milling or bagasse diffusion, the greater the extraction of sugar by dry crushing, at the first mill, the less difficult is the task left to the following mills to recover more sugar by wet crushing and the better is the overall extraction of the tandem. In Queens land, it is considered that a gain of 1% in extraction of the first mill gives a gain in total extraction of 0.12% in 4 mill tandems and 0.10% in five mill tandems (Hugot, 1982) Since the primary juice extraction may vary between 60 to 80%, it has a huge influence of extraction on the result. There are two different parameters that can help to evaluate the effectiveness of the sugar mill. The first one is the Brix extraction. Brix (degree Brix) is defined as the sugar content of an aqueous solution. But if there are sugars other than sucrose, then degree Brix will be equal to the dissolved solid content. On the other hand, pol is defined as the polarization of the solution, i.e., it measures the amount of sucrose in a sample. For practical uses, pol and sucrose contents are really close, but Brix extraction may significantly differ.

1.2 Statement of the Problems

Performance evaluation of the milling plant is one of a systematic process for measuring and evaluating the effort or the potential for recovery the sucrose from the prepared cane. The existing milling process has certain drawbacks. The extraction performance of the milling plant was low, i.e. the pol and moisture content of the final bagasse was high. Currently the respective pol and moisture % of existing WSSF is averagely 2.02% & in range 48 to 53 % of moisture in final bagasse and but the recommended pol % is less than 1.5 and moisture content is below 50%. The high pol content of the final bagasse were lead to loss of sugar through bagasse, as a result it decreases the efficiency and performance and as well as economic growth of the company. The highest moisture or humidity of the final bagasse were lead to decrease the efficiency of boiler plant consequently resulted in the capacity reduction of the factory due to insufficient generation of steam. The efficiency decrement of the boiler plant was due the accumulation of sucrose (cake) on the boiler steam tubes, this would hinder the heat transfer, not only this but also the moist bagasse does not easily bunt out. In line with this, one of the most outstanding problems that WSSF currently facing was the low performance of the extraction process. This condition is a major setback which calls for improvement in the extraction process, particularly for the milling plant. During the milling process the Brix free water was never extracted and remains attached to the fiber of the bagasse, we only extract undiluted and diluted juices. Therefore, how can we use an expression which was closely associated with brix free water to measure the loss of a juice which does not contain brix free water? For all these reasons, it would appear that lost absolute juice % fiber is not a reliable yardstick to measure accurately milling losses and does not express clearly and correctly milling efficiency. The performance of the milling plant in the case of wonji-shoa sugar factory during crushing season would be evaluated in terms of Brix of juice extracted at the various mills in the milling train, for that matter bagasse pol % would be the main criterion used for estimating the milling performance in the sugar mills. Therefore, due to all above mentioned problems performance evaluation of milling plants and process optimization of the sugar milling parameters are mandatory to improve the efficiency of the milling plant thereby maximize the factory throughput with specified quality of sugar.

1.3 Objective of the Study

1.3.1 General Objective

The main objective of this study was to improve the efficiency of the milling plant and minimize sucrose loss through final bagasse.

1.3.2 Specific Objectives

The most specific objectives of this research works are as follows:

- To increase the mill juice extraction.
- To increase the yield by improving different losses through the extraction process;
- Study the effect of varying quantity of imbibition water and hydraulic pressure on Bagasse for the performance of the last mill;

1.4 Significance of the Research

In these days the competitiveness of industries, mainly depends on their own performance utilizing all available resources and maximizing the output with a specified range of sugar quality with minimizing waste. The main aim of this paper will provide vital information for sugar producing factories, especially for WSSF with view of performance evaluation of sugar cane milling plant and optimizing the milling process parameters, thereby decreasing the cost of production by using available resources. In addition, it could also serve as a reference for sugar manufacturing process in the area.

Sucrose extraction is one of important unit operations, which can lead to either success or failure of the sugar manufacturing process. Good work performed at the extraction plant would pay a considerable benefit in terms of production volume, product quality, reduced cost of production, energy efficiency, decrease in pol % the bagasse, increasing the efficiency of boiler plant and generally it decreases the sugar losses through the milling process while to increase the capacity of the factory. A fractional loss of sugar in the milling process within a single cane would become a big loss throughout the year, when we convert this into Ethiopian currency it accounted as billions of Ethiopian Birr per annual; this would decrease the economic growth of the factory as well as the organization. Therefore, this study would help to minimize this fractional loss of sugar in order to increase the profit of the factory and thereby increase the well soundness of the organization. In addition to this, increasing the extraction performance of the existing milling equipment is of interest to factory staff, as replacing the existing equipment is difficult to justify because of high capital cost.

1.5 Frame Work of Experiment

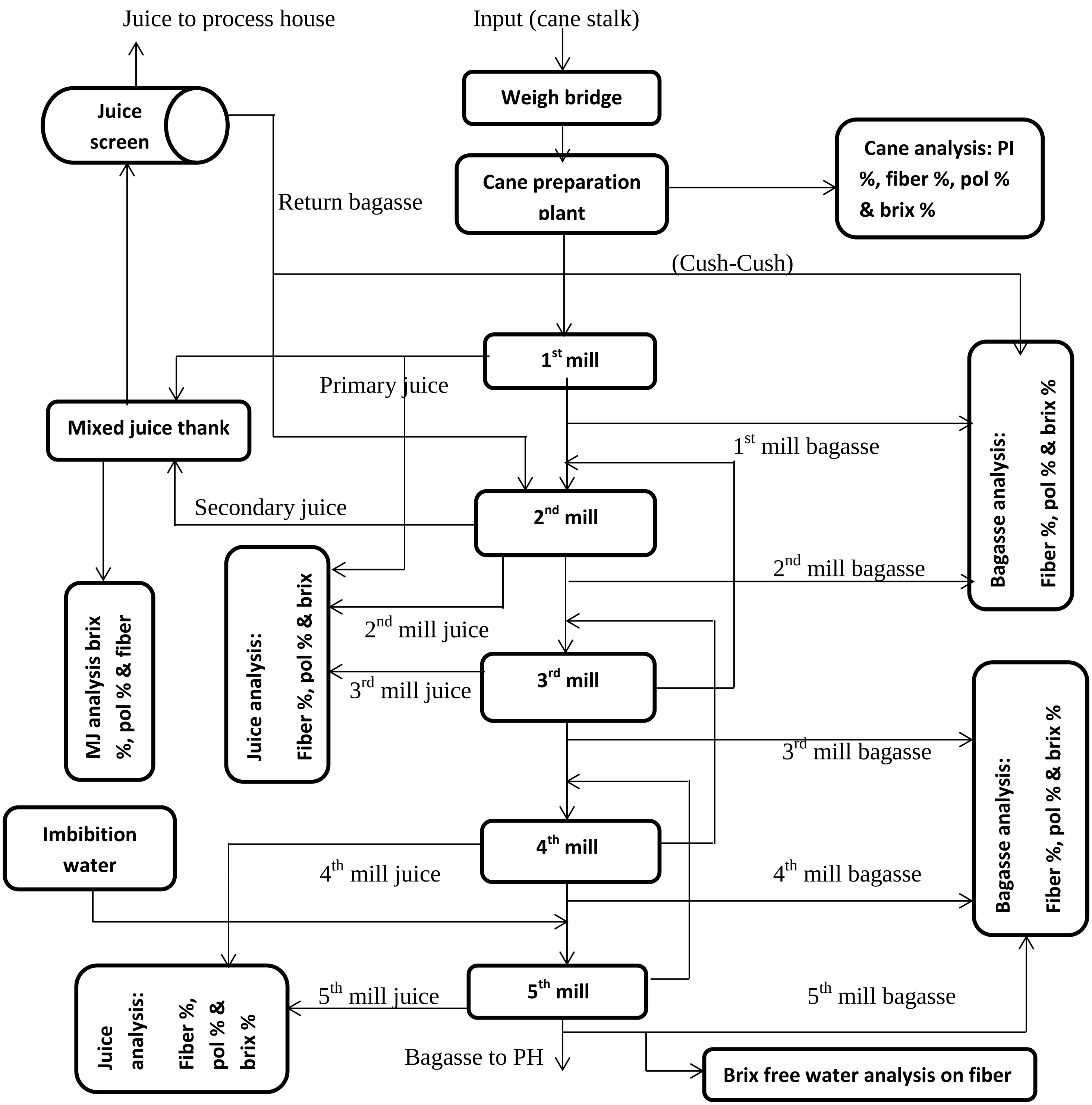


Figure1.1: Schematic diagram of experimental frame work

CHAPTER TWO

2. LITRATURE REVIEW

2.1 Sugar Economy in Ethiopia

Sugar in Ethiopia serves for direct household consumption and as an intermediate input for other industries like pastries, bottling companies and breweries. The per capita consumption in Ethiopia is one of the lowest in the world. The current level of per capita consumption is estimated to be about 3.6 kg, which is even below the world average minimum of 5 to 6 kg. The Ethiopian consumption of sugar was forecasted for the coming 10 years, taking into account the current Ethiopian population of 108 million in 2019, population growth rate per annum of 2.53 % and an annual average economic growth rate of 13.09%. It is assumed that the per capita sugar consumption could increase at the rate of the economic growth of the nation.

2.2 General Overview of Wonji - Shoa Sugar Factory

The factory is found at the Oromiya Regional State near Nazareth City at 110 Kilo Meters from Addis Ababa. Commencing production in 1954 it was the oldest and the pioneer in the history of Ethiopia's sugar industry. Shoa Sugar Factory constructed in 1962 is the second oldest and both, being obsolete, have stopped production since July, 2012 and July, 2013 respectively. The two factories constructed by the Holland Company known as H.V.A (Handlers-Vereeniging Amsterdam) had a capacity of producing 750,000 quintals of sugar per a year. The sugarcane plantation land of these two factories was 7,000 hectares out of which 1,000 had been planted by outgrows.

In a bid to replace these two oldest factories with a new and modern one, an expansion project had been carried out both in the cane cultivation field and the factory since 2010. And, the factory plant expansion project has come into its completion in July, 2013. Accordingly, the newly built and modern Wonji/Shoa Sugar Factory has currently a design capacity of crushing 6,250 tons of cane a day and producing over 174,000 tons of sugar per annum, which with further expansion have reached up to 12,500 TCD maximizing its production to 220,700 tons of sugar a year. The new ethanol plant planned to be built, will have a capacity of producing 12,800 meter cube. The Factory is currently contributing 20 megawatt electric powers to the national grid in addition to satisfying its own demand which is around 11 megawatts.

Its agricultural expansion project is currently being carried out around the areas known as Wakie Tiyo, Welenchiti and North Dodota areas. The factory, with the help of this agricultural expansion project, would have 16,000 hectares of sugarcane plantation field in total. The total cane cultivation field of the factory was currently reached 12,800 hectares. And, the 7,000 hectares of the factory's sugar cane field cultivated with the agricultural expansion project are owned by out grower farmers of the surrounding area. There are 32 Sugar Cane out Growers associations which in total have 9,100 member farmers. The Factory, beyond supplying the farmers with selected seeds, and rendering professional as well as technical support to them, has made irrigable land available to all.

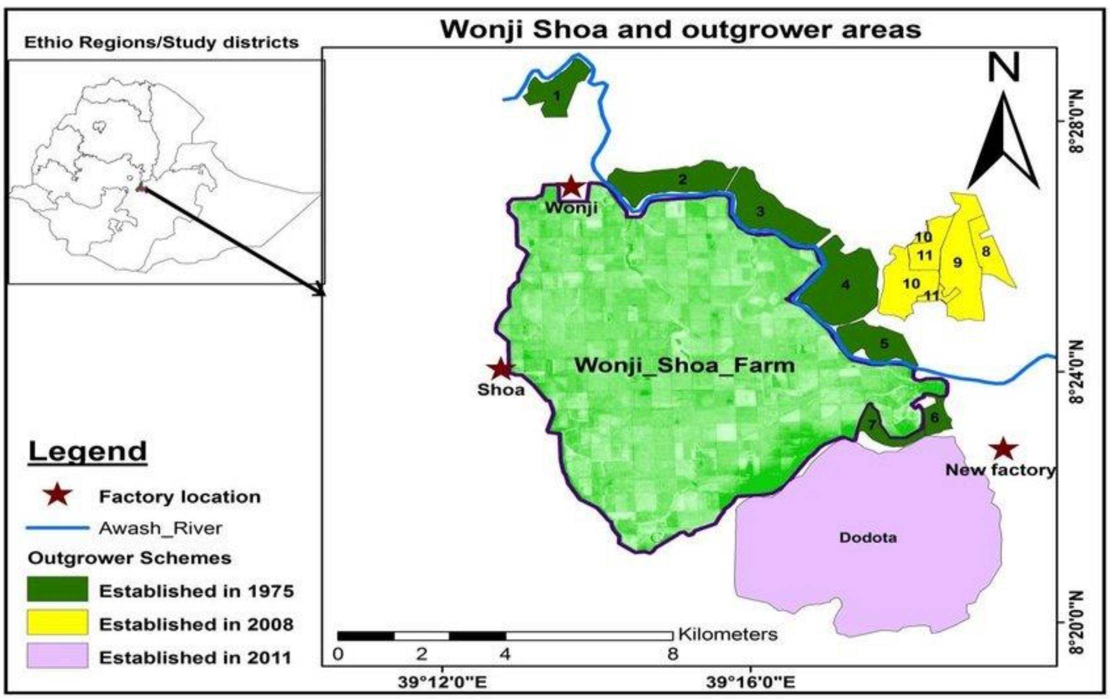


Figure 2.1: Map of WSSF, factory-operated plantation, and plots of outgrow

2.3 Over View of Extraction Process

Sugar cane juice extraction is the mill operation that takes place after cane receivable, cleaning, and preparation, in which the water and sugars contained in the cane are removed. Basically, there are two ways to perform this operation commercially: by cane preparation and mechanical squeezing. The goal of extraction is to remove the maximum mass amount of the sugar present in the prepared cane and, at the same time, produce bagasse with suitable moisture content to be burnt in biomass or bagasse boilers (Wever and Olivério, 2006)

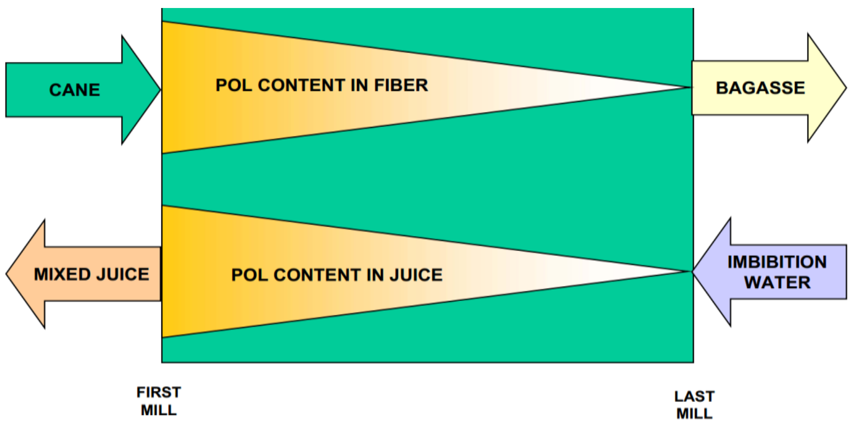


Figure 2.2: Juice Extraction Operation

2.3.1 The Milling Train

The milling process essentially involves the removal of juice from sugar cane by squeezing the cane between pairs of large cylindrical rollers in a series of milling units collectively called a milling train. The first milling unit is generally identified as #1 mill; the second milling unit is generally identified as #2 mills, and so on. The last milling unit is generally called the final mill. The milling units between the first and final mills are collectively known as the intermediate mills.

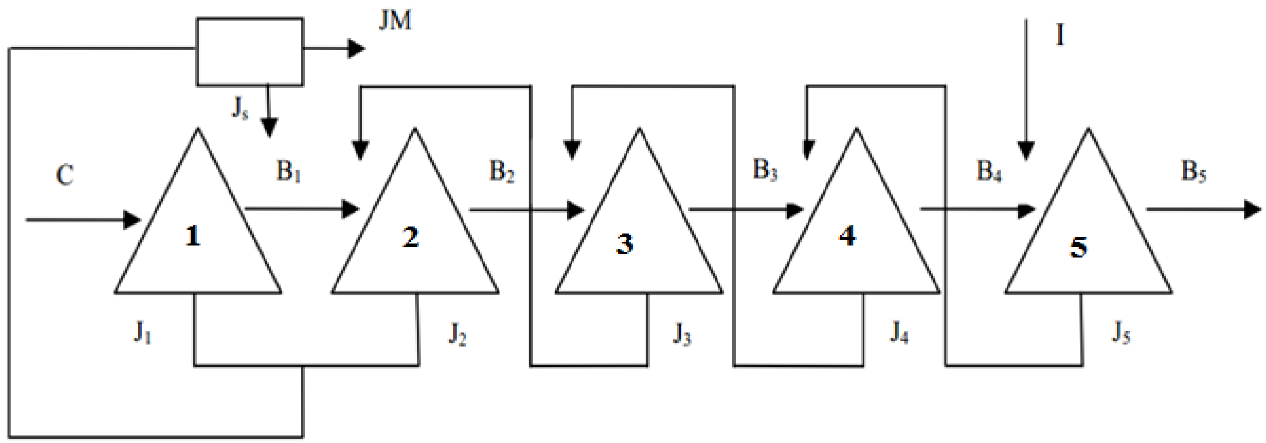


Figure 2.3: Schematic Diagram of Milling Train.

Legend: **C** – Cane; **J** – Expressed juice stream; **I** - Imbibition; J_s - Return stream from juice screen; **B** – Bagasse stream; **JM** – Mixed juice stream

2.4 Cane Preparation Process

Cane preparation is the process by which sugarcane stalks are reduced to smaller pieces which are suitable for efficient sucrose extraction. It is the most critical factor that affects the extraction process (Rein, 2007). This is the process of reducing the cane fed to the mill into small pieces, so as to suitable for the subsequent extraction process. The main purposes of cane preparation are: (a) To increase the capacity, by increasing the bulk density of the feed. (b) To assist extraction at the mills by breaking down the structure of the cane. (c) To render the juice more readily available for the action of imbibition's by breaking and opening the cells. Cane with a greater breakage of cells (i.e. More highly prepared) generally results in the increased mill extraction, lower pol % bagasse figures and lower final bagasse humidity. Several suggestions have been made as the increase in extraction possible. Moor (1974) suggests 0.045 units of extraction per 1 % increase in preparation index; Edwards (1995) suggested a 0.1 % increase in extraction per 1 % increase in preparation index.

The aims of cane preparation are to: (a) increase the surface area for maximum sucrose extraction from sugarcane by ensuring that high levels of opened or ruptured sugar containing cells (parenchyma cells) are obtained, and (b) prepare cane with the right characteristics for milling or diffusion (Ensinasetal, 2007; Rein, 2007). Knives and shredders are used to cut and hammer the cane into smaller pieces and stiller in long strands of fiber (Smith, 1978; Rein, 2007). Although the better sucrose extraction is achieved from finely shredded cane, knives usually go before the shredders to reduce the size of the cane to smaller pieces. This prevents choking of the shredders (Hugot, 1986; Rein, 2004).

2.4.1 Cane Preparation Effect on Extraction.

The effect of preparation on extraction can be readily realized by considering the structure of the cane stalk. The sugar juice is contained in soft interior pith cells, while the high concentration of longitudinal bundles in the rind and at the nodes forms a hard cylindrical outer casing with transverse dividing walls. Thus the cane stalk may be regarded as a hollow cylinder with available juice in a series of soft thin walled cells. Hence, if the hard outer structure is broken up by suitable preparation, the pressure applied at the mills will readily extract the juice, whereas with the whole sticks the mills are first occupied in breaking down this hard structure as the first step before the juice is made readily available. Thus preparatory devices relieve the mills of much of this breaking up duty and facilitate extraction of the juice. With knife sets, the influence on extraction is less marked than that on capacity, as pieces of knifing cane retain much of the original structure of rind and nodes. The action of a shredder, on the other hand, breaks up the structure of the cane completely and gives a definite gain in extraction, of the order of that which would be obtained by the addition of a further mill to the tandem. This improved extraction is largely due to improved work by imbibition consequent on higher extraction at the first mill.

2.4.2 Cane Preparation Effect on Crushing Capacity

Whole canes in a more or less tangled condition have a low bulk density due to the large proportion of void space (air space) between the stalks. When the cane has been broken up by preparatory plant, it consists of smaller and more or less uniform pieces, with a much smaller void volume in consequence. The quantity of cane gripped by the mills will be correspondingly greater. With the whole cane, moreover, the mill rollers are more liable to slip on the smooth, waxy and hard rind of the cane with prepared cane, the initial portion of the stick is exposed, and this is more readily gripped by the rollers. Thus, the effect of cane preparation is one of the factors for improving crushing capacity. The main preparatory plants are: - crushers, shredders: disc shredder, hammer mill shredder, sear by shredder, Maxwell shredder and knives: knife sets are generally supplementary to crushers and shredders.

A shredder supplements the work of the knives and can also assist substantially towards improved capacity. Cane preparation is one of the milling process in which the cane preparation is accomplished in different ways by either of the cane preparatory plants or combination of them. Preparation by revolving knives extracts no juice. By shredders that tears the cane into shredder but extracts no juice. Crushers that breaks, crushes the structure of the cane, and extracting a large proportion of the juice. Cane preparation can be done also by combinations of any or all the above means.

2.4.3 Cane Preparation Index (PI)

The quality of cane preparation in South Africa is measured by calculating the Preparation Index (PI) (Payne, 1968). The level of cane preparation is measured in laboratories situated in the mill. This is done by taking two equal samples of prepared cane and adding equal amounts of water to each of them. One sample is gently tumbled to wash out all the sucrose from the broken cells, whilst the other is homogenized in a blender. The latter represents the maximum preparation as all sucrose-bearing cells are broken during homogenization, whilst the former represents the sucrose extracted from only the cells broken during preparation. A refracto-meter is then used to measure the sum of dissolved sugars (brix) present in each of the extracts. The PI is calculated and defined as the ratio of the percentage Brix concentration of tumbler extract to that of blender extract. It provides proof of the amount of sucrose-bearing cells broken during cane preparation and hence gives a rough estimate of the recoverable sucrose (Rein, 2007)

2.4.4 Extent of Cane Preparation

We have considered the effect of cane preparation on the capacity and extraction of the milling train. The first requirement, for any sound assessment of such effects, is to have some quantitative measure of "Degree of preparation". The state of disintegration of the cane is expressed by the preparation Index (PI). (PI) is the percentage of pol in the open calls. PI is obtained from the laboratory determination of pol by extraction in cold water, relative to complete disintegration of the cane in the cold. Sometimes this proportion is expressed in brix instead of by pol. The values are thus fairly close, the free pol being slightly higher than the free brix. The preparation index can be as follows. After knives, PI = 65 – 70 % after conventional shredder PI = 78 – 85%, after heavy duty shredder PI = 86 – 92%, exceptionally we may obtain 94 – 95 %.

$$PI = \frac{\text{Pol extracted by cold washing}}{\text{pol extracted by desintigration}} \times 100 \qquad \textbf{(2.1}$$

Figure 2.4: Wet disintegrator machine

2.5 Juice Extraction Process

The cane is first prepared by revolving knives that cut the stalks into chips which are then cut by heavy duty shredder into long fibers before entering the milling plant. The latter consists of five units of three-roller combinations through which the crushed cane or the cellulosic fiber (bagasse) successively passes. Fresh water is sprayed on the mat of bagasse as it enters the last mill to help leach out the maximum sugar. In this context, the thin juice extracted by each mill is sprayed on the bagasse entering the previous mill. This process is termed imbibition, and the water used imbibition or maceration water. The combined juice collected after the first mill is called mixed juice. The fiber from the last mill, the final bagasse, contains un-extracted sugar 1.4 – 2.5 % and 45 – 53% moisture. Bagasse normally goes to the boiler plant as fuel to produce steam and electricity for the factory's own demand. The surplus bagasse can be used to produce electricity for the national grid.

The sugar content of cane is dissolved in juice contained in millions of plant cells. There are two different systems of extracting the sugar containing juice from the cane. Such methods of extraction are: (a) By means of pressure in a number of mills provided with three rollers through which the cane is forced. (b) By means of diffusion, extracting juice by applying heat and immersion in water and squeezing of the bagasse. The former method is applied in the WSSF, but the latter is applied for both methahara and fincha sugar factory case. As the well prepared cane is passed through the three rollers, it is extracted twice on between the three rollers. First, the cane is extracted with between the feed and top roller, then the juice extracted in this is called first extracted juice (first expressed juice). Secondly, the cane again extracted with in between the top and delivery roller is, then the juice is called last mill extracted juice.

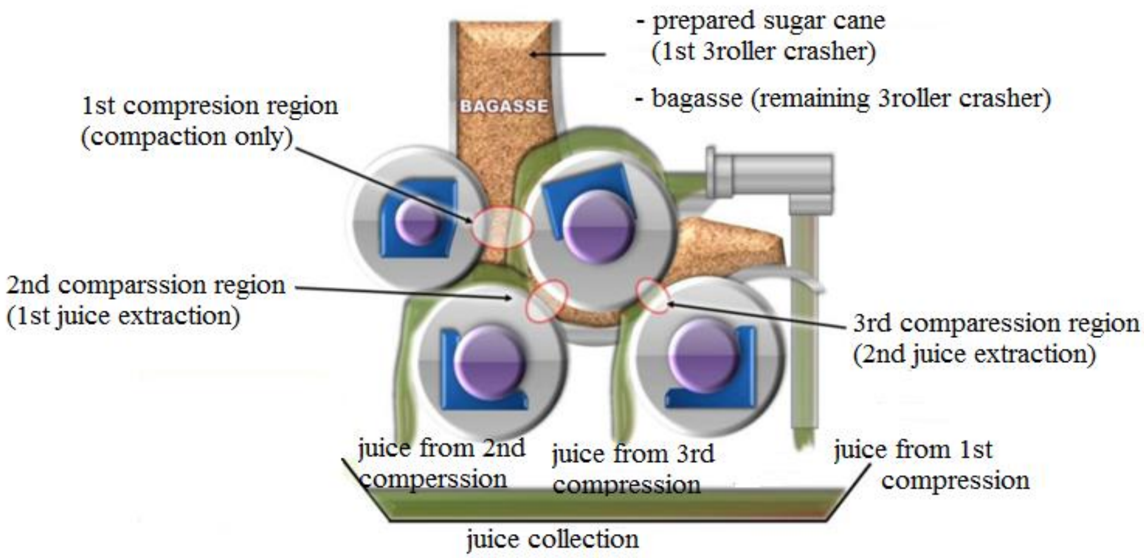


Figure 2.5: Juice Extraction system by mill.

As the cane flows uniformly, the extraction is best and as the flow varies the extraction will vary. Therefore, the recommended cane flows should be between 80-85% (Hugot, 1986); this can increase the extraction of the mills and its capacity. The hydraulic pressure that pushes the top roller based on the amount of the bagasse would pass through the mill roller. If the flow of the bagasse would be larger, the pressure of hydraulic press would be larger and the more extraction would take place. As the cane flow below 60%, then the extraction would be low and low hydraulic press on the top roller and decreases the efficiency of the mill.

As separation efficiency increases, Brix extraction increases, and as juice/fiber ratio of the return stream from the juice screen increases, Brix extraction decreases. Increasing the separation efficiency from 93% to 96% increased extraction by 0.2 units. Reducing the juice/fiber ratio of the return stream of the juice screen from 12 to 10, increased extraction by about 0.1 units (Omker P Thaval, Researcher: September 2012).

Figure 2.6: Schematic diagram of mill roller

2.5.1 Application of Hydraulic Pressure

Without this application there were no more extraction would take place. It depends on the thickness of the bagasse mate. A constant pressure always applied to the bagasse independent to lift the top roller and variations in the feed. The accumulator is field with oil and nitrogen gas at the top of the cylinder used to push the oil into the piston stroke and to lift and push the top roller. Pressure is supplied by oil accumulation containing oil under pressure, in the case of WSSF application of the respective hydraulic pressure for five mills are as follows in table 2.1:

Table 2.1: Application of hydraulic pressure of each milling unit

s/n	Mills	Hydraulic Pressure (Kg/Cm^2)
1	1st mill	160
2	2nd mill	170
3	3rd mill	180
4	4th mill	190
5	5th mill	200

The hydraulic pressure is on the increasing order from the 1st mill for the last mill in order to extract the bagasse that is not extracted from the preceding mills. In the second and the third mill there is the greatest increase in pressure and the last mills carry the heaviest load.

(a) Oil filling cylinder

(b) Pressure gauges

Figure 2.7: Schematic diagram of hydraulic pressure.

2.5.2 Donnelly Chute

The shredded canes, free from rocks and metal, will now feed the first mill through a vertical chute (Donnelly chute) equipped with electrodes which will adjust (regulate) the speed of the cane carriers so as to maintain a constant level of cane in the vertical chute to assure a regular cane feeding to the milling train. The vertical chute will contribute to the good feeding of the first mill. That results in to best extraction. Roller connectors detecting the height of cane adjusting according to the conveyors and allows the bagasse to be forced into the mill under its own weight. They are also used in conjunction with feed rollers.

2.5.3 Imbibition Water (Juice)

Imbibition is the process in which the water or juice is put in the bagasse to mix with and dilute the juice present in the bagasse. The water so used is termed imbibition water. It is not possible to remove all the juice from the bagasse by pressure. Even after repeated application of heavy pressures, the bagasse retains a quantity of juice approximately equal to the weight of fiber. It means that the fiber bagasse reaches a limiting condition where its fiber content is about 50 %. In order to obtain a satisfactory extraction of sugar, it is necessary to dilute the juice remaining in the bagasse. Such dilution is done in several stages, so that the 50 % of juice remaining in the final bagasse is much more dilute than the original juice in the cane. With dry crushing the limit of extraction is soon reached after the first mill, the fiber content of the bagasse would be about 30 %. The bagasse leaving the succeeding mills would have fiber content of the order of 38, 45 and 50 % from 2^{nd} 3^{rd} and 4^{th} mills respectively. Dry crushing in any succeeding mills will not give an appreciable increase in extraction or in fiber contact of bagasse. Hence, to achieve any further extraction, it is necessary to dilute the residual juice in the bagasse before further crushing. In practice, the imbibition process is commenced after the first mill without waiting to obtain maximum extraction by dry crushing. Imbibition and juice maceration plays important role in achieving better mill extraction. Imbibition water dilutes the juice in bagasse and reduces its viscosity. The characteristics of low viscosity of juice increases the flow of juice through bagasse. The hot water further helps in reducing the viscosity of the juice. However the higher temperature of water sometimes leads to slippage of bagasse in the mill. The higher imbibition water is restricted due to capacity of boiling house and availability of steam and therefore it restrains to increase the crushing rate. It may please be noted that higher imbibition water does not increase the moisture in the bagasse. But inadequate juice drainage, low compression, higher speed, improper cane preparation are the main reasons for the increase in moisture of bagasse.

2.5.4 Influence of Imbibition on Bagasse Moisture

The quantity of water introduced to bagasse would facilitate rather than hinder the extraction of juice by the following mill. Actually, experience shows that the moisture of the final bagasse increases slightly with the quantity of imbibition. In Australia, a case has been found where the moisture increased from 47.4 to 50 % when imbibition per unit fiber was increased from 200 to 285 %. It is suggested that the last mill does not succeed in removing completely from the bagasse all the excess of water, which has been added to it. The higher, the imbibition water, the higher is extraction obtained. However, the gain of extraction is beyond a certain limit of imbibition is less marked. Small quantities of imbibition do not completely saturate the bagasse. A very high quantity of imbibition makes the bagasse very wet as it approaches the following mill, and difficulty is experienced in feeding. There is also an argument that the higher temperatures of imbibition may compensate this effect by influencing slight reduction of bagasse moisture on account of possible evaporation. Thus, these are a practical limit to the quantity of imbibition water to be used. Additional fuel is to be purchased for additional imbibition water added, to evaporate it. The value of sugar recovered is to be balanced against the cost of fuel involves. However, in modern factories, very rarely the evaporation capacities limit the quantity of imbibition. Most often, it is chocking at the mills that govern the imbibition and practical limit is reached below optimal quantity.

2.5.5 Effect of Imbibition Water Temperature on Extraction

It is experienced that there is no significant difference or effect up to imbibition temperatures of 60^{o}C to 70^{o}C. However, beyond this, there is a fairly marked positive difference in extraction; the gain in extraction may be up to 0.4%. It is believed that the high temperature of the imbibition tends to cause destruction of the tissues of the cell walls of the bagasse fibers on account of the heat. The material of the cell walls, which is impermeable, gets softened and water, thus gets direct access to the juice contained in the bagasse fiber cells, resulting in higher extraction efficiency besides dissolution of the juice. However, it is to be noted that the cane carries on its rind a certain quantity of wax, which is found at the “wax ring” below the node. Some varieties of the cane may be richer in wax contents than the others. This wax, up on melting, may cause assistance for slippages in the Mills.

2.6 Cush-Cush (Return Bagasse)

It is common for the Cush-Cush from the primary juice and the secondary juice to be combined and returned to the inter carrier between the first and second mills. In some cases it is returned to the cane before the first mill, but this is less common from an extraction efficiency of view, the material should be returned to the cane or bagasse stream that is closest to the Cush-Cush in of the juice Brix, which case returning Cush-Cush after the first mill is probably the better option. The optimum situation involves screening primary and secondary juice separately, returning the primary juice Cush-Cush to the cane before the first mill and the secondary juice Cush-Cush between the first and second mills. When this change was made at Darnall in South Africa, an increase in the extraction of 0.3 % ensued as a result. This was at a mill achieving 97 % extractions the benefit is to be greater when the extraction level is lower (Rein, 2007).

The extracted juice normally contains significant quantities of fiber probably between about 5 and 18 % of the fiber passing through the mill in most cases (Rein, 2007). For the case of WSSF fiber % of extracted juice is averagely 22.7 %, but this is not in the recommended range. This large amount of fiber would re-absorb the extracted pol in the juice and it minimizes the amount of pol content in extracted juice. To the extent that the fiber exits the system with extracted juice, the fiber mass flow rate of the feed will be higher than the fiber mass rate at the work opening. Therefore, it was advisable to minimize the fiber flow rate through the extracted juice.

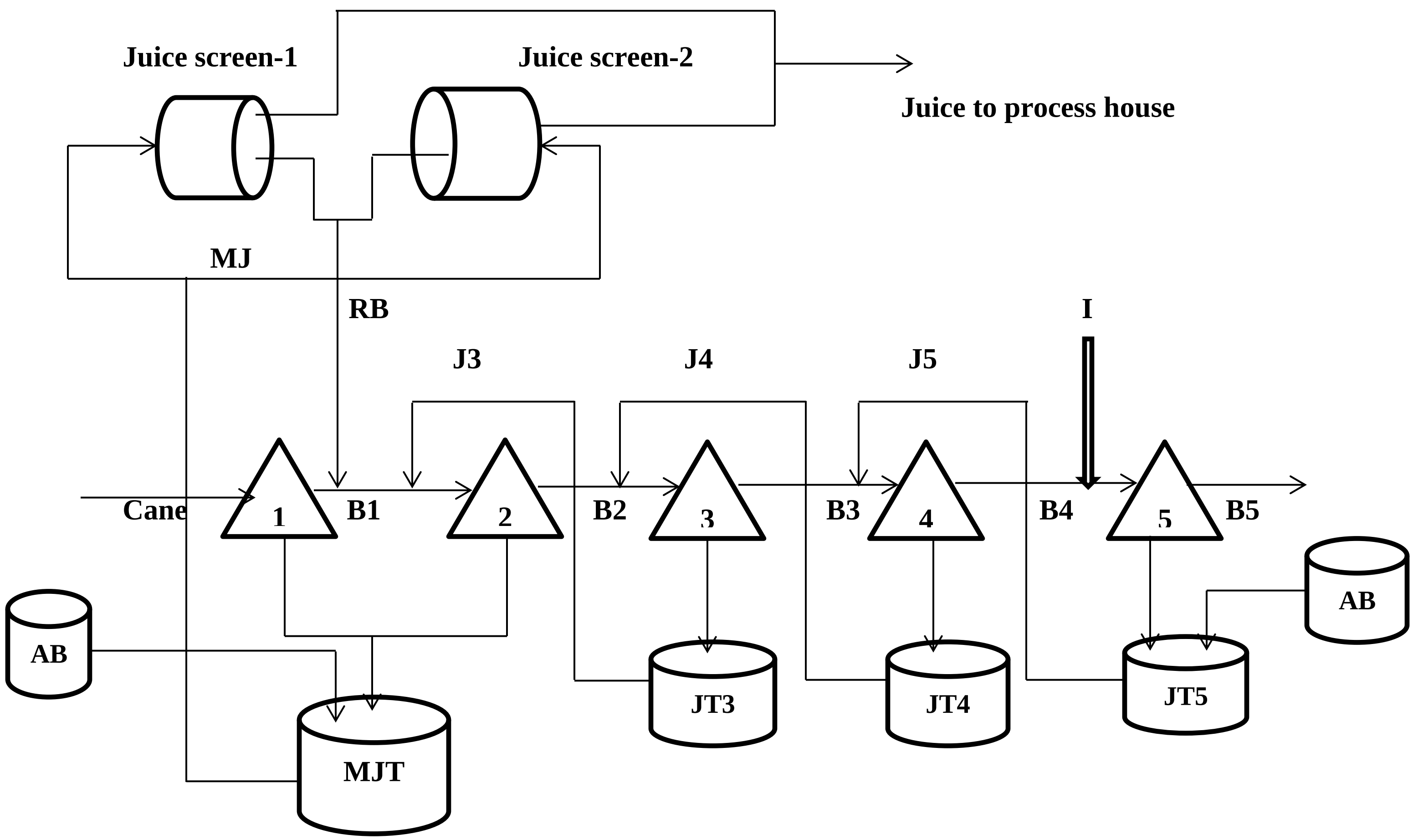


Figure 2.8: Existing milling plant flow diagram

Keys Terms:

MJT – mixed juice tank, **AB-** anti-bacteria, **B1-** 1st mill bagasse, **B2-** 2nd mill bagasse, **B3-** 3rd mill bagasse, **B4-** 4th mill bagasse, **B5-** 5th mill bagasse, **RB-** return bagasse, **J3-** 3rd mill juice, **J4-** 4th mill juice, **J5-** 5th mill juice. **I** – imbibition

2.7 Extraction Performance Parameters

Extraction is accepted to be a volumetric process and extraction performance of a single milling unit may be calculated from the filling ratio, reabsorption factor and imbibition coefficient (Rusell, 1968). If these three parameters are known, the output quantities of the milling unit can be calculated from the input bagasse analysis.

2.7.1 Filling Ratio

Filling ratio is the non-dimensional representation of the delivery setting of the mill. It is defined as the no void volume of fiber per unit escribed volume (Murry, 1959). The no void volume is defined as the volume without air entrapped in it.

$$V_{Fn} = \frac{V_{CF}}{V_{En}} \quad \textbf{(2.2)}$$

Where: V_{CF} is the volume rate of cane fiber (m^3/s),

V_{En} is the volume rate escribed by the top and delivery roller of n^{th} mill (m^3/s).

The escribed volume is defined as the product of the work opening (w), the top roller surface speed (S) and the length of the roller (L).

$V_{En} = L \times W \times S.$ Where: L is the length of the roller (m),

W is work opening (m),

S is top roller surface speed (m/s).

$$W = \frac{TCH \times Fiber\ \%\ Cane}{330 \times n \times D \times L \times f \times 100} \quad \textbf{(2.3)}$$

By Dowes Dekker and Van Hengel (South Africa)

$$\text{Volume Rate Cane Fiber} = \{\text{Fiber \% Cane}\} \times \{\text{Flow Rate of Bagasse Leaving each Mill}\}$$

The filling ratio definition for a mill is based on bagasse occupying the escribed volume of delivery roller. In practice, filling ratio is a function of mechanical loading and control parameters of the milling unit.

2.7.2 Re-absorption Factor

If the no-void volume of bagasse, leaving a mill in unit time is measured, it is found in most cases to be in excess of the escribed volume of the delivery nip. Hence, the juice which ideally should be extracted must be passing the feed side of the delivery rollers through the work opening to the delivery side (Crawford, 1957). Re-absorption factor is a term used to describe this phenomenon. Re-absorption factor represents the volumetric juice extraction performance of the mill.

$$K_n = \frac{V_{Bn}}{V_{En}} \quad \text{(2.4)}$$

Where: K_n is Re-absorption factor of n^{th} mill

V_{Bn} is no void volume rate of bagasse of the n^{th} mill (m^3/s).

V_{En} is the volume rate escribed by the top and delivery roller of the n^{th} mill (m^3/s).

No-Void Volume: The volume of cane or bagasse calculated on the basis that it consists of juice and fiber only, i.e. all air or gas has been removed.

$$\text{No Void Volume} = \frac{f}{1.52} + 0.36\,f + \frac{1-1.2\,f}{d} \quad \text{(2.5)}$$

"f" is Fiber % Unit of Bagasse. "d" is Density of Juice Left in the Bagasse *1.01 to account for variation of juice density due to pressure.

The term "0.36 f" is used to account the brix free water associated with the fiber (just like water % crystallization of chemical compound) estimated to be around 30.6 % of the fiber.

$$\text{Fiber Loading } 'q' = \frac{TCH \times F\,\%\,Cane \times 1000}{60 \times \pi \times n \times D \times L} \quad \text{(2.6)}$$

2.7.3 Imbibition Coefficient

The imbibition coefficient is defined as the ratio of the actual Brix extraction to the theoretical Brix extraction of the mill (assuming perfect mixing of the imbibition liquid and residual juice in bagasse from the previous mill) (Munro, 1963, 1964). It is the measure of the performance of the mill in extracting Brix.

$$I_{cn} = \frac{E_{Bn}}{E_{kBn}} \quad \textbf{(2.7)}$$

Where: I_{cn} is imbibition coefficient of the n^{th} mill,

E_{Bn} is Brix extraction of the n^{th} mill,

E_{kBn} is theoretical Brix extraction of the n^{th} mill

Imbibition efficiency: - defined as extracted juice Brix / residual juice Brix.

The Brix of juice extracted by a mill is generally lower than the Brix of residual free juice remaining in the bagasse leaving the mill. The Brix extracted in juice is always lower than that of the Brix found in bagasse leaving the mill. This is true for all mills.

Table 2.2: Actual designed data for top rollers of WSSF milling plant.

s/n	Mill type	Length of top roller (m)	Surface speed of top roller (m/min)	Diameter of top roller (m)	Mill speed in (rpm)
1	1^{st} mill	2.134	7.63	1.140	3.4
2	2^{nd} mill	2.134	7.63	1.140	3.6
3	3^{rd} mill	2.134	7.63	1.140	3.8
4	4^{th} mill	2.134	7.63	1.140	4.0
5	5^{th} mill	2.134	7.63	1.140	4.2

Source: WSSF milling house

2.8 Extraction Theory

The fundamental equation for the mass balance for the entire milling plant is given by the following equation; evaporation is ignored in this equation.

$$m_c + m_w = m_{jm} + m_b \quad \textbf{(2.8)}$$

Where: m_c is mass rate of cane (kg/s m_w is mass rate of added water (kg/s).

m_{jm} is mass rate of mixed juice (kg/s). m_b is mass rate of final bagasse (kg/s).

Extraction is calculated by the percentage of sucrose extracted from the cane. The percentage of the sucrose in the original cane removed with the mixed juice is termed "sucrose extraction", E_s (Rein, 2007).

$$E_s = \frac{m_{jms}}{m_{cs}} \times 100 \qquad \textbf{(2.9)}$$

Where: m_{jms} is mass flow of sucrose in mixed juice (kg/s).

m_{cs} is mass flow of sucrose in cane (kg/s).

The mill engineer does not have control over the sucrose but has control over the Brix and hence it would be reasonable to report Brix extraction.

$$E_b = \frac{m_{jmb}}{m_{cb}} \times 100 \qquad \textbf{(2.10)}$$

Where: E_b is Brix Extraction

m_{cb} is mass flow of Brix in cane (kg/s),

m_{jmb} is mass flow of Brix in mixed juice (kg/s).

On the basis that the fiber rate through each milling unit is the same, the Brix extraction of the single milling unit is determined from:

$$E_{bn} = \{[\frac{P_{b(n-1)b}}{P_{b(n-1)f}}] - [\frac{\frac{P_{bnb}}{P_{bnf}}}{\frac{P_{b(n-1)b}}{P_{b(n-1)f}}}]\} \qquad \textbf{(2.11)}$$

Where: E_{bn} is Brix extraction of n^{th} mill, $P_{b(n-1)b}$ is percent Brix of $(n-1)^{th}$ mill,

$P_{b(n-1)f}$ is percent fiber of $(n-1)^{th}$ mill, P_{bnb} is percent Brix of n^{th} mill

P_{bnf} is the percent fiber of n^{th} mill.

2.8.1 Determining Extraction of Single Milling Unit

The figure below shows the flow of brix and water through a single milling unit 'n'. The input quantities,$P_{B(n-1)B}$, $P_{B(n-1)W}$ and $P_{B(n-1)F}$, are the mass percentage of Brix, moisture and fiber respectively in bagasse from the preceding mill. The output quantitiesP_{BnB}, P_{BnW} andP_{BnF}, are the mass percentage of Brix, moisture and fiber respectively in bagasse. P_{InB} Is the mass percentage of Brix in imbibition and P_{InW} is the mass percentage of moisture in imbibition. The extraction quantities, X_{JnB} and X_{JnW} are the mass fraction of Brix and moisture in juice respectively.

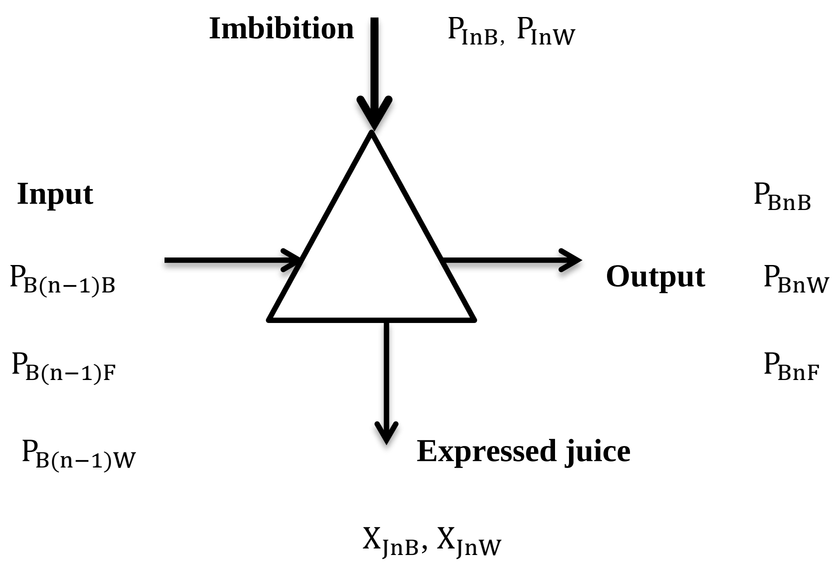


Figure 2.9: Schematic diagram of single milling unit extraction system

Using three mill parameters viz. filling ratio, reabsorption factor and imbibition coefficient defined in section above, the composition of delivery bagasse and expressed juice may be calculated from the given feed quantities. It is assumed that no fiber passes in to the expressed juice, so that the weights of fiber in the feed and delivery bagasse are identical.

$$M_{B(n-1)F} = M_{BnF}$$

Where: $M_{B(n-1)F}$ is the mass rate of fiber in delivery bagasse of the preceding mill (kg/s).

M_{BnF} is the mass rate of fiber in delivery bagasse of the n^{th} mill (kg/s)

Then the ratio of reabsorption factor to filling ratio is given by,

$$\frac{K_n}{C_n} = \frac{V_{Bn}}{V_{BnF}} \quad (2.12)$$

Where: K_n is reabsorption factor for the n^{th} mill

C_n is the filling ratio of the n^{th} mill

V_{Bn} is the volume of delivery bagasse of the n^{th} mill

V_{BnF} is the volume of fiber in delivery bagasse of the n^{th} mill

Rearranging the equation we get: $V_{Bn} = (\frac{K_n}{C_n}) \times V_{BnF}$

The volume of juice in bagasse is given by:

$V_{Bnj} = V_{Bn} - V_{BnF}$ where: V_{Bnj} is the volume of juice in delivery bagasse of the n^{th} mill

Substituting the equations and rearranging the terms we get:

$V_{Bnj} = V_{BnF} \times (\frac{K_n}{C_n} - 1)$

The theoretical Brix fraction in bagasse is calculated from,

$$Y_{kBnB} = \frac{X_{InB} + X_{B(n-1)B}}{X_{InB} + X_{B(n-1)B} + X_{InW} + X_{B(n-1)W}} \quad (2.13)$$

Where: Y_{kBnB} is the theoretical Brix fraction in bagasse of the n^{th} mill

X_{InB} is the mass fraction of Brix in imbibition of the n^{th} mill

$X_{B(n-1)B}$ is the mass fraction of Brix in bagasse of the preceding mill

X_{InW} is the mass fraction of moisture in imbibition of the n^{th} mill

$X_{B(n-1)W}$ is the mass fraction of moisture in bagasse of the preceding mill

The theoretical density of juice in bagasse is determined from the Brix extraction density factor (Russell, 1968). The theoretical mass of juice in bagasse is calculated from.

$X_{kBnJ} = V_{Bnj} \times d_{kBnj}$ where: X_{kBnJ} is the theoretical mass of juice in bagasse of the n^{th} mill.

d_{kBnj} is the theoretical density of juice in bagasse of the n^{th} mill.

The theoretical mass of Brix in bagasse is calculated from,

$X_{kBnB} = X_{kBnJ} \times Y_{kBnB}$ where: X_{kBnB} is theoretical mass of Brix in bagasse of the n^{th} mill.

The actual mass of Brix in bagasse is calculated from

$$X_{BnB} = (1 - I_{cn}) \times X_{B(n-1)B} + I_{cn} \times X_{kBnB} \quad \textbf{(2.14)}$$

Where: X_{BnB} is mass of Brix in bagasse of n^{th} mill

I_{cn} is the imbibition coefficient of n^{th} mill

The Brix fraction density factor as demonstrated by Russell (1968) is given by

$$Y_{BnB}\,d = \frac{X_{BnB}}{V_{Bnj}} \quad \textbf{(2.15)}$$

Where: $Y_{BnB}\,d$ is the Brix fraction density factor of n^{th} mill

2.9 Composition of Mill Juice

The juice from the crusher and each of the succeeding mills differ according to the pressure and extent of saturation. With continued crushing a reduction occurs in the Brix, pol and purity such reduction is due to increase is the non-sugars both organic and inorganic. In general, the juice from the back roll (delivery roll) is higher Brix and greater purity than that from the front (feed) roll. Because feed roll extracts the superficial imbibition water on the exterior of the bagasse particles, whereas the back roll extracts part of the juice in the inner cells. Hugot, adds that the feed roller of the later mills with wet crushing should furnish about three-fourths of the juice and the back roller only one- fourth. The more sucrose extracted, the greater the proportion of non-sugars (impurity) that will accompany the sucrose. The characters of impurities reduce the purity of the juice.

Table 2.3: Factory performance data taken from WSSF from date 1 – 24 /03/2019

Description	Unit	Plan	Actual	Deviation
Cane crashed per day	Qts	47637	45895.58	-1741.42
Sugar produced per day	Qts	5529	3059.56	-2469.44
Final molasses produced per day	Qts	1905.50	1332.83	-572.67
Sucrose % cane	%	14.11	12.89	-1.22
Fiber % cane	%	13-15	13.44	+0.44
Purity cane	%	>84	86.55	+2.55
Expected field yield	%	11.83	10.76	-1.07
Expected factory yield	%	11.81	10.74	-1.07
Preparation index (PI)	%	85	85.08	+0.08
Primary juice extraction	%	>60	60.58	+0.58
Imbibition % fiber	%	250	216.39	-33.61
Imbibition % cane	%	30	29.07	-0.93
Mill extraction	%	95	96.59	+1.59
Reduced mill extraction	%	>96	96.80	+0.80
Pol % bagasse	%	2	1.90	-0.10
Moisture % bagasse	%	50	50.26	+0.26
Bagasse % cane	%	28-32	28.47	+0.47
Mixed juice % cane	%	105	99.95	-5.05
Brix % primary juice	%	>20	20.27	+0.27
Apparent purity primary juice	%	>86	89.60	+3.60
Brix % mixed juice	%	15	16.72	+1.72
Apparent purity mixed juice	%	>85	86.98	+1.98

Source: WSSF daily factory performance report data book.

2.10 Performance Evaluation of Individual Mills

Performance evaluation of the individual mills was passed through the following major steps;

- Plotting of Brix curves for feed and discharge sides.
- Analysis of bagasse, leaving the mills for free pol and total pol.
- Measurement of temperature of juice on feed and discharge.
- Measurement pol % bagasse, leaving a mill and juice from back roller of same mil

2.11 Performance Evaluation of all Mills.

Performance evaluation of all mills was passed through the following major steps;

- Pol percent final bagasse.
- Brix percent of last expressed juice.
- Primary extraction (PE).
- Reduced mill extraction (RME)

2.12 Brix-Free Water in Cane Fibers

Natural fibers have associated water, which is separate from the water in the juice and which cannot be removed by mechanical means. This water is generally termed Brix-free water or hydrated water in South Africa, and adsorption water or hygroscopic water in Australia. Brix-free water is present in varying amounts for a particular substance depending on the vapor pressure of water in the atmosphere and the temperature. Prinsen Geerligs (1897) and Steuerwald (1912) studied the change in concentration of solutes dissolved in water brought about by the addition of fiber to the solution. Previous determinations of Brix-free water in cane reported by Steuerwald (1912), Foster (1962, 1963) and Richardson (1970) gave values ranging from 10 % to 50 % on fiber.

2.12.1 Effect of Brix-free Water in Cane on Milling Control

Brix-free water is characterized as water strongly adsorbed onto the cane fiber and unavailable for the solution of the soluble components present in sugar cane. As a result, it is incorrect to assume that the mass of juice that can be extracted from cane can be obtained by deducting the mass of fiber as found by drying, from the mass of the cane sample from which the juice is extracted. The mass of fiber plus Brix-free water should be subtracted:

$$\text{Mass of Juice Extracted} = (\text{Mass of Cane}) - \{(\text{Mass of Fiber}) + (\text{Mass of Brix} - \text{Free Water})\}$$

$$\text{Mass of Fiber} = \text{Fiber \% Cane} \times \text{Mass of Cane}$$

$$\text{Mass of Brix Free Water} = \text{Mass of Fiber} \times \text{Brix Free Water \% on Fiber}$$

This juice is termed undiluted (or normal) juice and is the juice expressed by the mills or retained in the bagasse corrected for Brix-free water. For purposes of calculation, it has the Brix of the primary juice. The concept of Brix-free water expressed as a percentage of dry fiber, or a factor, is used in assessing the accuracy of the various variables used in milling control, to correct the Brix of primary juice to that of juice in cane and so bridge the gap in the mass balance. To calculate the Brix of the undiluted juice from the Brix of the first expressed juice, a 'dry milling factor' can be used. This is obtained by periodically operating the mills briefly without imbibition water, determining the Brix of the first expressed juice and of the mixed juice so obtained. For example, if they are 20.0 and 19.4 respectively, the dry milling factor is 19.4 divided by 20.0 = 0.97. It is then assumed that this factor is the relationship between the first expressed juice and the undiluted juice when imbibition water is used, and under these conditions, mixed juice is of much lower density. For example, if the Brix of the first expressed juice is 19.21 in regular milling, the undiluted juice Brix will be 19.21 times 0.97 = 18.63 (Chen and Chou, 1993).

2.12.2 Influence of Brix- Free Water on Milling Performance

Whenever mill engineers are at a loss to explain the fluctuations of the milling performance of their mills, they blame the quality of the cane. from the milling point of view, the cane can be defined as being composed of bon dry fiber + Brix free water + undiluted juice, which means that natural fiber = bon dry fiber + Brix free water. Brix free water % of fiber is not always present in fixed quantity, but varies considerably from day to day, week to week and month to month. Weather such variations are due to varieties and age of the cane, climatic conditions, burnt or trashed cane it is hard to say. But several researchers stated that Brix free water % fiber can vary by some 10 %. The mill manipulating cane of higher Brix free water percent will have a higher milling performance than that of lower brix free water % and the final bagasse will contain 5 % less diluted juice. For example, from the table 2.4 below, the Brix free water % on fiber for day- 1, 2 and 3 is 17.5 %, from day- 4 to day -7 Brix free water on fiber is 40 to 47.5 %, the same manner for others there were a big variation of brix free water on fiber day to day, week to week and so on. It is clear that tandem handling cane of higher Brix free water will extract more juice in mill unit than the tandem with cane of lower Brix free water on fiber. The Brix free water % of WSSF was averagely, 30.63 % on cane fiber.

Table 2.4: Calculated values of mass of fiber, Brix free water and undiluted juice extracted

Days	MCD (Qts)	Fiber % of cane	Brix free water % on fiber	Mass of fiber (Qts)	Mass of brix free water (Qts)	MUJE (Qts)
day-1	36549	14.39	17.50	5259.40	920.40	30,369.20
day-2	33694	13.37	17.50	4504.89	788.36	28,400.75
day-3	24962	13.55	17.50	3382.35	591.91	20,987.74
day-4	27513	13.56	40.00	3730.76	1492.30	22,289.94
day-5	32019	13.18	47.50	4220.10	2004.55	25,794.35
day-6	28136	13.64	47.50	3837.75	1822.93	22,475.32
day-7	30784	13.69	47.50	4214.33	2001.81	24,567.86
day-8	12550	13.89	57.50	1743.20	1002.34	9,804.46
day-9	28112	13.17	35.20	3702.35	1303.23	23,106.42
day-10	36184	13.45	21.10	4866.75	1026.88	30,290.37
day-11	28261	13.20	28.20	3730.45	1051.99	23,478.56
day-12	25473	13.23	16.40	3370.08	552.69	21,550.23
day-13	5198	13.11	14.90	681.46	101.54	4,415
day-14	46147	13.41	27.30	6188.31	1689.41	38,269.28
day-15	35934	13.29	24.80	4775.63	1184.36	29,974.01
day-16	23994	13.55	29.70	3251.19	965.60	19,777.21

******MCD*** - is mass of cane crashed per day, ***MUJE***- is mass of undiluted juice extracted, ***Qts*** - is quintals of cane

2.13 Mill Control

2.13.1 Micro Biological Control

During the milling operation the warm juice provides an ideal environment for the growth of many species of micro-organisms which enter with the cane, mud and trash. Dead spots and reduced juice flow areas are inherent in mill design and they provide favorable condition for the re-infection of the entire milling system. Many of these micro-organisms produce enzyme invertase responsible for rapid inversion of the sucrose resulting in significant economic loss. Special attention must therefore be given to both locating and treating suspect areas typically juice conveyance system, troughs, imbibition water distribution decks, inner side of mill cheeks, trash plate bridges, and the back of juice separating screens. Preventive maintenance chemical cleaning specifically designed to reduce or eliminate micro-biological contamination before problems occur. Studies have shown that such treatment not only pays for itself but also produces profit in the form of additional sucrose recovery and reduce mill maintenance and wash up. Each hosing of the mill train places additional water in the juice, thereby increasing the demands in the clarification, filtration and evaporation. In all cases chemical control should be augmented by frequent equipment cleaning (minimum once/shift). Cleaning can be in the form of hot water washing, at temperature in excess of 70 ^{0}C to 80 ^{0}C, all biological functions cease) steam cleaning, and/or manual scrubbing of the equipment surface.

2.13.2 Mill Control Criteria

For optimal throughput and extraction, it is important to achieve steady milling conditions without gaps in mill feeds and without rapid changes in mill speeds. The first point of focus must be to achieve a steady rate of cane feed within the cane preparation stage - preferably by the feed into the final preparation device.

Criteria for cane table, cane preparation, roughing cane cuter, first finishing cane cuter, fiberizer, Electromagnetic separator and milling process.

Cane Table Criteria: There should be sufficient and uniform cane distribution on the cane table and also proper functioning of the cane leveler shall be assured. Communication between unloader and cane table operators during unloading the cane on the cane table is essential. Stones with the cane shall effectively inspect and removed.

Cane Preparation Criteria: One of the criteria for cane preparation is uniform feeding of cane to the cane cutters considering the variety of the cane and cane Knife loading. The cane should be free from stone and metallic materials. Fiberize knives tips should be provided with hammer for proper preparation of cane. Checking and replacing reversing the cane knives when the preparation index is less than 79. Cane drops shall immediately be returned back on the carrier frequently.

Roughing and Finishing Cane Cutters Criteria: The maximum load current allowed should be maintained. Clearance between the tip of the knives and the highest portion of the cane carrier slat shall be maintained as per the design. For the case of first finishing cane cutter the maximum load current allowed should be maintained Clearance between the cane knives and carrier slat shall be maintained as per the design.

Fiberizer Criteria: The maximum load current allowed should be maintained. Clearance between the cane knives and the slat shall be maintained as per the design. Opening between the cane cutters tip and the steel board at the inlet (feed) side and opening at discharge end (side) shall be maintained as per the design. Bearing temperature; lubrication & vibration shall be continuously monitored.

Electromagnetic Separator Criteria: Constant supply of electric power should be needed. The surface should be always clean

Milling plant Criteria: First mill feeding chute should always be half full level and shall always be provided with effective carrier's speed regulating devices for smooth feeding. All mill chutes should run full and mill speeds should be adjusted accordingly. All mills should work with preset hydraulic loads and proper floating of top rollers. Top rollers of all mills shall be continuously monitored for proper lifting. Proper functioning of rollers, scrapers and messchart grooves should be monitored. Mill opening should be measured periodically and mill ratios should be adjusted comparing to performance accordingly. Mill setting data’s and actual measurement should be taken at the regular time. Mills should be kept absolutely clean and should be continuously treated with disinfectant to avoid bacteriological developments. Mills rollers should be roughed continually to improve the performance.

2.13.3 Mills Sanitation

To conserve the juice and prevent losses due to inversion or purity drop, it is best to reduce retention to a minimum and keep the mills as clean as possible. Otherwise, the freshly extracted mill juice is infected with large number of microorganisms, which begin to multiply soon under favorable conditions. The juice surrounding the mill tandem has a temperature that favors bacterial growth and even small quantities of infected juice or bagasse bring about disastrous infection. The infection of juice results a rapid decrease of juice purity from first mill to last mill. The deterioration of juice in the first mill is slower than in last mill because of its large quantity, higher density and higher velocity through the tandem. However, last mill juice, travels through all mills, has a lower Brix, which is favorable for bacterial action and its quantity is less with longer retention. It is therefore highly essential to keep the mills cleaned. This can be achieved by: (a) Frequent washing, cleaning and steaming of the mills at short intervals and (b) the use of disinfectants. Disinfectants usually used are formaldehyde, sodium fluoride, calcium chloride etc. that prevents the growth of leuconostoc bacteria.

2.13.4 The Effect of Cane Quality on the Performance of Milling Plant

How the cane quality that affect the extraction performance? The cane qualities that affect the performance or the capacity of the milling plant are as follows: (a) The fiber content of the cane; (b) Trash content of the cane; (c) Age of the cane (maturity). Cane quality is expressed in terms of pol and fiber content of the cane.

Table 2.5: Terms used to describe cane quality (after Meyers et al., 2013)

Terms	Definition
Brix	A percentage by mass total dissolved solids in sugarcane or juice.
Pol	A percentage by mass apparent sucrose in sugarcane or juice.
Non-pol	Brix minus Pol.
Fiber	Dry and all insoluble matter found in sugarcane

Changes in cane quality are in the changes in fiber and non-sucrose in the cane. Cane with excessive tops and leaves for instance, will increase both these inputs significantly. Reductions in juice purity due to cane delays or any other causes also affect the input of non-sucrose. Deterioration of one of these cane quality parameters can lead to a situation where one part of the factory becomes a bottleneck while there is surplus capacity elsewhere in the factory. Conversely improvements resulting from reductions in extraneous matter or higher juice purities can lead to effective additional capacity (performance), with no capital expenditure. It has been reported that a reduction of 1% leaves in cane increases the crashing rate by 3 % (Scott, 1977). The work reported by (Reid and Lionnet, 1989) provides that excessive tops and leaves results in a reduction in milling capacity. However, the fiber rate through the mills remained reasonably constant at the same mill speed; thus the reduction observed is due directly to the additional fiber that has to be processed. Similar findings are reported by (Kent et al, 2003), which showed that a reduction in the tops and leaves content of about 7 % led to an increase in the crushing rate of 15% however in this case, too, the fiber crushing rate was virtually constant. A reduction in bulk density in the transport vehicles is another capacity effect with an excessively trashy cane. (Kent et al., 2003) found a reduction in bin weights of 15 % with dirty cane, (de Beer et al, 1989) showed a reduction of 44% in payload when whole cane with all the tops and leaves is transported relative to transport of clean burnt cane. (Reid and Lionnet, 1989) showed that with an excessively trashy cane, the non -sucrose input into a factory can double compared with clean cane. This can have a severe effect on the back end capacity required. By saying this, the theoretical fiber content of WSSF is in between 13 to 15 % of cane but the current actual fiber content on cane is 13.44 %. Several researchers found that the standard fiber content of five milling tandem is 14 % of cane by (Kent, 2001). Logically, as the fiber content increases the juice extraction decreases and as the fiber content will decrease the juice extraction will increase. Therefore, the fiber content of WSSF is best as compared to the standard values, so the juice extraction is good.

2.13.4.1 Age of cane (Maturity)

The age of the cane at the WSSF state is divided into three stages; early matured (16 – 18 month), matured (18 – 24 month) and late matured or over matured (above 24 months). In case of the early stage the sucrose accumulation increasing on the cane stalk it continues and does not stop, at this age the leaves and tops of the cane stalk are green it also called young cane. For the second stage i.e. matured stage the accumulation of the sucrose on the cane stalk is finished. This stage is the recommended and the best stage for sucrose accumulation and the biomass of the cane also larger, leaves and tops are smaller than that of early stage. In the late matured or over the matured stage the highest accumulation of sucrose is completely decreasing as the time goes and directly converted to reducing sugars known as fructose and glucose. Not only decrement of sucrose but also the biomass of cane stalk is decreasing. These reducing sugars occur in abundance in growing and immature portions of cane, but decrease in the lower parts of cane stalk. Immature cane is rich in reducing sugars, which decrease as cane reaches maturity, but once the maturity phase is crossed they tend to increase. The invert sugar formed by inversion of sucrose shows negative specific rotation, on account of higher levorotatory activity of fructose over the dextrorotatory power of glucose or dextrose. The reducing sugars are sensitive to alkaline conditions being decomposed into coloring compounds and organic acids under influence of alkali. Therefore, early matured and late or over matured cane have not recommended for factory crashing because they have reached in reducing sugars, fructose and glucose. When this type of can introduce to the factory only reducing sugars, no more sucrose extraction would be done. Due to this fact the age (maturity of) the cane can affect the performance of the milling plant.

2.14 Sucrose Losses along Milling Train

1. Physical losses.
2. Sucrose destruction losses.
3. Biological losses.

2.14.1 Physical Losses

The physical loss of sucrose starts from cane unloading throughout the milling tandem. During this research work the first point that sucrose loss was seen through the spillage of cane during unloading of cane. Cane left unloaded on a cart, poor housekeeping and poor management can result in very significant sucrose losses along the milling tandem like juice spillage, leaks in pipes, gutters and pump glands, careless washing down and juice mixing with roll lubrication or cooling systems are obvious physical losses that need to be prevented by careful observation and attention to detail. All drains from the mill area should be regularly monitored for sucrose content.

Heavy spillage of cane during unloading of cane was observed at unloading station. From this part of spilled cane during unloading area return to the cane table using man power while part of it pushed away as trash. Most of spilled canes are damaged by cane carts tyer. Latter spilled canes are pushed to the front side of cane table and deteriorated by microbial activity and finally disposed as trash or May recycle back to cane table.

During unloading of cane, all canes are not unloaded from cart to cane table, due to unloading chain problem. All the canes left on carts must be collected and return back to cane table as soon as possible because as the time goes sucrose deterioration increases, most of the time left canes are picked by manpower. Since this unloading area is far from the cane table, it creates challenges on returning the left cane to the process immediately. Peter Rain and different Authors states that "Deterioration starts in burnt cane from the moment it is burnt, because the heat of the fire generally cracks the rind and exposes some juice". Therefore, since this canes are exposed to deterioration by microbes, there is no chance of recovering the sucrose even if the cane recycled back to cane table. In addition to direct loss of sugar due to microbial infection, the recycling of the deteriorated cane back to cane table increase loss of sugar in final molasses and final result in lower recovery of sugar.

Spilled cane (a)

Spilled cane damaged by tyer (b)

Spilled cane ready for disposal (c)

Spilled cane pushed to side (d)

Figure 2.10: Spilled cane stalk during unloading

2.14.2 Sucrose Destruction Losses

Less obvious than the physical losses, but often greater, is the destruction of sucrose within the milling process. Destruction occurs in three ways: acid inversion, enzymatic inversion and infection. In a tandem that is poorly cleaned and sanitized, losses are 2 % of the total sucrose in cane. In a well-managed plant, the losses should be reduced to about half of this figure (Hugot. 1986:326).

Acid inversion: - involves the chemical inversion of sucrose into fructose and glucose and occurs under acidic conditions, the inversion rate increasing with lower pH and higher temperature levels. Even at the natural pH of cane juice of the order of 5.5, the extent of inversion is negligible at mill temperatures.

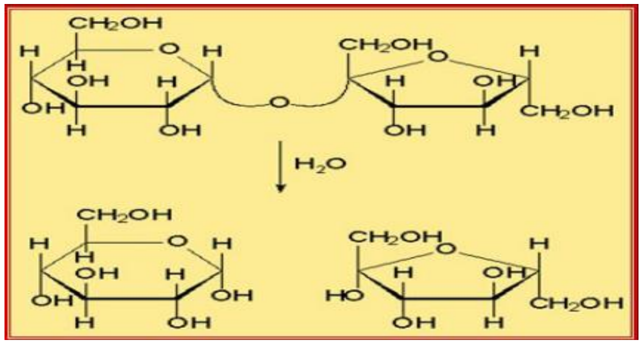


Figure 2.11: Inversion of sucrose

Enzymatic destruction: - results from proteins, mainly invertases that act as catalysts to promote sucrose inversion. Invertase may be present in the cane naturally or be produced by saccharomyces species and is inactivated at temperatures above about 65 degree cilices. The products are fructose and glucose that do not crystallize and so are not recoverable as sugar. Instead they constitute melassigenic non sucrose, which increases the quantity of molasses and therefore the sucrose loss in molasses.

2.14.3 Biological Losses.

Deterioration of sugarcane juice source and indicator: Dextran polysaccharide (formed mainly by leuconostoc bacteria) has often been reported as a cane deterioration indicator, and is responsible for many of the numerous negative impacts that cane deterioration has on factory processing, mostly associated with the rise in viscosity from this polysaccharide. Oligosaccharides are also products of cane deterioration (Eggleston et al., 2001; Morel du boil, 1995; Ravelo et al., 1995) and are responsible for crystal deformation problems (Morel du boil, 1991). Ravelo et al. (1991) reported that the formation of total oligosaccharides was greater than the formation of dextran and ethanol in cane subjected to delays and is, therefore, a more sensitive indicator of cane deterioration. A number of cane deterioration products including high invert sugars, polysaccharides (e.g. Dextran) and microbial contamination (e.g., ethanol and lactic acid formation) have been reported to predict and control processing problems at the factory (Solomon et al., 2006, Eggleston et al., 200 l, Lionnet, 1996, Morel du boil, 1995), but not all deterioration products effect factory processing. Polysaccharide produces soil born bacteria such as Leuconostoc spp. From cane field enters inside the cane through cut ends or damaged sites and thrives at the expense of stored sucrose, further reduces quality of milled juice. The Leuconostoc bacteria have the ability to synthesize alpha- glucan polysaccharide (dextran) from sucrose through an extracellular enzyme called dextan sucrose as shown below (Kirtiraj Gaikwad and P.K. More)

$$\text{Sucrose} + \text{Water} \xrightarrow[\text{Leuconostoc Spp}]{\text{Dextran sucrose}} \underset{\text{Dextran}}{\text{ID (Glucose)}} + \text{Fructose}$$

2.15 Measurement and Control Method of Sucrose Destruction Losses

In the case of WSSF sucrose destruction causes a reduction in the mass of sucrose and in purity, but the percentage changes in these parameters are relatively small and difficult to measure accurately. Their use as an indicator of losses is also compromised by the fact that the dextran produced is strongly dextrorotatory, which may mask the sucrose loss (Rein 1995). The microorganisms that are responsible for most of the sucrose fermentation are mesophiles. In addition, lactic acid producing bacteria are active. As an operating control measure, the products of fermentation can be measured. Depending on standard for the factory concerned, a lactic acid level of more than 300 to 400 mg/kg in mixed juice will indicate that hygiene and sanitation is inadequate and corrective action is required. To contain losses, the first essential is regular and diligent washing. Prevent or clear up any stagnant pools of juice. Every shift, steam to saturated exhaust steam or vapor or wash with hot water, accessible areas of the mills that are in contact with the juice. Pay particular attention to juice screens, inside the mill cheeks and juice gutters. On maintenance stops, thoroughly clean these and other potential contamination areas such as roll ends, juice trays, dumb turners and pump suction tanks. Ideally, steam cleaning should be for long enough to raise surface temperatures to > 75 °C for at least a minute or two.

2.16 Sucrose (Sugar) Loss through bagasse

2.16.1 Cause of Sucrose Loss through Bagasse

A) Degree of Extent of Cane Preparation

In Wonji Shoa sugar factory average value of preparation index shows 85 %, which is very good relative to the standard/optimum preparation index as recommended on Hugot a modern factory preparation index should be at least between 78-85%. However, in this factory the PI is good as indicated above. But for the case of metahar sugar factory PI is around 80 % both which are in the recommended range. In the case there were no significant problem would be seen in this cane preparation plant section, from my physical observation during the research work not always but sometimes little cane stalk passed through the prepared cane. This may be solved by supervision and operational follow up during the operation time.

B) Fluctuate Use of Imbibition's Water

In order to extract the sucrose from the bagasse, constant and favourable amount of imbibition's water should be applied. The application of imbibition water the case of WSSF is fully automated means that the flow of water totally depends on the bagasse flow. As the flow rate of bagasse increases simultaneously the flow rate of water increases. But the working range of imbibition flow is 62 -72 m^3/ hr. Most of the time sugar factories uses condensate water for the imbibition purpose, the temperature of this water is around (50 – 80 ^{0}C). The main problem that would be observed in WSSF is that shortage of the condensate water due to design problems on boiler house and scale problem in the evaporator tubes. Most of the time the evaporator tubes and in pan station callenderia tubes are deposited by scale and hinders heat transfer, this minimizes the evaporation capacity, as a result no more sufficient amount of condensate would be collected. Due to this fact, the milling station sometimes forced to use cold water as imbibition water. Logically, sucrose extraction is higher in hot imbibition than the cold one. Not only extraction, but also for hot imbibition the evaporative rate of moisture from bagasse is higher than that of cold imbibition. These cumulative results decrease the extraction efficiency of the milling plant and thereby increase loss of sugar through the final bagasse.

C) Application of Hydraulic Pressure and Pressure Gauge

Extraction of juice from cane has always been affected mainly by pressure. This shows the mill setting should be settled properly and carefully according to the input flow rate of cane crushed. In WSSF some hydraulic cylinders which are vital for hydraulic loading of mill rollers are not functioning. Thus the extraction is done by the weight exerted by the top rollers and other supportive forces. This could be one of the problems for sucrose loss through bagasse. One of the most problems in WSSF milling station was application of hydraulic pressure on the 4^{th} and 5^{th} mill. There was a leakage problem of hydraulic pressure of the last mill. Logically, hydraulic pressure of the mill increase from the first to the last, due to this leakage problem the hydraulic pressure application for the last mill does not applied; instead of this they applied more pressure to the fourth mill to compensate the pressure application of the last mill. This would show as increasing the load or stress to the fourth mill and decrease the load to the last mill, it is not recommended. Application of the hydraulic pressure beyond the recommended range may fall the mill rollers and accessory to wear and tear out.

2.17 Remedies to Prevent Loss of Sucrose through Bagasse

A) Increase Degree of Extent of Cane Preparation

It was known that as cane preparation increases the extraction of sucrose increases, thus would be done by adjusting the clearance between the knife and the cane height. It can be improved by checking the sharpness of the knives at least every month. Thus, if the cane cells are exposed, extraction of juice will be efficient. Hence loss through bagasse will decrease. Comparing the extraction properties of crushed and shredded cane and found that more cells are ruptured in the shredded cane. Thus the ruptured cells expose the juice directly to the mills.

B) Solve the Scale Problems in the Evaporator Tubes and Pan Station Callanderias.

Use hot imbibition rather than cold, hot water or usually called condensate water that collected from the evaporator station and if evaporator tubes are deposited by scale as the result it minimize the evaporation system, then thereby decrease the collection of condensate water. Therefore, the one option to maximize the collection of condensate water is by minimizing the scales on evaporator and pan station callenderias. If we solve scale problems we have to increase the heat transfer through evaporator tubes and then increase the evaporation rate. If the evaporation rate increased the production of vapor increases, the produced vapor will boil the sugar in the vacuum pan and finally the vapor will transfer the heat to the juice through callenderia tubes and then condense and collected for imbibition purpose.

C) Changing Present imbibition's Practice and Amount

Hugot and other technologists recommended that optimum imbibition's will be reached when the weight ratio of imbibition of water to fiber is 2, $\frac{W}{F} = 2$, Where: W = imbibition % cane

F = Fiber % cane

Taking a five years average data from the factory (WSSF)

- Average imbibition % on cane = 29.07
- Average fiber % on cane = 13.35 %

When we calculate it using the above formula gives the following result.

$\frac{W}{F} = \frac{29.07}{13.35} = 2.18$ This result shows the imbibition water used was almost above the optimum value. However, as we mentioned before on this project, when they increase the imbibition water beyond the optimum range, the moisture content of the bagasse also increase, which is a headache for those who work at the boiler house. If this was so, it could solve by pre-drying the bagasse counter-currently using the waste heat in the boiler flue gas with temperature 150-170 ^{0}C, to reduce the moisture content below 50%, this in turn boost up the boiler efficiency for better steam production. As a result not only may a great saving supplementary fuel be expected, but also some 10 to 15% of excess bagasse from total production may be available for other industrial purposes and the flue gas may be cooled as well as reduce its environmental impacts. Another problem which could be faced during evaporation due to increase the amount of water in the juice could be compensated by imputing the bagasse saved during pre-drying to the boiler house, so that a better steam could be gained in the evaporation of water or by improving the existing evaporator surface area we can solve the evaporation problem.

D) Plotting Juice Brix Curve for Controlling Individual Mill Setting

Performance evaluation of individual mill is done by plotting juice Brix curve to monitor each mill by analyzing feed and discharge roller juice simultaneously with the discharge bagasse for each milling unit. By drawing this curve it was possible to know which mill can perform well for the given extraction period. If there were some variation increment or decrement in the curve, this will shows that there was a problem at that point. Therefore, it was possible to increase the extraction process by look out this curve and adjusting the individual mill setting at the point where the problem happens. The Brix curve would show in the figure 4.1, the second mill the feed roller brix curve overlays the discharge roller Brix this is not true but the reverse is true. For the fact it would show as there was a problem with the discharge roller mill setting. These problems solved till the discharge roller Brix curve overlays the feed roller Brix curve.

E) Proper Use of Hydraulic Pressure

The proper application of hydraulic pressure on the mill, especially for the last mill we can prevent loss of sucrose through bagasse. If they could use the individual mill setting carefully and properly, we can prevent loss of sucrose through bagasse. But in order to know the present mill setting in the factory, we were intended to do the Brix curve this in turn used to investigate the mill setup. The oil leakage of the fifth mill hydraulic pressure must be solved either by full maintenance or by replacing the oil cylinders for better application. Anyhow, we want to say that applying a proper hydraulic pressure will decrease the moisture content of the bagasse. An increasing number of mills are the other option used to help the existing process.

2.18 Basic Dry Lead Acetate and Effect on Clarification

It has been close to 150 years since lead is the only clarifying agent being used internationally for sugar work. It has a great efficiency of clarification on the other hand, lead has many disadvantages. The chemical formula for dry lead acetate is (Horne's dry lead) $3Pb(C_2H_3O_2)_2 . 2PbO$. Lead precipitate formed during clarification of the sample has a marked influence in polarization. If a solution made to a fixed volume contains a solid of lead precipitate, the concentration in the remaining liquid will be higher than if the solid were not present. This will result on inflated pol reading. It is necessary to stop short of complete precipitation because an excess of the solid, which doesn't produce corresponding precipitate serves to swell the volume the solution, and corresponding error is introduced.

2.18.1 Effect on Horne's Dry Lead Method

The finely powdered lead salt is added to the sample solution after dilution of the volume. Hence, there is no dilution of the solution by the lead and the volume of the precipitate doesn't alter the concentration of sugar in the solution. Only hydrous lead sub acetate specially prepared for sugar analysis should be employed which contain 72.8% lead, 0.3g.of the salt is equal to 1ml of the wet 54 Brix lead solution.

2.18.2 Effect of Lead on Sucrose

Basic lead acetate forms with sucrose a noticeable precipitate only at a very high pH, which do not occur in cane sugar factories. Bates and Balke carried out an experiment on normal sucrose solution and proved that excessive amount of lead causes error on a rotation of sucrose.

Table 2.6: The effect of dry lead acetate on rotation of sucrose

s/n	Excess lead	Diminution of polarization (^{o}S)
1	½ ml	- 0.10°
2	1 ml	- 0.12
3	2 ml	- 0.11
4	3 ml	- 0.09
5	6 ml	0
6	10 ml	+ 0.20
7	50 ml	+ 1.00

The rotation reaches a minimum value when an excess of 1ml is present. It returns to its initial value when 6ml in excess has been added and continues to increase linearly with the amount of lead solution added. If as much as 50ml is present, the rotation is then increased by a whole degree sugar. These sources of error are avoided if the minimum quantity of lead solution necessary for clarification is added. Lead decreases the rotation of laevulose and precipitates levulose as the lead salt. Thus, in the levulose bearing sucrose solutions, lead increases the pol by suppressing the laevorotation of levulose.

2.19 Response Surface Experimental Design

An experiment is a series of tests, called runs, in which changes are prepared in the input variables in order to recognize the reasons for changes in the output response (Montgomery & Runger). Design of Experiments (DOE) is a powerful technique used for exploring new processes; gaining increased knowledge of the existing processes and optimizing these processes for achieving world class performance (Jiju Antony, 2003). Often, Engineering experimenters wish to find the conditions under which a certain process attains the optimal results. That is, by careful design of experiments, they want to determine the levels of the design parameters at which the response reaches its optimum. The optimum could be either a maximum or a minimum of a response (output variable) which is influenced by several independent variables (input variables). One of methodologies for obtaining the optimum results is response surface methodology. Response Surface Methodology (RSM), invented by Box and Wilson, is defined as a collection of mathematical and statistical tools or techniques useful for modeling, analyzing, and simultaneously solving problems in which a response of interest is influenced by several variables and the objectives is to optimize this response (Giovanni, 1983). Response surface methodology also quantifies the relationship between the controllable input parameters and the obtained response surfaces. It is a well-known up to date approach to constructing approximation models based on physical experimented observations (Boxetal., Montgomery). The main advantage of RSM is the reduced number of experimental runs needed to provide sufficient information for statistical acceptable results (Montgomery 2001). The design procedure of response surface methodology is as follows: (i) Designing of a series of experiments for adequate and reliable measurement of the response of interest. (ii) Developing a mathematical model of the second order response surface with the best fittings. (iii) Finding the optimal set of experimental parameters that produce a maximum or minimum value of the response.

2.20 Suggested Solution for the Problems.

1. For maintaining the uniformity of the cane quality and supply, the awareness is necessary for all levels for growers to miller. Better cane variety selection agro-ecological factors, land use suitability. Healthy crop, better planting, harvesting schedules and efficient transportation planning.
2. For improving the mill house efficiency the efficient cutting and shredding of the Sugar cane to create a uniform layer for the mill. Accurate mill settings, timely adjustments and smooth operations. Proper extraction methods-optimized imbibition’s for achieving the required efficiency use of the best equipment, tools and skill operators, least breakdowns,

stoppages and optimized shutdowns are necessary to minimize losses in the manufacturing process of sugar.

3. For bagasse generations and utilization, Cane Variety, raw material uniformity and supply of raw material is essential for continuous operations. This is directly related to proper extraction efficiency, bags, quality, sugar and moisture content, minimum breakdowns and stoppages during the manufacturing process.
4. For maximum juice extraction and evaporation procedure optimum imbibition's, minimum heat and energy losses, well calculated co-ordinate heat energy utilization are necessary for mill-boiler houses.
5. Overall sugar recovery is an important factor in the profitability level of sugar manufacturing units. Use of best equipment, Proper and planned preventive and shutdown maintenance.
6. As much as possible, it is advisable to protect the cane spillage by proper unloading of cane on cane tables. "Prevention is better than curing." Once spillage occurred, the cane must be collected on time and immediately feed to the cane table, because the effect of microbial activity increases with time.
7. If the spilled cane became infected, it is not recommended to put it into operation since it is considered as multiplying microorganisms/bacteria for the fresh cane. The current area of collecting cane left unloaded is far from cane table, it needs to be changed to place near the cane table.
8. Bagasse thickness sensors are important in the chute and so as to have uniform bagasse feeding to the rollers. Because uniform flow bagasse would increase the extraction of juice in the milling train.
9. More attention should be taken at a milling plant which are not physically visible during operation, but highly affect the extraction process and capacity. These are: Appropriate trash plate position (this affects juice drainage and bagasse re-absorption), the optimum clearance between rollers, optimum roller speed and the size of each roller, because the size of roller shell would decrease as the time goes.

CHAPTER THREE

3. MATERIALS AND METHOD

The methodology that would be followed to evaluate the performance of sugar cane milling plant was going to be conducted by primary and secondary data collection methods. Primary data collection means performing a laboratory work and then analyzing and discussing the results we obtained. When it comes to secondary method it includes literature survey, internet serf, data and information gathering, industry survey, peer discussion and interview.

3.1 Materials

Materials like prepared cane, bagasse, intermediate mill bagasse, return bagasse (Cush-Cush), primary juice, intermediate mill juice, mixed juices, last mill juice, distilled water, Sample measuring cylinder, beakers, funnels, stirrer road, flasks, wet disintegrator (Jeffico Grinder), high pressure vacuum ovens, hydraulic press, plastic bags, plastic containers for sampling and sample preparation.

Horne's Dry Lead acetate, filter aid and Whattmann No. 91 filter paper would be used to clarify the samples for analysis of polarization. Weighing balance, refractometer and saccharometer, have been used for measurement of the samples; the material obtained from sugar corporation research center and wonji-Shoa sugar factory.

3.2 Methods

3.2.1 Study Variables

Study variables were variables that studied during the research work; those variables are dependent or independent variables. Such variables were hydraulic pressure, quantity of imbibition water flow rate, pol (sucrose) % of bagasse and moisture % of bagasse. The first two are input or independent variables and the rest two are output or dependent variables, they are also called response variables. Variation or change on input variables was affected the output variables that mean a change of hydraulic pressure would affect both output variables pol % and moisture % of bagasse. In similar way a change on quantity of imbibition water flow rate on the bagasse had also affect moisture and pol % of bagasse.

3.2.2 Study Design

Two portion of study had been designed on this study, first the performance evaluation of sugar cane milling plant. During this study the quantitative analysis of maximum loss areas was identified, this was done by analyzing bagasse and juice samples on each mill sections. Secondly, after identifying the most loss areas, process optimization were done for the loss of sugar would be minimum. The study was done by varying the application of hydraulic pressure and quantity of imbibition water flow rate on the last mill for the output of pol and moisture content of final leave bagasse.

3.2.3 Sample Receptacles

Plastic, stainless steel or copper receptacles were used. They were cylindrical in shape to facilitate handling and cleaning and of sufficient capacity to hold enough samples for the desired sampled period. The containers were cleaned, sterilized by means of a steam jet and dried before used. At least two sets of containers were available so that they were drained completely after washed. Their lids tightly fitted to prevent evaporation of the samples. Permanent labels (marking) were painted on the containers for easy identification.

3.2.4 Design of Sample Taking Devices

Sampling devices should be designed according with (Kass H., 2010). The sample taken was representative and proportional to the total quantity of the material processed during the sampling interval. The sampling devices were self- cleaning as possible and can be cleaned easily, they were not subjected to mechanical fail as well. It also protected from evaporation or moisture absorption. In the process of juice sampling the container were rinsed with a portion of samples before filled up. All receiving vessels and carries were well fitted lids and preservative was added to bucket at the rate of 0.5 ml mercuric chloride per liter of the expected final volume, at the state of each sampled period. The sampling apparatus and containers were conscientiously cleaned and dried at the end of every sampled period. The samples were thoroughly mixed before transferred to another container, i.e., when transferred to carrier vessels or after each hour replaces the sample bucket with a cleaned one, and conveyed the sample to the laboratory. Then the samples were again mixed in the laboratory before screened in to smaller vessels. A composite was made by taking a proportional volume (mass) per ton of mixed juice. Preservative was added and the sample is stored in a glass jar in the refrigerator for the 8 or 24-hour analysis. The remaining part of the sample is analyzed two-hourly for purity and pH.

3.2.5 Juice and Bagasse Sampling Methods

3.2.5.1 Mill Juice Sampling

In mills where juice flow into an open gutter, it can be sampled automatically by means of oscillating spoon or revolving juice wheel. If automatic sampling was not possible catch samples was taken manually every 15 minutes and composited in a bucket during the 2 hours of sampling period. In this case the sample was taken from the gutter at a spot as remote as possible from the rollers since the flow of the juice in the gutter helps rendering it homogeneous. The sample was taken at regular frequent intervals so that a volume of 2-3 liters is obtained when the test was completed within 2 hours sampling period.

3.2.5.1 Bagasse Sampling

The purpose of bagasse sampling and analysis was to know sugar loss in bagasse which was directly associated with the material balance, moisture in bagasse and fiber % bagasse. Bagasse should be sampled as soon as it leaves the last mill and across the whole length of the roller and through the full depth of the bagasse blanket. The sample was collected every 2 hours. About four or five successive samples was taken at least in 5 minutes and thoroughly mixed, making sure that fine particles are not separated out to form a composite sample. From large enough representative samples, 2 kg sub-samples were collected in a covered sample bucket or plastic bag. Last expressed juice should be simultaneously sampled. As soon as the sampling test is completed the composite sample of bagasse, which should weigh about 2kgs was taken without delay to the laboratory, well mixed and analyzed. Bagasse from the 2nd and subsequent mills was usually sufficiently well disintegrated to yield reliable results when analyzed. But1st mill bagasse frequently contains large pieces of crushed cane. If these are quickly tear apart and mixed with the rest of the sample a reliable measure of accuracy was preserved. However, the results of analysis of 1st mill bagasse must be accepted with reservation.

3.2.6 Determination of Brix in Factory Products

Method: - The unit of Brix, which has been in common use in the sugar industry for many years, is intended to represent the dry substance content % m/m. The convenience in the use of Brix hydrometer has lost favor in sugar industries due to the rough approximate nature of the results obtained specially in low purity sugar products. Today sugar industries of the world have replaced the hydrometer measurement by Refractometric method in which the result of the later is closer to the true dry substance. But, the refractometric dry substance (RDS %) is still higher than the true dry substance obtained by official method oven drying GS 4/7-11. However, the term Brix continues to be used in parts of the sugar industry, even though ICUMSA (International Commission for Uniform Methods of Sugar Analysis.) recommended that its use to be discontinued. The method of determination of refractometric dry substance in sugar products is accepted by ICUMSA in GS4-13 1994.

Principle: - The refractive index of aqueous sugar solutions depends upon the amount of dissolved material and can therefore serve as measure of the sugar for pure sucrose content. However, the non-sugars present in the sugar products influence the refractive index in a different way to sucrose. For these reasons, the measurement of refractive index can be still utilized for an approximate determination of the dry substance content of solutions containing mainly sucrose. Measurements are generally carried out with sugar refractometers graduated in % sucrose (g/100 g)

3.2.6.1 Factors influence Brix Reading

i. Temperature: **-** The sample has to be brought till about room temperature in order to avoid undesired change during measuring.
ii. Suspended matter: **-** Turbid juices, such as mixed juice have to be left for some times for giving the suspended matter opportunity to settle before measuring the Brix.

iii. Air bubbles: - The juice has to be left for some time in order to become de-aerated, if necessary under vacuum.

Figure 3.1: Brix refract meter

3.2.7 Determination of Pol in Factory Products

Method: - The polar metric method of determination of Pol in sugar products is the officially accepted method in the sugar work throughout the sugar world. The method is based on the New International sugar scale adopted by ICUMSA (International Commission for Uniform Methods of Sugar Analysis.) in 1986, that is 100 ^{0}Z point is the optical rotation of the normal weight of sucrose (26 g weighed in air with brass weight), dissolved to 100 mL, polarized at the wavelength of the green line of the mercury isotope ^{198}Hg, wavelength = 546.2271 nm at 20 ^{0}C, in a tube length of 200 mm. for sugar products which need clarification, the Horne's dry lead method of clarification of the sample is preferable which is used almost exclusively in all modern sugar industries. In the Horn's method of clarification of the sample, the presence of insoluble matter in the juice is of no consequence. The Schmitz's method demands the establishment of correct volume on two occasions, 100 and 110 ml and evolves and error due to the volume of lead precipitate. In all cases, care should be taken to avoid the use of excessive lead acetate for clarification. The danger of over leading is greater in dry lead than in wet lead, particularly if the dry lead is not finely divided and readily soluble. In lead clarification, there always some change of volume error and some combination with any laevulose present. However, still lead acetate is accepted as the best clarifying agent for general laboratory purpose.

Principle: - Light is a form of electromagnetic radiation, which consists of trains of wave vibrating transversely. A beam ordinary light is made up of planes vibrations that proceed in an infinite number of planes. However, light can be made to vibrate entirely in a single plane by use of certain devices like Nicole prism. Such light is said to be plane polarized or Linear polarized. When the plane polarized light passes through a certain media, the orientation of the plane is changed. A special material causes the change of the plane, which is optically active. When a ray of polarized light passes through any given sugar solution the amount of rotation varies with the concentration of the solution, the length of the cell, the wavelength of the light, and the temperature. By having a fixed length of cell, standard temperature, standard weight, standard volume, and standard light source the rotation becomes a function of the concentration of the sugar in the solution, which is known as direct polarization or pol. The property of different sugar solution (optical activity) is not the same in nature. A substance which their solution rotates planes of polarized light towards the right (clockwise) are known as Dextrorotatory. And those towards left (anticlockwise) are Laevorotatory. The specific rotation of the main sugars is:

Table 3.1**:** Specific rotation of the main sugars

s/n	Description	Angle of rotation
1	Sucrose	+ 66.54 ^{0}arc
2	Dextrose	+ 52.50 ^{0}arc
3	Laevulose	- 92.50 ^{0}arc
4	Invert	- 20 ^{0}arc

**(+) degree rotation in clockwise direction. *(-) degree rotation in anti-clockwise direction*

The value pol obtained by direct polarization is the resultant of optical rotation of all optically active substances present in the solution. It can indicate the true measure of sucrose only when no other optically active substance present in the solution rather than sucrose.

For any substance of known specific rotation, the concentration of that substance in a solution may be determined by observing the rotation of polarized light as the solution is tested in a polariscope tube of known length with correct combination of temperature and light. This is the basic principle of calibration of the modern polariscope known as Sacchrimeter. A saccharimeter is a polarimeter graduated not in angular degree, but with an evenly divided scale calibrated to read from -100^0 to $+100\ ^0Z$,

The angular rotation corresponding to the $+ 100\ ^0$ mark is that of a standard concentration m/v of sucrose in water tested under standard conditions. The pol readings on the scale may then be interpreted directly as concentration as m/v of sucrose in water.

For the determination of the m/m pol % of the juice or similar liquors by direct polarization, clarification of the sample either with Horne's dry lead or wet lead solution is carried out prior to polarization. But, the Horne's dry lead method is more preferable.

$$\text{Pol }\% = \text{Pol Reading} \times \text{Pol Factor} \quad \textbf{(3.1)}$$

(a) Clarified juice (b) Polarimeteric instrument

Figure 3.2: Clarified juice and Polarometeric instrument

3.2.8 Determination of Brix and Pol Content Bagasse

Cold digestion method:

The apparatus used for this method were heavy duty, readable 0.01g balance, wet disintegrator or bagasse digester and 200 mm pol tube saccharometer. The reagents that used were basic lead acetate, filter aid or acid washed sodium carbonate solution of 5 % and Whatman No 91 or equivalent diameter 185 mm filter paper as a reagent and materials. The lead acetate was confirming to the international commission uniform methods of sugar analysis specification.

Procedure:

By weighing through electronic weight balance, each 200 g of bagasse were taken for each testing. For each test 2000 ml of water was collected in a measuring cylinder. Then after each 200 g of bagasse were mixed with the collected 2000 ml of water and the total contents are poured in a wet disintegrator and are run for around 10 minutes which was sufficient to bring out a consistent liquid. Now, a sample of 200 ml from the wet disintegrator were taken and 2 g of basic lead acetate was added , then after transferring the contents in a beaker contained in the string and filtering of the solution. Then the filtrates were taken in a 400 mm pol tube. The zero point of the polariscope was determined before any observation was made. This was done by turning the screw controlling the quartz wedge until a uniform faint tint was obtained. Then the pol tube was placed in the trough of the polariscope and readings from the main scale and vernier scale were noted down.

$$\text{Pol \% Bagasse} = \text{Pol Reading}\ (2.6 + 0.0026\ \text{M}) \qquad \textbf{(3.2)}$$

(a) Wet disintegrator (b) Distilled water

Figure 3.3: Preparation of bagasse extract on wet disintegrator

3.2.9 Determination of Moisture Content of Bagasse (Dry Substance % Bagasse)

Procedure:

The apparatus used for the determination of moisture and dry substance and fiber content of bagasse were heavy duty balance, drying oven and moisture teller complete with sample pans. Fist weighed the clean, empty drying oven sample container and recorded the mass (m_1). Then about 100 g of bagasse from the sample in a plastic bag to the empty container were added and evenly distributed over the sieve and weighed. Recorded the mass of the container plus or bagasse (m_2). Transferred the container with the wet sample of bagasse in the drying oven (moisture teller) then placed the sample pan in a moisture teller and set the temperature for 127^{o}C (260^{o}F). Dry for 45 minutes until constant weight. The accepted weight loss after re-drying for 5 min is not more than 0.1 g. Then finally, weighed the hot container plus dried bagasse sample without any delay (to avoid errors due to absorption of moisture by the hot sample) and record the mass (m_3).

$$\text{Moisture \% Bagasse} = \frac{m_2 - m_3}{m_2 - m_1} * 100 \qquad \textbf{(3.3)}$$

where: m_1 is the weight of the empty container

m_2 is the weight empty container plus the sample

m_3 is the weight empty container plus dried sample

Dry substance % bagasse = 100 – moisture % bagasse

The fiber content of bagasse was given by the following expressions:

$$F = \frac{D - 4\ be}{1 - 0.00125\ be} \qquad \textbf{(3.4)}$$

Where D is the dry mater content of bagasse

be is the refractometer Brix reading

(a) Prepared bagasse (b) Moisture teller

Figure 3.4: Prepared bagasse & moisture teller

3.2.10 Determination of Preparation Index (PI)

Method: - The method is based on the determination of preparation index of cane by measuring the extent of cell rupture. It is used to obtain the empirical measure of the degree of preparation of cane, which is accepted by ICUMSA in general subject – 7 (GS7 – 3 1994). The method can be applied to a sample of prepared cane after knives or shredder. It is not suitable for samples, which contain large pieces of unprepared cane and is therefore restricted to a shredded cane or well knifed cane.

Principle:- The method asses the degree of cane preparation of measuring the extent of the rupture of the cells in the prepared cane, established by mixing the cane and water for a preset time and measuring the concentration of dissolved solids in the extract from a wet disintegrator in which it is assumed that all cells are ruptured. The result of the test is only comparable if the procedure is carried out precisely.

Procedure:

The apparatus used for the determination of preparation index were; Tumbler with driving mechanism, Refractometer with accuracy 0.01 degree Brix, Wet Disintegrator – water jacketed sieve 200 mm diameter and 1.2 mm mesh opening and Heavy duty balance. Filter aid or acid washed used for filtration of the extract before Brix determination and Whatman No. 91 or equivalent diameter 185 mm filter paper was used as reagents. Then the procedures followed for the preparation index was first weighed 500 g of prepared cane in the tumbler from the sample collected for the analysis. 1500 g of water were added and screw on lid, and rotated the number for 30 minutes, ensuring that there was no leakage on the lid. Sieved out the extract into 500 ml bottle and discarding the first 100 ml of the sieved extract. Then after, transferred 100 ml of the sieved extract to a 300 ml bottle; add about 1 g of filter aid and shake to disperse. Transferred the solution to the filtration funnel supported by the run of the beaker. Cover the funnel with a watch glass to minimize evaporation. Discarded the first 100 ml filtrate and collected about 25 ml. Measured its Brix on precision refractometer (B_1). A portion of prepared cane from the sample collected for analysis in similar way were taken and disintegrated in jeffeco cutter to insured a full opening of the cells. About 1 kg of the Disintegrated cane was weighed in a wet disintegrator bowl and then added 3 kg of water and digest for 20 minutes. Sieved out the extract, cool to 20 degree centigrade and determine its Brix with refractometer (B_2)

$$PI = \frac{B_1}{B_2} \times 100 \qquad \textbf{(3.5)}$$

3.2.11 Determination of Brix-Free Water on Fiber

Determination of Brix free water was conducted by Mangion and Player (1991) Method.

$$\text{Brix Free Water \%} = \frac{\frac{W_4\,(1 - P_4)}{P_3}}{W_3} \qquad \textbf{(3.6)}$$

Where: W_3 is the mass of fiber sample, P_3 is the brix of sucrose solution before mixing of fiber. W_4 is the mass of sucrose contact solution, P_4 is the brix of sucrose solution after mixing of fiber

Procedures:

First, 20 g of sucrose free fiber was weighed. The fiber was dried out at vacuum at 80 degree cilices and at 825mbar for 3hours. Then 10 degree Brix sucrose solutions were prepared, by taking 220 g of sugar with 2000 – 2500 ml of distilled water. Then 500 g of sucrose contact solution in to a beaker was taken each sample. The dried sucrose free fibers were added to this solution. For one and half hours mixed out the dried fiber with the prepared sucrose solution continuously.

The samples were Extracted and filtered through 91 Whattman filter paper, for determination of pol after mixing and prior to brix determination.

(a) Prepared sucrose free fiber (b) H ydraulic press (c) 10^0 Brix sucrose solution

Figure 3.5: Hydraulic press, sucrose free fiber and sucrose contact solutions

Table 3.2**:** Standard values for five milling tandem unit fiber analysis (Kent, 2001)

s/n	Product stream	Fiber %
1	Cane	14
2	1^{st} mill bagasse	30
3	2^{nd} mill bagasse	36
4	3^{rd} mill bagasse	41
5	4^{th} mill bagasse	44
6	5^{th} mill bagasse	47
7	Expressed juice	2, 3
8	Return stream	8, 12

Extraction is affected by the percentage of fiber. The greater the amount of fiber will be the less the extraction for the same milling efficiency. Mills handling high fiber cane is at a disadvantage. To eliminate the influence of fiber Noel Deer suggested that all extraction for comparative purpose be corrected to standard fiber content 12.5 % and this is adopted by most of sugar authorities.

3.2.12 Estimation of Extraction Performance Parameters

The extraction performance parameters of WSSF of the milling plant were estimated by the equation 2.2, 2.4 and 2.7 above in literature part of this study. The work openings of each mill were determined by using equation 2.3 (Dowes Dekker and Van Hengel (South Africa). The respective estimated values of work opening, filling ratio, reabsorption factor and imbibition coefficient was shown in the table 3.3, 3.4, 3.5 and 3.6 respectively. The no- void volume and fiber loading was determined by using equation 2.5 and 2.6 respectively.

Table 3.3**:** Calculated values of work opining of top rollers

s/n	Mill type	Length of top roller (m)	Surface speed of top roller (m/min)	Work opining of top roller (m)
1	1st mill	2.134	7.63	0.032
2	2nd mill	2.134	7.63	0.029
3	3rd mill	2.134	7.63	0.021
4	4th mill	2.134	7.63	0.019
5	5th mill	2.134	7.63	0.017

Table 3.4**:** Filling ratio of each five mills

s/no.	Mills	Volume rate of Cane fiber (m^3/hr.)	Speed of mill roller (n) rpm	Escribed volume (L*W*S)	Filling Ratio
1	mill 1	22.16	3.4	31.26	0.71
2	mill 2	20.82	3.6	28.33	0.73
3	mill 3	19.47	3.8	20.52	0.95
4	mill 4	18.13	4.0	18.56	0.98
5	mill 5	18.00	4.2	16.61	1.08

Table 3.5: Reabsorption factor for each five mills

s/no.	Mills	No void volume rate of bagasse (m^3/ton)	Escribed volume (L*W*S)	Fiber Loading 'q' (kg/m^2)	Reabsorption factor
1	mill 1	0.941	31.26	15.10	0.04
2	mill 2	0.938	28.33	14.24	0.03
3	mill 3	0.924	20.52	13.49	0.05
4	mill 4	0.919	18.56	12.80	0.05
5	mill 5	0.916	16.61	12.20	0.06

Table 3.6**:** Imbibition coefficient for each five mills

s/no.	Mills	Actual brix extraction	Theoretical brix extraction	Imbibition coefficient (average)
1	1st	0.9045	3.62	0.25
2	2nd	0.448	3.19	0.14
3	3rd	0.5597	2.09	0.27
4	4th	0.288	1.06	0.27
5	5th	0.388	1.04	0.37

3.2.13 Brix Extraction along Milling Train

All the respective samples of bagasse and juice were taken from each milling unit across the tandem and analyzed in the research and development center laboratory with the same procedure as hand book of laboratory methods and chemical control for Ethiopian sugar factories (kassa H. 2010). Then after the Brix extraction for each milling unit determined according to Researcher (Omker P Thaval: September 2012) method.

Table 3.7**:** Analysis result of Brix and fiber % bagasse of each mill unit

Brix % cane = 20		Fiber % cane = 13.43		
s/n	Mill type	Brix % juice	Brix % bagasse	Fiber %
1	1^{st} mill	17.38	3.62	25.45
2	2^{nd} mill	10.27	3.19	27.25
3	3^{rd} mill	6.11	2.09	36.84
4	4^{th} mill	4.62	1.06	39.11
5	5^{th} mill	2.98	1.04	41.24

First mill Brix extraction:

$$E_{b1} = \frac{\left\{\frac{\text{brix \% cane}}{\text{fiber \% cane}} - \frac{\text{brix \% }1^{st}\text{ mill juice}}{\text{fiber \% }1^{st}\text{ mil bagasse}}\right\}}{\frac{\text{brix \% cane}}{\text{fiber \% cane}}} \quad \textbf{(3.33)}$$

Second mill Brix extraction:

$$E_{b2} = \frac{\left[\frac{\text{brix \% }1^{st}\text{ mill juice}}{\text{fiber \% }1^{st}\text{ mill}} - \frac{\text{brix \% }2^{nd}\text{ mill juice}}{\text{fiber \% }2^{nd}\text{ mill}}\right]}{\frac{\text{brix \% }1^{st}\text{ mill}}{\text{fiber \% }1^{st}\text{ mill}}} \quad \textbf{(3.34)}$$

Third mill Brix extraction:

$$E_{b3} = \frac{\left[\frac{\text{brix \% }2^{nd}\text{ mill juice}}{\text{fiber \% }2^{nd}\text{ mill bagasse}} - \frac{\text{brix \% }3^{rd}\text{ mill juice}}{\text{fiber \% }3^{rd}\text{ mill bagasse}}\right]}{\frac{\text{brix \% }2^{nd}\text{ mill juice}}{\text{fiber \% }2^{nd}\text{ mill juice}}} \quad \textbf{(3.35)}$$

Fourth mill Brix extraction:

$$E_{b4} = \frac{\left[\frac{\text{brix \% } 3^{rd} \text{ mill juice}}{\text{fiber } 3^{rd} \text{mill bagasse}} - \frac{\text{brix \% } 4^{th} \text{ mill juice}}{\text{fiber \% } 4^{th} \text{ mill bagasse}}\right]}{\frac{\text{brix \% } 3^{rd} \text{ mill bagasse}}{\text{fiber \% } 3^{rd} \text{ mill bagasse}}} \quad (3.36)$$

Fifth mill Brix extraction:

$$E_{b5} = \frac{\left[\frac{\text{brix \% } 5^{th}\ 4^{th} \text{ mill juice}}{\text{fiber \% } 4^{th} \text{ mill bagasse}} - \frac{\text{brix \% } 5^{th} \text{ mill juice}}{\text{fiber \% } 5^{th} \text{ mill bagasse}}\right]}{\frac{\text{brix \% } 5^{th} \text{ mill juice}}{\text{fiber \% } 5^{th} \text{ mill bagasse}}} \quad (3.37)$$

3.2.14 Milling Plant Pol Extraction

The following parameters Brix, pol, fiber and moisture %, were obtained from laboratory analysis result of the milling plant of first to last mill. The data were used to calculate the pol extraction of each mill in the milling train in the tandem. This calculation would help to know and to differentiate the performance of each mill in the tandem. By using the following values the pol extraction of each mill was determined from equation 3.33 to 3.37 step by step.

Pol % cane = 20

Fiber % cane = 13.5

1st mill discharge roller juice Brix % = 20.45

1st mill discharge roller juice pol % = 18.3

2nd mill discharge roller juice Brix % =13.62

2nd mill discharge roller juice pol % = 12.86

3rd mill discharge roller juice Brix % =10.84

3rd mill discharge roller juice pol % = 9.56

Moisture % 1st mill bagasse = 70.3

Moisture % 2nd mill bagasse =73.8

Moisture % 3rd mill bagasse =62.8

Moisture % 4th mill bagasse =60.65

Moisture % 5th mill bagasse = 50.6

4th mill discharge roller juice Brix % = 7.85

4th mill discharge roller juice pol % =7.02

5th mill discharge roller juice Brix % =4.08

5th mill discharge roller juice pol % = 3.79

Pol % 1st mill bagasse = 10.16

Pol % 2nd mill bagasse =7.34

Pol % 3rd mill bagasse =4.61

Pol % 4th mill bagasse =3.83

Pol % 5th mill bagasse =2.78

Purity of 1st mill discharge juice = 90.36

Purity of 2nd mill discharge juice = 94.48

Purity of 3rd mill discharge juice = 89.21

Purity of 4th mill discharge juice = 91.17

Purity of 5th mill discharge juice = 94.02

Pol Extraction of n^{th} Mill

$$\text{Brix \% bagasse } n^{th} \text{ mill} = \frac{\text{Pol \% bagasse } n^{th} \text{ mill}}{\text{Pty discharge roller juice } n^{th} \text{mill}} \times 100 \qquad (3.39)$$

$$\text{Fiber \% bagasse } n^{th} \text{ mill} = 100 - (\text{Moisture \% bagasse } n^{th} \text{ mill} + \text{Brix \% bagasse } n^{th} \text{ mill}) \qquad (3.40)$$

$$n^{th} \text{ mill bagasse \% cane} = \frac{\text{Fiber \% cane}}{\text{Fiber \% bagasse } n^{th} \text{ mill}} \times 100 \qquad (3.41)$$

$$\text{Pol in } n^{th} \text{ mill bagasse \% cane} = \frac{\text{Pol \% bagasse } n^{th} \text{ mill} \times n^{th} \text{ mill bagasse \% cane}}{100} \qquad (3.42)$$

$$\text{Pol in } n^{th} \text{ mill juice \% cane} = \text{Pol \% cane} - \text{Pol in } n^{th} \text{ mill bagasse \% cane} \qquad (3.43)$$

$$n^{th} \text{ Mill pol extraction} = \frac{\text{Pol in nth mill juice \% cane}}{\text{Pol \% cane}} \times 100 \qquad (3.44)$$

Table 3.8: Five years average data taken from WSSF

Description	2013/2014	2014/2015	2015/2016	2016/2017	2017/2018	Average
Cane crashed/year ($\mathbf{Q}_{ts}$)	6,816,705	9,060,895	8,127,917	7,680,365	6,064,321	7,550,040.6
PI %	86.10	85.5	86.40	85.40	86.20	85.92
Moisture % bagasse	51.20	52.35	49.21	51.13	52.12	51.20
Imbibition % cane	29.10	29	30	29	29.10	29.24
Bagasse Brix %	0.89	1.01	0.79	0.98	1.20	0.97
Field yield %	12.82	12.64	12.15	11.27	10.89	11.95
Factory yield %	11.81	12.24	12.25	10.80	10.07	11.43
Wt. of mixed juice ($\mathbf{Q}_{ts}$)	3,210,277.26	3,410,347.45	3,340,034.98	3,124,119.7	3,034,567.63	3,223,869.4
Brix % of mixed juice	16.91	17.02	16.92	17.30	16.81	16.99
Pol % of mixed juice	15.47	16.01	15.47	16.43	15.19	15.71
Fiber % cane	13.41	13.29	13.55	13.84	13.04	13.43

Purity last expressed juice	74.00	75.90	68.40	77.40	72.01	73.54
Pol % bagasse	1.56	1.71	2.30	2.40	2.13	2.02

*****PI- is the cane preparation index. *Q_{ts}. – quintals of cane crashed per year. *Wt. = weight

$$\text{Weight of Bagasse} = \text{Weight of Cane Crashed} + \text{Weight of Imbibition} - \text{Weight of Mixed Juice}$$

3.2.15 Quantitative Analysis of Milling Losses before and after Optimization

The quantitative analysis of milling losses before and after optimization was done by using equation 7.1 to 7.26 in the appendix – G, and substituting the values step by step. The milling losses before optimization was done for the existing plant and after optimization was done by optimizing the pol and moisture content of the last mill bagasse. Then after, the recovery of money after optimization through the real values was estimated.

Table 3.9**:** Quantitative values of milling losses before and after optimization

Description	Unit	Before Optimization	After Optimization
Pol % bagasse	%	2.02	1.63 – 1.88
Moisture % bagasse	%	48 - 53	50.47 – 51.00
Brix % bagasse	%	2.75	2.56
Sucrose in bagasse % cane	%	1.75	1.63
Brix % absolute juice	%	13.46	14.49
Absolute juice % cane	%	60.15	59.98
Absolute juice extracted % cane	%	53.90	54.78
Mill extraction	%	79.33	81.48
Reduced mill extraction	%	97.11	96.86
Extraction ratio	%	153.91	145.35
Milling loss	%	4.39	4.06
Weight of sucrose in bagasse	Q_{ts}	131,982.82	122,835.50

3.2.16 Recovery of Money after Optimization through Real Values

Milling loss before optimization = 4.39 %

Milling loss after optimization = 4.06 %

Recovery of sugar = 4.39 – 4.06 = 0.33 %

For cane crashed per year, 7,550,040.6 Q_{ts}

Sugar recovered = 7,550,040.6 * 0.33 % = **24,915.13** Q_{ts} / year

Cost estimation (saving of money)

Unit cost of sugar = 20 ETB per KG

24915.13 Q_{ts} / year = 24915.13 Q_{ts} / year * 1000 KG/ Q_{ts} = 24,915,130 KG /year

Therefore, saving in ETB is = 24915130 KG /year * 20 ETB / KG

= **498,302,600 ETB**

CHAPTER FOUR

4. RESULTS AND DISCUSION

4.1 Laboratory Analysis Result

The analysis methods used in this study for each sample are listed in the table below. The method numbers refers to Ethiopian Sugar Factory Laboratory manual for sugar mills (Kassa H., 2010). A digital refractometer and polarmeter was used to measure the Brix and pol content of the juice samples respectively from the bagasse and Cush –Cush disintegrator extracts and from the juice samples. The juices were analyzed as soon as possible or else preservation was added and kept in to refrigerator so as to minimize the inversion or degradation of sucrose by the action of microorganisms, as the time goes reproduction of microorganisms on sucrose solution is very high. The most important parameters that were done in the juice and bagasse laboratory analysis result were Brix, pol, moisture, and fiber and purity percent for each sample.

4.1.1 Bagasse Analysis Result

The pol %, Brix % and moisture % of the bagasse from first milling unit and return bagasse (Cush -Cush) were analyzed and shown in the table 4.1 & table 4.2 respectively.

Table 4.1**:** Analysis result of Return bagasse (Cush -Cush)

Days	Moisture %	Pol % bagasse	Brix %	Fiber %
day 1	79.27	9.68	0.46	18.90
day 2	75.10	12.77	0.77	21.84
day 3	74.30	13.97	0.76	22.68
day 4	71.55	14.93	0.72	25.59
day 5	72.50	15.14	0.72	24.64
Average	74.54	13.30	0.67	22.73

Table 4.2**:** First mill bagasse analysis result

Days	Moisture %	Pol % bagasse	Brix %	Fiber %
day 1	58.60	9.63	3.62	26.92
day 2	60.40	9.65	3.67	24.92
day 3	57.60	11.36	3.61	27.96
day 4	57.75	12.54	3.65	27.65
day 5	58.15	10.95	3.63	27.33
Average	58.50	10.83	3.64	26.96

From the ideas explained in the literature review part in section 2.6 above, the material should be returned to the cane or bagasse stream that is closest to the Cush-Cush in of the juice Brix, which case returning Cush-Cush after the first mill is probably the better option. Now for this study, this was not true because the first mill juice Brix was 17.38 % in the table 4.3 below, but the brix content of return bagasse (Cush-Cush) was very small. As we have seen from the experimental result from table 4.1 and 4.2, the pol % of return bagasse was greater than first mill bagasse, For example in day 4 and 5, the pol % of return bagasse was 14.93 and 15.14 respectively, but the pol % of fresh cane was from 15 – 21 %, then the pol % of return bagasse was approach to fresh cane, therefore it was better to recycle the return bagasse to prepared cane prior to the first mill because it was the duty of the first mill until some decrement on pol % of bagasse. This increment of pol % was due the concentration of the primary juice, While we return this Cush-Cush (return bagasse) directly to the point between the first and second mill this would increases the load to the second mill and disturbing the performance of the second mill and thereby decrease the extraction of the milling train. The optimum situation involves screening primary and secondary juice separately, returning the primary juice Cush-Cush to the cane before the first mill and the secondary juice Cush-Cush between the first and second mills. The other options to increase the efficiency of the milling plant is by screening the primary juice and secondary juice separately and return the respective primary Cush-Cush to prior to the first mill and the secondary Cush-Cush to between the first and the second mill. From the figure 2.8 existing milling plant flow diagram were modified to figure 4.1 proposed, by recycling of the Cush-Cush (return bagasse) to the recommended point for improving the milling house efficiency for the existing plant.

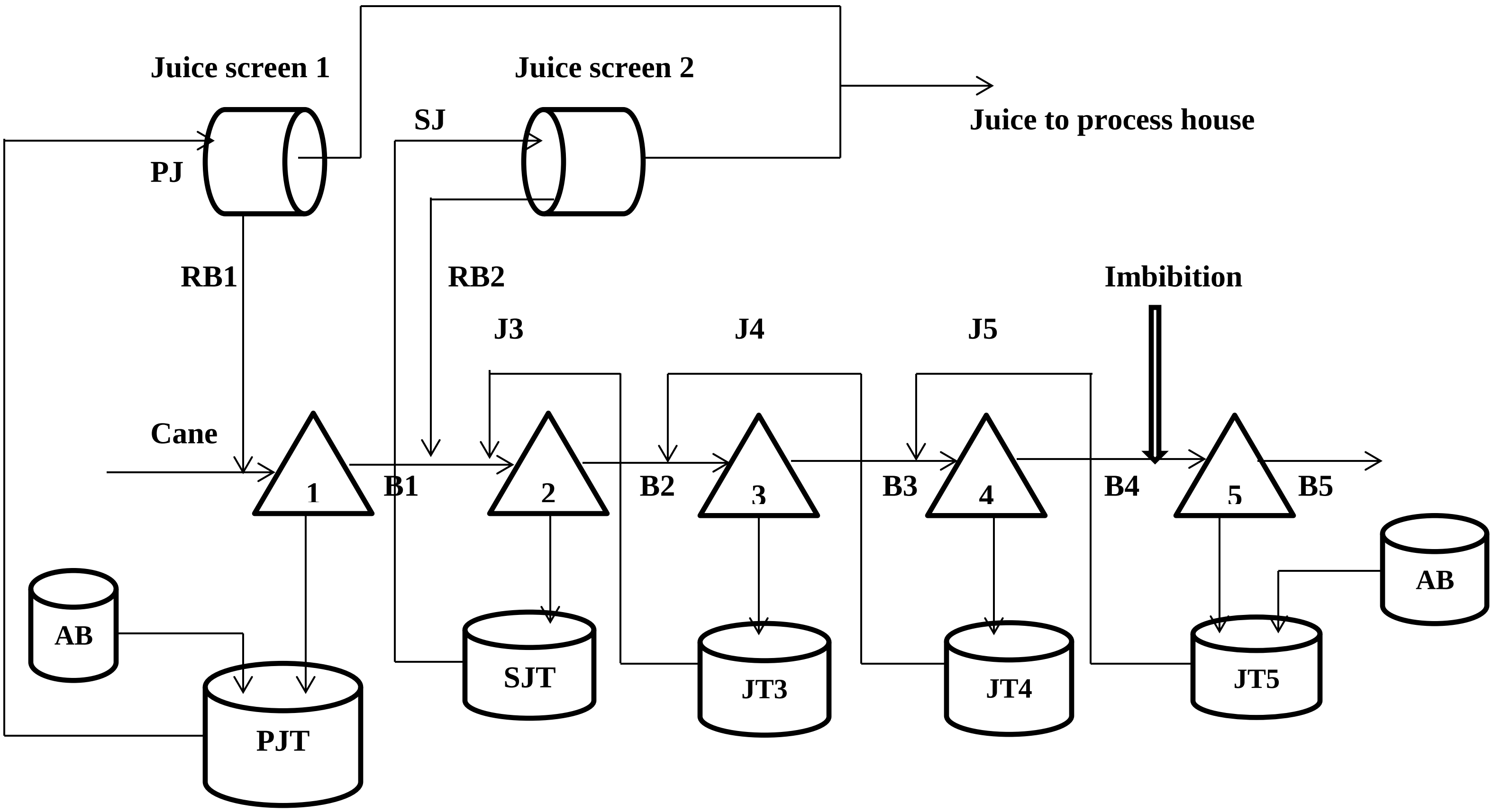


Figure 4.1: Proposed milling plant flow diagram

Keys Terms:

SJT – Secondary juice tank, **AB-** anti-bacteria, **B1-** 1st mill bagasse, **B2-** 2nd mill bagasse**, B3-** 3rd mill bagasse, **B4-** 4th mill bagasse, **B5-** 5th mill bagasse, **RB1-** return bagasse1, **RB2-** return bagasse 2, **J3-** 3rd mill juice, **J4-** 4th mill juice, **J5-** 5th mill juice, **PJT-** primary juice tank, **JT5-** 5th mill juice tank, **JT4-** 4th mill juice tank, **JT3-** 3rd mill juice tank, **PJ-** primary juice, **SJ-** secondary juice.

4.1.2 Juice and Bagasse Analysis Result for Existing Milling Plant

Juice and bagasse analysis for existing milling plant was analyzed. For juice analysis Brix and pol content of the mill juice for each milling section at existing condition of the milling plant were sampled and simultaneously analyzed and the results were shown in the table 4.3 and table 4.4 below.

Table 4.3**:** Mill juice analysis result

s/n	Juice type	Brix %	Pol %	Purity %
1	1st mill juice	17.38	14.93	85.93
2	2nd mill juice	10.27	8.83	85.90
3	3rd mill juice	6.11	5.22	85.43
4	4th mill juice	4.62	3.87	87.76
5	5th mill juice	2.98	2.47	82.89

Table 4.4**:** Bagasse analysis result of each milling unit

s/n	Bagasse type	Moisture % bagasse	Pol % bagasse	Brix % bagasse	Fiber %
1	1st mill bagasse	70.30	10.16	3.62	26.08
2	2nd mill bagasse	73.80	7.34	3.19	23.01
3	3rd mill bagasse	62.80	4.61	2.09	35.11
4	4th mill bagasse	60.65	3.83	1.06	38.29
5	5th mill bagasse	52.60	2.78	1.04	46.36

4.1.3 Analysis Result for First Expressed Juice and Mixed Juice Brix Content

The juice samples were analyzed with in four day trails, the samples were analyzed according to hand book of laboratory methods and chemical control for Ethiopian sugar factories (kassa H. 2010) and the analysis results was shown in the table 4.5 below. Then by taking the average values of each result the dray crashing milling factor were determined and that of undiluted juice % extracted were approximated with this factor (Chen and Chou, 1993). According to Chen and Chou, 1993: The dry milling or crashing factor for the case of WSSF was given by using average first expressed juice Brix % with mixed juice Brix %. For now the current first expressed juice Brix % is averagely 19.82**,** and that of mixed juice Brix % is averagely 16.57 then dry milling factors is 16.57 divided by 19.82 = 0.84. For the case of sample trials in the table 4.5 below, the undiluted juice Brix was given by: $\text{First expressed juice Brix \%} \times \text{Dry milling factor}$

Table 4.5**:** Analysis result of Brix % of first expressed juice and mixed juice

Sample trials	First expressed juice brix %	Mixed juice brix %
Trial 1	19.86	16.88
Trial 2	20.36	17.58
Trial 3	18.51	16.32
Trial 4	20.54	15.49
Average	19.82	16.57

4.1.4 Analysis Result of Brix Free Water on Cane Fiber

Determination of Brix-Free Water on Fiber was analyzed by Mangion and Player (1991) Method. The fibers were taken from the last mill of WSSF and prepared by using hydraulic press by pressing the bagasse to pressure at160 bar so as to remove the residual moisture and sucrose found on it. The result of fiber was free from any sucrose and moisture, because the methods were applied on bone dry cane fibers. The samples were analyzed for each 16 days and the results are shown in the table 4.6 below.

Table 4.6: Analysis result of Brix free water on cane fiber

Days	Mass of sucrose free fiber (m_3) g	Mass of sucrose contact solution (m_4) g	Brix of sucrose sol.(P_3) ° Brix	Brix of sucrose Sol.(P_4) ° Brix	Pol % of extract	Brix free water on fiber
day-1	20.00	500.00	10.00	9.93	41.95	17.50
day-2	20.00	500.00	10.00	9.93	42.07	17.50
day-3	20.00	500.00	10.00	9.93	42.02	17.50
day-4	20.00	500.00	10.00	9.84	41.43	40.00
day-5	20.00	500.00	10.00	9.81	41.46	47.50
day-6	20.00	500.00	10.00	9.81	41.70	47.50
day-7	20.00	500.00	10.00	9.81	41.62	47.50
day-8	20.00	500.00	10.00	9.77	41.48	57.50
day-9	20.00	500.00	10.64	10.49	45.91	35.20
day-10	20.00	500.00	10.64	10.55	45.80	21.10
day-11	20.00	500.00	10.64	10.52	44.97	28.20
day-12	20.00	500.00	10.64	10.57	45.34	16.40
day-13	20.00	500.00	10.09	10.03	42.16	14.90
day-14	20.00	500.00	10.09	9.98	42.56	27.30
day-15	20.00	500.00	10.09	9.99	42.86	24.80
day-16	20.00	500.00	10.09	9.97	42.55	29.70
Average						**30.63**

*P_3 – brix of sucrose solution before mixing with fiber. *P_4 – is brix of sucrose solution after mixing with fiber.

4.1.5 Analysis Result of Feed and Discharge Roller Juice of each Milling Unit.

The feed and discharge roller juice samples from the primary mill was sampled at each milling unit and throughout the length of roller. The samples were subjected to laboratory analysis for the parameters of Brix and Pol % feed and discharge roller juice. The samples was analyzed for three runs, for the first run : 10 juice samples was analyzed from first mill to last mill, for both second and third run the same juice samples was analyzed. The total of 30 feed and discharge roller juice samples were analyzed. The result was shown in the table 4.7 below.

Table 4.7: Feed and discharge roller juice analysis result

Mill juices	Type of rollers						
		Feed &Top rollers juice			Discharge &Top rollers juice		
	Sample runs	Brix%	Pol %	Purity	Brix %	Pol %	Purity
1st mill juice	Run-1	19.86	19.55	98.44	20.36	19.18	94.20
	Run-2	20.60	20.29	98.49	20.54	17.42	84.81
	Run-3	21.90	20.30	92.69	21.56	19.85	92.07
Average		20.25	19.92	96.54	20.45	18.3	90.36
2nd mill juice	Run-1	13.33	12.42	93.17	12.34	11.55	93.59
	Run-2	15.53	12.08	77.78	12.89	12.48	96.82
	Run-3	15.46	14.28	92.37	15.64	14.55	93.03
Average		14.77	12.93	87.77	13.62	12.86	94.48
3rd mill juice	Run-1	7.85	7.41	94.39	7.49	7.13	95.19
	Run-2	12.89	10.28	79.75	12.89	10.24	79.44
	Run-3	11.39	10.65	93.50	12.15	11.30	93.00
Average		10.71	9.45	89.21	10.84	9.56	89.21
4th mill juice	Run-1	4.19	4.13	98.57	4.75	4.65	97.89
	Run-2	9.83	7.94	80.77	10.12	8.19	80.93
	Run-3	8.31	7.79	93.74	8.67	8.21	94.69
Average		7.44	6.62	91.03	7.85	7.02	91.17
5th mill juice	Run-1	2.64	2.49	94.32	2.81	2.77	98.58
	Run-2	4.60	3.87	84.13	5.74	5.12	89.19
	Run-3	3.60	3.39	94.17	3.68	3.47	94.29
Average		3.61	3.25	90.87	4.08	3.79	94.02

4.1.6 Analysis Result of Primary, Mixed and Last Mill Juice

The samples were analyzed for consecutive 10 days, Brix and pol % of primary, mixed juice and last mill juice were analyzed according to (kassa H. 2010). Then the purity % was calculated by using Brix and pol % of juices. The analysis results were recorded as shown in the table 4.8 below.

Table 4.8**:** Analysis result of primary, mixed and last mill juice Brix, pol and purity%

Days	Primary juice			Mixed juice			Last mill juice		
	Brix%	Pol %	Purity%	Brix%	Pol %	Purity %	Brix %	Pol %	Purity %
day 1	21.55	19.33	89.70	16.88	14.68	87.00	2.15	1.72	80.00
day 2	22.54	20.00	88.70	17.58	15.28	86.90	4.37	3.48	79.60
day 3	20.10	17.65	87.80	16.32	14.11	86.50	3.90	3.03	77.70
day 4	18.51	16.52	89.20	15.49	13.31	85.90	2.72	1.86	68.40
day 5	20.16	17.83	88.40	17.61	15.47	87.80	3.38	2.50	74.00
day 6	20.60	18.56	90.10	18.01	16.01	88.90	4.45	3.64	80.80
day 7	21.12	18.10	89.50	17.43	15.47	88.80	3.04	2.45	80.60
day 8	20.24	17.89	88.40	18.20	16.43	90.300	2.97	2.37	79.80
day 9	20.63	18.41	89.20	16.79	15.05	89.60	2.58	2.02	78.30
day 10	19.90	18.23	91.60	17.21	15.19	88.30	2.90	2.20	75.90
Average	16.46	18.25	89.26	17.15	15.10	87.96	3.25	2.53	77.51

4.2 Juice Brix Curves

One of the best methods of controlling the milling plant is to construct a graph of the Brix of juices from the successive mills. The graph shows at a glance, the degree of dilution of each of the wet crashing unit and enables to recognize any departure from normal conditions. The degree to which the values obtained in the mills approach the theoretical curve indicates how well each mill was doing its work. In general the juice from the back roll is of higher Brix and greater purity than that from the front or feed roll because the feed roll extracts the superficial imbibition water on the exterior of the bagasse particles, whereas the back roll extracts part of the juice in the inner cells. The feed roller of the later mills with wet crushing should furnish about three fourths of the juice and the back roller only one fourth.

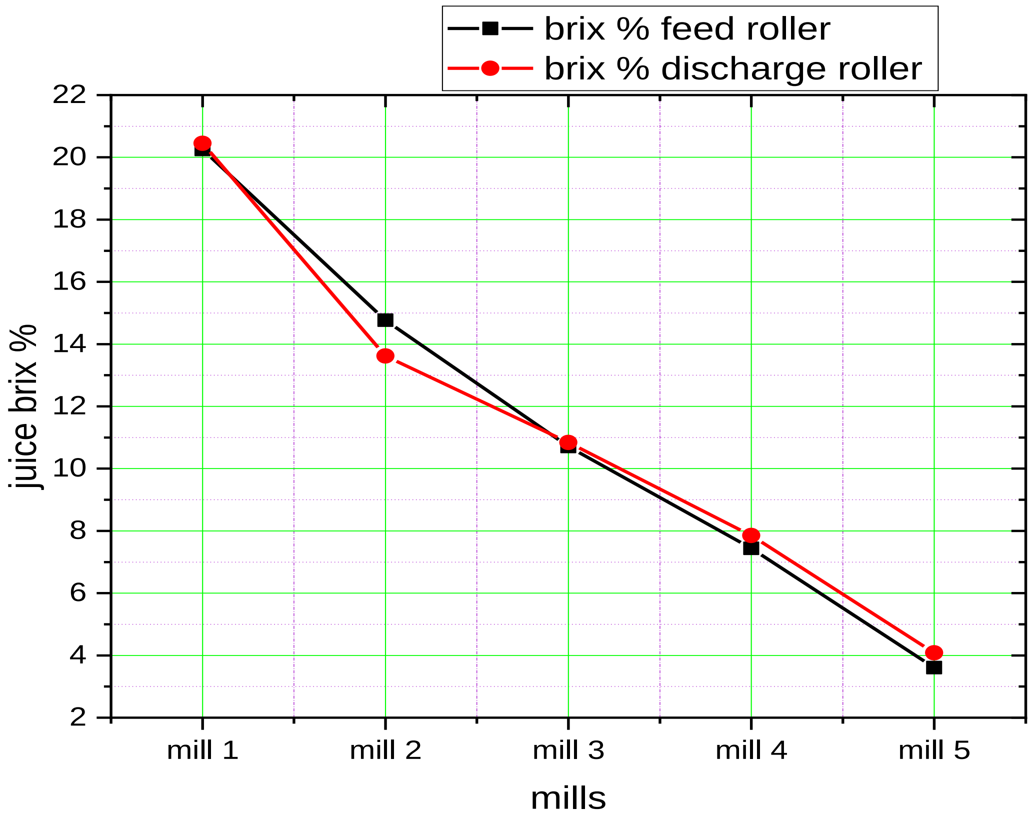


Figure 4.2: Juice Brix curve diagram of milling unit

From the graph above figure 4.2; the brix curve of the discharge roller was greater than the feed roller i.e. red curve was overlays the black one which indicates that the Brix extraction were normal. But when we come to the next mill or mill #2 the feed roller Brix curve overlays the discharge roller this shows as there were a problems on the second mill delivery setting. From the laboratory analysis result data shows for the second mill Brix % was about 14.77 % for feed roller and that of discharge roller was 13.62 %. In general the back (discharge) roller would done the greater Brix extraction than that of front (feed) roller, but this figure did not represent the true figure, and would shows there were a problem on the second mill delivery setting. From mill #3 to mill #5 the discharge roller Brix curve overlays the feed roller Brix curve, this it show as the discharge roller would meet its duty and there were no problems on the roller mill setting.

4.3 Milling Plant Pol Extraction Trend

The pol extraction of each milling plant was determined by using equation from 3.39 to equation 3.44 by substituting the values obtained from the first equation to the last step by step. From the table 4.9 shown below, the Brix % of the bagasse was decreasing trend from first mill to the last mill because the application of hydraulic pressure increases and the clearance between the rollers decreases from first to last mill. It was the fact that the fiber % bagasse and pol in juice % cane was increasing trend, because as the pressure increases and the clearance between the rollers decrease then the separation of juice from the cane (bagasse) stream increases and the extraction percent increases. The pol extraction % of the mill was increasing trend across the tandem.

Table 4.9**:** Summary of mill bagasse criteria and pol extraction

s/n	Description	Mill type				
		Mill 1	Mill 2	Mill 3	Mill 4	Mill 5
1	Brix % bagasse	11.24	7.77	5.17	4.20	2.96
2	Fiber % bagasse	18.46	18.43	32.03	35.15	46.44
3	Bagasse % cane	73.13	73.25	42.15	38.41	29.07
4	Pol in bagasse % cane	7.43	5.40	1.94	1.47	0.81
5	Pol in juice % cane	12.57	14.60	18.06	18.53	19.19
6	Pol extraction %	62.85	73.00	90.30	92.95	95.95

From the extraction percent of the bagasse criteria shown in the figure 4.3 below, the extraction percent of pol, pol % juice on cane, fiber % bagasse and pol extraction % along mill to mill was increasing trend through the tandem. But, Bagasse % cane, Brix % cane and pol % bagasse (sucrose %) on cane were decreasing trend across mill to mill in the tandem.

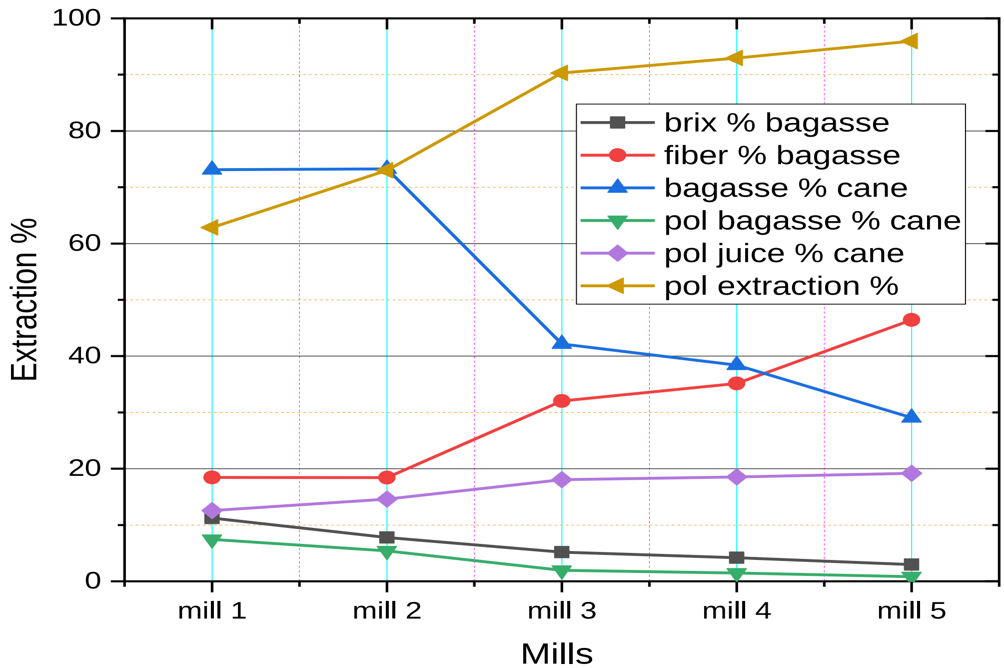


Figure 4.3: Extraction percent of bagasse criteria

Table 4.10**:** Summary of Brix and pol extraction percent of each mill

s/n	Mills	Brix Extraction %	Pol Extraction %
1	1st mill	90.45	62.85
2	2nd mill	44.82	73.00
3	3rd mill	55.97	90.30
4	4th mill	28.80	92.65
5	5th mill	38.80	95.95

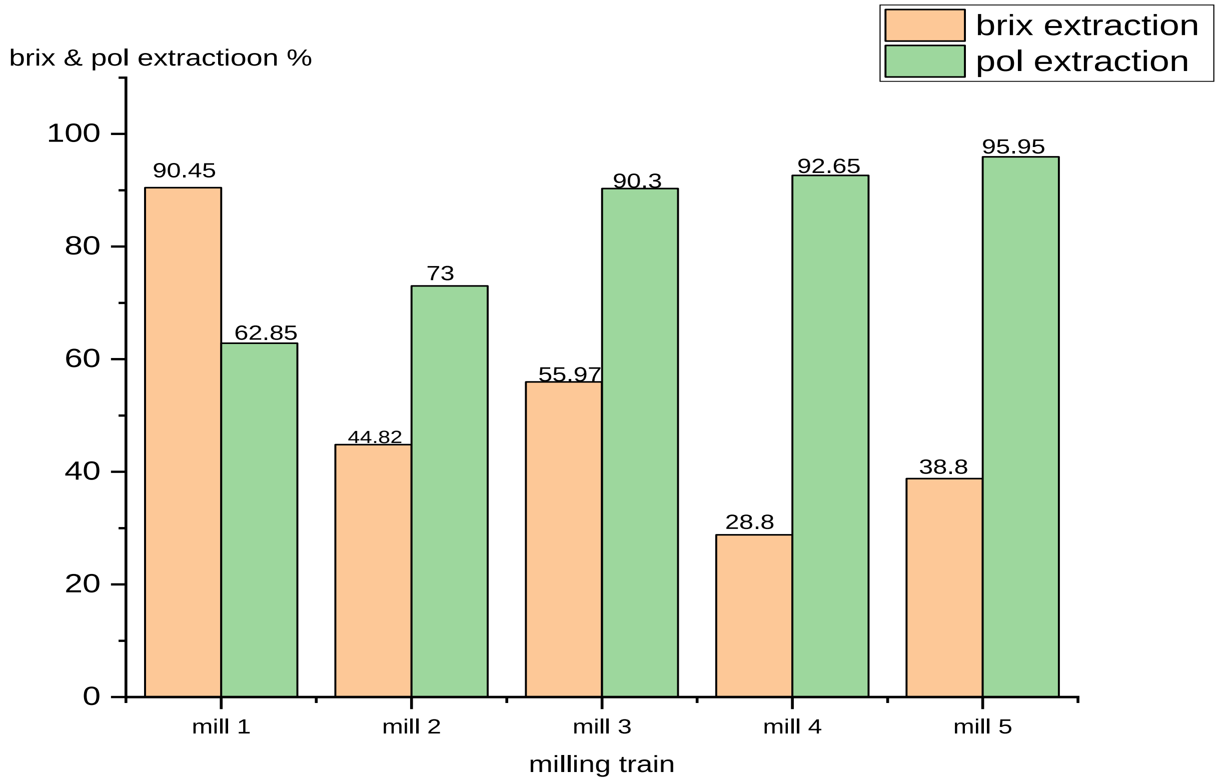


Figure 4.4: Brix and pol extraction trend

As we have seen from the bar chart in figure 4.4 above, the extraction of the pol in the milling train was increasing trend. The pol extraction for first mill was 62.85 % of cane but for the last mill was 95.95 % of cane; the rest of pol was not extracted and it probably can go with final bagasse. Actually, the Brix extraction was decreasing trend, it decreases from first mill to second mill, it increases from second to third mill, decrease from third to fourth mill and finally increasing. The increasing trend for Brix extraction was not true rather it was decreasing trend.

4.4 Design for Optimization of Pol and Moisture % Bagasse

Response surface methodology (RSM) was implemented to identify the optimum pol and moisture % of final bagasse. Two factors at two levels were employed; the factors were hydraulic pressure and quantity of imbibition water flow rate on bagasse. The design of optimization was conducted on central composite design method, the design of experimental combination was held by inserting the lowest and highest values on the design expert software. The resulting output was shown in the table 4.11 below;

Table 4.11**:** Central composite design for optimization of response variables

Std	Run	Block	Factor 1 hydraulic pressure (kg/cm^2)	Factor 2 imbibition water (m^3/hr)	Response 1 pol %	Response 2 moisture %
1	1	Block 1	195.00	62.00	*	*
7	2	Block 1	197.50	59.93	*	*
13	3	Block 1	197.50	67.00	*	*
5	4	Block 1	193.96	67.00	*	*
11	5	Block 1	197.50	67.00	*	*
10	6	Block 1	197.50	67.00	*	*
8	7	Block 1	197.50	74.07	*	*
4	8	Block 1	200.00	72.00	*	*
2	9	Block 1	200.00	62.00	*	*
6	10	Block 1	201.04	67.00	*	*
12	11	Block 1	197.50	67.00	*	*
9	12	Block 1	197.50	67.00	*	*
3	13	Block 1	195.00	72.00	*	*

4.4.1 Analysis Result of Design of Optimization Pol & Moisture %Bagasse.

The samples were taken for each design of combination and analyzed for responses of pol and moisture % of last mill bagasse. The analysis was done as usually based on hand book of laboratory methods and chemical control for Ethiopian sugar factories (kassa H. 2010). The sampling system for each combination the respective bagasse and juice samples were simultaneously sampled at the same time and analysis were done parallel. The sampling system was by varying the application of both hydraulic pressure and quantity of imbibition water flow on the last mill. For each thirteen combinations the representative samples were taken, but the sampling period were different. The analysis result for both responses was shown in the table 4.12 below.

Table 4.12**:** Bagasse analysis result for response variables

Std	Run	Block	Factor 1 hydraulic pressure (kg/cm^2)	Factor 2 imbibition water (m^3/hr)	Response 1 pol %	Response 2 moisture %
1	1	Block 1	195.00	62.00	2.51	51.4
7	2	Block 1	197.50	59.93	3.30	50.10
13	3	Block 1	197.50	67.00	2.67	52.00
5	4	Block 1	193.96	67.00	2.37	53.00
11	5	Block 1	197.50	67.00	2.78	54.00
10	6	Block 1	197.50	67.00	2.73	50.10
8	7	Block 1	197.50	74.07	1.89	53.00
4	8	Block 1	200.00	72.00	1.53	52.55
2	9	Block 1	200.00	62.00	3.30	50.10
6	10	Block 1	201.04	67.00	1.89	50.80
12	11	Block 1	197.50	67.00	2.40	50.30
9	12	Block 1	197.50	67.00	3.02	51.70
3	13	Block 1	195.00	72.00	1.53	52.55

Table 4.13**:** Juice analysis result for design combination of HP and IMB

Std	Run	Factor 1 hydraulic pressure (kg/cm^2)	Factor 2 imbibition water (m^3/hr)	Pol % juice	Brix % juice
1	1	195.00	62.00	4.34	4.56
7	2	197.50	59.93	5.21	5.28
13	3	197.50	67.00	4.53	4.66
5	4	193.96	67.00	4.54	4.56
11	5	197.50	67.00	4.60	4.66
10	6	197.50	67.00	4.61	4.63
8	7	197.50	74.07	5.19	5.27
4	8	200.00	72.00	5.27	5.51
2	9	200.00	62.00	5.21	5.28
6	10	201.04	67.00	5.19	5.27
12	11	197.50	67.00	4.52	4.63
9	12	197.50	67.00	4.48	4.56
3	13	195.00	72.00	5.27	5.51

4.4.2 Data Analysis for Optimization of Pol and Moisture % Bagasse

Data were modeled by multiple regression analysis and the statistical significance of the terms was examined by analysis of variance for each response. The statistical analysis of the data and three dimensional plotting were performed using design expert software (6.0.8, 2002). The adequacy of regression model was checked by R^2, Adj R^2, Pred R^2, Adeq precision and F-test (montgomery 2001). The significance of F value was judged at 95% confidence level. The regression coefficients were then used to make statistical calculation to generate three dimensional plots from the regression model. The degree of relationship between the variables was also checked by using correlation matrix of the Factors and response variables. Linear and quadratic model was suggested by the design program for this response. All statistical analysis including ANOVA test, Post ANOVA statistics, lack of fit test, normal plot of residuals, Predicated vs Actual plot, Residual vs. Predicted plot, Counter plot, 3D Response surface plot, Residual vs. Run, Sequential Model Sum of Squares, Model Summary Statistics, Correlation Matrix of Regression Coefficients, Correlation Matrix of Factors [Pearson's R], Coefficient of estimate for the factors and Diagnostics Case Statistics response etc. were done for the pol and moisture % data.

4.4.3 Data Analysis of Response -1

Quadratic model was suggested by the design program for this response to test for its adequacy and to describe its variation with independent variables. From ANOVA test in Table 4.13 below, the model F-value of 9.04 implies the model is significant. There is only a 0.58% chance that a "Model F-Value" this large could occur due to noise.

Table 4.14**:** ANOVA test for pol % of bagasse

Source	Sum of Squares	DF	Mean of square	F-Value	Prob>F	
Model	3.76	5	0.75	9.04	0.0058	Significant
A	1.545E-003	1	1.545E-003	0.019	0.8954	
B	2.81	1	2.81	33.85	0.0007	
A^2	0.76	1	0.76	9.18	0.0191	
B^2	0.068	1	0.068	0.82	0.3963	
AB	0.16	1	0.16	1.88	0.0130	
Residual	0.58	7	0.083			
Lack of Fit	0.38	3	0.13	2.57	0.1918	not significant
Pure Error	0.20	4	0.050			
Cor Total	4.34	12				

******A*** – is application hydraulic pressure of factor 1. * ***B*** – quantity of flow rate of imbibition water on bagasse.

Values of "Prob > F" less than 0.0500 indicate model terms were significant. In this case B, A^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model.

The "Lack of Fit F-value" of 2.57 implies the Lack of Fit is not significant relative to the pure error. There is a 19.18% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.

Table 4.15**:** Post ANOVA statistics for response -1 (pol % bagasse)

Std. Dev.	0.29	R-Squared	0.8659
Mean	2.46	Adj R-Squared	0.7701
C.V.	11.74	Pred R-Squared	0.3003
PRESS	3.04	Adeq Precision	9.434

The "Pred R-squared" of 0.3003 is in reasonable agreement with the "Adj R-squared" of 0.7701. "Adeq precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 9.434 indicates an adequate signal. This model can be used to navigate the design space (Montgomery 2001).

Table 4.16**:** Correlation Matrix of Regression coefficient

	Intercept	A	B	A^2	B^2	AB
Intercept	1.000					
A	-0.000	1.000				
B	-0.000	-0.000	1.000			
A^2	-0.590	-0.000	-0.000	1.000		
B^2	-0.590	-0.000	-0.000	0.130	1.000	
AB	-0.000	-0.000	-0.000	-0.000	-0.000	1.000

4.4.4 Correlation Matrix for Optimization of Pol % Bagasse

From correlation matrix of factors (Pearson’s R), it was clearly observed that almost all factor-to-factor correlations are zero and it is good. For the factors- to-factors correlation, off-diagonal values close to zero are better.

Table 4.17**:** Correlation Matrix of Factors [Pearson's R] for optimization of pol % bagasse

	A	B	A^2	B^2	AB
A	1.000				
B	0.000	1.000			
A^2	0.000	0.000	1.000		
B^2	0.000	0.000	-0.130	1.000	
AB	0.000	0.000	0.000	0.000	1.000

Where: A and B are factors

4.4.5 Equation for Optimization of Pol Content of Last Mill Bagasse

Model equations are given in terms of coded factors and actual factors. Coded factors indicate when the minimum and maximum values of the factors are represented by -1 and +1 respectively instead of their actual values.

Final Equation in Terms of Coded Factors:

$$\text{Pol} = +2.72 + 0.014 \times A - 0.59 \times B - 0.33 \times A^2 - 0.099 \times B^2 - 0.20 \times A \times B \qquad \textbf{(4.1)}$$

Final Equation in Terms of Actual Factors:

$$\text{Pol} = -2284.56791 + 21.99916 \times \text{Hydrualic Pressure} \times 3.53120 \times \text{Imbibition Water} - 0.053000 \times \text{Hydrualic Pressure}^2 - 3.95000\text{E} - 003 \times \text{Imbibition Water}^2 - 0.015800 \times \text{Hydrualic Pressure} \times \text{Imbibition Water} \qquad \textbf{(4.2)}$$

The coefficient of deteremination of corroliation is 0.8659 which is 86.59 %, it indicates that degree of fitting is good and the reliability of the trend is good. The model reaches a very significant level of the probability value ($p < 0.01$). In addition the regression coefficient and the regression intercept have reached significant level ($p < 0.01$). Increasing the negative terms will decrease the responses and decreasing the positive terms will increases the responses.

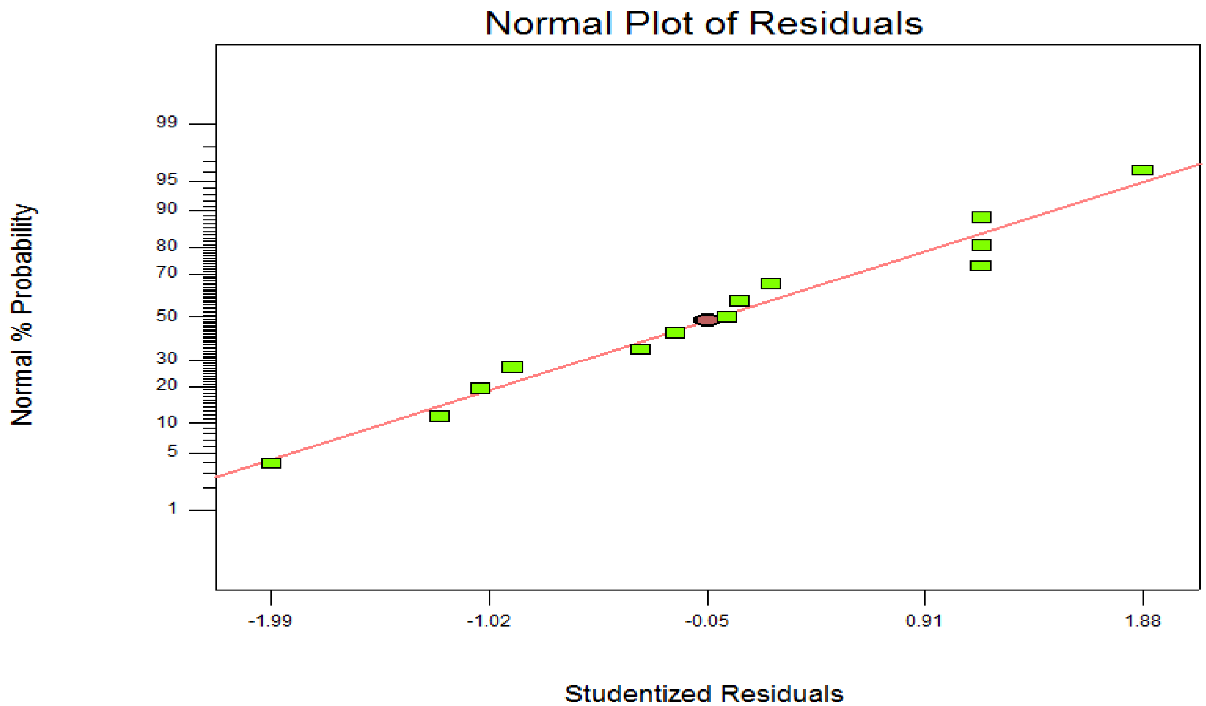


Figure 4.5: Normal probability plot

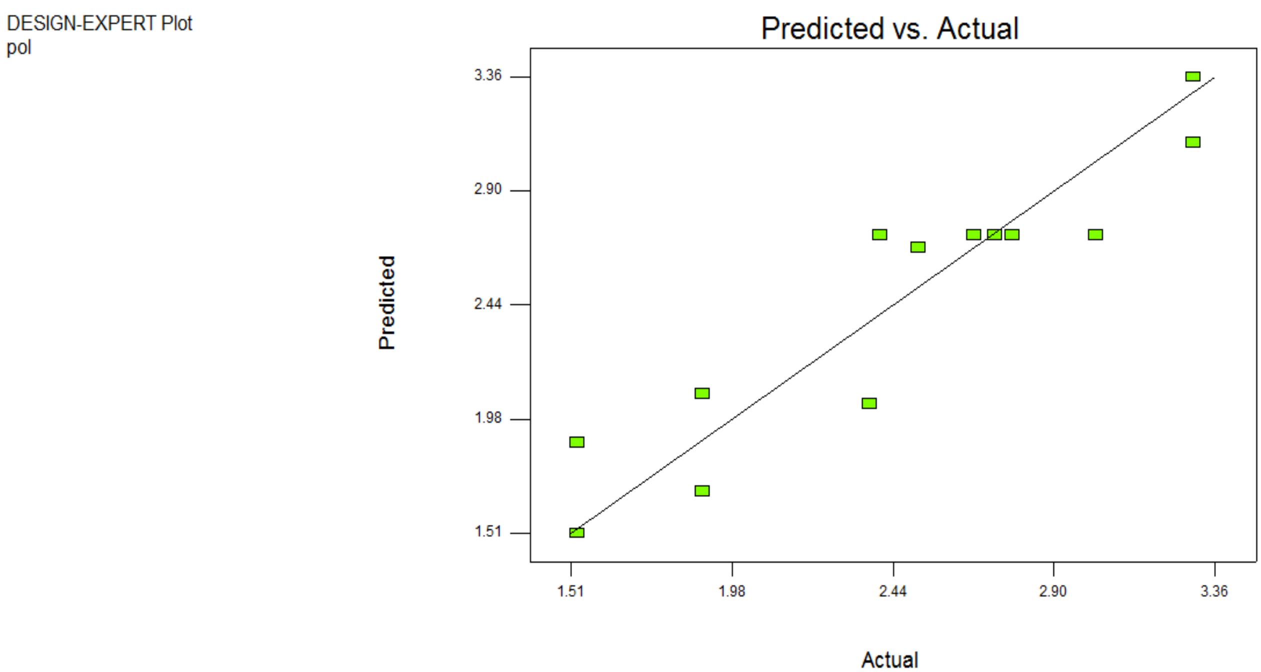


Figure 4.6: Predicated vs. Actual plot

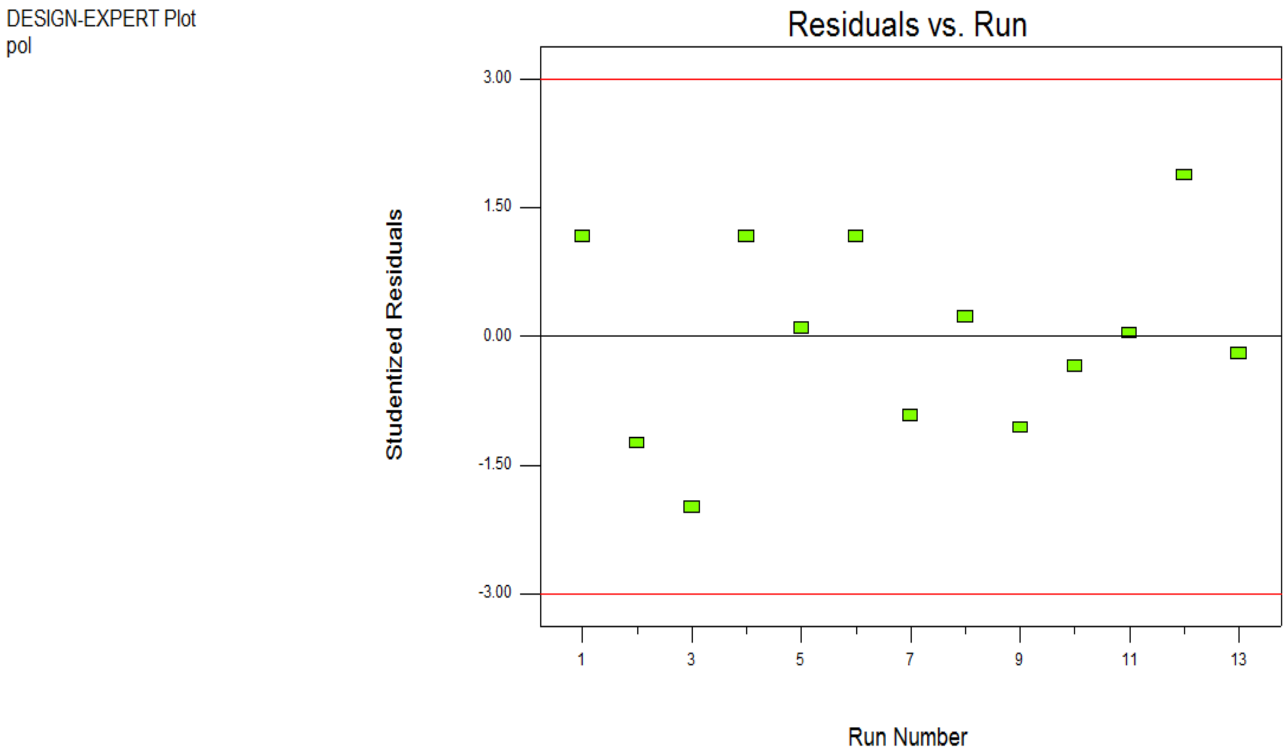


Figure 4.7: Residual vs. Run plot

4.4.6 Residual Analysis

The patterns for the residual plots somehow satisfactory, all the data points are near to the predicted values shown in the figure 4.8 below. The normal plots of residuals were checked for all responses and all indicated the validity of the model equations. The residual data were almost aligned with the predicted values. If the scattered data were away from the boundary axis above and below then the result were not satisfactory. For the case all the data points are in the range, if one of the data points far from the origin it affects our result. If the data points are near close to each other approach to the origin then our model equation are satisfactory with the residual values and our modeling is valid.

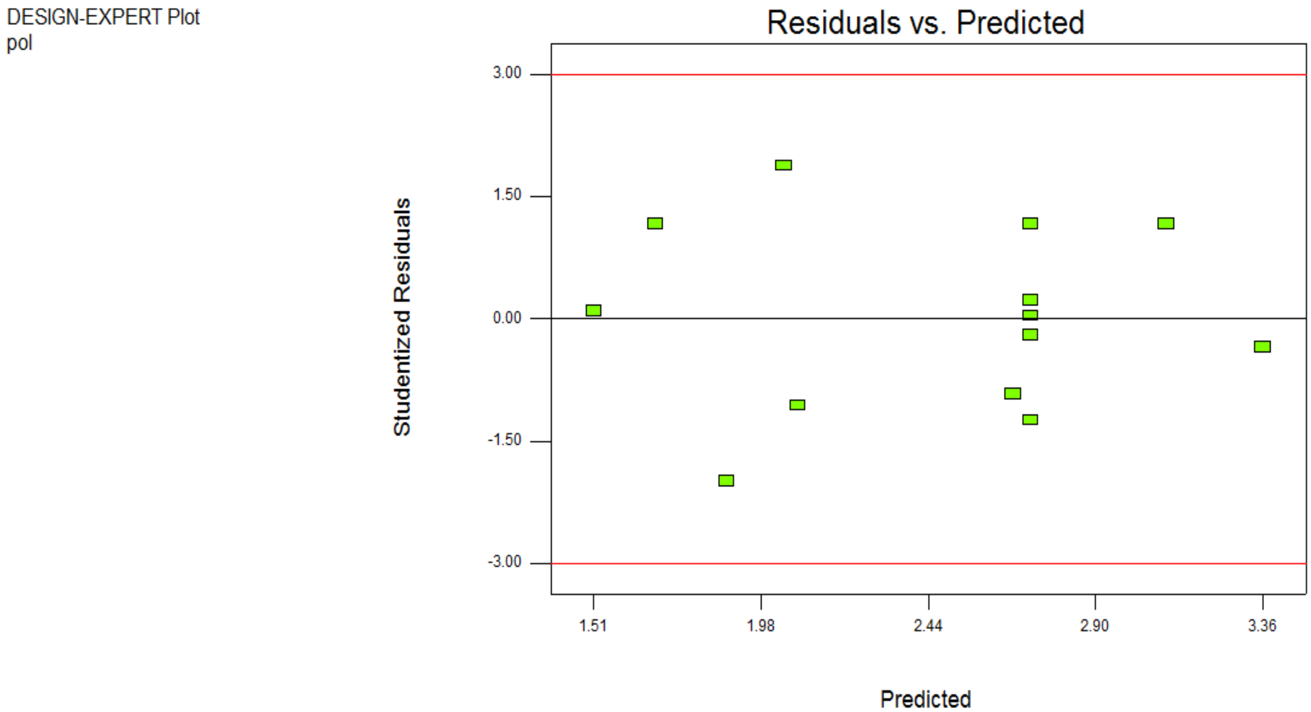


Figure 4.8: Residual vs. Predicted plot

4.4.7 Analysis of Pol Content of Bagasse on Contour Plot

In figure 4.9, 2D plot show that, for constant hydraulic pressure of 197.5 kg/cm^2 increasing the quantity of imbibition water flow rate from 62 m^3/hr. to 64.5 m^3/hr. then the pol % of last mill bagasse is around 2.95878 %, for the same application of hydraulic pressure and increasing the quantity of water from 64.5 m^3/hr. to 67 m^3/hr. then the pol % of bagasse is 2.67. In the same manor increasing the quantity of imbibition from 67m^3/hr. to 69.5m^3/hr. then the pol % is 2.38. The plot shows that applying the constant hydraulic pressure of 197.5 kg/cm^2 and whenever increases the quantity of imbibition flow then the pol % of last mill bagasse decreases. The application of quantity of water beyond 72 m^3/hr.at constant pressure of 197.5 kg/cm^2 the pol % of last mill bagasse will never change. As increasing the hydraulic pressure from 197.5 kg/cm^2 to 200kg/cm^2 and the increasing the quantity of imbibition water flow rate from 62 m^3/hr.to 72m^3/hr. then the pol % of last mill bagasse will reduced to 1.80%.

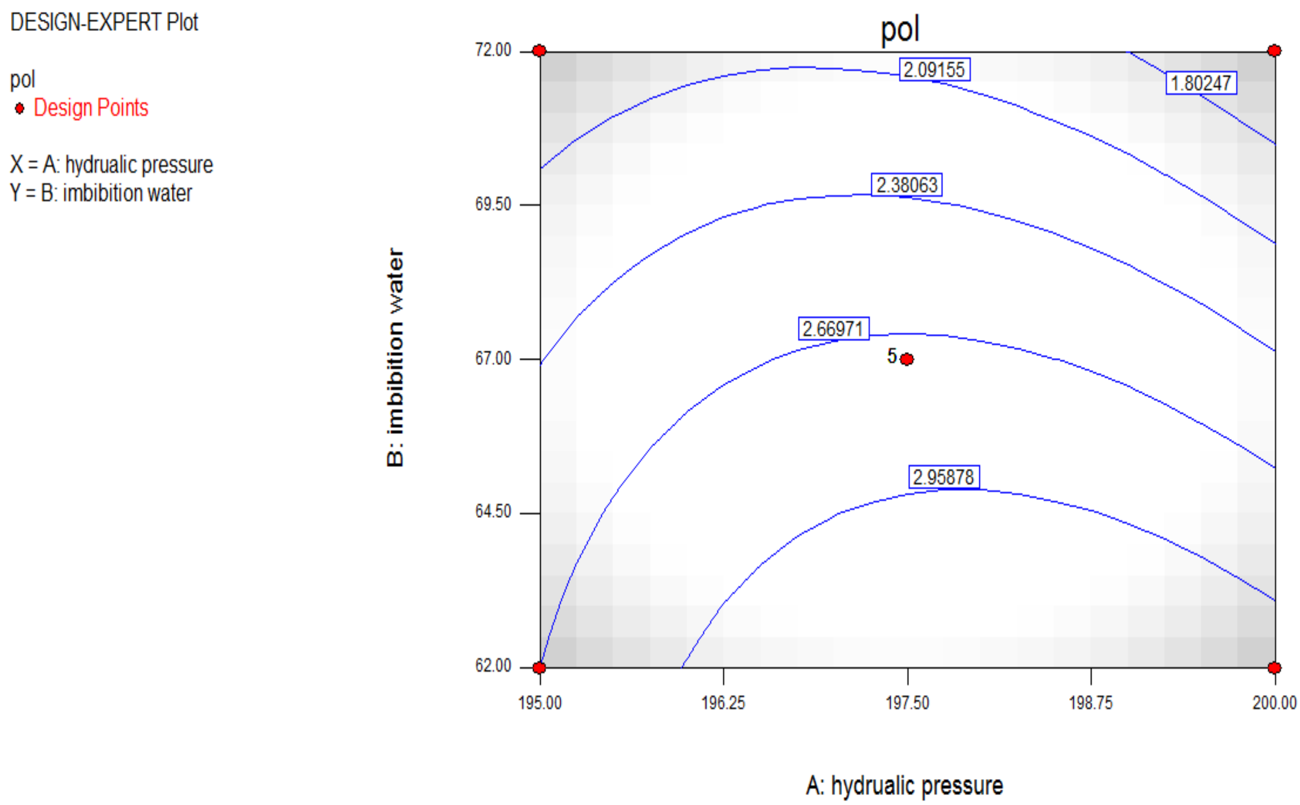


Figure 4.9: Contour plot for response of pol % bagasse

4.4.8 Analysis for Pol % of Last Mill Bagasse

As we have seen from the surface plot figure 4.10 below, as the plot indicates that at some were, decreasing both factors to some point the interaction may be there. As the hydraulic pressure increases from 195 kg/cm^2 up to 197.5 kg/cm^2 and increasing the quantity of imbibition flow rate, then the pol % of last mill bagasse is decreasing trend. As we increase the hydraulic pressure beyond the 197.5 kg/cm^2 with increasing the quantity of imbibition flow the pol % of last mill bagasse decreases. Holding hydraulic pressure 197.5 kg/cm2 as constant and increasing the quantity of imbibition water flow on the last mill, will result the pol % of last mill bagasse decreases. At constant hydraulic pressure 197.5 kg/cm2 and decreasing the quantity of imbibition water flow, then the pol % of bagasse become increasing trend.

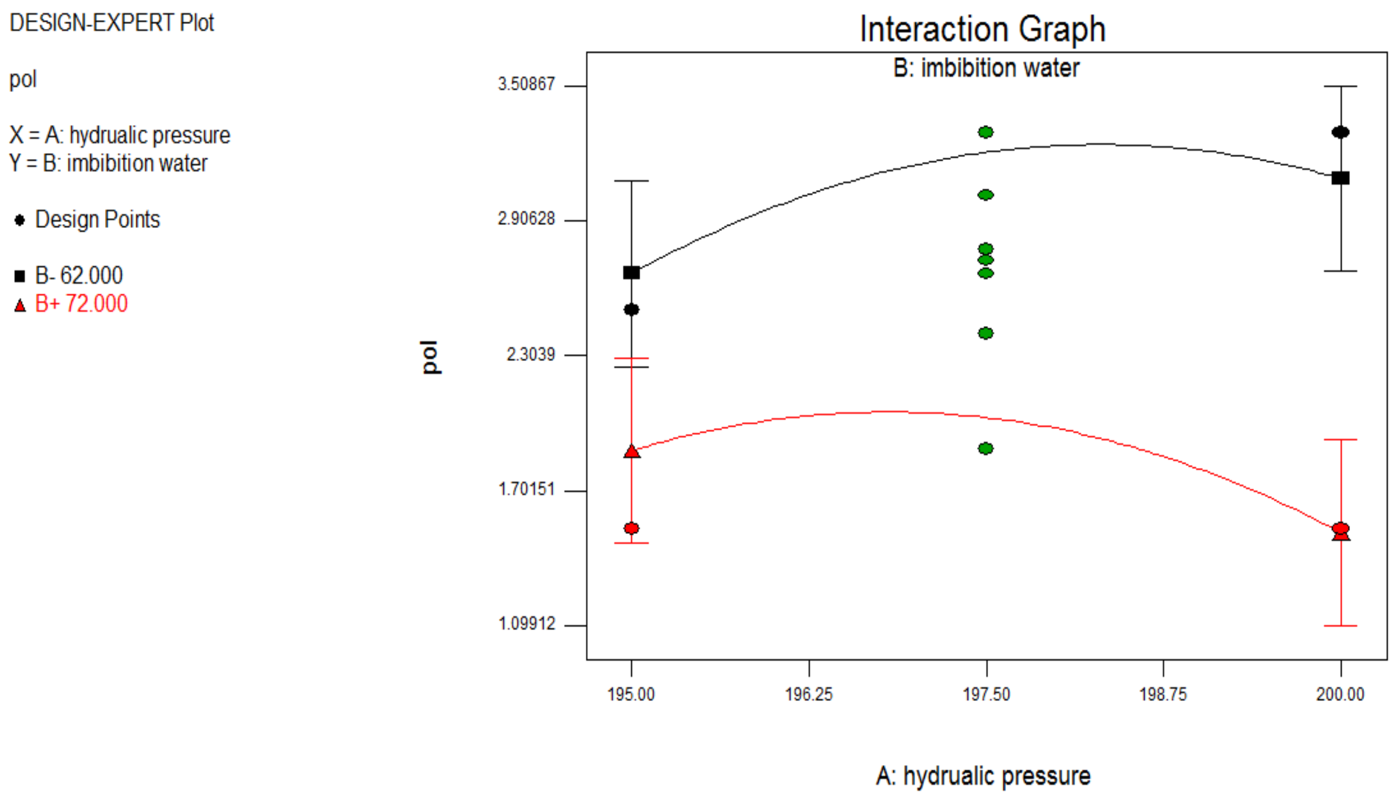


Figure 4.10: Interaction graph for response -1 (pol % bagasse)

4.4.9 Response Surface Plot for Pol % Bagasse

The 3D- response surface plot in the figure 4.11 below, indicates that the effect of varying the hydraulic pressure and quantity of imbibition flow rate in the ranges of 195 kg/cm^2 – 200 kg/cm^2 for hydraulic pressure and 62 m^3/hr. – 72 m^3/hr. for imbibition water flow rate. It was clearly seen on the response surface plot is that as increasing the hydraulic pressure and quantity of imbibition water flow rate then the pol % of the last mill bagasse was decreasing trend. Whenever separately increase the amount of hydraulic pressure to 200 kg/cm^2 and imbibition water flow at72 m^3/hr. increasing the hydraulic pressure alone to 200 kg/cm^2 values would not minimize either of pol % of bagasse. On the other hand increasing application of quantity of imbibition water alone to 72 m^3/hr. value would not minimize the sucrose content of the final bagasse.

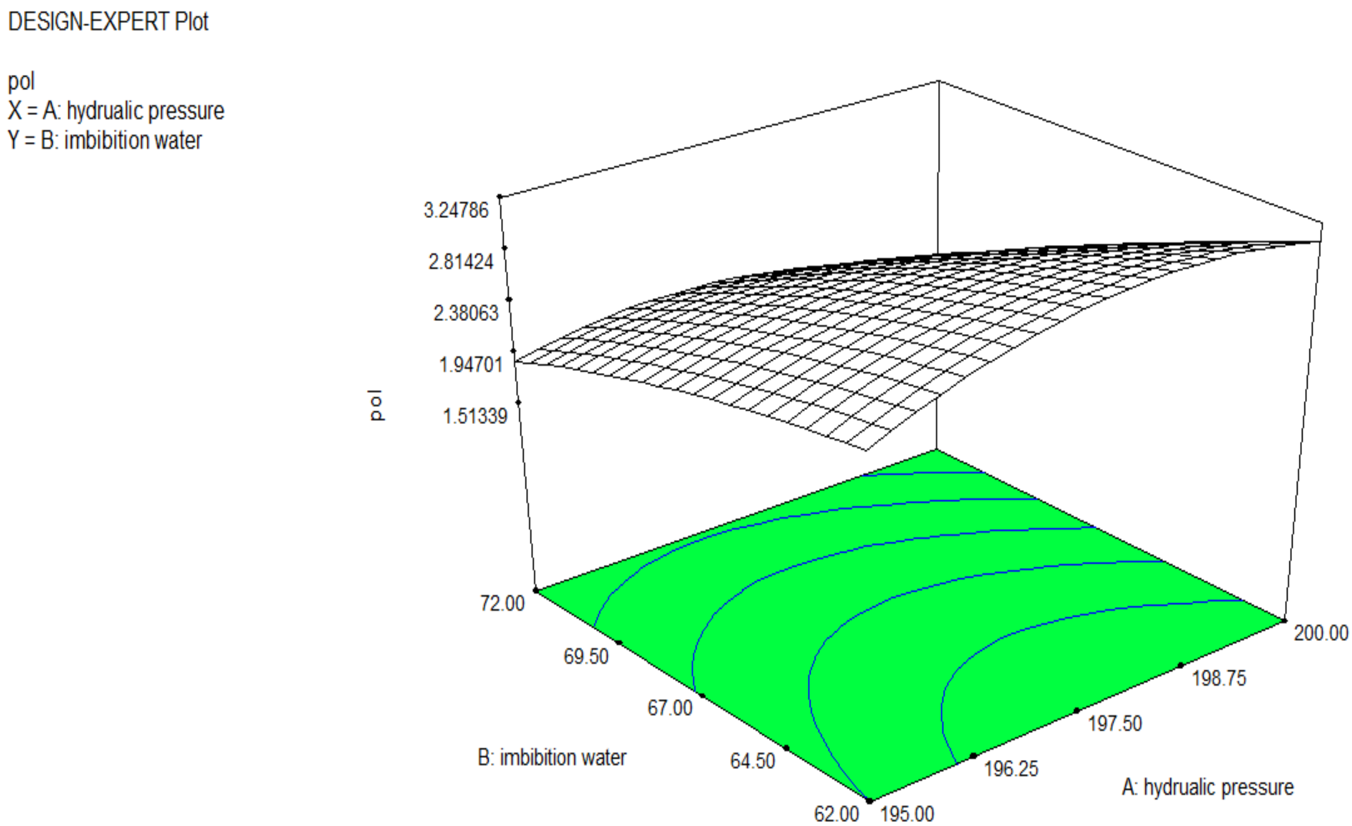


Figure 4.11: 3D-Response surface plot for pol % bagasse

Table 4.18**:** Numerical optimization range for pol % bagasse

Constraints Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
HP	is in range	195	200	1	1	3
IMB	is in range	62	72	1	1	3
Pol	minimize	1.53	3.30	1	1	3
Moisture	minimize	50.1	54	1	1	3

Where **HP*- hydraulic pressure, **IMB* – imbibition water

The result of optimum data analysis using design expert softeware indicated that the following paremeters were selected as the optimum values of the factor levels and the responses.

Table 4.19**:** Optimization values (solution) of pol % bagasse

Number	hydrualic pressure (kg/cm^2)	imbibition water (m^3/hr)	Pol %	Moisture %	Desiribility	
1	195.00	72.00	1.88062	50.472	0.605	Selected
2	200.00	71.37	1.63609	51.3225	0.604	
3	199.67	71.72	1.67437	51.3087	0.504	

Three solutions were obtained and the optimum outputs of pol % of last mill bagasse were 1.88062, 1.63609 and 1.67437 with the desiribility of 60.5, 60.4 and 50.4 % respectively. For the first solution the optimum pol % bagasse was 1.88062, this was obatained at optimum hydrualic pressure of 195 kg/cm^2 and quantity of imbibition water flow rate of 72 m^3/hr at this value the moisture % bagasse was found 50.472 %. For the second case the optimum pol % was 1.63609, for this the optimum hydraulic pressure and quantity of imbibition flow rate was 200 kg/cm^2 and 71.37 m^3/hr respectvely and the moistuture content was 51.3225%. The last selected optimum pol % bagasse was 1.67437, this was found at hydrualic pressure and quantity of imbibition flow rate of 199.67 kg/cm^2 and 71.72 m^3/hr respectively and also moisture content bagasse found 51.3087%.

Table 4.20**:** Starting points for numerical optimization of pol % bagasse

Number	Hydrualic pressure	Imbibition water
1	199.72	67.81
2	197.85	67.26
3	197.48	69.47
4	199.96	65.15
5	197.48	62.50
6	199.87	65.03
7	199.60	62.36
8	199.72	62.36
9	196.89	67.16
10	195.22	64.37

4.5 Data Analysis for Response-2 (ANOVA for Response Surface Linear Model)

Linear model is suggested by the design program for this response to test for its adequacy and to describe its variation with independent variables. From ANOVA test in Table 4.21 shown below, the model F-value of 4.52 implies the model is significant. There is a 3.99 % chance that a "Model F-value" this large could occur due to noise.

Table 4.21**:** ANOVA test for moisture % of bagasse

Source	Sum of Squares	DF	Mean of square	F-Value	Prob>F	
Model	9.85	2	4.92	4.52	0.0399	Significant
A	2.43	1	2.43	2.24	0.1657	
B	7.41	1	7.41	6.81	0.0260	
Residual	10.88	10	1.09			
Lack of Fit	1.01	6	0.17	0.068	0.9970	not significant
Pure Error	9.87	4	2.47			
Cor Total	20.73	12				

Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case B are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model. The "Lack of Fit F-value" of 0.07 implies the Lack of Fit is not significant relative to the pure error. There is a 99.70% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.

Table 4.22**:** Post ANOVA statistics for response-2 (moisture % bagasse)

Std. Dev.	1.04	R-Squared	0.4751
Mean	51.66	Adj R-Squared	0.3701
C.V.	2.02	Pred R-Squared	0.3339
PRESS	13.81	Adeq Precision	6.043

The "Pred R-squared" of 0.3339 is in reasonable agreement with the "Adj R-squared" of 0.3701. "Adeq precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 6.043 indicates an adequate signal. This model can be used to navigate the design space (Montgomery 2001).

4.5.1 Equation for Optimization of Moisture Content of Bagasse

Final Equation in Terms of Coded Factors:

$$\text{Moisture \%} = +51.66 - 0.55 \times A + 0.96 \times B \quad \textbf{(4.3)}$$

Final Equation in Terms of Actual Factors:

$$\text{Moisture \%} = +82.32329 - 0.22056 \times \text{Hydrualic Pressure} + 0.1925 \times \text{Imbibition Water} \quad \textbf{(4.4)}$$

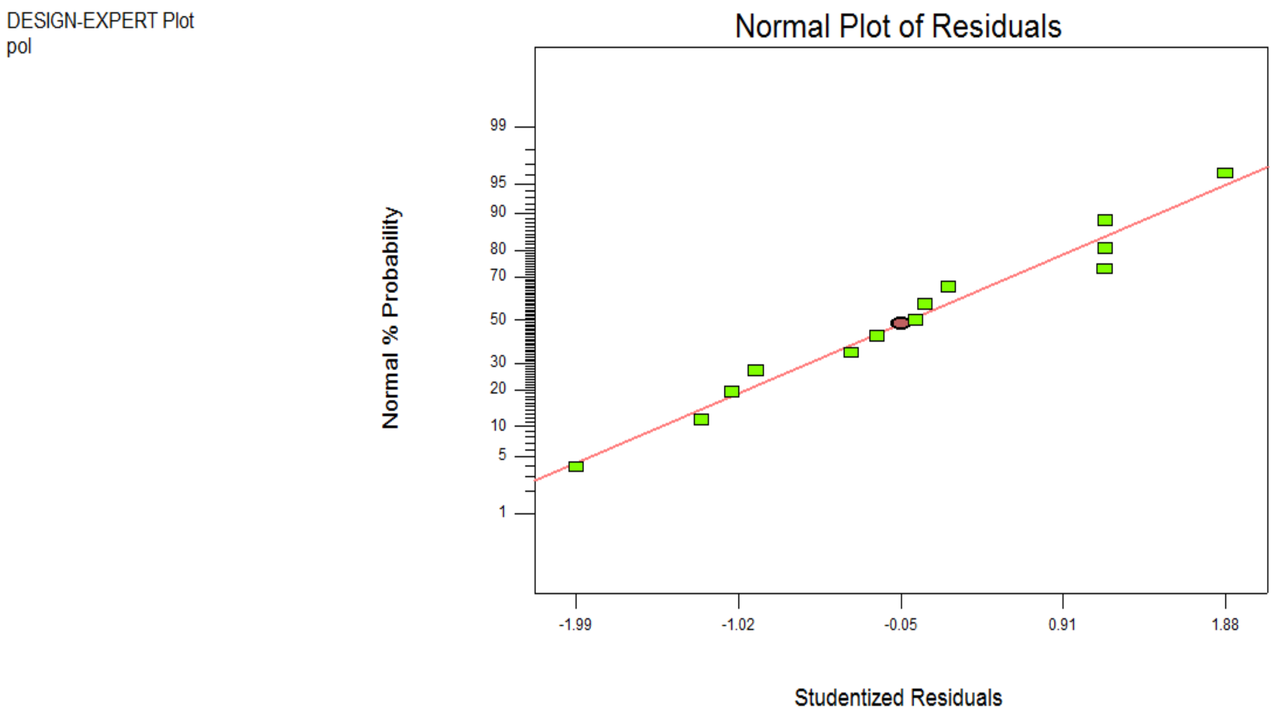


Figure 4.12: Normal probability plot for responses

4.5.2 Diagnostic Test for the Responses

All diagnostic plots are also tested for all responses for adequacy of the models (normal plot of residuals, residual vs. predicted value, residual vs. factor, box cox plot, studentzed residuals, leverage etc.). For example, fig 4.12 above shows how precisely the pol % of bagasse is modeled, because all the points line up nicely and the deviation of points for pol % or sucrose % bagasse from normality is insignificant. Similar results were observed for other responses (moisture percent of bagasse).

4.5.3 Analysis for Moisture% of Bagasse on Interaction Surface Graph

As the surface plot in the figure 4.13 below, indicates that when increasing hydrualic pressure from 195 kg/cm^2 to 197.5 kg/cm^2 with decreasing the quantity of imbibition flow rate, then the moisture % of bagasse is decreasing trend. When hydrualic pressure is held constant at 197.5 kg/cm^2 and with decreasing quantity of imbibition flow result decreasing the moisture content of the bagasse. As increasing the hydrualic pressure beyond 197.5 kg/cm^2 to 200kg/cm^2 and decreasing imbibition flow, then the moisture content of the bagasse was decreases.

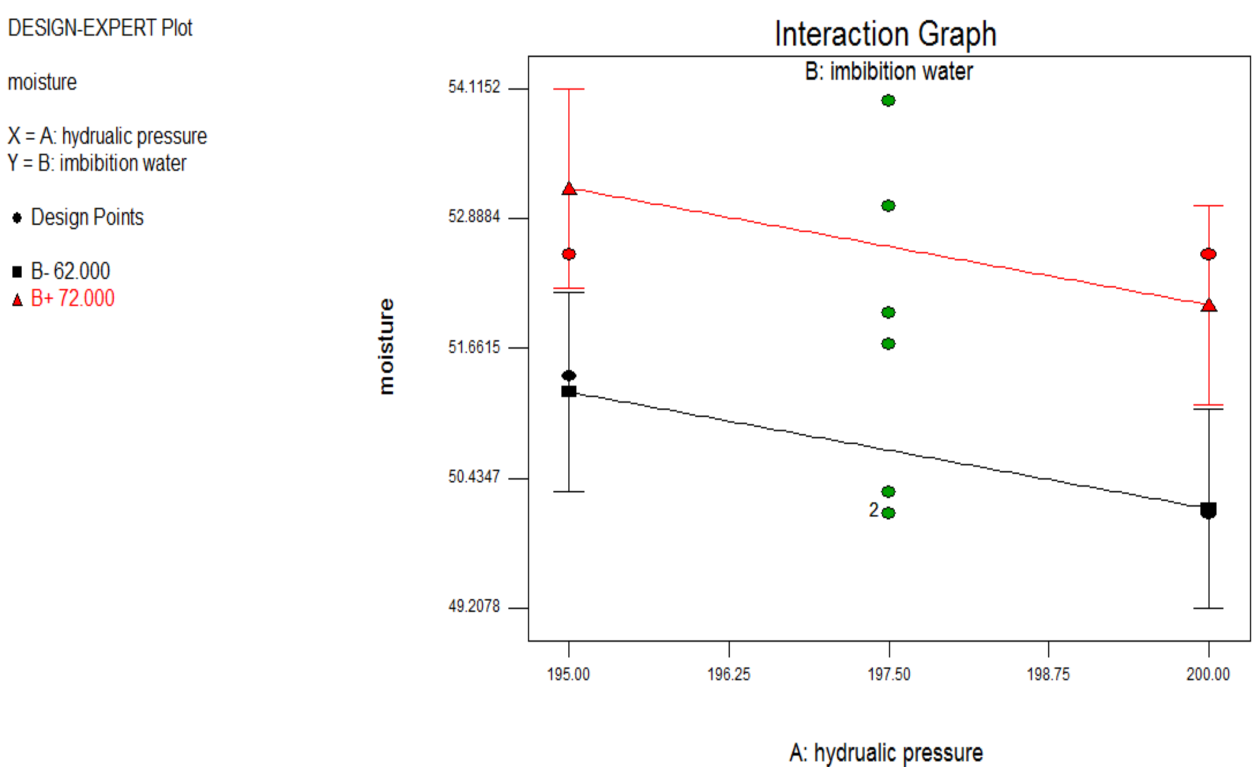


Figure 4.13: Interaction surface graph for response -2 (moisture % bagasse)

4.5.4 Analysis for Moisture Content of Bagasse on Contour Plot

In figure 4.14, 2D plot show that, for constant hydraulic pressure of 197.5 kg/cm^2 increasing the quantity of imbibition water flow rate from 62 m^3/hr. to 67 m^3/hr. then the moisture % of last mill bagasse is around 51.7 %, for the same application of hydraulic pressure and increasing the quantity of water from 67 m^3/hr. to 69.50 m^3/hr. then the moisture % of bagasse is 51.17. In the same manor increasing the quantity of imbibition from 69.50 m^3/hr.to 72 m^3/hr. then moisture % is around 52.6. The plot shows that applying the constant hydraulic pressure of 197.5 kg/cm^2 and whenever increases the quantity of imbibition flow then the moisture % of last mill bagasse increasing. Increasing the application of hydraulic pressure from 197.5 kg/cm^2 to 198.75 kg/cm^2 and decreasing the quantity of imbibition water flow from 72 m^3/hr.to 64.5m^3/hr. then the moisture % of bagasse decreasing trend.

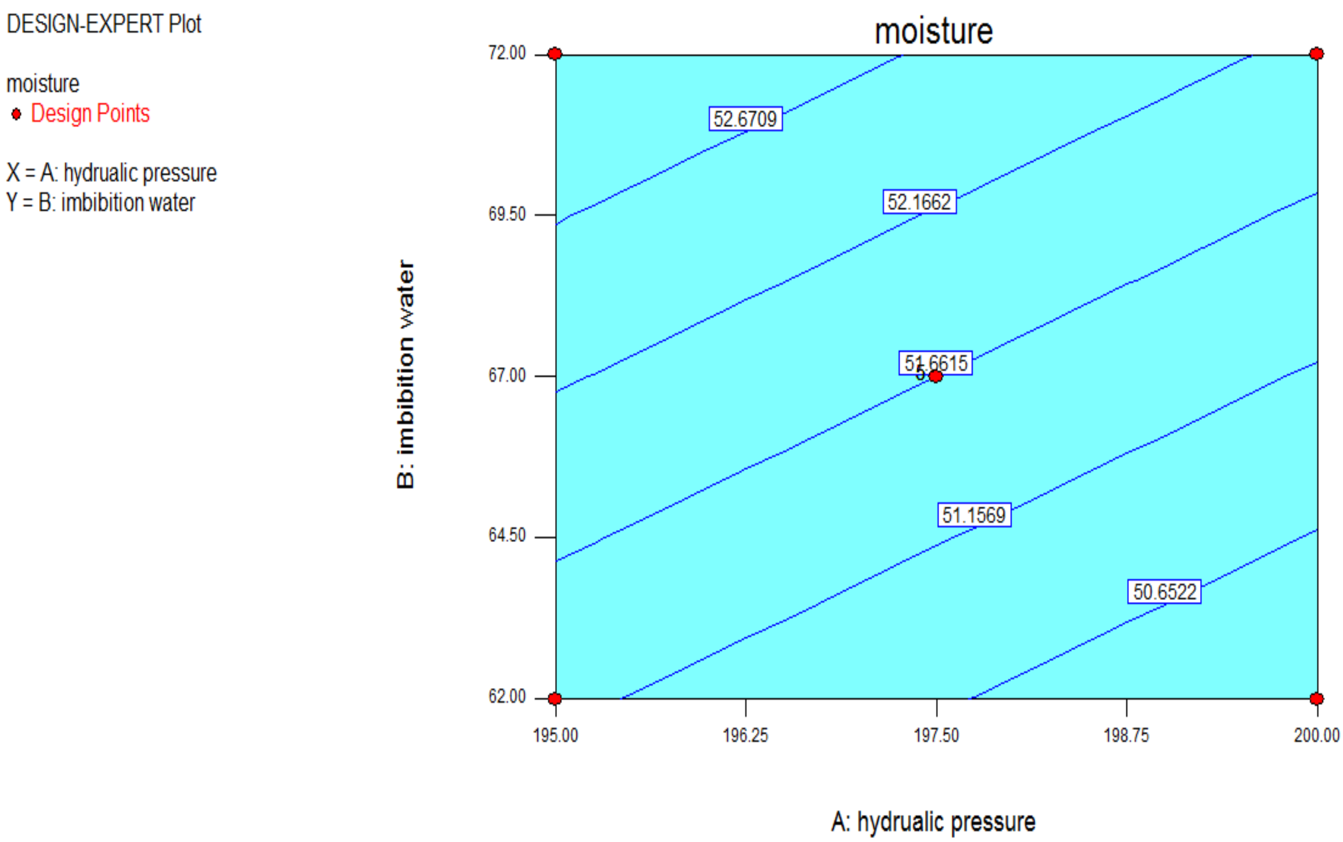


Figure 4.14: Contoure plot for response -2 (moisture % bagasse)

4.5.5 Response Surface Plot for Moisture % Bagasse

The 3D – response surface plot in the figure 4.15 below, indicates that the effect of varying the hydraulic pressure and quantity of imbibition flow rate in the ranges of 195 kg/cm^2 – 200 kg/cm^2 for hydraulic pressure and 62 m^3/hr. – 72 m^3/hr. for imbibition water flow rate. It was clearly seen on the response surface plot as increasing the hydraulic pressure and quantity of imbibition water flow rate, then the moisture % of the last mill bagasse was increasing trend. Whenever separately increase the amount of hydraulic pressure to 200 kg/cm^2 then the moisture % bagasse constant, this was done by holding the quantity of imbibition water flow constant at 62 m^3/hr. and whenever increasing the quantity of imbibition water flow to 72 m^3/hr., holding hydraulic pressure constant at 195 kg/cm^2, then the moisture% of bagasse was increasing. Therefore, increasing the hydraulic pressure alone to 200 kg/cm^2 values would not minimize moisture % of bagasse. On the other hand increasing application of quantity of imbibition water alone to 72 m^3/hr. the moisture content of bagasse was increasing trend, if the moisture content of bagasse increases it was difficult for boiler operation for sufficient energy generation.

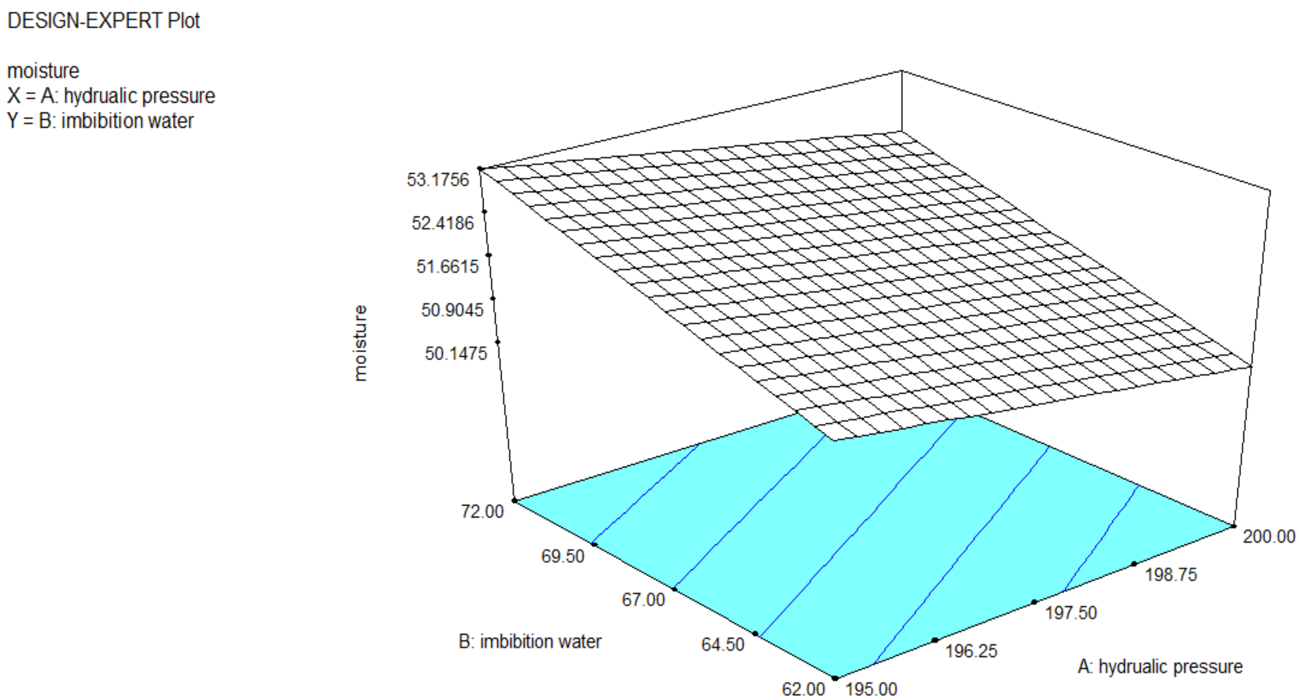


Figure 4.15: 3D surface plot for response – 2 (moisture % bagasse)

From the figure 4.16 below, one factor plot show that, the quantity of imbibition water flow rate was sated at 67 m^3/hr. holding as constant flow and whenever increasing the hydraulic pressure from 195 kg/cm^2 up to 200 kg/cm^2 then the moisture content of the last mill bagasse decreasing trend. Whenever decreasing hydraulic pressure from 200 kg/cm^2 then the moisture content was increasing. Generally, as the application of pressure increase to top rollers and more extraction was done on the successive rollers. The graph shows as the moisture content was maximum at hydraulic pressure of 195 kg/cm^2 and minimum at 200 kg/cm^2. For the fact the moisture content is not zero whatever pressure is applied.

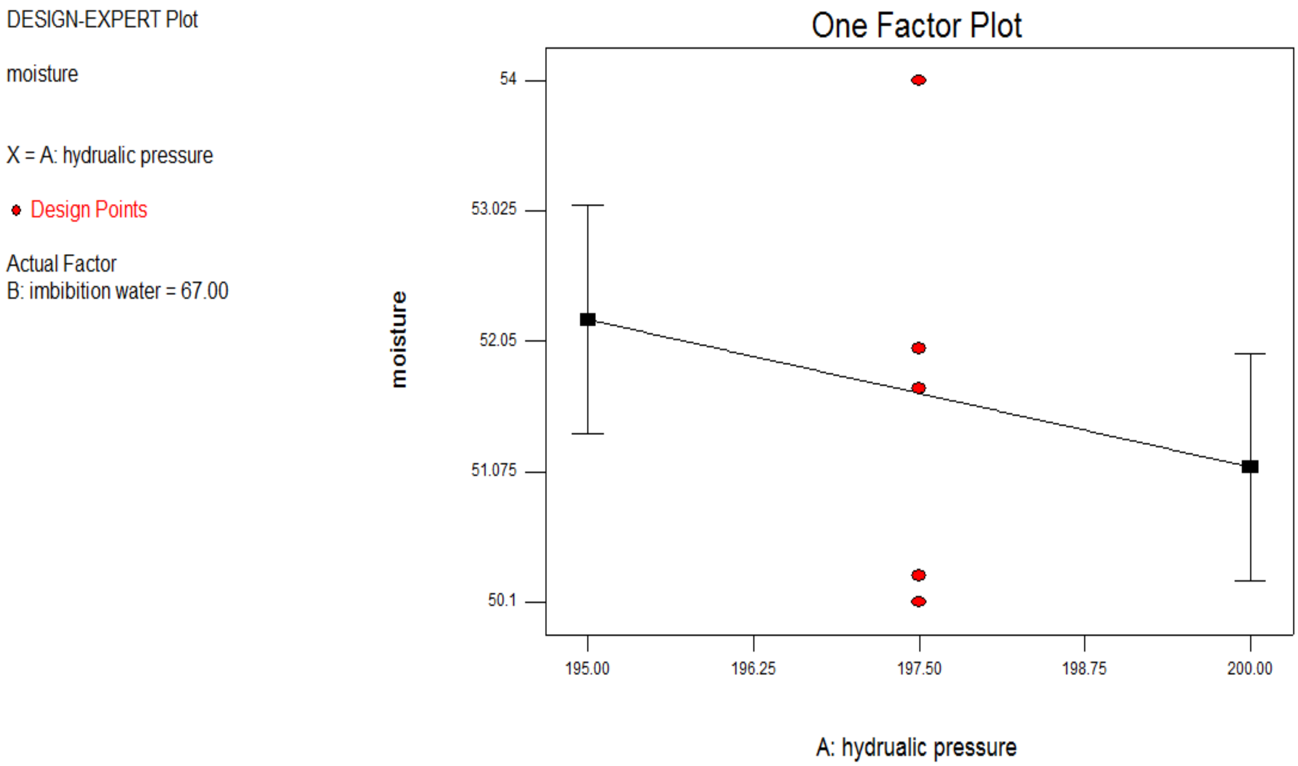


Figure 4.16: Interaction surface plot for moisture % bagasse (one factor plot)

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study mainly focused on two things: first, performance evaluation of sugar cane milling plant and second, optimization of milling process parameters that could lead to a reduction of milling losses. After identifying the most loss areas, then the process optimization of parameters was carried out along the milling train. The optimization experiment have been successfully designed, analyzed, proper data are generated and statically validated. RSM has been employed to optimize the parameters since it is an indispensable tool for Process Optimization. This study clearly indicates that there can be significant technical potential for minimizing the sucrose losses across the milling train. The experiment was designed in a series of steps aiming to reducing the pol (sucrose) content of bagasse through optimizing the application of hydraulic pressure and imbibition flow rate on the bagasse mate for last mill. The existing factory pol % bagasse was 2.02% and the moisture % bagasse were in the range 48 to 53%, this can be reduced to three optimum solutions to 1.63 - 1.88% of the pol content of bagasse and 50.47 - 51.31% of moisture content of final bagasse, this optimum value found in optimum hydraulic pressure and quantity of imbibition flow rate of 195 - 200kg/cm^2 and, 71.37 - 72m^3/hr. respectively. The optimization of moisture content of last mill bagasse was found at three optimized solutions in the table 4.19 in chapter four above, which was 50.47 - 51.31% with a desirability of 50.4 - 60.5%, respectively. The most striking findings of the research lie in the significant reduction of milling losses. The milling loss of existing plant was found to be 4.39 %, and after optimization of the process parameter it was found to be 4.06 %. The annual money saving after optimization was found to be 498,302,600 ETB per annual was recovered. From juice Brix curve chapter four in the figure 4.1above, the findings show that, the Brix curve of feed (front) roller for the second mill overlays the discharge (back) roller Brix curve, this is not actually acceptable but the reverse is acceptable. Thus, second mill discharge roller setting should be needed.

Our final conclusion goes to agricultural part, the age or maturity of the cane can also affect the performance of the milling plant as explained in the literature part of this study. Our aim is to extract maximum sucrose and minimum, reducing sugar from sugar cane stalks. The reducing sugars are very important for the crystallization purpose in the back factory. For the fact, reducing sugar is low when the sugar cane is ripe (mature) and reducing sugar is high when the sugar cane is immature or overripe; especially when the quality of sugar cane juice tends to be worse, reducing sugar increases significantly. During the period of the growth and maturity of sugar cane, after sucrose produced by sugar cane leaves is transported to the cane and then decomposed again, the ratio for growth in the form of reducing sugar decrease gradually. Reducing sugar is again constantly used for growth and synthesized to sucrose in the cane. Coupled with the consumption of respiration, so reducing sugar is decreasing with the increasing of the plant age. Therefore, over matured and under matured cane stalks are reach in reducing sugars, this cane stalk entered to the factory no more sucrose extraction rather than reducing sugar extraction dominated then finally will affect the extraction efficiency of the milling plant.

5.2 Recommendations

According to the experimental results and practical observations, the following recommendations to be implemented at WSSF to reduce loss of sugar through final bagasse:

Put in practice and strictly control the optimum process parameters obtained by this study for pol and moisture % of last mill bagasse. Implement the second mill discharge roller mill setting for improvement of the extraction process and for best recovery of sucrose losses through the extraction process. Solve the boiler house design problems and scale problems in the evaporation plant to minimize the shortage of hot water as imbibition purpose in order to minimize the sucrose loss through last mill bagasse. Solve and replace the last mill existing plant hydraulic pressure leakages to improve the performance of last mill. Apply and use the juice brix curve for monitor the daily performance of each mill in the milling train. Implement and practice the recycling of return bagasse or Cush-Cush prior to the first mill or screening the primary juice Cush-Cush and secondary juice Cush-Cush separately, then recycling the respective primary juice Cush-Cush prior to the first mill and the secondary juice Cush-Cush to the point between the first and the second mill in order to improve the mill and juice screen efficiency. The implementation does not require any investment cost, but it requires arrangement of the existing lines. Minimize and apply cane spillage during unloading time and don't return the deteriorated cane back to cane table, because as the time it goes the production of microbial duplicated and deteriorations of sucrose will increase. Training and awareness to be given for operators and other workers at mill station, so as to control the process parameters i.e. the proper application of hydraulic pressure and quantity of imbibition flow. Apply and implement the brix free water of 30.63% in cane fiber for real and exact determination of milling losses.

5.2.1 Recommended Future Study

While the research undertaken in this study is considered comprehensive, there remain several tasks required to make the work more applicable. While further study is recommended on the following areas:

- Study and implement mill sanitation system at WSSF
- Study and implement evaporator scales and boiler house design problems so as to solve shortage of hot water as an imbibition purpose.

6. REFERENCES

Dogulas C. Montgomery. (2008).Design and Analysis of Experiments.7th edition. John Wiley & Sons Inc.

Peter Rein.(2007). Cane Sugar Engineering Verlas Dr. Albert Bartens Kg - Berlin 2007.

Meyer, J, Rein, P, Turner, P. and Mathias, K. 2013. Good management practices for the cane sugar industry. VerlagDr. Albert Bartens KG, Berlin, Germany.

Edwards, B.P. (1995). Extraction Performance of Milling Trains- Imbibition Process and Calculations. Proceedings of the Australian Society of Sugar Cane Technologists; 17, pp. (346-351).

Crawford, W.R (1957). Improving Extraction at No.1 Mill. Proceedings of the Queensland Society of Sugar Cane Technologists; 24, pp (89 - 103)

Payne, JH. 1968. Sugar cane factory analytical control. Elsevier Publishing Co., London, New York

Kassa H. 2010, Hand Book of Laboratory Methods and Chemical Control for Ethiopian Sugar Factories.

Training Manual on Manufacturing of Plantation White Sugar from Sugar Cane by Ethiopian Sugar Corporation Research and Training Directorate, Wonji-Shoa.

T.H. FOURMOND, March 1965, The Influence of Brix Free Water when Assessing Milling Performance.

E.Hugot (1982) Hand Book of Cane Sugar Engineering, 3rd Edition, Elesevier Science Publisher Company INC., Netherlands.

Smith, D. 1978. Cane Sugar World. Palmer Publications, New York, U.S.A.

ICUMSA. (2007). ICUMSA Methods Book, Bartens the Sugar and Sweeteners Publishers, England

Moor, GM and Wynne, AT. 2001. Economic Maximization of Grower and Miller Sugar Cane Profits: Optimizing the Length of Milling Season at South African Sugar Factories. Proceedings of the International Society of Sugar Cane Technologists 24:245-249

Jiju Antony. (2003). Design of Experiments for Engineers and Scientists

Chen J.C.P. and C.C. Chou, 1993. Cane sugar handbook – a manual for cane sugar manufacturers and their chemists. 12th Edition. John Wiley and Sons Inc. pp 1090

Kulkarni D.P. (2005). Cane Sugar Manufacturing in India. The Sugar Technologists' Association of India

Scott R.P. (1977). The limitations imposed on crushing rate by tops and trash. Proceedings of South African Sugar Technologists Association. 51:164-166.

Richardson I.J. (1970). Automatic Cane Sampling and Analysis by wet disintegrator. CSR Internal Report.

Foster D.H. (1962). Fibre Water and Juice. Proceedings of Queensland Society of Sugar Cane Technologists. 29:179-184.

Foster D.H. (1963). A Tentative Method of Analysis of cane. Proceedings of Queensland Society of Sugar Cane Technologists. 30:163-165.

Ravnö A. B.(1985). SASTA Laboratory Manual including the Official Methods. South African Sugar Technologist Association

Kent, G.A. (2003). Increasing the Capacity of Australian Raw Sugar Factory Milling Units. PhD Thesis, James Cook University.

de Beer A.G., M.M.W. Boast and B. Worlock (1989). The agricultural consequences of harvesting sugar cane containing various amounts of tops and trash. Proceedings of South African Sugar Technologists' Association. 63:107-110.

A WIENESE, June 1995. The Effect of Imbibition and Cane Quality on the Front End Mass Balance, Sugar Milling Research Institute, Durban.

Lionnet, GRE. 1996. A review of cane quality in South Africa and its effect on factory performance. Proceedings of the South African Sugar Technologists' Association Durban, South Africa 74: 19-24.

Omkar P Thaval B.Tech (Sugar Technologist). September 2012, Modeling the Flow of Cane Consitutents through the Milling process of a Raw Sugar Factory, Queensland University of Technology.

J.L. OLIVERIO, A.C.R. D AVILA, A.N. FABER, P.A. SOARES, April 2013, JUICE EXTRACTION SYSTEMS: Mills and Diffusers - The Brazilian Experience.

Kornvalai Panpae1*, Wasna Jaturonrusmee1, Withawat Mingvanish1, Chantana Nuntiwattanawong2, Surapon
Chunwiset 2 , Kittisak Santudrob1 and Siriphan Triphanpitak1 The Malaysian Journal of Analytical Sciences, Vol 12, No 3 (2008): 513 – 519.

PR Kwenda, (2015) Master Thesis, A Review of The Sugar Milling Process in South Africa and How it Influences the Length of the Milling Season, School of Engineering University of KwaZulu-Natal Pietermaritzburg.

Wonji – Shoa Sugar Factory, 2013/14 – 2018/19 Factory Performance Report

Rein P.W. and Smith I.A.(1981). Molasses exhaustibility studies based on sugars analysis by gas-liquid chromatography. Proc.S. Afr. Sugar Technol. Ass.73, 85-91.

Mangion M.J. and M.R.Player (1991). Hygroscopic Water in Sugar Cane. Proceedings of Australian Society of Sugar Cane Technologists. 13:285-290.

Kirtiraj Gaikwad and P.K. More, April, 2014 (International Journal of Agricultural Engineering; Volume 7, | 259–263 by Suman Singh,).

7. APPENDICES

Appendix-A

1. 1: Logical Framework Matrix

	Narrative Summary	Objectively verifiable (Performance) Indicator	Means of verification	Important Assumptions
Program Goal	**Development objectives** - Securing internationally competent sugar industry through adoption and improvement of sugar and co-products utilization technology that minimizes cost of production.	**Impact Indicator** -to minimizes the poverty of the country and to attain demand satisfaction.	**Source of information** - RDC research reports	**Important events** - Commitment of the top management in improving and adopting sugar production technologies - Competent researchers and factory staffs are hired - Conducive working conditions and fringe benefits are available.
Project Purpose	**Immediate Objective** - To improve the efficiency of sugar cane milling plant. - To increase the mill juice extraction. - To increase the yield by minimizing different losses. - Study the effect of varying quantity of imbibition water & hydraulic pressure on bagasse for performance of last mill.	**Effect Indicator** - Performance evaluation of sugar cane milling plant and optimization of process parameters.	**Source of information** - Performance reports of the WSSF. - RDC Research reports	**Important events** - Competent researchers and appropriate facilities are available - Commitment of stakeholders to implement the completed research - Transport, accommodation and financing facilities are improved.
Research Outputs	**Research results** - Reduced pol % bagasse, well prepared juice brix diagram, reduced moisture % bagasse, maximum sucrose extraction, minimum non-sugar extraction	**Output Indicators** - Improved-sugar yield &well planned management practice of the plant.	**Source of information** - Performance reports of the WSSF. - RDC Research	**Important events** - Research staff and facilities are available. - Transport and other facilities are available. - Released technologies are

	and well planned sugar milling management practice.		reports	implemented
Activities	**Major activities** - Studying the existing conditions of the milling plant. - Conduct laboratory work and sample analysis. - Identify the operation that cause for losses. - Optimization of process parameters.	**Progress Indicators** - Monthly & quarterly report. -Experiments conducted -Laboratory analytical results - Progress reports	**Source of information** -Research proposals -Progress reports -Research reports	**Important events** - Cooperation sugar factory personnel - Appropriate and skilled supporting manpower is available - If necessary inputs are available - If released recommendations are applied accordingly
Inputs	**Necessary Inputs** - Appropriate research laboratory at Wonji. - Senior researchers at RDC. - School advisors at AAiT. - Laboratory technicians -Transportation facilities -Adequate advance payments.	**Resource (grounds and services)** - Manpower - Vehicle - Lab technician	**Source of information** -Progress repot -lab test report - Documents	**Preconditions** - Equipped laboratory is available - Manpower is available -Vehicle available and financial service are improved

1. 2: Monitoring and Evaluation

Output/ Process	Monitoring & evaluation objectives	Indicators	Information to be collected	Methods of collecting information	Tools of collecting information	Method of analysis
Output -Optimized pol & moisture % bagasse.-Well prepared juice brix diagram. -Improved sugar yield	- To assess the experiments whether-conducted properly.	- Number of experments, samples collected & number of analysis done as per the schedule	-Factory operation personal& research result implementation department.	-Laboratory experiments, internet sources,recent documents & related other activities	- Primary data using experiments & secondary data from internet sources, internationally published papers, journal articles	-Mean comparison method.
Process -Sample collection and laboratory analysis.	-To asses proper method of test and analytical methods used.	- The value of Responses.	pol, brix, moisture, fiber, imbibition water, PI, yield,	- Lab experiments and related other activities	- Primary data using experiments and secondary data from internet sources, internationally published papers, journal articles	- Descriptive analysis.
- **Conduct** laboratory experiment	- To asses that experiments are carried out according to the proposal and that the data will be collected properly.	- Number of experiments and the data collected form	- Responses	-Interview factory personnel -progress reports	- Recording on note book. -Personal observation	Descriptive analysis

Appendix -B

2. 1: Pol or Sucrose Factors According to Refractometer Solids.

To obtain pol multiply the saccharometer reading obtained from dry lead sub-acetate Clarification by the factor corresponding to the refractometer solids. To obtain sucrose multiply the calculated sucrose reading by the factor: $\text{Pol Factor} = \dfrac{26}{99.718 \times \text{ap.sp gr at } 20^{0}\text{C}/20^{0}\text{C}}$

Example Saccharometer reading = **41.5**

Refractometer solids = **11.50**

Pol = 41.5 x 0.24920 = **10.34**

Refr. solid	Pol factor 0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.1	0.26064	0.26063	0.26062	0.26061	0.26060	0.26059	0.26057	0.26056	0.26055	0.26054
0.2	0.26053	0.26052	0.26051	0.26050	0.26049	0.26048	0.26047	0.26046	0.26045	0.26044
0.3	0.26043	0.26042	0.26041	0.26040	0.2603	0.26038	0.26037	0.26036	0.26035	0.26034
0.4	0.26033	0.26032	0.26031	0.26030	0.26029	0.26028	0.26027	0.26026	0.26025	0.26024
0.5	0.26023	0.26022	0.26021	0.26020	0.26019	0.26018	0.26017	0.26016	0.26015	0.26014
0.6	0.26013	0.26012	0.26011	0.26010	0.26009	0.26008	0.26007	0.26006	0.26005	0.26004
0.7	0.26003	0.26002	0.26001	0.26000	0.25999	0.25997	0.25996	0.25995	0.25994	0.25993
0.8	0.25992	0.25991	0.25990	0.25989	0.25988	0.25987	0.25986	0.25985	0.25984	0.25983
0.9	0.25982	0.25981	0.25980	0.25979	0.25978	0.25977	0.25976	0.25975	0.25974	0.25973
1.0	0.25972	0.25971	0.25970	0.25969	0.25968	0.25967	0.25966	0.25965	0.25964	0.25963
1.1	0.25962	0.25961	0.25960	0.25959	0.25958	0.25957	0.25956	0.25955	0.25954	0.25953
1.2	0.25952	0.25951	0.25950	0.25949	0.25948	0.25947	0.25946	0.25945	0.25944	0.25943
1.3	0.25942	0.25941	0.25940	0.25939	0.25938	0.25937	0.2593	0.25935	0.2593	0.25933
1.4	0.25932	0.25931	0.25930	0.25929	0.25928	0.25927	0.25926	0.25925	0.25924	0.25923
1.5	0.25922	0.25921	0.25920	0.25919	0.25918	0.25917	0.25916	0.25915	0.25914	0.25913
1.6	0.25912	0.25911	0.25910	0.25909	0.25908	0.25907	0.25906	0.25905	0.25904	0.25903
1.7	0.25902	0.25901	0.25900	0.25899	0.25898	0.25897	0.25896	0.25895	0.25894	0.25893
1.8	0.25892	0.25891	0.25890	0.25889	0.25888	0.25887	0.25886	0.25885	0.25884	0.25883
1.9	0.25882	0.25881	0.25880	0.25879	0.25878	0.25877	0.25876	0.25875	0.25874	0.25873
2.0	0.25872	0.25871	0.25870	0.25869	0.25868	0.25867	0.25866	0.25865	0.25864	0.25863
2.1	0.25862	0.25861	0.25860	0.25859	0.25858	0.25857	0.25856	0.25855	0.25854	0.25853
2.2	0.25852	0.25851	0.25850	0.25849	0.25848	0.25846	0.25845	0.25844	0.25843	0.25842
2.3	0.25841	0.25840	0.25839	0.25838	0.25837	0.25836	0.25835	0.25834	0.25833	0.25832
2.4	0.25831	0.25830	0.25829	0.25828	0.25827	0.25826	0.25825	0.25824	0.25823	0.25822
2.5	0.25821	0.25820	0.25819	0.25818	0.25817	0.25816	0.25815	0.25814	0.25813	0.25812

2.6	0.25811	0.25810	0.25809	0.25808	0.25807	0.25806	0.25805	0.25804	0.25803	0.25802
2.7	0.25801	0.25800	0.25799	0.25798	0.25797	0.25796	0.25795	0.25794	0.25793	0.25792
2.8	0.25791	0.25790	0.25789	0.25788	0.25787	0.25786	0.25785	0.25784	0.25783	0.25782
2.9	0.25781	0.25780	0.25779	0.25778	0.25777	0.25776	0.25775	0.25774	0.25773	0.25772
3.0	0.25771	0.25770	0.25769	0.25768	0.25767	0.25766	0.25765	0.25764	0.25763	0.25762
3.1	0.25761	0.25760	0.25759	0.25758	0.25757	0.25756	0.25755	0.25754	0.25753	0.25752
3.2	0.25751	0.25750	0.25749	0.25748	0.25747	0.25746	0.25745	0.25744	0.25743	0.25742
3.3	0.25741	0.25740	0.25739	0.25738	0.25737	0.25736	0.25735	0.25734	0.25733	0.25732
3.4	0.25731	0.25730	0.25729	0.25728	0.25727	0.25726	0.25725	0.25724	0.25723	0.25722
3.5	0.25721	0.25720	0.25719	0.25718	0.25717	0.25716	0.25715	0.25714	0.25713	0.25712
3.6	0.25711	0.25710	0.25709	0.25708	0.25707	0.25706	0.25705	0.25704	0.25703	0.25702
3.7	0.25701	0.25700	0.25699	0.25698	0.25697	0.25696	0.25695	0.25694	0.25693	0.25692
3.8	0.25691	0.25690	0.25689	0.25688	0.25687	0.25686	0.25685	0.25684	0.25683	0.25682
3.9	0.25681	0.25680	0.25679	0.25678	0.25677	0.25676	0.25675	0.25674	0.25673	0.25672
4.0	0.25671	0.25670	0.25669	0.25668	0.25667	0.25666	0.25665	0.25664	0.25663	0.25662
4.1	0.25661	0.25660	0.25659	0.25658	0.25657	0.25656	0.25655	0.25654	0.25653	0.25652
4.2	0.25651	0.25650	0.25649	0.25648	0.25647	0.25646	0.25645	0.25644	0.25643	0.25642
4.3	0.25641	0.25640	0.25639	0.25638	0.25637	0.25636	0.25635	0.25634	0.25633	0.25632
4.4	0.25631	0.25630	0.25629	0.25628	0.25627	0.25626	0.25625	0.25624	0.25623	0.25622
4.5	0.25621	0.25620	0.25619	0.25618	0.25617	0.25616	0.25615	0.25614	0.25613	0.25612
4.6	0.25611	0.25610	0.25609	0.25608	0.25607	0.25606	0.25605	0.25604	0.25603	0.25602
4.7	0.25601	0.25600	0.25599	0.25598	0.25597	0.25596	0.25595	0.25594	0.25593	0.25592
4.8	0.25591	0.25590	0.25589	0.25588	0.25587	0.25586	0.25585	0.25584	0.25583	0.25582
4.9	0.25581	0.25580	0.25579	0.25578	0.25577	0.25576	0.25575	0.25574	0.25573	0.25572
5.0	0.25571	0.25570	0.25569	0.25568	0.25567	0.25566	0.25565	0.25564	0.25563	0.25562
5.1	0.25561	0.25560	0.25559	0.25558	0.25557	0.25556	0.25555	0.25554	0.25553	0.25552
5.2	0.25551	0.25550	0.25549	0.25548	0.25547	0.25546	0.25545	0.25544	0.25543	0.25542
5.3	0.25541	0.25540	0.25539	0.25538	0.25537	0.25536	0.25535	0.25534	0.25533	0.25532
5.4	0.25531	0.25530	0.25529	0.25528	0.25527	0.25526	0.25525	0.25524	0.25523	0.25522
5.5	0.25521	0.25520	0.25519	0.25518	0.25517	0.25516	0.25515	0.25514	0.25513	0.25512
5.6	0.25511	0.25510	0.25509	0.25508	0.25507	0.25506	0.25505	0.25504	0.25503	0.25502
5.7	0.25501	0.25500	0.25499	0.25498	0.25497	0.25496	0.25495	0.25494	0.25493	0.25492
5.8	0.25491	0.25490	0.25489	0.25488	0.25487	0.25486	0.25485	0.25484	0.25483	0.25482
5.9	0.25481	0.25480	0.25479	0.25478	0.25477	0.25476	0.25475	0.25474	0.25473	0.25472
6.0	0.25471	0.25470	0.25469	0.25468	0.25467	0.25466	0.25465	0.25464	0.25463	0.25462
6.1	0.25461	0.25460	0.25459	0.25458	0.25457	0.25456	0.25455	0.25454	0.25453	0.25452
6.2	0.25451	0.25450	0.25449	0.25448	0.25447	0.25446	0.25445	0.25444	0.25443	0.25442
6.3	0.25441	0.25440	0.25439	0.25438	0.25437	0.25436	0.25435	0.25434	0.25433	0.25432
6.4	0.25431	0.25430	0.25429	0.25428	0.25427	0.25426	0.25425	0.25424	0.25423	0.25422
6.5	0.25421	0.25420	0.25419	0.25418	0.25417	0.25416	0.25415	0.25414	0.25413	0.25412
6.6	0.25411	0.25410	0.25409	0.25408	0.25407	0.25406	0.25405	0.25404	0.25403	0.25402
6.7	0.25401	0.25400	0.25399	0.25398	0.25397	0.25396	0.25395	0.25394	0.25393	0.25392
6.8	0.25391	0.25390	0.25389	0.25388	0.25387	0.25386	0.25385	0.25384	0.25383	0.25382
6.9	0.25381	0.25380	0.25379	0.25378	0.25377	0.25376	0.25375	0.25374	0.25373	0.25372
7.0	0.25371	0.25370	0.25369	0.25368	0.25367	0.25366	0.25365	0.25364	0.25363	0.25362

7.1	0.25360	0.25359	0.25358	0.25357	0.25356	0.25355	0.25354	0.25353	0.25352	0.25351
7.2	0.25350	0.25349	0.25348	0.25347	0.25346	0.25345	0.25344	0.25343	0.25342	0.25341
7.3	0.25340	0.25339	0.25338	0.25337	0.25336	0.25335	0.25334	0.25333	0.25332	0.25331
7.4	0.25330	0.25329	0.25328	0.25327	0.25326	0.25325	0.25324	0.25323	0.25322	0.25321
7.5	0.25320	0.25319	0.25318	0.25317	0.25316	0.25315	0.25314	0.25313	0.25312	0.25311
7.6	0.25310	0.25309	0.25308	0.25307	0.25306	0.25305	0.25304	0.25303	0.25302	0.25301
7.7	0.25299	0.25298	0.25297	0.25296	0.25295	0.25294	0.25293	0.25292	0.25291	0.25290
7.8	0.25289	0.25288	0.25287	0.25286	0.25285	0.25284	0.25283	0.25282	0.25281	0.25280
7.9	0.25279	0.25278	0.25277	0.25276	0.25275	0.25274	0.25273	0.25272	0.25271	0.25270
8.0	0.25269	0.25268	0.25267	0.25266	0.25265	0.25264	0.25263	0.25262	0.25261	0.25260
8.1	0.25260	0.25259	0.25258	0.25257	0.25256	0.25255	0.25254	0.25253	0.25252	0.25251
8.2	0.25250	0.25249	0.25248	0.25247	0.25246	0.25245	0.25244	0.25243	0.25242	0.25241
8.3	0.25240	0.25239	0.25238	0.25237	0.25236	0.25235	0.25234	0.25233	0.25232	0.25231
8.4	0.25230	0.25229	0.25228	0.25227	0.25226	0.25225	0.25224	0.25223	0.25222	0.25221
8.5	0.25220	0.25219	0.25218	0.25217	0.25216	0.25217	0.25215	0.25214	0.25213	0.25212
8.6	0.25210	0.25209	0.25208	0.25207	0.25206	0.25205	0.25204	0.25203	0.25202	0.25201
8.7	0.25200	0.25199	0.25198	0.25197	0.25196	0.25195	0.25194	0.25193	0.25192	0.25191
8.8	0.25190	0.25189	0.25188	0.25187	0.25186	0.25185	0.25184	0.25183	0.25182	0.25181
8.9	0.25180	0.25179	0.25178	0.25177	0.25176	0.25175	0.25174	0.25173	0.25172	0.25171
9.0	0.25170	0.25169	0.25168	0.25167	0.25166	0.25165	0.25164	0.25163	0.25162	0.25161
9.1	0.25160	0.25159	0.25158	0.25157	0.25156	0.25155	0.25154	0.25153	0.25152	0.25151
9.2	0.25150	0.25149	0.25148	0.25147	0.25146	0.25145	0.25144	0.25143	0.25142	0.25141
9.3	0.25140	0.25139	0.25138	0.25137	0.25136	0.25135	0.25134	0.25133	0.25132	0.25131
9.4	0.25130	0.25129	0.25128	0.25127	0.25126	0.25125	0.25124	0.25123	0.25122	0.25121
9.5	0.25120	0.25119	0.25118	0.25117	0.25116	0.25115	0.25114	0.25113	0.25112	0.25111
9.6	0.25110	0.25109	0.25108	0.25107	0.25106	0.25105	0.25104	0.25103	0.25102	0.25101
9.7	0.25100	0.25099	0.25098	0.25097	0.25096	0.25095	0.25094	0.25093	0.25092	0.25091
9.8	0.25090	0.25089	0.25088	0.25087	0.25086	0.25085	0.25084	0.25083	0.25082	0.25081
9.9	0.25080	0.25079	0.25078	0.25077	0.25076	0.25075	0.25074	0.25073	0.25072	0.25071
10.0	0.25070	0.25069	0.25068	0.25067	0.25066	0.25065	0.25064	0.25063	0.25062	0.25061
10.1	0.25060	0.25059	0.25058	0.25057	0.25056	0.25055	0.25054	0.25053	0.25052	0.25051
10.2	0.25050	0.25049	0.25048	0.25047	0.25046	0.25045	0.25044	0.25043	0.25042	0.25041
10.3	0.25040	0.25039	0.25038	0.25037	0.25036	0.25035	0.25034	0.25033	0.25032	0.25031
10.4	0.25030	0.25029	0.25028	0.25027	0.25026	0.25025	0.25024	0.25023	0.25022	0.25021
10.5	0.25020	0.25019	0.25018	0.25017	0.25016	0.25015	0.25014	0.25013	0.25012	0.25011
10.6	0.25010	0.25009	0.25008	0.25007	0.25006	0.25005	0.25004	0.25003	0.25002	0.25001
10.7	0.25000	0.24999	0.24998	0.24997	0.24996	0.24995	0.24994	0.24993	0.24992	0.24991
10.8	0.24990	0.24989	0.24988	0.24987	0.24986	0.24985	0.24984	0.24983	0.24982	0.24981
10.9	0.24980	0.24979	0.24978	0.24977	0.24976	0.24975	0.24974	0.24973	0.24972	0.24971
11.0	0.24970	0.24969	0.24968	0.24967	0.24966	0.24965	0.24964	0.24963	0.24962	0.24961
11.1	0.24960	0.24959	0.24958	0.24957	0.24956	0.24955	0.24954	0.24953	0.24952	0.24951
11.2	0.24950	0.24949	0.24948	0.24947	0.24946	0.24945	0.24944	0.24943	0.24942	0.24941

11.3	0.24940	0.24939	0.24938	0.24937	0.24936	0.24935	0.24934	0.24933	0.24932	0.24931
11.4	0.24930	0.24929	0.24928	0.24927	0.24926	0.24925	0.24924	0.24923	0.24922	0.24921
11.5	0.24920	0.24919	0.24918	0.24917	0.24916	0.24915	0.24914	0.24913	0.24912	0.24911
11.6	0.24910	0.24909	0.24908	0.24907	0.24906	0.24905	0.24904	0.24903	0.24902	0.24901
11.7	0.24900	0.24899	0.24898	0.24897	0.24896	0.24895	0.24894	0.24893	0.24892	0.24891
11.8	0.24890	0.24889	0.24888	0.24887	0.24886	0.24885	0.24884	0.24883	0.24882	0.24881
11.9	0.24880	0.24879	0.24878	0.24877	0.24876	0.24875	0.24874	0.24873	0.24872	0.24871
12.0	0.24870	0.24869	0.24868	0.24867	0.24866	0.24865	0.24864	0.24863	0.24862	0.24861
12.1	0.24860	0.24859	0.24858	0.24857	0.24856	0.24855	0.24854	0.24853	0.24852	0.24851
12.2	0.24850	0.24849	0.24848	0.24847	0.24846	0.24845	0.24844	0.24843	0.24842	0.24841
12.3	0.24840	0.24839	0.24838	0.24837	0.24836	0.24835	0.24834	0.24833	0.24832	0.24831
12.4	0.24830	0.24829	0.24828	0.24827	0.24826	0.24825	0.24824	0.24823	0.24822	0.24821
12.5	0.24820	0.24819	0.24818	0.24817	0.24816	0.24815	0.24814	0.24813	0.24812	0.24811
12.6	0.24810	0.24809	0.24808	0.24807	0.24806	0.24805	0.24804	0.24803	0.24802	0.24801
12.7	0.24800	0.24799	0.24798	0.24797	0.24796	0.24795	0.24794	0.24793	0.24792	0.24791
12.8	0.24790	0.24789	0.24788	0.24787	0.24786	0.24785	0.24784	0.24783	0.24782	0.24781
12.9	0.24780	0.24779	0.24778	0.24777	0.24776	0.24775	0.24774	0.24773	0.24772	0.24771
13.0	0.24771	0.24770	0.24771	0.24769	0.24768	0.24767	0.24766	0.24765	0.24764	0.24763
13.1	0.24762	0.24761	0.24760	0.24759	0.24758	0.24757	0.24756	0.24755	0.24754	0.24753
13.2	0.24752	0.24751	0.24750	0.24749	0.24748	0.24747	0.24746	0.24745	0.24744	0.24743
13.3	0.24742	0.24741	0.24740	0.24739	0.24738	0.24737	0.24736	0.24735	0.24734	0.24733
13.4	0.24732	0.24731	0.24730	0.24729	0.24728	0.24727	0.24726	0.24725	0.24724	0.24723
13.5	0.24722	0.24721	0.24720	0.24719	0.24718	0.24717	0.24716	0.24715	0.24714	0.24713
13.6	0.24712	0.24711	0.24710	0.24709	0.24708	0.24707	0.24706	0.24705	0.24704	0.24703
13.7	0.24702	0.24701	0.24700	0.24699	0.24698	0.24697	0.24696	0.24695	0.24694	0.24693
13.8	0.24692	0.24691	0.24690	0.24659	0.24658	0.24657	0.24656	0.24655	0.24654	0.24653
13.9	0.24652	0.24651	0.24650	0.24649	0.24648	0.24647	0.24646	0.24645	0.24644	0.24643
14.0	0.24642	0.24641	0.24640	0.24639	0.24638	0.24637	0.24636	0.24635	0.24634	0.24633
14.1	0.24632	0.24631	0.24630	0.24629	0.24628	0.24627	0.24626	0.24625	0.24624	0.24623
14.2	0.24622	0.24621	0.24620	0.24619	0.24618	0.24617	0.24616	0.24615	0.24614	0.24613
14.3	0.24612	0.24611	0.24610	0.24609	0.24608	0.24607	0.24606	0.24605	0.24604	0.24603
14.4	0.24602	0.24601	0.24600	0.24599	0.24598	0.24597	0.24596	0.24595	0.24594	0.24593
14.5	0.24592	0.24591	0.24590	0.24589	0.24588	0.24587	0.24586	0.24585	0.24584	0.24583
14.6	0.24582	0.24581	0.24580	0.24579	0.24578	0.24577	0.24576	0.24575	0.24574	0.24573
14.7	0.24572	0.24571	0.24570	0.24569	0.24568	0.24567	0.24566	0.24565	0.24564	0.24563
14.8	0.24562	0.24561	0.24560	0.24559	0.24558	0.24557	0.24556	0.24555	0.24554	0.24553
14.9	0.24582	0.24581	0.24580	0.24579	0.24578	0.24577	0.24576	0.24575	0.24574	0.24573
15.0	0.24572	0.24571	0.24570	0.24569	0.24568	0.24567	0.24566	0.24565	0.24564	0.24563
15.1	0.24562	0.24561	0.24560	0.24559	0.24558	0.24557	0.24556	0.24555	0.24554	0.24553

15.2	0.24552	0.24551	0.24550	0.24549	0.24548	0.24547	0.24546	0.24545	0.24544	0.24543
15.3	0.24542	0.24541	0.24540	0.24539	0.24538	0.24537	0.24536	0.24535	0.24534	0.24533
15.4	0.24532	0.24531	0.24530	0.24529	0.24528	0.24527	0.24526	0.24525	0.24524	0.24523
15.5	0.24522	0.24521	0.24520	0.24519	0.24518	0.24517	0.24516	0.24515	0.24514	0.24513
15.6	0.24512	0.24511	0.24510	0.24509	0.24508	0.24507	0.24506	0.24505	0.24504	0.24503
15.7	0.24502	0.24501	0.24500	0.24499	0.24498	0.24497	0.24496	0.24495	0.24494	0.24493
15.8	0.24492	0.24491	0.24490	0.24489	0.24488	0.24487	0.24486	0.24485	0.24484	0.24483
15.9	0.24482	0.24481	0.24480	0.24479	0.24478	0.24477	0.24476	0.24475	0.24474	0.24473
16.0	0.24472	0.24471	0.24470	0.24469	0.24468	0.24467	0.24466	0.24465	0.24464	0.24463
16.1	0.24462	0.24461	0.24460	0.24459	0.24458	0.24457	0.24456	0.24455	0.24454	0.24453
16.2	0.24452	0.24451	0.24450	0.24449	0.24448	0.24447	0.24446	0.24445	0.24444	0.24443
16.3	0.24442	0.24441	0.24440	0.24439	0.24438	0.24437	0.24436	0.24435	0.24434	0.24433
16.4	0.24432	0.24431	0.24430	0.24429	0.24428	0.24427	0.24426	0.24425	0.24424	0.24423
16.5	0.24422	0.24421	0.24420	0.24419	0.24418	0.24417	0.24416	0.24415	0.24414	0.24413
16.6	0.24412	0.24411	0.24410	0.24409	0.24408	0.24407	0.24406	0.24405	0.24404	0.24403
16.7	0.24402	0.24401	0.24400	0.24399	0.24398	0.24397	0.24396	0.24395	0.24394	0.24393
16.8	0.24392	0.24391	0.24390	0.24389	0.24388	0.24387	0.24386	0.24385	0.24384	0.24383
16.9	0.24382	0.24381	0.24380	0.24379	0.24378	0.24377	0.24376	0.24375	0.24374	0.24373
17.0	0.24372	0.24371	0.24370	0.24369	0.24368	0.24367	0.24366	0.24365	0.24364	0.24363
17.1	0.24362	0.24361	0.24360	0.24359	0.24358	0.24357	0.24356	0.24355	0.24354	0.24353
17.2	0.24352	0.24351	0.24350	0.24349	0.24348	0.24347	0.24346	0.24345	0.24344	0.24343
17.3	0.24342	0.24341	0.24340	0.24339	0.24338	0.24337	0.24336	0.24335	0.24334	0.24333
17.4	0.24332	0.24331	0.24330	0.24329	0.24328	0.24327	0.24326	0.24325	0.24324	0.24323
17.5	0.24322	0.24321	0.24320	0.24319	0.24318	0.24317	0.24316	0.24315	0.24314	0.24313
17.6	0.24312	0.24311	0.24310	0.24309	0.24308	0.24307	0.24306	0.24305	0.24304	0.24303
17.7	0.24302	0.24301	0.24300	0.24299	0.24298	0.24297	0.24296	0.24295	0.24294	0.24293
17.8	0.24292	0.24291	0.24290	0.24289	0.24288	0.24287	0.24286	0.24285	0.24284	0.24283
17.9	0.24282	0.24281	0.24280	0.24279	0.24278	0.24277	0.24276	0.24275	0.24274	0.24273
18.0	0.24272	0.24271	0.24270	0.24269	0.24268	0.24267	0.24266	0.24265	0.24264	0.24263
18.1	0.24262	0.24261	0.24260	0.24259	0.24258	0.24257	0.24256	0.24255	0.24254	0.24253
18.2	0.24252	0.24251	0.24250	0.24249	0.24248	0.24247	0.24246	0.24245	0.24244	0.24243
18.3	0.24242	0.24241	0.24240	0.24239	0.24238	0.24237	0.24236	0.24235	0.24234	0.24233
18.4	0.24232	0.24231	0.24230	0.24229	0.24228	0.24227	0.24226	0.24225	0.24224	0.24223
18.5	0.24222	0.24221	0.24220	0.24219	0.24218	0.24217	0.24216	0.24215	0.24214	0.24213
18.6	0.24212	0.24211	0.24210	0.24209	0.24208	0.24207	0.24206	0.24205	0.24204	0.24203
18.7	0.24202	0.24201	0.24200	0.24199	0.24198	0.24197	0.24196	0.24195	0.24194	0.24193

Appendix– C

3.1: WSSF SOP for Cane Preparation and Extraction Plant.

Operational parameters	Actual operational values	Operational standard range
Recoverable sugar (Field Yield)	10.48	≥ 12%
Fiber content	13.43	13.5 – 14.5 %
Knives and hammers Status	Checking, replacing and reversing them when the preparation index is less than the set value	
Cane preparation index, %	86.20	≥86%
Primary Juice extraction	60.38	60-65
Primary juice Brix %	20.27	20 ± 0.5
Primary juice Purity %	90.40	85
Secondary juice Brix %	8.20	10 – 11
Secondary juice purity %	85.12	82 – 83
Last expressed juice Brix %	3.24	2 – 3
Last expressed juice Purity %	74	70 – 75
Hot Imbibition % fiber	217.90	250
Mill extraction	96.65	95%
Reduced mill extraction	96.89	≥96%
Moisture% bagasse	51.00	< 50
Pol% bagasse	1.77	< 1.5
1^{st} mill hydraulic pressure **(kg/cm^2)**	160	180-205
2^{nd} mill hydraulic pressure “ “	170	185-210
3^{rd} mill hydraulic pressure “ “	180	190-215
4^{th} mill hydraulic pressure “ “	190	195-220
5^{th} mill hydraulic pressure “ “	200	195-220
Mill operating speed (rpm)	4.25	4.25
Mill motor derive speed (rpm)	300-1000	300-1000
Brix % mixed juice	16.90	13.0 – 15
pH mixed juice	5.40	5.2 - 5.4
P_2O_5 % of mixed juice	300 – 350	300 – 350
Imbibition % cane	29.10	30
Apparent purity of mixed juice	86.10	>85
Mixed juice % cane	100	105
Bagasse % cane	28.50	28 – 32
Purity of cane	86	>86
Sucrose % cane	13.60	13.92

Appendix-D

4.1: Degrees Brix, True density and specific gravity of sugar solutions.

Degrees Brix or percent age of sucrose by weigh	Specific gravity at $20^0/4^0C$	Specific gravity at $20^0/20^0C$	Grams of Sucrose per 100 ml weight in Vacuo	Degrees Brix or percent age of sucrose by weight	Specific gravity at $20^0/4^0C$	Specific gravity at $20^0/20^0C$	Grams of Sucrose per 100 ml weight in Vacuo
0.0	0.99823	1.00000	0.0000	**4.0**	1.01388	1.01567	4.0555
0.1	0.99862	1.00039	0.0999	**4.1**	1.01428	1.01607	4.1585
0.2	0.99901	1.00078	0.1998	**4.2**	1.01467	1.01647	4.2616
0.3	0.99940	1.00117	0.2998	**4.3**	1.01507	1.01687	4.3648
0.4	0.99979	1.00155	0.3999	**4.4**	1.01547	1.01726	4.4681
0.5	1.00017	1.00194	0.5001	**4.5**	1.01586	1.01766	4.5714
0.6	1.00056	1.00233	0.6003	**4.6**	1.01626	1.01806	4.6748
0.7	1.00095	1.00272	0.7007	**4.7**	1.01666	1.01846	4.7783
0.8	1.00134	1.00311	0.8011	**4.8**	1.01706	1.01886	4.8819
0.9	1.00173	1.00350	0.9016	**4.9**	1.01746	1.01926	4.9856
1.0	1.00212	1.00389	1.0021	**5.0**	1.01785	1.01965	5.0892
1.1	1.00251	1.00428	1.1028	**5.1**	1.01825	1.02005	5.1931
1.2	1.00290	1.00467	1.2035	**5.2**	1.01865	1.02045	5.2970
1.3	1.00329	1.00506	1.3043	**5.3**	1.01905	1.02085	5.4010
1.4	1.00368	1.00545	1.4052	**5.4**	1.01945	1.02125	5.5050
1.5	1.00406	1.00584	1.5061	**5.5**	1.01985	1.02165	5.6092
1.6	1.00445	1.00623	1.6071	**5.6**	1.02025	1.02206	5.7134
1.7	1.00484	1.00662	1.7082	**5.7**	1.02065	1.02246	5.8177
1.8	1.00523	1.00701	1.8094	**5.8**	1.02105	1.02286	5.9221
1.9	1.00562	1.00740	1.9107	**5.9**	1.02145	1.02321	6.0266
2.0	1.00602	1.00779	2.0120	**6.0**	1.02186	1.02366	6.1312
2.1	1.00641	1.00818	2.1135	**6.1**	1.02226	1.02407	6.2358
2.2	1.00680	1.00858	2.2150	**6.2**	1.02266	1.02447	6.3405
2.3	1.00719	1.00897	2.3165	**6.3**	1.02306	1.02487	6.4453
2.4	1.00758	1.00936	2.4182	**6.4**	1.02346	1.02527	6.5501
2.5	1.00797	1.00976	2.5199	**6.5**	1.02387	1.02568	6.6552
2.6	1.00836	1.01015	2.6217	**6.6**	1.02427	1.02608	6.7602
2.7	1.00876	1.01054	2.7237	**6.7**	1.02467	1.02648	6.8653
2.8	1.00915	1.01093	2.8256	**6.8**	1.02508	1.02689	6.9705
2.9	1.00954	1.01133	2.9277	**6.9**	1.02548	1.02729	7.0758
3.0	1.00993	1.01172	3.0298	**7.0**	1.02588	1.02770	7.1812
3.1	1.01033	1.01211	3.1320	**7.1**	1.02629	1.02810	7.2867
3.2	1.01072	1.01251	3.2343	**7.2**	1.02669	1.02851	7.3922
3.3	1.01112	1.01290	3.3367	**7.3**	1.02710	1.02892	7.4978

3.4	1.01151	1.01330	3.4391	**7.4**	1.02750	1.02932	7.6035
3.5	1.01190	1.01369	3.5416	**7.5**	1.02791	1.02973	7.7093
3.6	1.01230	1.01409	3.6443	**7.6**	1.02832	1.03013	7.8152
3.7	1.01269	1.01448	3.7470	**7.7**	1.02872	1.03054	7.9211
3.8	1.01309	1.01488	3.8497	**7.8**	1.02913	1.03095	8.0272
3.9	1.01348	1.01528	3.9526	**7.9**	1.02954	1.03136	8.1334

Source: Hand book of laboratory methods and chemical control for Ethiopian sugar factories (kassa H. 2010)

Appendix-E

5.1: Sequential Model Sum of Squares for response -1(pol % bagasse)

Source	Sum of Squares	DF	Mean Square	F- Value	Prob > F	
Mean	78.38	1	78.38			
Linear	2.81	2	1.41	9.24	0.0053	Suggested
2FI	0.16	1	0.16	1.03	0.3373	
Quadratic	0.79	2	0.39	4.72	0.0503	Suggested
Cubic	0.34	2	0.17	3.54	0.1101	Aliased
Residual	0.24	5	0.048			
Total	82.71	13	6.36			

5.2: Lack of Fit Tests for response -1(pol % bagasse)

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Linear	1.32	6	0.22	4.45	0.0852	Suggested
2FI	1.17	5	0.23	4.71	0.0793	
Quadratic	0.38	3	0.13	2.57	0.1918	Suggested
Cubic	0.042	1	0.042	0.85	0.4095	Aliased
Pure Error	0.20	4	0.050			

5.3: Model Summary Statistics for response -1(pol % bagasse)

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	0.39	0.6489	0.5787	0.3558	2.79	Suggested
2FI	0.39	0.6849	0.5798	0.1260	3.79	
Quadratic	0.29	0.8659	0.7701	0.3003	3.04	Suggested
Cubic	0.22	0.9445	0.8669	0.3080	3.00	Aliased

5.4: Coefficient of estimate for the factors for response – 1(pol % bagasse)

Factor	Coefficient Estimate	DF	Standard Error	95% CI Low	95% CI High	VIF
Intercept	2.72	1	1	0.13	2.42	
A-hydrualic pressure	0.014	1	1	0.10	-0.23	1.00
B-imbibition water	-0.59	1	1	0.10	-0.83	1.00
A^2	-0.33	1	0.11	-0.59	-0.073	1.02
B^2	-0.099	1	0.11	-0.36	0.16	1.02
AB	-0.20	1	0.14	-0.54	0.14	1.00

5. 5: Diagnostics Case Statistics for response - 1 (pol % bagasse)

Standard Order	Actual Value	Predictd Value	Residual	Leverage	Student Residual	Cook's Distance	Outlier T	Run Order
1	2.510	2.670	-0.160	0.625	-0.915	0.233	-0.903	1
2	3.300	3.090	0.210	0.625	1.165	0.377	1.201	9
3	1.530	1.880	-0.350	0.625	-1.986	1.096	-2.783	13
4	1.530	1.510	0.017	0.625	0.094	0.002	0.087	8
5	2.370	2.040	0.330	0.625	1.881	0.983	2.478	4
6	1.890	2.080	-0.190	0.625	-1.060	0.312	-1.071	10
7	3.300	3.360	-0.061	0.625	-0.346	0.033	-0.323	2
8	1.890	1.680	0.210	0.625	1.168	0.379	1.205	7
9	3.020	2.720	0.300	0.200	1.163	0.056	1.199	12
10	2.730	2.720	1.000E-002	0.200	0.039	0.000	0.036	6
11	2.780	2.720	0.060	0.200	0.233	0.002	0.216	5
12	2.400	2.720	-0.32	0.200	-1.241	0.064	-1.301	11
13	2.670	2.720	-0.050	0.200	-0.194	0.002	-0.180	3

5. 6: Sequential Model Sum of Squares for Response -2(moisture % bagasse)

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	34695.89	1	34695.89			
Linear	9.85	2	4.92	4.52	0.0399	Suggested
2FI	0.42	1	0.42	0.36	0.5614	
Quadratic	0.14	2	0.068	0.046	0.9550	
Cubic	0.44	2	0.22	0.11	0.8965	Aliased
Residual	9.88	5	1.98			
Total	34716.62	13	2670.51			

5. 7: Lack of Fit Tests for Response -2 (moisture %)

Source	Sum of Squares	DF	Mean Square	F -Value	Prob > F	
Linear	1.01	6	0.17	0.068	0.9970	Suggested
2FI	0.59	5	0.12	0.048	0.9975	
Quadratic	0.45	3	0.15	0.061	0.9776	
Cubic	0.011	1	0.011	4.560E-003	0.9494	Aliased
Pure Error	9.87	4	2.47			

5. 8: Coefficient of estimate for the factors response – 2 (moisture % bagasse)

Factor	Coefficient Estimate	DF	Standard Error	95% CI Low	95% CI High	VIF
Intercept	51.66	1	0.29	51.02	52.31	
A- HP	-0.55	1	0.37	-1.37	0.27	1.00
B- IMB	0.96	1	0.37	0.14	1.78	1.00

5. 9: Model Summary Statistics for Response -2 (moisture %)

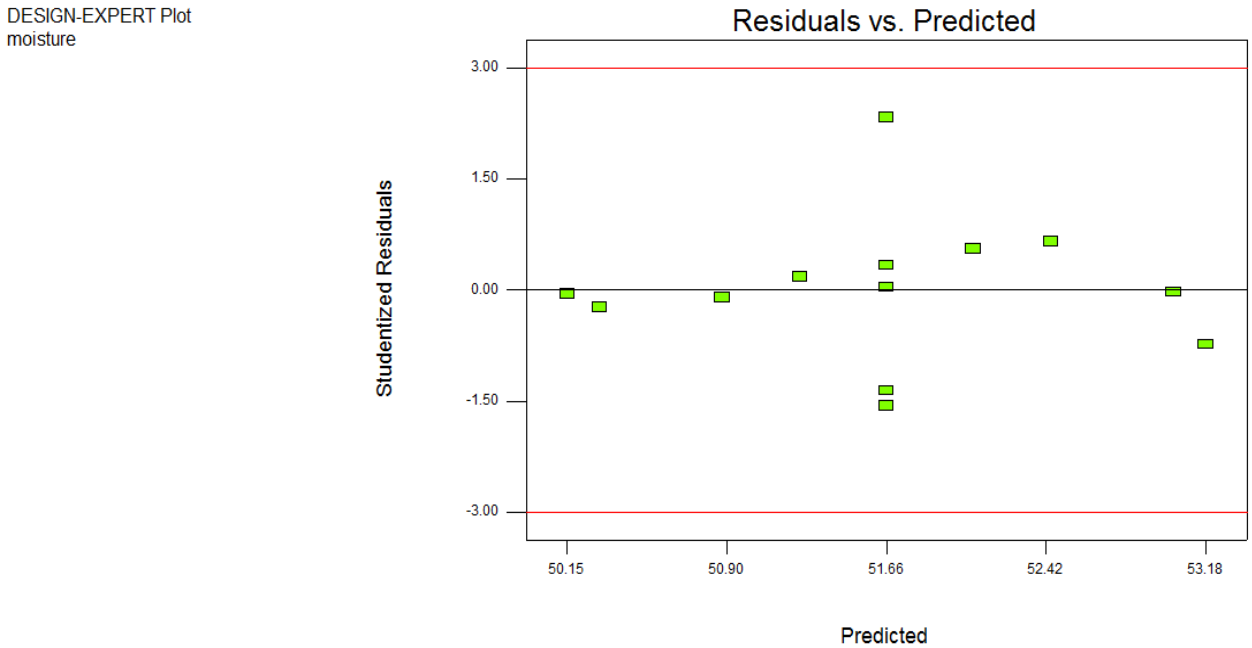
Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	1.04	0.4751	0.3701	0.3339	13.81	Suggested
2FI	1.08	0.4954	0.3273	0.3428	13.62	
Quadratic	1.21	0.5020	0.1463	0.1007	18.64	
Cubic	1.41	0.5233	-0.1440	0.2213	16.14	Aliased

5. 10: Diagnostics Case Statistics Response - 2 (moisture % bagasse)

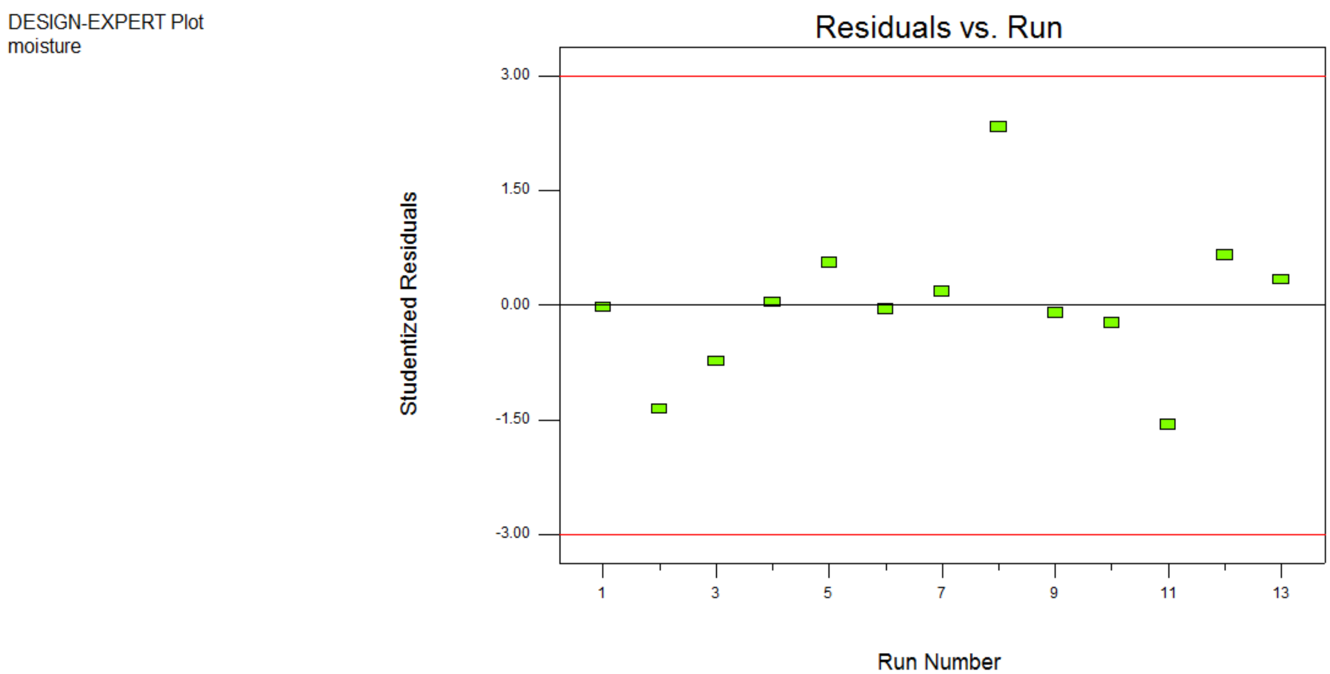
Standard Order	Actual Value	Predictd Value	Residual	Leverage	Student Residual	Cook's Distance	Outlier T	Run Order
1	51.40	51.25	0.15	0.327	0.175	0.005	0.166	1
2	50.10	50.15	-0.047	0.327	-0.055	0.000	-0.053	9
3	52.55	53.18	-0.63	0.327	-0.731	0.087	-0.713	13
4	52.55	52.07	0.48	0.327	0.558	0.050	0.537	8
5	53.00	52.44	0.56	0.327	0.653	0.069	0.633	4
6	50.80	50.88	-0.082	0.327	-0.096	0.001	-0.091	10
7	50.10	50.30	-0.20	0.327	-0.234	0.009	-0.222	2
8	53.00	53.02	-0.023	0.327	-0.027	0.000	-0.025	7
9	51.70	51.66	0.038	0.077	0.038	0.000	0.036	12
10	50.10	51.66	-1.56	0.077	-1.558	0.067	-1.699	6
11	54.00	51.66	2.34	0.077	0.233	0.151	3.280	5
12	50.30	51.66	-1.36	0.077	2.333	0.051	-1.427	11
13	52.00	51.66	0.34	0.077	0.338	0.003	0.322	3

Appendix - F

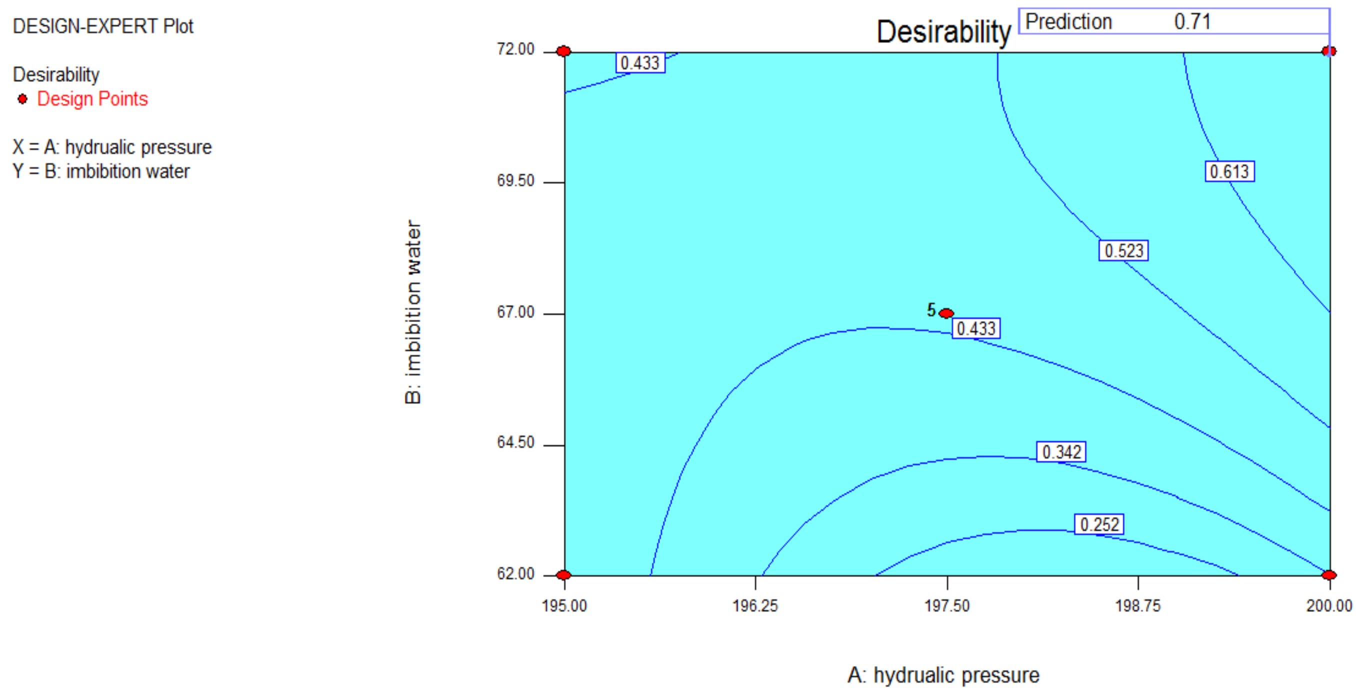
6. 1: Surface Plot for Residual vs. Predicted Values for Response -2 (moisture %)



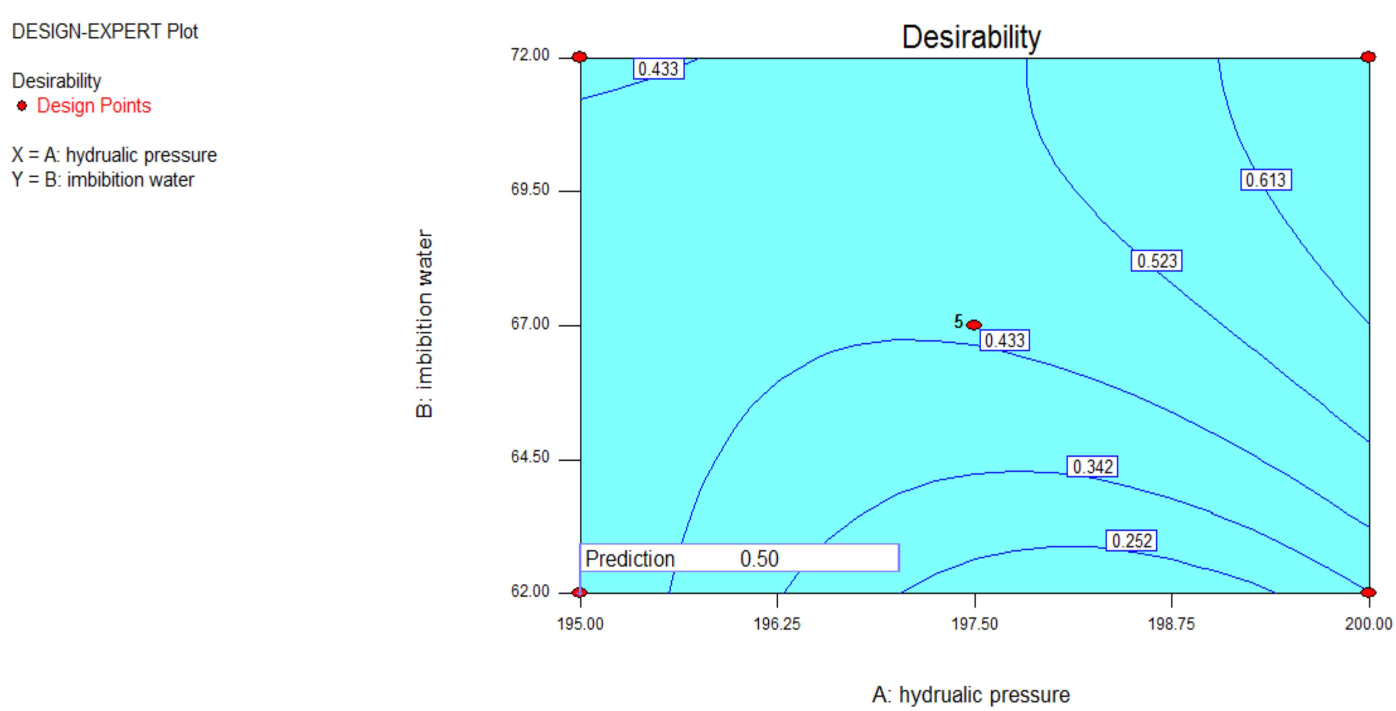
6. 2: Surface Plot for Residual vs. Run Plot



6. 3: Contour Plot for Moisture % Bagasse with Desirability 71%



6. 4: Contour Plot for Moisture % Bagasse with Desirability 50%



Appendix - G

7. 1: Formulas to Estimate Quantitative Terms and Process Parameters of Milling Plant.

$$\text{Brix \% of bagasse} = \frac{\text{pol \% of bagasse}}{\text{purity of last expressed juice}} \times 100 \quad \textbf{(7.1)}$$

$$\text{Fiber \% of bagasse} = 100 - \text{moisture \% of bagasse} - \text{brix \% of bagasse} \quad \textbf{(7.2)}$$

$$\text{Weight of bagasse} = \text{weight of cane crashed} + \text{weight of imbibition} - \text{weight of mixed juice.}$$

$$\text{Bagasse \% of cane} = \frac{\text{weight of bagasse}}{\text{weight of cane crashed}} \times 100 \quad \textbf{(7.3)}$$

$$\text{Weight of fiber} = \frac{\text{weight of bagasse} \times \text{fiber \% of bagasse}}{100} \quad \textbf{(7.4)}$$

$$\text{Fiber \% cane} = \frac{\text{weight of fiber}}{\text{weight of cane crashed}} \times 100 \quad \textbf{(7.5)}$$

$$\text{Mixed juice \% of cane} = \frac{\text{weight of mixed juice}}{\text{weight of cane crashed}} \times 100 \quad \textbf{(7.6)}$$

$$\text{Weight of brix in mixed juice} = \frac{\text{weight of mixed juice} \times \text{brix \% mixed juice}}{100} \quad \textbf{(7.7)}$$

$$\text{Weight of sucrose in mixed juice} = \frac{\text{weight of mixed juice} \times \text{sucrose \% of mixed juice}}{100} \quad \textbf{(7.8)}$$

$$\text{Weight of brix in bagasse} = \frac{\text{brix \% of bagasse} \times \text{weight of bagasse}}{100} \quad \textbf{(7.9)}$$

$$\text{Weight of sucrose in bagasse} = \frac{\text{pol \% of bagasse} \times \text{weight of bagasse}}{100} \quad \textbf{(7.10)}$$

$$\text{Sucrose in bagasse \% of cane} = \frac{\text{weight of sucrose in bagasse}}{\text{weight of cane crashed}} \times 100 \quad \textbf{(7.11)}$$

$$\text{Weight of absolute juice} = \text{weight of cane crashed} - \text{weight of fiber}$$

$$\text{Weight of brix in absolute juic} = \text{weight of brix in bagasse} + \text{weight of brix in mixed juice}$$

$$\text{Weight of sucrose in absolute juie} = \text{weight of sucrose in bagasse} + \text{weight of sucrose in mixed juice}$$

$$\text{Brix \% of absolute juice} = \frac{\text{weight of brix in absolute juice}}{\text{weight of absolute juice}} \times 100 \quad \textbf{(7.12)}$$

$$\text{Sucrose \% of absolute juice} = \frac{\text{weight of sucrose in absolute juice}}{\text{weight of absolute juice}} \times 100 \tag{7.13}$$

$$\text{Gravity purity of absolute juice} = \frac{\text{weight of sucrose in absolute juice}}{\text{weight of brix in absolute juice}} \times 100 \tag{7.14}$$

$$\text{Weight of absolute juice extracted} = \frac{\text{weight of brix in mixed juice}}{\text{brix \% of absolute juice}} \times 100 \tag{7.15}$$

$$\text{Absolute juice \% cane} = \frac{\text{weight of absolute juice}}{\text{weight of cane crashed}} \times 100 \tag{7.16}$$

$$\text{Absolute juice extracted \% cane} = \frac{\text{weight of absolute juice extracted}}{\text{weight of cane crashed}} \times 100 \tag{7.17}$$

$$\text{Weight of absolute juice in bagasse} = \frac{\text{weight of bagasse}}{\text{weight of cane crashed}} \times 100 \tag{7.18}$$

$$\text{Imbibition water \% cane} = \frac{\text{weight of imbibition water}}{\text{weight of cane crashed}} \times 100 \tag{7.19}$$

$$\text{Imbibition water \% absolute juice} = \frac{\text{weight of imbibition water}}{\text{weight of absolute juice}} \times 100 \tag{7.20}$$

$$\text{Weight of dilution water} = \text{weight of mixed juice} - \text{weight of absolute juice extracted}$$

$$\text{Dilution water in cane} = \frac{\text{weight in dillution water}}{\text{weight in cane crashed}} \times 100 \tag{7.21}$$

$$\text{Dilution water \% absolute juice extracted} = \frac{\text{weight of dillution water}}{\text{weight of absolute juice extracetd}} \times 100 \tag{7.22}$$

$$\text{Mill extraction} = \frac{\text{weight of sucrose in mixed juice}}{\text{weight of sucrose in absolute juice}} \times 100 \tag{7.23}$$

$$\text{Reduced mill extraction} = 100 - \frac{[100 - \text{mill extraction}] \times [100 - \text{fiber \% cane}]}{\text{fiber \% bagasse} \times \text{fiber \% cane}} \tag{7.24}$$

$$\text{Extraction ratio} = \frac{100 - \text{mill extraction} \times 100}{\text{fiber \% cane}} \tag{7.25}$$

$$\text{Milling loss} = \frac{\text{weight of sucrose in bagasse}}{\text{weight of fiber}} \times 100 \tag{7.26}$$

Appendixes - H

8. 1: Definition of Various Terminologies Used in this Paper.

Bagasse: - The residual obtained from crushing cane. Its components are fiber, pith, water, solids, lost sucrose all water insoluble in the cane.

Cane preparation: - The knifing and shredding of cane to rupture the juice storage cells prior to juice extraction. The efficiency of cane preparation is measured by determining the ratio of Brix or pol in open cells to total Brix or Pol. The Brix ration is known as preparation Index and the Pol ratio as Pol in open cells.

Pol: - The apparent sucrose content of a sugar product determined by direct or single polarization. Reading on the scale of polarimeter, indicating the apparent sucrose content of the sample to be analyzed. If the sample is a pure sugar solution, the Pol equals to sucrose percentage.

Brix %:- The percent by mass of soluble solid matter (sucrose and soluble non-sucrose) in a solution as indicated by a sugar refractometer.

Fiber %:- The dry water insoluble component of cane. Natural fiber is the fiber with chemically bound Brix-free water present in its structure.

Mixed juice: - The juice sent from the extraction plant to the boiling house.

Cush-Cush: - is fine bagasse found in mixed juice.

PI %:- is the percentage of pol in the open calls.

First mill juice: - The Juice separated by the first mill of the tandem.

First expressed juice: - Juice separated from the cane by the first two rollers of a mill tandem.

Last mill juice: - The Juice expressed by the last mill of the tandem.

Last expressed juice: - The Juice expressed by the last two rollers of the tandem.

Absolute juice: - All water is containing all soluble (dissolved) solids from the cane. It thus equal to (cane – Fiber.)

Normal (undiluted) juice: - Juice pressed out by the mill tandem if no water is used for imbibition by dry crushing.

Diluted juice: - Weight of diluted juice percent weight of cane.

Extraction: It is the portion of a component of cane in percent, which is removed by the milling process. The familiar components are juice, Brix, pol and sucrose and the term extraction need accompanying specification of the.

Pol extraction: - Pol in mixed Juice (diluted juice) percent Pol in cane or (Pol in cane - Pol in bagasse).

Mill extraction: - is the total sugar extracted by the milling tandem, as percent of sugar in cane

Reduced mill extraction: - The reduced mill extraction is extraction obtained by the tandem, modified hypothetically, to that which it would have been if the fiber in cane had been equal to a standard figure, chosen by convention as 12.5%

Sucrose extraction: - Sucrose in mixed juice percent sucrose in cane or (sucrose in cane-pol in bagasse) or, the percentage of the sucrose in the original cane that is removed with the raw juice. **Extraction ratio: -** The percentage ration of sucrose or Pol un-extracted by the mills to fiber in cane.

Brix free water: - water, which is not available for dissolving sucrose & it, is bound water in fiber of cane or bagasse. This sorption water cannot be separated from the natural fiber by mechanical means. Nevertheless, is driven off at raised temperature. The amount of brix free water is approximately 30% on bone-dry fiber or 23% on natural fiber.

Saccharometer:-is simply a polarometer specially designed for measuring the polarization of sugars.

Purity: - Indicates what percentage of the solids in a sugar solution is composed of sugar. It is percentage ratio of pol to brix.

Reducing sugars: - The reducing substances in the cane and its products calculated as invert sugar. (Glucose, Fructose).

Escribed volume: - The volume escribed by a pair of mill rollers in a given time. The escribed volume is equal to the roller length multiplied by the work opening multiplied by the surface speed of the roller.

No-void volume: - The volume of cane or bagasse calculated on the basis that it consists of juice and fiber only. I.e. all air or gas has been removed.

Reabsorption factor: - The ratio between the no-void volumes of bagasse leaves a mill opening in a given time and the escribed volume for the opening over the same period of time.

Hydraulic pressure: - is the pressure applied to the top rollers of all mills.

Sucrose: - It is the pure chemical compound disaccharide, α -D gluco-pyranosyl β - D fructo-furanoside with the formula $C_{12}H_{22}O_{11}$.

Milling Loss: - is the percentage ratio of pol in bagasse to fiber in bagasse.

Extraneous mater: - All foreign matter delivered with cane, or the unwanted vegetable material with cane.

Trash content: - Materials consisting of cane leaves, root, tops, dead sticks of cane and other vegetable matter from the field in which the cane was grown.

Response Surface Methodology (RSM):- is defined as a collection of mathematical and statistical tools or techniques useful for modeling, analyzing, and simultaneously solving problems in which a response of interest is influenced by several variables and the objectives is to optimize this response (Giovanni, 1983).

Design of experiment (DOE):- is a powerful technique used for exploring new processes; gaining increased knowledge of the existing processes and optimizing these processes for achieving world class performance (Jiju Antony, 2003).

Dilution water: - The portion of imbibition water that goes to the diluted juice (Imbibition water minus water left in the bagasse).