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My profound gratitude goes first of all to Almighty God whose sufficiency has granted me the grace, strength, sound health, wisdom and provision to complete this design work.

My gratitude also goes to my wonderful Parents, Rev and Pastor (MRS.) N. I. Obayojie for their support and encouragement throughout my studies. My special thanks goes to my supervisor Engr. A. G. Isah for all his kind gestures, support and good guidance throughout the period of this research. My thanks also goes to my siblings for their support and encouragement throughout my degree programme.

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Lastly, I would like to appreciate every one individual who has in one way or another been of help, encouragement and support to me throughout the period of this design work. God will never forget your labour of love and will bless everyone abundantly, Amen.

ABSTRACT

This project was carried out to design a plant for the production of sugar from sugar cane. Among the various methods available for the production of sugar, sugar production using sugar cane was selected in this project. The design of the plant was carried out with the aid computer packages which are Spreadsheet for the material balance and MathCAD Professional for the energy, equipments' balance and economic analysis. The results of the project revealed that the total capital investment which was calculated for the production of sugar from sugar cane was found to be ₦$1.02X10^8$. Based on that, the net profit was calculated to be ₦$2.486X10^7$. At the end of all the calculations that were carried on the design of the plant, it was concluded that the plant the economic viability is real with a payback period of at most 5 years.

DESIGN OF A PLANT TO PRODUCE ONE TON PER DAY OF SUGAR FROM SUGAR CANE

BY

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2000/9608EH

A DESIGN PROJECT SUBMITTED TO THE DEPARTMENT OF CHEMICAL ENGINEERING, SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY, IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B. ENG.) IN CHEMICAL ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE.

OCTOBER, 2006.

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NOMENCLATURE

Symbol		Meaning
M_S	=	Marshall and Smith Index
Fm	=	Factor associated with material
Fp	=	factor associated with pressure
PC	=	Purchase Equipment Cost
er	=	Exchange rate

CHAPTER ONE

1.0 INTRODUCTION

1.1 General Introduction

Sugar is found all foods from the benevolent carrot to the wicked donut. Sugar is some form or another is hidden in a billion processed foods, beneath a thousand disguises and under as many aliases. What is it with sugar that has us hooked, line and sinker?

Sugarcane is a common name for certain species of perennial herbs of a genus of the grass family. The common sugarcane is extensively cultivated in tropical and subtropical countries throughout the world for the sugar contained within its many-jointed stems (*see* Sugar). Sugarcane grows to a height of 3 to 6 m (about 8 to 20 ft) and has stems 2 to 5 cm (1 to 2 in) thick. The small spikelets are borne in panicles and are surrounded by long, silky fibers. Several horticultural varieties are known, differing in stem color and height.

The common sugarcane has been cultivated from stem cuttings since ancient times; some varieties do not produce fertile seed. Cane grown in the southern United States is usually planted in the winter and remains in the ground approximately eight months before being harvested. In tropical areas such as Hawaii and Cuba, cane has a growth period of from one year to 18 months and is harvested from January to August.

Although several cane-cutting machines have been used with some success, most of the sugarcane in the world is harvested by hand. The cutting instrument most commonly used consists of a large steel blade about 50 cm (about 18 in) long and about 13 cm (about 5 in) wide, equipped with a small hook on the back, and set into a wooden handle. Cane is cut at or near the surface of the ground, stripped of its leaves by the knife hook, and trimmed at the top near the last mature joint. The cane is then piled in rows along the ground until picked up by hand or machine, tied in bundles, and transported by cart or truck to the sugar factory, where the grinding mill extracts the sugar from the cane.

Scientific classification: Sugarcanes belong to the family Poaceae (formerly Gramineae). The common sugarcane is classified as *Saccharum officina* (www.encarta.com)

DECLARATION

I hereby declare that this Design project is my original work which was duly supervised by Engr. A. G. Isah and has never, to the best of my knowledge, been submitted elsewhere either partly or wholly for the award of any degree. All references were acknowledged appropriately.

O. C. O	09-11-2006.
OBAYOJIE CHRISTIANA O.	DATE

DEDICATION

This Design project work is humbly dedicated to my beloved Parents, Rev and Pastor (MRS.) N. I. Obayojie and It is also dedicated to my lovely Husband Olufemi O. Osifuye.

Sugar, term applied loosely to any of a number of chemical compounds in the carbohydrate group that are readily soluble in water; are colorless, odorless, and usually crystallizable; and are more or less sweet in taste. In general, all monosaccharides, disaccharides, and trisaccharides are termed sugars, as distinct from polysaccharides such as starch, cellulose, and glycogen. Sugars, which are widely distributed in nature, are manufactured by plants during the process of photosynthesis and are found in many animal tissues. (Encarta, 2004)

People all around the world eat sugar as part of a healthy, nutritious and balanced diet. Many people worry that eating sugar may be bad for their health. Their concern is unnecessary as extensive research has not been able to link the consumption of sugars to any chronic disease except dental caries (tooth decay). And even though dental caries has been associated with sugar consumption, there are many other factors (including the consumption of other carbohydrates and oral hygiene) which play an important role in the development of caries. (www.wsro.org/public/sugarandhealth/factsaboutsugar.html)

Sugar is an important source of food energy. During digestion, all food carbohydrates (starches and sugars) break down into single molecule sugars. These sugars are absorbed from the gut into the blood stream and travel to the cells, where they are used to provide energy for cellular functions. In parts of the world where people suffer from energy malnutrition and are undernourished, sugar is an inexpensive source of energy to support human activities. (www.wsro.org/public/sugarandhealth/factsaboutsugar.html)

The function of sugar in foods cannot be overemphasized. For instance, sugars have a number of functions in the manufacture of foods, such as improving taste and texture. Important uses of sugars in food processing include providing sweetness to some foods, serving as preservatives in jams and jellies, increasing the boiling point or reduces the freezing point of foods, allowing fermentation by yeast, reacting with amino acids to produce colour and flavour compounds important to the taste and golden brown colour of baked goods and making foods that have limited moisture content crisp. (www.wsro.org/public/sugarandhealth/factsaboutsugar.html)

1.2 Problem Statement

The statement of this work is "Design a Plant to Produce 1 ton/day of Sugar from Sugar Cane".

1.3 Aims and objectives of the study

The aim of this project is to design a plant for the production of sugar from sugar cane. This aim will be achieved via the realization of the following objectives:

(1) Preparation of a flow diagram of the plant.

(2) Calculation of the material balances of the components across the individual units.

(3) Calculation of the energy balances of the components across the individual units.

(4) Carry out the detail design of all the units of the plant.

(5) Preparation of the cost estimation of the plant using Marshall and Smith Method.

(6) Others

1.4 Design Data

The process data required in this design project were sourced from literatures (past projects and textbooks) and internet. In a situation where particular pieces of information are not available, reasonable assumptions will be made.

1.5 Need for the study

It has been reported that sugar cane has many medicinal values. For instance, it is used as sweetening agent for foods in the manufacture of candies,cakes puddings,preserves, soft and alchoholic beverages and many other foods.This calls for the need to set up this plant in Minna, Niger State where any plant producing such product does not yet exist.

1.6 Scope of Work

This work is limited to the chemical engineering design of the plant for the production of sugar from sugarcane.

1.7 Methodology of the Design

Based on the problem statement outlined above, this work will be will be made Computer-Aided Design (CAD) by carrying out the material balances and flow sheeting with the aid of Spreadsheet (Microsoft Excel) and the energy balances, equipment design; reactor optimization and economic analysis will also be carried using MathCAD 2000 Professional while the qualitative flow chart will be drawn with Microsoft Visio.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Sugar

Sugar is a carbohydrate which contains the functional group $(CH_2O)_n$). Sugars are sweet to taste and are used in food and drink as a source of sweetness and energy making them important in biochemistry. In general use, "sugar" is taken to mean sucrose, also called "table sugar", or saccharose, a disaccharide which is a white crystalline solid. It is the most commonly used sugar for altering the flavor and properties (such as "mouthfeel", preservation, and texture) of beverages and food. Table sugar is commercially extracted from either sugar cane or sugar beet. The "simple" sugars, or monosaccharides, such as glucose (which is produced from sucrose by enzymes or acid hydrolysis), are a store of energy which is used by biological cells. A sugar is any word on the ingredient list that ends with "ose." (http://en.wikipedia.org/wiki/Sugar)

In precise culinary terms, sugar is a type of food associated with one of the primary taste sensations, that of sweetness. (http://en.wikipedia.org/wiki/Sugar)

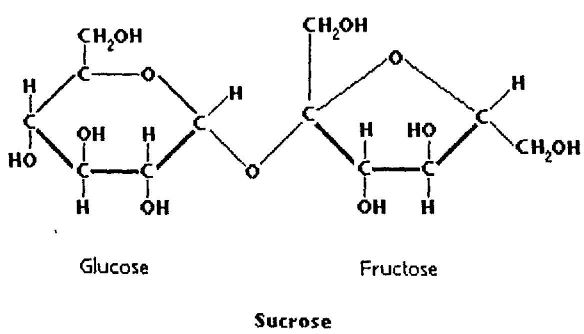


Fig. 2.1: Structure of sucrose (sugar)

2.1.1 Historical background of sugar

Sugarcane is a tropical grass, probably native to New Guinea. In the course of prehistory, its culture spread throughout the Pacific Islands and into India. By 800 B.C., it was being grown in China as well. Westerners discovered sugarcane in the course of military expeditions into India. Nearchos, one of Alexander the Great's commanders, described it as "a reed that gives honey without bees." (http://en.wikipedia.org/wiki/Sugar)

Originally, the cane was chewed raw to extract its sweetness. Sugar refining was developed in the Middle East, India and China, where it became a staple of cooking and desserts. In early refining methods, the cane was ground or pounded to extract the juice, and the juice then boiled down or dried in the sun to yield sugary solids that resembled gravel. The Sanskrit word for sugar (sharkara), also means gravel. Similarly, an ancient Chinese word for sugar means "stone honey." (http://en.wikipedia.org/wiki/Sugar)

Later sugar spread to other areas of the world through trade. It arrived in Europe with the arrival of the Moors. Crusaders also brought sugar home with them after their campaigns in the Holy Land, as there they encountered caravans carrying this "sweet salt" as it was called. While sugar cane could not be grown in northern Europe, sugar could be extracted from certain beets and these began to be widely cultivated around 1801, after the British control of the seas during the Napoleonic wars isolated mainland Europe from the Caribbean. (http://en.wikipedia.org/wiki/Sugar)

2.1.1.1 The history of sugar in the West

In the 1390s, a better press, which doubled the juice obtained from the cane, was developed. This permitted economic expansion of sugar plantations to Andalusia and the Algarve. In the 1420s, sugar was carried to the Canary Islands, Madeira and the Azores. (http://en.wikipedia.org/wiki/Sugar)

In 1493, Christopher Columbus stopped, intending to stay only four days, at Gomera in the Canary Islands, for wine and water. Columbus became romantically involved with the Governor of the Island, Beatrice. He stayed a month. When he finally sailed she gave him cuttings of sugarcane, the first to reach the New World. (http://en.wikipedia.org/wiki/Sugar)

The Portuguese took sugar to Brazil. Hans Staden, published in 1555, writes that by 1540 there were 800 sugar mills on Santa Catalina Island and another 2000 up the north coast of Brazil, Demarara and Surinam. Approximately 3000 small mills built before 1550 in the New World created an unprecedented demand for cast iron gears, levers, axles and other implements. Specialist trades in mold making and iron casting were inevitably created in Europe by the expansion of sugar. Sugar mill construction is the missing link of the technological skills needed for the Industrial Revolution that is recognized as beginning in the first part of the 1600s. (http://en.wikipedia.org/wiki/Sugar)

After 1625, the Dutch carried sugarcane from South America to the Caribbean islands from Barbados to the Virgin Islands. In the years 1625 to 1750, sugar was worth its weight in gold. Price declined slowly as production became multi-sourced especially through British colonial policy. Sugar production also increased in the American Colonies, Cuba, and Brazil. African slaves became the dominant plantation worker as they were resistant to the diseases of malaria and yellow fever. European indentured servants were in shorter supply, succeptible to disease and a less economic investment. Local Native Americans had been reduced by European diseases like smallpox. (http://en.wikipedia.org/wiki/Sugar)

start

With the European colonization of the Americas, the Caribbean became the world's largest source of sugar. Sugar cane could be grown on these islands using slave labour at vastly lower prices than cane sugar imported from the East. Thus the economies of entire islands such as Guadaloupe and Barbados were based on sugar production. The largest sugar producer in the world, by 1750, was the French colony known as Saint-Domingue, which is today the independent country of Haiti. Jamaica was another major producer in the 1700s.

stop

During the eighteenth century, sugar became enormously popular and went through a series of booms. The main reason for the heightened demand and production of sugar was a great change in the eating habits of many Europeans. For example, they began consuming jams, candy, tea, coffee, cocoa, processed foods, and other sweet victuals in much greater numbers. Reacting to this increasing craze, the islands took advantage of the situation and began harvesting sugar in extreme amounts. In fact, they produced up to ninety percent of the sugar that the western Europeans consumed. Of course some islands were more successful than others when it came to producing the product. For instance, Barbados and the British Leewards can be said to have been the most successful in the production of sugar because it counted for ninety-three and ninety-seven percent of the island's exports, respectively. (http://en.wikipedia.org/wiki/Sugar)

Planters later began developing ways to boost production even more. For example, they began using more animal manure when growing their crops. They also developed more advanced mills and began using better types of sugar cane. Despite these and other improvements, the prices of sugar reached soaring heights, especially during events such as the revolt against the Dutch and the Napoleonic wars. Sugar was a highly desired product, and the islands knew exactly how to take advantage of the situation. (http://en.wikipedia.org/wiki/Sugar)

As Europeans established sugar plantations on these larger Caribbean islands, prices fell, especially in Britain. What had previously been a luxury good began, by the eighteenth century, to be commonly consumed by all levels of society. At first most sugar in Britain was used in tea, but later candies and chocolates became extremely popular. Sugar was commonly sold in solid cones and required a sugar nip, a pliers-like tool, to break off pieces. (http://en.wikipedia.org/wiki/Sugar)

Sugar cane quickly exhausts the soil and larger islands with fresher soil were pressed into production in the nineteenth century. For example, it was in this century that Cuba rose as the richest land in the Caribbean (with sugar being its dominant crop) because it was the only major island that was free of mountainous terrain. Instead, nearly three-quarters of its land formed a rolling plain which was ideal for planting crops. Cuba also prospered above other islands because they used better methods when harvesting the sugar crops. They had been introduced to modern milling methods such as water mills, enclosed furnaces, steam engines, and vacuum pans. All these things increased their production and production rate. (http://en.wikipedia.org/wiki/Sugar)

After the world's only successful slave revolution established the independent nation of Haiti, sugar production in that country declined and Cuba replaced Saint-Domingue as the world's largest producer. Production spread to South America as well as to new European colonies in Africa and the Pacific.

2.1.2 Types of sugar

Raw sugars are yellow to brown sugars made from clarified cane juice, boiled down to a crystalline solid with minimal chemical processing. Types of raw sugar available as a specialty item outside the tropics include demerara, muscovado, and turbinado. Mauritius and Malawi are significant exporters of such specialty sugars. Raw sugar is sometimes prepared as loaves rather than as a crystalline powder: in this technique, sugar and molasses are poured together into molds and allowed to dry. The resulting sugar cakes or loaves are called jaggery or gur in India, pingbian tong in China, and panela, panocha, pile, and piloncillo in various parts of Latin America. (http://en.wikipedia.org/wiki/Sugar)

Mill white sugar, also called plantation white, crystal sugar, or superior sugar, is raw sugar whose colored impurities have not been removed, but rather bleached white by exposure to sulfur dioxide. This is the most common form of sugar in sugarcane growing areas, but does not store or ship well; after a few weeks, its impurities tend to promote discoloration and clumping. (http://en.wikipedia.org/wiki/Sugar)

Blanco directo is a white sugar common in India and other south Asian countries. In producing blanco directo, many impurities are precipitated out of the cane juice by using phosphatation a treatment with phosphoric acid and calcium hydroxide similar to the carbonatation technique used in beet sugar refining. In terms of sucrose purity, blanco directo is more pure than mill white, but less pure than white refined sugar. (http://en.wikipedia.org/wiki/Sugar)

White refined sugar is the most common form of sugar in North America and Europe. Refined sugar can be made by dissolving raw sugar and purifying it with a phosphoric acid method similar to that used for blanco directo, a carbonatation process involving calcium hydroxide and carbon dioxide, or by various filtration strategies. It is then further decolorized by filtration through a bed of activated carbon or bone char depending on where the processing takes place. Beet sugar refineries produce refined white sugar directly without an intermediate raw stage. White refined sugar is typically sold as granulated sugar, which has been dried to prevent clumping. (http://en.wikipedia.org/wiki/Sugar)

Granulated sugar is available in various crystal sizes, for home and industrial use depending on the application:

Brown sugars are obtained in the late stages of sugar refining (stopping the refinement before sugar becomes white and free of molasses), or by coating white refined sugar with a cane molasses syrup. Their color and taste become stronger with increasing molasses content, as does their moisture retaining properties. They are also prone to hardening if exposed to the atmosphere although this is reversible. (http://en.wikipedia.org/wiki/Sugar)

2.1.3 Chemistry of sugar

In biochemistry, a sugar is the simplest molecule that can be identified as a carbohydrate. These include monosaccharides and disaccharides, trisaccharides and the oligosaccharides; these being sugars composed of 1, 2, 3 or more units. Sugars contain either aldehyde groups (-CHO) or ketone groups (C=O), where there are carbon-oxygen double bonds, making the sugars reactive. Most sugars conform to $(CH_2O)_n$ where n is between 3 and 7. A notable exception is deoxyribose, which as the name suggests is "missing" an oxygen. As well as being classified by their reactive group, sugars are also classified by the number of carbons they contain. Derivatives of trioses ($C_3H_6O_3$) are intermediates in glycolysis. Pentoses (5 carbon sugars) include ribose and deoxyribose, which are present in nucleic acids. Ribose is also a component of several chemicals that are important to the metabolic process, including NADH and ATP. Hexoses (6 carbon sugars) include glucose which is a universal substrate for the production of energy in the form of ATP. Through photosynthesis plants produce glucose which is then converted for storages as an energy reserve in the form of other carbohydrates such as starch, or as in cane and beet as sucrose. (http://en.wikipedia.org/wiki/Sugar)

Many pentoses and hexoses are capable of forming ring structures. In these closed-chain forms the aldehyde or ketone group is not free, so many of the reactions typical of these groups cannot occur. Glucose in solution exists mostly in the ring form at equilibrium, with less than 0.1% of the molecules in the open-chain form.

Monosaccharides in a closed-chain form can form glycosidic bonds with other monosaccharides, creating disaccharides, such as sucrose, and polysaccharides such as starch. Glycosidic bonds must be hydrolysed or otherwise broken by enzymes before such compounds can be used in metabolism. After digestion and absorption the pricipal monosaccharieds present in the blood and internal tissues are: glucose, fructose, and galactose. (http://en.wikipedia.org/wiki/Sugar)

The term "glyco-" indicates the presence of a sugar in an otherwise non-carbohydrate substance: for example, a glycoprotein is a protein to which one or more sugars are connected.

Simple sugars include sucrose, fructose, glucose, galactose, maltose, lactose and mannose. As far as disaccharides are concerned, the most common are sucrose (cane or beet sugar - made from one glucose and one fructose), lactose (milk sugar - made from one glucose and one galactose) and maltose (made of two glucoses). The formula of these disaccharides is $C_{12}H_{22}O_{11}$.

Sucrose can be converted by hydrolysis into a syrup of fructose and glucose, producing what is called invert sugar. This resulting syrup is sweeter than the original sucrose, and is useful for making confections sweeter and softer in texture. (http://en.wikipedia.org/wiki/Sugar)

2.1.4 Uses of sugar

Sugar is used not only as a constituent in home-produced and industrially produced foods, but also as the raw material from which fermentation produces ethyl alcohol, butyl alcohol, glycerine, citric acid, and levulinic acid,it is used as sweetening agent for foods in the manufacture of candies,cakes puddings,preserves, soft and alchoholic beverages and many other foods. Sugar is an ingredient in some transparent soaps, and it can be converted to esters and ethers, some of which yield tough, insoluble, and infusible resins. (Encarta, 2004)

Other uses of sugar include:

- Sugar helps heal serious wounds and burns.
- A teaspoon of sugar is a great home remedy for hiccups.
- Sugar, in solid form, is used to make the harmless stunt glass people fall through in movies.
- Sucrose is found in detergents, paint and plastics.
- The glue industry uses sugar to slow down the setting process.
- Sugar plays an important role in leather tanning and in the manufacturing of paper ink and dyes. (www.rogerssugar.com/products/liquid.html)

2.2 Sugar cane

Gramineae, Poaceae Saccharum officinarum L.

Fig. 2.2: Sugar cane plant

Sugar cane is composed of six species of perennial grasses of the genus Saccharum L., in tribe Andropogoneae of the Gramineae. There are two wild species, S. spontaneum L. and S. robustum Brandes & Jeswiet ex Grassl, and 4 cultivated species, S. officinarum L., S. barberi Jeswiet, S. sinense Roxb., and S. edule Hassk. (Purseglove 1979). The four cultivated species are complicated hybrids, and all intercross readily. All commercial canes grown today are inter-specific hybrids (Wrigley 1982, www.siu.edu/~ebl/leaflets/sugar.htm).

Sugar cane is the source of sugar in all tropical and subtropical countries of the world. Estimates for 1966 and 1967 indicate world production of cane sugar was between 40 and 41 million tons. Production in the United States, excluding Puerto Rico, averaged 2,550,000 tons during those years - from 592,000 acres of cane in Hawaii, Florida and Louisiana. Sugar production in Puerto Rico averaged 850,000 tons for the two years. (Magness et al. 1971, http://www.almac.co.uk/personal/roberts/cane.html)

Several species of Saccharum are found in Southeast Asia and neighboring islands, and from these cultivated cane probably originated. The sweet juice and crystallized sugar were known in China and India some 2500 years ago. Sugar cane reached the Mediterranean countries in the eighth century A.D., and reached the Americas in early colonial times. (Magness et al. 1971, http://www.almac.co.uk/personal/roberts/cane.html)

2.2.1 Historical background of sugar cane

Sugar cane has been known for at least 2200 years. Alexander's army saw sugar cane during its conquest of India in 326 BC (Purseglove 1979). Nearchus mentioned sugar cane in western India in 325 BC. Sugar cane was probably introduced into China around 110 BC when a botanical garden was founded near Pekin for the introduction of exotic-plants (Deerr 1949). Theophrastus described 'honey produced from reeds,' while Dioscorides, in the first century AD, described 'a honey called sakkharon collected from reeds in India and Arabia Felix with the consistency of salt and which could be crunched between the teeth'. The mountains and deserts of Afghanistan, Baluchistan, and eastern Persia served as natural barriers against the spread of cane to other areas for centuries. It eventually reached Persia in the sixth century. The Arabs were responsible for much of its spread as they took it to Egypt in 641 AD during their conquests. They also carried it with them as they advanced around the Mediterranean. Sugar cane spread by this means to Syria, Cyprus, and Crete, eventually reaching Spain around 714 AD. The sugar industry in Spain was very successful, with about 30,000 ha of cane being cultivated by about 1150 AD. Around 1420 the Portuguese introduced cane into Madeira, from where it soon reached the Canary Islands, the Azores, and West Africa (Purseglove 1979). Columbus transported sugar cane from the Canary Islands to Hispaniola (now the Dominican Republic) on his second voyage in 1493 (Deerr 1949, Purseglove 1979).

The first New World sugar cane mill began grinding in about 1516 in the Dominican Republic. Sugar production spread to Cuba, Jamaica, Puerto Rico, and the other Greater Antilles by the end of the 1500's (Hagelberg 1985).

Sugar cane originated in New Guinea where it has been known for thousands of years. Sugar cane plants spread along human migration routes to Asia and the Indian subcontinent. Here it cross-bred with some wild sugar cane relatives to produce the commercial sugar cane we know today. (www.plantcultures.org.uk/plants/sugar_cane_history.html)

In the 1400s and 1500s in India, cows belonging to the Sultan of Mandu were fed sugar cane for weeks to make their milk sweet for use in puddings.

Sugar cane originated in New Guinea where it has been known since about 6000 BC. From about 1000 BC its cultivation gradually spread along human migration routes to Southeast Asia and India and east into the Pacific. It is thought to have hybridised with wild sugar canes of India and China, to produce the 'thin' canes. It spread westwards to the Mediterranean between 600-1400 AD. (www.plantcultures.org.uk/plants/sugar_cane_history.html)

Arabs were responsible for much of its spread as they took it to Egypt around 640 AD, during their conquests. They carried it with them as they advanced around the Mediterranean. Sugar cane spread by this means to Syria, Cyprus, and Crete, eventually reaching Spain around 715 AD. (www.plantcultures.org.uk/plants/sugar_cane_history.html)

Around 1420 the Portuguese introduced sugar cane into Madeira, from where it soon reached the Canary Islands, the Azores, and West Africa. Columbus transported sugar cane from the Canary Islands to what is now the Dominican Republic in 1493. The crop was taken to Central and South America from the 1520s onwards, and later to the British and French West Indies. (www.plantcultures.org.uk/plants/sugar_cane_history.html)

Sugar cane has a very long history of cultivation in the Indian sub-continent. The earliest reference to it is in the Atharva Veda (c. 1500-800 BC) where it is called ikshu and mentioned as an offering in sacrificial rites. The Atharva Veda uses it as a symbol of sweet attractiveness. (www.plantcultures.org.uk/plants/sugar_cane_history.html)

Sugar cane was originally grown for the sole purpose of chewing, in southeastern Asia and the Pacific. The rind was removed and the internal tissues sucked or chewed. Production of sugar by boiling the cane juice was first discovered in India, most likely during the first millennium BC.

The word 'sugar' is thought to derive from the ancient Sanskrit sharkara. By the 6th century BC sharkara was frequently referred to in Sanskrit texts which even distinguished superior and inferior varieties of sugarcane. The Susrutha Samhita listed 12 varieties; the best types were supposed to be the vamshika with thin reeds and the paundraka of Bengal. It was also being called guda, a term which is still used in India to denote jaggery. A Persian account from the 6th century BC gives the first account of solid sugar and describes it as coming from the Indus Valley. This early sugar would have resembled what is known as 'raw' sugar: Indian dark brown sugar or gur. (www.plantcultures.org.uk/plants/sugar_cane_history.html)

At this time honey was the only sweetener in the countries beyond Asia and all visitors to India were much taken with the 'reed which produced honey without bees'. The Greek historian Herodotus knew of the sugarcane in the 5th century BC and Alexander is said to have sent some home when he came to the Punjab region in 326 BC. Practically every traveller to India over the centuries mentions sugarcane; the Moroccan Ibn Battuta wrote of the sugarcanes of Kerala which excelled every other in the 14th century; Francois Bernier, in India from 1658-59, wrote of the extensive fields of sugarcane in Bengal.

Until the 1930s, the main types of sugar cane grown in India were the 'thin' canes. They were well suited to the north Indian climate, though yields were fairly low. In the southern or tropical zone of the country, where the climate was more suitable for sugar cane cultivation, thicker 'noble' canes were more important. (www.plantcultures.org.uk/plants/sugar_cane_history.html)

Thicker varieties of sugarcane were brought in from the West Indies and the area under sugarcane was greatly expanded. Various hybrids were developed leading to a doubling of cane production in the Indian subcontinent. (www.plantcultures.org.uk/plants/sugar_cane_history.html)

2.2.2 Harvesting of sugar cane

Harvesting of cane in Hawaii and Louisiana is highly mechanized. Machines top the canes at a uniform height, cut them off at ground level, and deposit them in rows. In Florida, cane is mainly cut by hand. Leaves .and trash are burned from the cane in the rows by use of flame thrower type machines. An alternate method is to burn the leaves from the standing cane, after which it is cut and taken directly to the mill. Delay between cutting and milling in either case should be as short as possible since delay results in loss of sugar content. Machines are under development that will cut, clean and load the cane so it can be taken directly to the mill. (Magness et al. 1971, http://www.almac.co.uk/personal/roberts/cane.html)

In continental United States, where winter freezing is a hazard, cane harvest must start earlier than is desirable for maximum yields. When plants are killed by freezing sugar loss occurs rapidly. While such plants are suitable for sugar extraction if harvested promptly after freezing, this may not be possible when large acreages are involved. In non-mechanized areas cane is still cut and the leaves stripped off by using cane knives. This is arduous and time consuming work. (Magness et al. 1971, http://www.almac.co.uk/personal/roberts/cane.html)

2.2.3 Uses of sugar cane

2.2.3.1 General uses of sugar cane

Sugar is used not only as a constituent in home-produced and industrially produced foods, but also as the raw material from which fermentation produces ethyl alcohol, butyl alcohol, glycerine, citric acid, and levulinic acid. Sugar is an ingredient in some transparent soaps, and it can be converted to esters and ethers, some of which yield tough, insoluble, and infusible resins (Encarta, 2006).

2.2.3.2 Traditional medicinal uses of sugar cane

Sugar cane features in both folk and traditional systems of medicine in South Asia. It has been used to treat a wide variety of health complaints from constipation to coughs. It has been used externally to treat skin problems, a use that is being supported by scientific evidence. (www.plantcultures.org.uk/plants/sugar_cane_traditional_medicine.html)

2.2.3.2.1 Ayurvedic medicine

Both the roots and stems of sugar cane are used in Ayurvedic medicine to treat skin and urinary tract infections, as well as for bronchitis, heart conditions, loss of milk production, cough, anaemia, constipation as well as general debility. Some texts advise its use for jaundice and low blood pressure. (www.plantcultures.org.uk/plants/sugar_cane_traditional_medicine.html)

2.2.3.2.2 Folk medicine

A common folk remedy is to mix fresh stem juice with dry ginger in order to relieve hiccups . A plaster made from equal parts of sugar and yellow soap is used externally for treating boils, while crude sugar is applied to carbuncles. (www.plantcultures.org.uk/plants/sugar_cane_traditional_medicine.html)

Fig. 2.3: Sugar cane stem is used in Ayurvedic medicine.

2.2.3.3 Western medicinal use of sugar cane

Sugar has a bad reputation in western countries as a key factor in obesity. However, the main medicinal use of sugar cane is as the juice crushed from the stems. Studies are now showing that sugar may also have some interesting health benefits. (www.plantcultures.org.uk/plants/sugar_cane_western_medicine.html)

2.2.3.3.1 Wound healing

Sugar cane juice is rich in a wide range of compounds apart from sucrose (sugar). It is likely to be some of these that are responsible for observed wound healing properties, and which may help to stimulate the immune system. (www.plantcultures.org.uk/plants/sugar_cane_western_medicine.html)

2.2.3.3.2 Safety

Sugar cane juice is widely consumed in Asia and is usually safe. Eating sugar cane, either as juice or as raw cane, can lead to tooth decay, but some compounds in the juice may protect teeth from the worst effects of sugar. (www.plantcultures.org.uk/plants/sugar_cane_western_medicine.html)

Poisonings have occurred from eating sugar cane stored in damp conditions. This leads to the growth of moulds containing toxins. Outbreaks of "mouldy sugar cane poisoning" have occurred in recent years in villages in northern China. (www.plantcultures.org.uk/plants/sugar_cane_western_medicine.html)

2.4 Processing Routes for the Production of Sugar

2.4.1 Description of Various Processing Routes for Sugar Production

2.4.1.1 Production of sugar from sugar cane

After harvesting, the thick stems of the sugarcane are stripped of leaves. In the sugar factory the stems are crushed and shredded between toothed rollers. The juice of the crushed stems is extracted in mills consisting mainly of a system of rollers, often 9 or 12 in number, through which the shredded material passes. This process is called grinding. During grinding, hot water is sprayed over the crushed material to dissolve out some of the remaining sugar. The solid, pulpy material remaining after extraction of the juice is known as bagasse; it is dried and used as fuel. Lime is added to the raw juice drawn from the mill and the mixture is heated to boiling; during this heating, unwanted organic acids form insoluble compounds with the lime, which can be filtered off along with other solid impurities. Often the juice is treated with gaseous sulfur dioxide to bleach it and is then passed through filter presses. The resulting clear juice is then evaporated in a partial vacuum and heated until it forms a thick syrup containing many crystals of sugar. The dense mass of crystals and syrup is known as massecuite. The massecuite is placed in a centrifuge turning at a rate of 1000 to 1500 rpm; the centrifuge walls are pierced by small holes through which the syrup, called molasses, is forced out during centrifuging. The yellowish or brown sugar removed during the centrifuging process is called first sugar, or raw sugar. The first sugar is sprayed with water to remove any molasses that may have clung to the crystals, and is then moved to the refinery. The molasses may be boiled again and reevaporated in an attempt to crystallize out some of the rich sucrose content of this liquid; in modern cane-sugar manufacture, the syrup is usually crystallized only once. The molasses is a valuable by-product of the sugar industry, being used in the manufacture of ethyl alcohol and rum, as a table syrup and food flavoring, as food for farm animals, and in the manufacture of several processed tobaccos. At the refinery, the raw sugar is redissolved, decolorized, and recrystallized into crystals of desired size. Powdered, granulated, and lump sugar, as well as brown sugars, which contain some molasses, are produced in the refineries (Encarta, 2006).

2.4.1.2 Production of sugar from sugar beet

Sugar is manufactured from the roots of the sugar beet, the leaves and tops being removed after harvesting and used as stock feed. The roots are cut into cossettes, or chips, at the sugar factory, and the cossettes are crushed to remove the juice. The pulp remaining after the extraction of the juice is a rich food for domestic animals. After extraction lime is added to the juice, and the remainder of the process is similar to sugar production from sugarcane.

Beet molasses is fed to livestock; no table molasses is made from beets because of difficulties in purification. The sugar that is produced from the sugar beet is identical to the sugar that is derived from the sugarcane (Encarta, 2006).

2.4.2 Detail Description of the Selected Technology

At the sugar factory, the cane is piled as reserve supply in the cane yard so that the factory, which runs, 24 hr/day will always have cane to grind. The delivery of the cane to the factory depends upon the time of day, weather, and some other factors. Very closely controlled operations never have more than a few hours worth of cane in the cane yard, but more generally, the cane yard is fairly full toward evening and nearly empty the next morning.

2.4.2.1 Washing and Shredding

The cane is moved from the cane yard or directly from the transport to one of the cane table. Feed chains on the tables move the cane across the tables to the main cane carrier, which runs at constant speed carrying the cane into the factory. The operator manipulates the speed of the various tables to keep the main carrier evenly filled. In order to remove as much dirt and trash as possible, the cane is washed on the main carrier with as much water as is available. This includes decirculated wash water and all of the condenser water. Of the order of 1 –2 % of the sugar in the cane is washed out and lost in the washing, but it is considered advantageous to wash. In areas where there are rocks in the cane, it is floated through the so-called mud bath to help separate the rocks. The sugar recovered is normally 10-wt % of the cane, with some variation from region to region. Sugar cane has the distinction of producing the heaviest yield of all crops, both in weight of biomass and in weight of useful product per unit area of land (Hugot, 1999).

2.4.2.2 Crushing

The juice is extracted from the cane either by milling, in which the cane is pressed between the heavy rolls, or by diffusion, in which the sugar is leached out with water. In either case, the cane is prepared by breaking into pieces measuring a few centimeters. In the usual system, the magnets first remove the tramp iron, and the cane then passes through two sets of rotating knives. The first set, called cane knives turns at about 700 rpm, cuts the cane into pieces of 1 – 2 dm length, splits it up a bit, and also act as a leveler to distribute the cane more evenly on the carrier. The second set, called shredder knives turn faster and combine a cutting and a hammer action by having a closer clearance with the housing. These quite thoroughly cutter and shred the cane into a fluffy mat of pieces a few centimeters in the largest dimensions. In preparing cane for diffusion, it is desirable to break every plant cell. Therefore the cane for diffusion is put through an even finer shredder called a buster or fiberizer. No juice is extracted in the shredders. In milling, the cane then goes to the crusher rolls, which are similar to the mills, but have only two rolls, which have large teeth and are widely spaced. These complete the breaking up of the cane to pieces of the order of 1 – 3 cm. The large amount of juice is removed here (Hugot, 1999).

2.4.2.3 Milling

The prepared cane passes through a series of mills called a tandem or milling train. These mills are composed of massive horizontal cylinders or rolls in groups of three, one on the top and two on the bottom in the triangle formation. The rolls are 50 – 100 cm diameter and 1 – 3 m long and have grooves that are 2 –5 cm wide and deep around them. There may be anywhere from 3 – 7 of these 3 roll mills in tandem, hence the name. These mills, together with their associated drive and gearing, are among the most massive machinery used by industry. The bottom two rolls are fixed, and the top is free to move up and down. The top roll is hydraulically loaded with a force equivalent about 500 t. The rolls turn at 2 – 5 rpm, and the velocity of the cane through them is 10- 25cm/s. After passing through the mill, the fibrous residue, from the cane, called bagasse,(this can be removed , dried and used as fuel) is carried to the next mill by bagasse carriers and is directed from the first squeeze in a mill to the second by turn plate. In order to, achieve a good extraction, a system of imbibition is used, bagasse going to the final mill is sprayed with hot water to extract whatever sucrose remains; the resultant juice from the last mill is then sprayed on the bagasse mat going to the next to last mill, and so on. The combination of all these juices is collected from the first mill and is mixed with the juice from the crusher. The result is called the mixed juice and is the material that goes forward to make the sugar. The mills are powered with individual steam turbines. The exhaust steam from the turbines is used to evaporate water from the cane juice. The capacity of the sugarcane mills is 30 – 300 t of cane per hour (Hugot, 1999).

2.4.2.4 Mixing 1

In the mixing chamber lime is added during mixing, proper agitation is ensured in this component to ensure that it is well mixed and improve juice extraction, unwanted organic acid form insoluble compound with the lime this is fully enhanced in the boiler during the boiling operation and this can be easily filtered off with other solid impurities later in the filter plant.

Diffusion is used universally with sugar beets but is little used with sugarcane. The process in cane is mostly lixiviation (washing) with only a little true diffusion from unbroken plant cells. Since the lixiviation is much faster, great effort is expanded in preparing the cane by breaking it so thoroughly that nearly all of the plant cells are ruptured. In many instances, diffusers were added to an already existing mill, and, therefore, the diffuser unit was placed after the crusher rolls. In the diffusers, the shredded cane travels counter current to hot (75°C) water. In the ring diffuser, the cane moves around in an annular ring. In tower diffusers, the cane moves vertically, and in rotating drum diffusers, it travels in a spiral. Whatever the apparatus, the juice obtained is much like juice from mills (Hugot, 1999).

Milling achieves 95% extraction of the sucrose in the cane, mixing 97% extraction. Diffusion juice contains somewhat less suspended solids (dirt and fibre), and is of higher purity (sucrose as percent of solids). The mixing plant costs much less and takes much less energy to run. The bagasse from mixing plant contains much more water (Hugot, 1999).

2.4.2.5 Boiling

During boiling unwanted organic acid form insoluble compound with the lime this is fully enhanced in the boiler during the boiling operation and this can be easily filtered off with other solid impurities later in the filter plant.After boiling the juice is passed into another mixer where SO_2 is added to bleach it before passing it into a filter process.

In raw-sugar manufacture, the first strike of sugar is called the A strike, and the mother liquor obtained from this strike from the centrifuges is called A molasses. The pan yield in sugar boiling is about 50%. Because crystallization is an efficient purification process, the product sugar is much purer than the cane juice and the molasses much less pure. As an approximation, crystallization reduces the impurities by factor of 10 or more in the product sugar. Therefore, almost all of the impurities remain in the molasses. Enough molasses accumulates from boiling two first strikes to boil a second strike. The B sugar from the second strike is only half as pure as that from the first strike, but the B molasses is twice as impure. This can go on to a third strike. At this point, 7/8 of the sugar from the cane juice is in the form of crystals and 1/8 in the C molasses. In practice, three strikes is about all that can be gotten from cane juice. The trick is to maneuver to obtain good sugar, but at the same time have the C or final molasses as impure as possible. The purity of the feed to the final strike is adjusted to obtain the lowest possible purity of final molasses. Some of the C sugar is redissolved and started over, some is used as footing for A and B strikes. The C sugar is of very small crystal size so it is taken into the A or B pans as seed and grown to an acceptable size. This practice is actually a step backward because it hides impure C sugar in the center of better A and B sugars. The product raw sugar is a mixture of A and B sugars (Hugot, 1999).

There are many variations in the boiling scheme, such as two and four billings, blending molasses, and returning molasses to the same strike from which it came. All of these tricks are used, depending on cane purity and capabilities of the equipment available (Hugot, 1999).

2.4.2.6 Mixing 2

After boiling the juice is passed into another mixer where SO_2 is added to bleach it before passing it into a filter process.Proper agitation of the SO_2 must be ensured in this unit to increase the overall yield of the final product (sugar) and also make the process economical and more efficient.

2.4.2.7 Clarification

The juice from either milling or diffusion is about 12 – 18% solids, 10 – 15 pol (polarization) (percent sucrose), and 70 – 85% purity. These figures depend upon geographical location, age of cane, variety, climate, cultivation, condition of juice extraction system, and other factors. As dissolved material, it contains in addition to sucrose some invert sugar, salts, silicates, amino acids, proteins, enzymes, and organic acids; the pH is 5.5 – 6.5. It carries suspension cane fibre, field soil, silica, bacteria, yeasts, molds, spores, insect parts, chlorophyll, starch, gums, waxes, and fats. It looks brown and muddy with a trace of green from the chlorophyll (Hugot, 1999).

In the juice from the mill, the sucrose is inverting (hydrolyzing to glucose and fructose) under the influence of native invertase enzyme or an acid pH. The first step of processing is to stop the inversion by raising the pH to 7.5 and heating to nearly 100°C to inactivate the enzyme and stop microbiological action. At the same time, a large fraction of the suspended material is removed by settling. The cheapest source of hydroxide is lime, and this has the added advantage that calcium makes many insoluble salts (Hugot, 1999).

Clarification by heat and lime, a process called defecation, was practiced in Egypt many centuries ago and remains in many ways the most effective means of purifying the juice. Phosphate is added to juices deficient in phosphate to increase the amount of calcium phosphate precipitate, which makes a floc that helps clarification. When the mud settles poorly, polyelectrolyte flocculants such as polyacrylamides are sometimes used. The heat and high Ph serve to coagulate proteins, which are largely removed in clarification (Hugot, 1999).

The equipment used for clarification is of the Dorr clarifier type. It consists of a vertical cylindrical vessel composed of a number of trays with conical bottoms stacked one over the other. The limed raw juice enters the center of each tray and flows toward the circumference. A sweep arm in each tray turns quite slowly and sweeps the settled mud toward a central mud outlet. The clear juice from the top circumference overflows into a header (Hugot, 1999).

Diffusion juice contains less suspended solids than mill juice. In many diffusion operations, some or all of the clarification is carried out in the diffuser by adding lime. The mud from clarification is filtered on Oliver rotary vacuum filters to recovery the juice. The mud mostly consists of field soil and very fined divided fibre. It also contains nearly all the protein (0.5 wt% of the juice solids) and cane wax. The mud is returned to the fields. Although the clarification removes most of the mud, the resulting juice is not necessarily clear. The equipment is often run at beyond its capacity and control slips a little so that the clarity of the clarified juice is not optimum. Suspended solids that slip past the clarifiers will be in the sugar. Clarified juice is dark brown. The colour is darker than raw juice because the initial heating causes significant darkening (Hugot, 1999).

2.4.2.8 Filteration

After clarification the organic acids that form insoluble compound with lime are filtered off along with other solid impurities.Also the juice which was already treated with SO_2 is passed through a filter press ,after wards the evaporation is done.

2.4.2.9 Evaporation

After clarification the resulting clear juice is then evaporated in partial vacuum and heated until it forms a thick syrup containing many crystals of sugar.The dense mass of crystals and syrup is known as masscuite,the masscuite is then placed in a centrifuge later..

Cane juice has sucrose concentration of normally 15%. The solubility of sucrose in water is about 72%. The concentration of sucrose must reach the solubility point before crystals can start growing. This involves the removal by evaporation of 93% of the water in the cane juice. Since water has the largest of all latent heats of vapourization, this involves a very large amount of energy. In the energy crunch of the late 1970s, the DOE found that the sugar industry was one of the largest users of energy. The sugar industry already knew this very well and had been using multiple-effect evaporators for saving energy for more than a century (Hugot, 1999).

The working of multiple-effect evaporator can be seen in fig. In each succeeding effect, the vapours from the previous effect are condensed to supply heat. This works only because each succeeding effect is operating at a lower pressure and hence boils at lower temperature. The result is that 1 kg of steam is used to evaporate 4 kg of water. The steam used is exhaust steam from the turbines in the mill or turbines driving electrical generators. The steam has therefore already been used once and here in the second use it is made to give fourfold duty (Hugot, 1999).

The usual evaporator equipment is a vertical body juice-in-tube unit. Several variations are in use, but the result is the same. The only auxiliary equipment is the vacuum pump. Today, steam-jet-ejectors are general, although mechanical pumps were formerly used. Since the cane juice contains significant amounts of inorganic ions, including calcium and sulfate, the heating surfaces are quick to scale and require frequent cleaning. In difficult cases, the heating surfaces must be cleaned every few days. This requires shutting down the whole mill or at least one heat-exchanger unit while the cleaning is done. Inhibited hydrochloric acid or mechanical cleaners are usually employed (Hugot, 1999).

Magnesium oxide is sometimes used instead of lime as a source of hydroxide. Magnesium costs more, but it makes less boiler scale on the heaters. It is also easier to remove because it is more soluble; however, for the same reason, more gets into the sugar. Whether it is used or not depends upon the influence, standing, and persuasiveness of the chief engineer who must keep the plant running and the chief chemist who must make good sugar (Hugot, 1999).

The evaporation is carried on to a final brix of 65 – 68. The juice, after evaporation, is called syrup and is very dark brown, almost black, and a little turbid.

2.4.2.10 Crystallization

The crystallization of the sucrose from the concentrated syrup is traditionally a batch process. The solubility of sucrose changes rather little with temperature. It is about 68 brix at room temperature and 74 brix at 60°C. For this reason, only a small amount of sugar can be crystallized out of solution by cooling. Evaporating the water must instead crystallize the sugar. Sucrose solutions up to a super saturation of 1.3 are quite stable. Above this super saturation, spontaneous nucleation occurs, and new crystals form. The sugar boiler therefore evaporates water until the supersaturation is 1.25 and then seeds the pan. The seeding consists of introducing just the right number of small sugar crystals (powdered sugar) so that, when all have grown to the desired size, the pan will be full.

After seeding, the evaporation and feeding of syrup are balanced so that the supersaturation is as high as possible in order to achieve the fastest possible rate of crystal growth, without exceeding 1.3 (Hugot, 1999).

The boiling point of a saturated sugar solution at 101.3 kPa (1 atm) is 112°C. Sugar is heat-sensitive and, at this temperature, thermal degradation is too great. The boiling is therefore done under the highest practical vacuum at a boiling point of 65oC. The sugar boiler therefore must manipulate the vacuum along with the steam and feed. A proof stick on the vacuum pan allows the contents of the pan to be sampled while under vacuum. When the pan is full, the steam and feed are stopped, the vacuum is broken, and the batch, or strike, is dropped into a receiver below. A strike is 50 metric tons of sugar and it is boiled in 90 min. at the end of this time, the mixture of crystals and syrup, called massecuite, must still be fluid enough to be stirred and discharged from the pan. In practice, about half of the sugar in the pan is in crystal form and half remains in the syrup. In this case, the pan yield is said to be 50%. Some very good sugar boilers are able to achieve as much as 60% yields on first strike (Hugot, 1999).

2.4.2.11 Centrifuging

The massecuites from the vacuum pans enter a holding tank called a mixer that has a very solely turning paddle to prevent the crystals from settling. The mixer is a feed for the centrifuges. In a batch-type centrifuge, the mother liquor is separated from the crystals in batches of about 1 t at a time, the centrifuge turning at the rate of 1000 to 1500 rpm ; the centrifuge walls are pierced by small hole through which the syrup called molasses is forced out during centrifugation. The yellowish or brown sugar removed during centrifuging is known as the first sugar or raw sugar; this is later passed through a drying chamber for final processing (Hugot, 1999).

2.4.2.12 Drying

After the molasses as been separated from the raw sugar ,the resulting sugar is then dried to remove moisture.

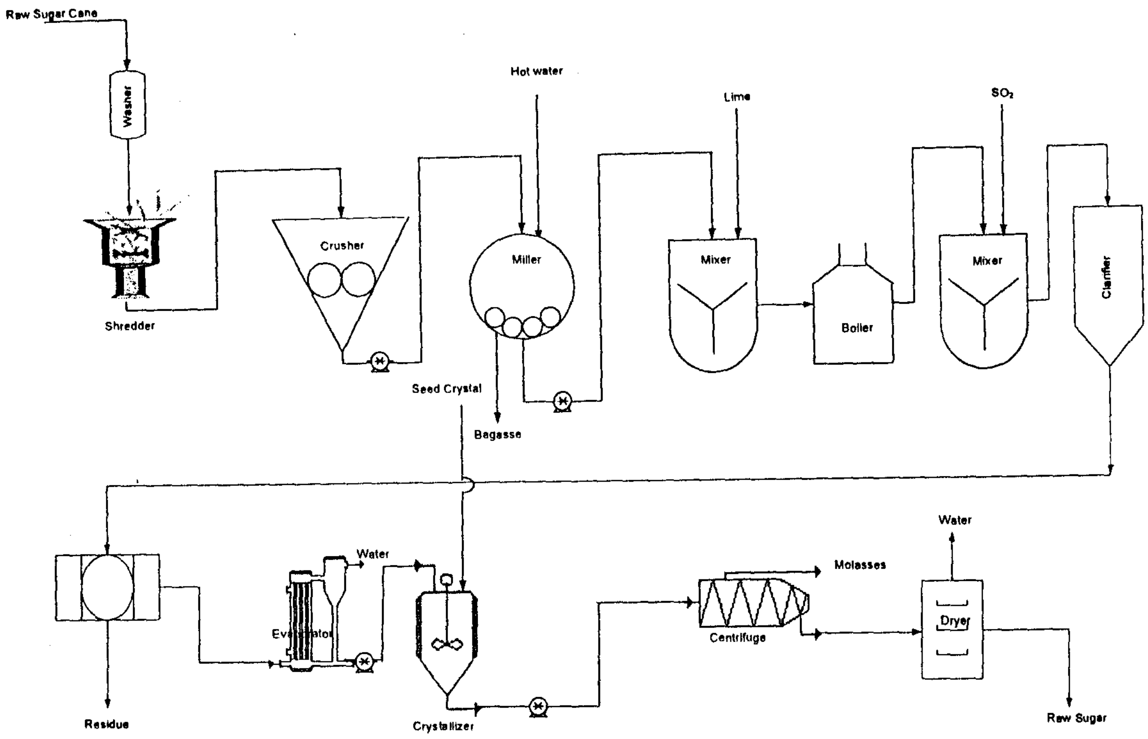


Fig. 2.5: Flow sheet for the production of sugar from sugar cane

2.4.3 Justification of the Selected Technology

The selected alternative route is the sugar production from sugar cane based on the fact that, in this process, sucrose extraction is easier because there is maintenance of quality and quantity characteristics. Apart from that, this process needs steam and electricity which are readily available to run it.

CHAPTER THREE

3.0 MATERIAL BALANCES

Basis = 100.00 kg/day of sugar cane

Composition of sugar cane

Component	wt%
Water	70.00
Saccharose	13.30
Impurities	2.70
Shreds	4.00
Bagasse	10.00
Total	100.00

Components

Component	Mol. Wt.
Water	18.00
Saccharose	342.00
Impurities	60.00
Shreds	162.00
Bagasse	162.00
Lime	56.00
SO2	64.00
Residue	162.00
Molasses	342.00

WASHER

Operation: Cleaning of the sugar cane to remove impurities (sand, debris and mud)

Assumptions:

;1: Water added is equal to 10.00 % wt of sugar cane

2: 90.00 % of the water added is removed

3: 100.00 % of the impurities is removed in this unit

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	70.00	70.00	10.00	100.00	9.00	76.92	71.00	72.23
Saccharose	13.30	13.30	0.00	0.00	0.00	0.00	13.30	13.53
Impurities	2.70	2.70	0.00	0.00	2.70	23.08	0.00	0.00
Shreds	4.00	4.00	0.00	0.00	0.00	0.00	4.00	4.07
Bagasse	10.00	10.00	0.00	0.00	0.00	0.00	10.00	10.17
Lime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Residue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Molasses	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	10.00	100.00	11.70	100.00	98.30	100.00
Grand total	110.00				110.00			

SHREDDER

Operation: Removal of the shreds of the sugar cane

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	71.00	72.23	0.00	#DIV/0!	0.00	0.00	71.00	75.29
Saccharose	13.30	13.53	0.00	#DIV/0!	0.00	0.00	13.30	14.10
Impurities	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Shreds	4.00	4.07	0.00	#DIV/0!	4.00	100.00	0.00	0.00
Bagasse	10.00	10.17	0.00	#DIV/0!	0.00	0.00	10.00	10.60
Lime	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
SO2	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Residue	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Molasses	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Total	98.30	100.00	0.00	#DIV/0!	4.00	100.00	94.30	100.00
Grand total	98.30				98.30			

CRUSHER

Operation: Size reduction of the sugar cane

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	71.00	75.29	0.00	#DIV/0!	0.00	#DIV/0!	71.00	75.29
Saccharose	13.30	14.10	0.00	#DIV/0!	0.00	#DIV/0!	13.30	14.10
Impurities	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Shreds	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Bagasse	10.00	10.60	0.00	#DIV/0!	0.00	#DIV/0!	10.00	10.60
Lime	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
SO2	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Residue	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Molasses	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Total	94.30	100.00	0.00	#DIV/0!	0.00	#DIV/0!	94.30	100.00
Grand total	94.30				94.30			

MILLER

Operation: Size reduction of the crushed sugar cane

Assumptions:

1: Hot water added equals to 15.00 % wt of sugar cane

2: 91.00 % wt bagasse is removed in this unit

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	71.00	75.29	14.15	100.00	0.00	0.00	85.15	85.71
Saccharose	13.30	14.10	0.00	0.00	0.00	0.00	13.30	13.39
Impurities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shreds	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bagasse	10.00	10.60	0.00	0.00	9.10	100.00	0.90	0.91
Lime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Residue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Molasses	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	94.30	100.00	14.15	100.00	9.10	100.00	99.35	100.00
Grand total	108.45				108.45			

MIXER

Operation: Addition and agitation of lime with the syrup

Assumption: Lime added equals to 3.00 % wt of sugar cane

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	85.15	85.71	0.00	0.00	0.00	#DIV/0!	85.15	83.21
Saccharose	13.30	13.39	0.00	0.00	0.00	#DIV/0!	13.30	13.00
Impurities	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Shreds	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Bagasse	0.90	0.91	0.00	0.00	0.00	#DIV/0!	0.90	0.88
Lime	0.00	0.00	2.98	100.00	0.00	#DIV/0!	2.98	2.91
SO2	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Residue	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Molasses	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Total	99.35	100.00	2.98	100.00	0.00	#DIV/0!	102.33	100.00
Grand total	102.33				102.33			

BOILER

Operation: Heating of the syrup to boiling

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	85.15	83.21	0.00	#DIV/0!	0.00	#DIV/0!	85.15	83.21
Saccharose	13.30	13.00	0.00	#DIV/0!	0.00	#DIV/0!	13.30	13.00
Impurities	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Shreds	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Bagasse	0.90	0.88	0.00	#DIV/0!	0.00	#DIV/0!	0.90	0.88
Lime	2.98	2.91	0.00	#DIV/0!	0.00	#DIV/0!	2.98	2.91
SO2	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Residue	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Molasses	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Total	102.33	100.00	0.00	#DIV/0!	0.00	#DIV/0!	102.33	100.00
Grand total	102.33				102.33			

MIXER

Operation: Addition and mixing of SO2 with the syrup

Assumption: 1.50 % wt sugar of SO2 is added

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	85.15	83.21	0.00	0.00	0.00	#DIV/0!	85.15	81.98
Saccharose	13.30	13.00	0.00	0.00	0.00	#DIV/0!	13.30	12.81
Impurities	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Shreds	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Bagasse	0.90	0.88	0.00	0.00	0.00	#DIV/0!	0.90	0.87
Lime	2.98	2.91	0.00	0.00	0.00	#DIV/0!	2.98	2.87
SO2	0.00	0.00	1.53	100.00	0.00	#DIV/0!	1.53	1.48
Residue	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Molasses	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Total	102.33	100.00	1.53	100.00	0.00	#DIV/0!	103.86	100.00
Grand total	103.86				103.86			

CLARIFIER

Operation: Coagulation of the impurities in the syrup

the remaining bagasse and other organic impurities make up the residue

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	85.15	81.98	0.00	#DIV/0!	0.00	#DIV/0!	85.15	81.98
Saccharose	13.30	12.81	0.00	#DIV/0!	0.00	#DIV/0!	13.30	12.81
Impurities	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Shreds	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Bagasse	0.90	0.87	0.00	#DIV/0!	0.00	#DIV/0!	0.90	0.87
Lime	2.98	2.87	0.00	#DIV/0!	0.00	#DIV/0!	2.98	2.87
SO2	1.53	1.48	0.00	#DIV/0!	0.00	#DIV/0!	1.53	1.48
Residue	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Molasses	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Total	103.86	100.00	0.00	#DIV/0!	0.00	#DIV/0!	103.86	100.00
Grand total	103.86				103.86			

FILTER

Operation: Separation of the coagulated impurities from the syrup

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	85.15	81.98	0.00	#DIV/0!	0.00	0.00	85.15	86.49
Saccharose	13.30	12.81	0.00	#DIV/0!	0.00	0.00	13.30	13.51
Impurities	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Shreds	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Bagasse	0.90	0.87	0.00	#DIV/0!	0.90	16.62	0.00	0.00
Lime	2.98	2.87	0.00	#DIV/0!	2.98	55.04	0.00	0.00
SO2	1.53	1.48	0.00	#DIV/0!	1.53	28.34	0.00	0.00
Residue	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Molasses	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Total	103.86	100.00	0.00	#DIV/0!	5.42	100.00	98.45	100.00
Grand total	103.86				103.86			

EVAPORATOR

Operation: Removal of water in the syrup

Assumption: 85.00 % of the water is removed

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	85.15	86.49	0.00	#DIV/0!	72.37	100.00	12.77	48.99
Saccharose	13.30	13.51	0.00	#DIV/0!	0.00	0.00	13.30	51.01
Impurities	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Shreds	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Bagasse	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Lime	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
SO2	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Residue	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Molasses	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Total	98.45	100.00	0.00	#DIV/0!	72.37	100.00	26.07	100.00
Grand total	98.45				98.45			

CRYSTALLIZER

Operation: Processing of the sugar to form crystals

Assumption 1: Seed crystal added is 1.00 % wt of sugar cane

Assumption 2: 15.00 % of the sugar form the molasses

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	12.77	48.99	0.00	0.00	0.00	#DIV/0!	10.86	41.23
Saccharose	13.30	51.01	0.26	100.00	0.00	#DIV/0!	11.57	43.92
Impurities	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Shreds	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Bagasse	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Lime	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
SO2	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Residue	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Molasses	0.00	0.00	0.00	0.00	0.00	#DIV/0!	3.91	14.85
Total	26.07	100.00	0.26	100.00	0.00	#DIV/0!	26.33	100.00
Grand total	26.33				26.33			

CENTRIFUGE

Operation: Separation of molasses from sugar crystals

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	10.86	41.23	0.00	#DIV/0!	0.00	0.00	10.86	48.42
Saccharose	11.57	43.92	0.00	#DIV/0!	0.00	0.00	11.57	51.58
Impurities	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Shreds	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Bagasse	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Lime	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
SO2	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Residue	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Molasses	3.91	14.85	0.00	#DIV/0!	3.91	100.00	0.00	0.00
Total	26.33	100.00	0.00	#DIV/0!	3.91	100.00	22.42	100.00
Grand total	26.33				26.33			

DRYER

Operation: Total removal of the remaining water

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	10.86	48.42	0.00	#DIV/0!	10.86	100.00	0.00	0.00
Saccharose	11.57	51.58	0.00	#DIV/0!	0.00	0.00	11.57	100.00
Impurities	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Shreds	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Bagasse	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Lime	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
SO2	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Residue	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Molasses	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Total	22.42	100.00	0.00	#DIV/0!	10.86	100.00	11.57	100.00
Grand total	22.42				22.42			

Calculation of scale up factor

Conversion:	1.00	ton/day =	1000.00	kg/day	
Production rate:	1.00	ton/day	which is equal to	1000.00	kg/day
Sugar obtained from the basis =			11.57		
Scale up factor is therefore equal to				86.46	

SCALED UP MATERIAL BALANCES

WASHER

Operation: Cleaning of the sugar cane to remove impurities (sand, debris and mud)

Assumptions:

;1: Water added is equal to 10.00 % wt of sugar cane

2: 90.00 % of the water added is removed

3: 100.00 % of the impurities is removed in this unit

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	6052.37	70.00	864.62	100.00	778.16	76.92	6138.83	72.23
Saccharose	1149.95	13.30	0.00	0.00	0.00	0.00	1149.95	13.53
Impurities	233.45	2.70	0.00	0.00	233.45	23.08	0.00	0.00
Shreds	345.85	4.00	0.00	0.00	0.00	0.00	345.85	4.07
Bagasse	864.62	10.00	0.00	0.00	0.00	0.00	864.62	10.17
Lime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Residue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Molasses	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	8646.24	100.00	864.62	100.00	1011.61	100.00	8499.26	100.00
Grand total	9510.87				9510.87			

SHREDDER

Operation: Removal of the shreds of the sugar cane

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	6138.83	72.23	0.00	#DIV/0!	0.00	0.00	6138.83	75.29
Saccharose	1149.95	13.53	0.00	#DIV/0!	0.00	0.00	1149.95	14.10
Impurities	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Shreds	345.85	4.07	0.00	#DIV/0!	345.85	100.00	0.00	0.00
Bagasse	864.62	10.17	0.00	#DIV/0!	0.00	0.00	864.62	10.60
Lime	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
SO2	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Residue	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Molasses	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Total	8499.26	100.00	0.00	#DIV/0!	345.85	100.00	8153.41	100.00
Grand total	8499.26				8499.26			

CRUSHER

Operation: Size reduction of the sugar cane

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	6138.83	75.29	0.00	#DIV/0!	0.00	#DIV/0!	6138.83	75.29
Saccharose	1149.95	14.10	0.00	#DIV/0!	0.00	#DIV/0!	1149.95	14.10
Impurities	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Shreds	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Bagasse	864.62	10.60	0.00	#DIV/0!	0.00	#DIV/0!	864.62	10.60
Lime	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
SO2	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Residue	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Molasses	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Total	8153.41	100.00	0.00	#DIV/0!	0.00	#DIV/0!	8153.41	100.00
Grand total	8153.41				8153.41			

MILLER

Operation: Size reduction of the crushed sugar cane

Assumptions:

1: Hot water added equals to 15.00 % wt of sugar cane

2: 91.00 % wt bagasse is removed in this unit

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	6138.83	75.29	1223.01	100.00	0.00	0.00	7361.84	85.71
Saccharose	1149.95	14.10	0.00	0.00	0.00	0.00	1149.95	13.39
Impurities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shreds	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bagasse	864.62	10.60	0.00	0.00	786.81	100.00	77.82	0.91
Lime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Residue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Molasses	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	8153.41	100.00	1223.01	100.00	786.81	100.00	8589.61	100.00
Grand total	9376.42				9376.42			

MIXER 1

Operation: Addition and agitation of lime with the syrup

Assumption: Lime added equals to 3.00 % wt of sugar cane

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	7361.84	85.71	0.00	0.00	0.00	#DIV/0!	7361.84	83.21
Saccharose	1149.95	13.39	0.00	0.00	0.00	#DIV/0!	1149.95	13.00
Impurities	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Shreds	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Bagasse	77.82	0.91	0.00	0.00	0.00	#DIV/0!	77.82	0.88
Lime	0.00	0.00	257.69	100.00	0.00	#DIV/0!	257.69	2.91
SO2	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Residue	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Molasses	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Total	8589.61	100.00	257.69	100.00	0.00	#DIV/0!	8847.30	100.00
Grand total	8847.30				8847.30			

BOILER

Operation: Heating of the syrup to boiling

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	7361.84	83.21	0.00	#DIV/0!	0.00	#DIV/0!	7361.84	83.21
Saccharose	1149.95	13.00	0.00	#DIV/0!	0.00	#DIV/0!	1149.95	13.00
Impurities	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Shreds	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Bagasse	77.82	0.88	0.00	#DIV/0!	0.00	#DIV/0!	77.82	0.88
Lime	257.69	2.91	0.00	#DIV/0!	0.00	#DIV/0!	257.69	2.91
SO2	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Residue	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Molasses	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Total	8847.30	100.00	0.00	#DIV/0!	0.00	#DIV/0!	8847.30	100.00
Grand total	8847.30				8847.30			

MIXER 2

Operation: Addition and mixing of SO2 with the syrup

Assumption: 1.50 % wt sugar of SO2 is added

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	7361.84	83.21	0.00	0.00	0.00	#DIV/0!	7361.84	81.98
Saccharose	1149.95	13.00	0.00	0.00	0.00	#DIV/0!	1149.95	12.81
Impurities	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Shreds	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Bagasse	77.82	0.88	0.00	0.00	0.00	#DIV/0!	77.82	0.87
Lime	257.69	2.91	0.00	0.00	0.00	#DIV/0!	257.69	2.87
SO2	0.00	0.00	132.71	100.00	0.00	#DIV/0!	132.71	1.48
Residue	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Molasses	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Total	8847.30	100.00	132.71	100.00	0.00	#DIV/0!	8980.01	100.00
Grand total	8980.01				8980.01			

CLARIFIER

Operation: Coagulation of the impurities in the syrup

the remaining bagasse and other organic impurities make up the residue

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	7361.84	81.98	0.00	#DIV/0!	0.00	#DIV/0!	7361.84	81.98
Saccharose	1149.95	12.81	0.00	#DIV/0!	0.00	#DIV/0!	1149.95	12.81
Impurities	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Shreds	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Bagasse	77.82	0.87	0.00	#DIV/0!	0.00	#DIV/0!	77.82	0.87
Lime	257.69	2.87	0.00	#DIV/0!	0.00	#DIV/0!	257.69	2.87
SO2	132.71	1.48	0.00	#DIV/0!	0.00	#DIV/0!	132.71	1.48
Residue	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Molasses	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Total	8980.01	100.00	0.00	#DIV/0!	0.00	#DIV/0!	8980.01	100.00
Grand total	8980.01				8980.01			

FILTER

Operation: Separation of the coagulated impurities from the syrup

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	7361.84	81.98	0.00	#DIV/0!	0.00	0.00	7361.84	86.49
Saccharose	1149.95	12.81	0.00	#DIV/0!	0.00	0.00	1149.95	13.51
Impurities	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Shreds	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Bagasse	77.82	0.87	0.00	#DIV/0!	77.82	16.62	0.00	0.00
Lime	257.69	2.87	0.00	#DIV/0!	257.69	55.04	0.00	0.00
SO2	132.71	1.48	0.00	#DIV/0!	132.71	28.34	0.00	0.00
Residue	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Molasses	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Total	8980.01	100.00	0.00	#DIV/0!	468.21	100.00	8511.79	100.00
Grand total	8980.01				8980.01			

EVAPORATOR

Operation: Removal of water in the syrup

Assumption: 85.00 % of the water is removed

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	7361.84	86.49	0.00	#DIV/0!	6257.57	100.00	1104.28	48.99
Saccharose	1149.95	13.51	0.00	#DIV/0!	0.00	0.00	1149.95	51.01
Impurities	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Shreds	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Bagasse	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Lime	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
SO2	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Residue	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Molasses	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Total	8511.79	100.00	0.00	#DIV/0!	6257.57	100.00	2254.23	100.00
Grand total	8511.79				8511.79			

CRYSTALLIZER

Operation: Processing of the sugar to form crystals

Assumption 1: Seed crystal added is 1.00 % wt of sugar cane

Assumption 2: 15.00 % of the sugar form the molasses

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	1104.28	48.99	0.00	0.00	0.00	#DIV/0!	938.64	41.23
Saccharose	1149.95	51.01	22.54	100.00	0.00	#DIV/0!	1000.00	43.92
Impurities	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Shreds	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Bagasse	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Lime	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
SO2	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Residue	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.00	0.00
Molasses	0.00	0.00	0.00	0.00	0.00	#DIV/0!	338.13	14.85
Total	2254.23	100.00	22.54	100.00	0.00	#DIV/0!	2276.77	100.00
Grand total	2276.77				2276.77			

CENTRIFUGE

Operation: Separation of molasses from sugar crystals

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	938.64	41.23	0.00	#DIV/0!	0.00	0.00	938.64	48.42
Saccharose	1000.00	43.92	0.00	#DIV/0!	0.00	0.00	1000.00	51.58
Impurities	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Shreds	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Bagasse	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Lime	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
SO2	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Residue	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Molasses	338.13	14.85	0.00	#DIV/0!	338.13	100.00	0.00	0.00
Total	2276.77	100.00	0.00	#DIV/0!	338.13	100.00	1938.64	100.00
Grand total	2276.77				2276.77			

DRYER

Operation: Total removal of the remaining water

	IN				OUT			
	Input		Addition		Loss		Output	
Comp	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Water	938.64	48.42	0.00	#DIV/0!	938.64	100.00	0.00	0.00
Saccharose	1000.00	51.58	0.00	#DIV/0!	0.00	0.00	1000.00	100.00
Impurities	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Shreds	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Bagasse	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Lime	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
SO2	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Residue	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Molasses	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Total	1938.64	100.00	0.00	#DIV/0!	938.64	100.00	1000.00	100.00
Grand total	1938.64				1938.64			

CHAPTER FOUR

4.0 ENERGY BALANCES

Definitions:

$kJ := 10^3 \cdot J$

$rev := rad$

$kmol := mol$

$kJ := 1000 \cdot J$

i = Input

$cP := 10^{-2} \cdot poise$

a = Addition

l = Loss

o = Output

Components and their molecular weights:

$$\begin{pmatrix} \text{Water} \\ \text{Saccharose} \\ \text{Impurities} \\ \text{Shreds} \\ \text{Bagasse} \\ \text{Lime} \\ SO_2 \\ \text{Residue} \\ \text{Molasses} \end{pmatrix} \qquad mw := \begin{pmatrix} 18 \\ 342.30 \\ 60.09 \\ 24 \\ 342.30 \\ 56 \\ 64 \\ 180.16 \\ 180.16 \end{pmatrix} \cdot \frac{kg}{kmol}$$

Themodynamic Properties:

$$coeff := \begin{bmatrix} 18.296 & 0.472 & -(1.34 \cdot 10^{-3}) & 1.31 \cdot 10^{-6} & -285.84 & 4.07 \cdot 10^4 \\ -56.667 & 1.71 & -(1.11 \cdot 10^{-3}) & 2.65 \cdot 10^{-7} & -(2.23 \cdot 10^3) & 4.55 \cdot 10^4 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1.00 \cdot 10^{-3} & 0 & 0 & 0 & 0 & 4.55 \cdot 10^4 \\ 41.84 & 2.03 \cdot 10^{-2} & -452000 & 0 & 0 & 0 \\ 38.91 & 3.90 \cdot 10^{-2} & -(3.10 \cdot 10^{-5}) & 8.61 \cdot 10^{-9} & 0.00 & 24920 \\ 1.00 \cdot 10^{-3} & 0 & 0 & 0 & 0 & 4.55 \cdot 10^4 \\ 1.00 \cdot 10^{-3} & 0 & 0 & 0 & 0 & 4.55 \cdot 10^4 \end{bmatrix} \begin{pmatrix} \text{Water} \\ \text{Saccharose} \\ \text{Impurities} \\ \text{Shreds} \\ \text{Bagasse} \\ \text{Lime} \\ SO_2 \\ \text{Residue} \\ \text{Molasses} \end{pmatrix}$$

$$a := \overrightarrow{\frac{coeff^{\langle 1 \rangle}}{mw}} \cdot \frac{kJ}{kmol \cdot K} \qquad b := \overrightarrow{\frac{coeff^{\langle 2 \rangle}}{mw}} \cdot \frac{kJ}{kmol \cdot K^2}$$

$$c := \overrightarrow{\frac{coeff^{\langle 3 \rangle}}{mw}} \cdot \frac{kJ}{kmol \cdot K^3} \qquad d := \overrightarrow{\frac{coeff^{\langle 4 \rangle}}{mw}} \cdot \frac{kJ}{kmol \cdot K^4}$$

$$H_r := \overrightarrow{\frac{coeff^{\langle 5 \rangle}}{mw}} \cdot \frac{kJ}{kmol} \qquad H_v := \overrightarrow{\frac{coeff^{\langle 6 \rangle}}{mw}} \cdot \frac{kJ}{kmol}$$

Reference temperature: $T_r := 298 \cdot K$

4.1 Energy Balances on Washer

Since this equipment does not have any heating element, its energy balance is not required.

4.2 Energy Balances on Shredder

Since this equipment does not have any heating element, its energy balance is not required.

4.3 Energy Balances on Crusher

Material flows of the crusher **Temperature**

$$m' := \begin{pmatrix} 6138.83 & 0.00 & 0.00 & 6138.83 \\ 1149.95 & 0.00 & 0.00 & 1149.95 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 864.62 & 0.00 & 0.00 & 864.62 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \end{pmatrix} \cdot \frac{kg}{day} \qquad \begin{pmatrix} T_i \\ T_a \\ T_l \\ T_o \end{pmatrix} := \begin{pmatrix} 303 \\ 0 \\ 0 \\ 313 \end{pmatrix} \cdot K$$

$m'_i := m'^{\langle 1 \rangle}$ $\quad m'_a := m'^{\langle 2 \rangle}$ $\quad m'_l := m'^{\langle 3 \rangle}$ $\quad m'_o := m'^{\langle 4 \rangle}$

$T_i = 303\,K$ $\quad T_a = 0\,K$ $\quad T_l = 0\,K$ $\quad T_o = 313\,K$

Energy In

Energy of input

$$\Delta H_i := m'_{i_1}\cdot\left[\int_{T_r}^{T_i}\left(a_1 + b_1\cdot T + c_1\cdot T^2 + d_1\cdot T^3\right)dT\right] + m'_{i_2}\cdot\left[\int_{T_r}^{T_i}\left(a_2 + b_2\cdot T + c_2\cdot T^2 + d_2\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{i_3}\cdot\left[\int_{T_r}^{T_i}\left(a_3 + b_3\cdot T + c_3\cdot T^2 + d_3\cdot T^3\right)dT\right] + m'_{i_4}\cdot\left[\int_{T_r}^{T_i}\left(a_4 + b_4\cdot T + c_4\cdot T^2 + d_4\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{i_5}\cdot\left[\int_{T_r}^{T_i}\left(a_5 + b_5\cdot T + c_5\cdot T^2 + d_5\cdot T^3\right)dT\right] + m'_{i_6}\cdot\left[\int_{T_r}^{T_i}\left(a_6 + b_6\cdot T + c_6\cdot T^2 + d_6\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{i_7}\cdot\int_{T_r}^{T_i}\left(a_7 + b_7\cdot T + c_7\cdot T^2 + d_7\cdot T^3\right)dT + m'_{i_8}\cdot\int_{T_r}^{T_i}\left(a_8 + b_8\cdot T + c_8\cdot T^2 + d_8\cdot T^3\right)dT\ldots$$
$$+ m'_{i_9}\cdot\left[\int_{T_r}^{T_i}\left(a_9 + b_9\cdot T + c_9\cdot T^2 + d_9\cdot T^3\right)dT\right]$$

$$\Delta H_i = 1.335\times 10^5\,\frac{kJ}{day}$$

$$\Delta H_{in} := \Delta H_i$$

Energy Out

Energy of Output

$T_o = 313\,K$

$$\Delta H_o := m'_{o_1}\cdot\left[\int_{T_r}^{T_o}\left(a_1 + b_1\cdot T + c_1\cdot T^2 + d_1\cdot T^3\right)dT\right] + m'_{o_2}\cdot\left[\int_{T_r}^{T_o}\left(a_2 + b_2\cdot T + c_2\cdot T^2 + d_2\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{o_3}\cdot\left[\int_{T_r}^{T_o}\left(a_3 + b_3\cdot T + c_3\cdot T^2 + d_3\cdot T^3\right)dT\right] + m'_{o_4}\cdot\left[\int_{T_r}^{T_o}\left(a_4 + b_4\cdot T + c_4\cdot T^2 + d_4\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{o_5}\cdot\left[\int_{T_r}^{T_o}\left(a_5 + b_5\cdot T + c_5\cdot T^2 + d_5\cdot T^3\right)dT\right] + m'_{o_6}\cdot\left[\int_{T_r}^{T_o}\left(a_6 + b_6\cdot T + c_6\cdot T^2 + d_6\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{o_7}\cdot\int_{T_r}^{T_o}\left(a_7 + b_7\cdot T + c_7\cdot T^2 + d_7\cdot T^3\right)dT + m'_{o_8}\cdot\int_{T_r}^{T_o}\left(a_8 + b_8\cdot T + c_8\cdot T^2 + d_8\cdot T^3\right)dT\ldots$$
$$+ m'_{o_9}\cdot\left[\int_{T_r}^{T_o}\left(a_9 + b_9\cdot T + c_9\cdot T^2 + d_9\cdot T^3\right)dT\right]$$

$$\Delta H_o = 4.012\times 10^5\,\frac{kJ}{day}$$

Total energy out: $\Delta H_{out} := \Delta H_o$

$$\Delta H_{out} = 4.012\times 10^5\,\frac{kJ}{day}$$

Heat load: $\Delta H_3 := \Delta H_{out} - \Delta H_{in}$

$$\Delta H_3 = 2.677\times 10^5\,\frac{kJ}{day}$$

4.4 Energy Balances on Miller

Material flows of the miller **Temperature**

$$m' := \begin{pmatrix} 6138.83 & 1223.01 & 0.00 & 7361.84 \\ 1149.95 & 0.00 & 0.00 & 1149.95 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 864.62 & 0.00 & 786.81 & 77.82 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \end{pmatrix} \cdot \frac{kg}{day} \qquad \begin{pmatrix} T_i \\ T_a \\ T_l \\ T_o \end{pmatrix} := \begin{pmatrix} 313 \\ 303 \\ 319 \\ 319 \end{pmatrix} \cdot K$$

$m'_i := m'^{\langle 1 \rangle}$ $m'_a := m'^{\langle 2 \rangle}$ $m'_l := m'^{\langle 3 \rangle}$ $m'_o := m'^{\langle 4 \rangle}$

$T_i = 313\,K$ $T_a = 303\,K$ $T_l = 319\,K$ $T_o = 319\,K$

Energy In

Energy of input

$$\Delta H_i := m'_{i_1} \cdot \left[\int_{T_r}^{T_i} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT\right] + m'_{i_2} \cdot \left[\int_{T_r}^{T_i} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{i_3} \cdot \left[\int_{T_r}^{T_i} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT\right] + m'_{i_4} \cdot \left[\int_{T_r}^{T_i} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{i_5} \cdot \left[\int_{T_r}^{T_i} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT\right] + m'_{i_6} \cdot \left[\int_{T_r}^{T_i} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{i_7} \cdot \int_{T_r}^{T_i} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + m'_{i_8} \cdot \int_{T_r}^{T_i} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \ldots$$
$$+ m'_{i_9} \cdot \left[\int_{T_r}^{T_i} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT\right]$$

$$\Delta H_i = 4.012 \times 10^5 \frac{kJ}{day}$$

Energy of addition

$T_a = 303\ \text{K}$

$$\Delta H_a := m'_{a_1} \cdot \left[\int_{T_r}^{T_a} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT\right] + m'_{a_2} \cdot \left[\int_{T_r}^{T_a} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{a_3} \cdot \left[\int_{T_r}^{T_a} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT\right] + m'_{a_4} \cdot \left[\int_{T_r}^{T_a} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{a_5} \cdot \left[\int_{T_r}^{T_a} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT\right] + m'_{a_6} \cdot \left[\int_{T_r}^{T_a} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{a_7} \cdot \int_{T_r}^{T_a} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + m'_{a_8} \cdot \int_{T_r}^{T_a} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \ldots$$
$$+ m'_{a_9} \cdot \left[\int_{T_r}^{T_a} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT\right]$$

$$\Delta H_a = 2.537 \times 10^4 \frac{\text{kJ}}{\text{day}}$$

Total energy in: $\Delta H_{in} := \Delta H_i + \Delta H_a$

$$\Delta H_{in} = 4.265 \times 10^5 \frac{\text{kJ}}{\text{day}}$$

Energy Out

Energy of Loss

$T_l = 319\ \text{K}$

$$\Delta H_l := m'_{l_1} \cdot \left[\int_{T_r}^{T_l} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT\right] + m'_{l_2} \cdot \left[\int_{T_r}^{T_l} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{l_3} \cdot \left[\int_{T_r}^{T_l} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT\right] + m'_{l_4} \cdot \left[\int_{T_r}^{T_l} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{l_5} \cdot \left[\int_{T_r}^{T_l} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT\right] + m'_{l_6} \cdot \left[\int_{T_r}^{T_l} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{l_7} \cdot \int_{T_r}^{T_l} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + m'_{l_8} \cdot \int_{T_r}^{T_l} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \ldots$$
$$+ m'_{l_9} \cdot \left[\int_{T_r}^{T_l} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT\right]$$

$$\Delta H_l = 0.048 \frac{\text{kJ}}{\text{day}}$$

Energy of Output

$T_o = 319\,K$

$$\Delta H_o := m`_{o_1}\cdot\left[\int_{T_r}^{T_o}\left(a_1 + b_1\cdot T + c_1\cdot T^2 + d_1\cdot T^3\right)dT\right] + m`_{o_2}\cdot\left[\int_{T_r}^{T_o}\left(a_2 + b_2\cdot T + c_2\cdot T^2 + d_2\cdot T^3\right)dT\right]\ldots$$
$$+ m`_{o_3}\cdot\left[\int_{T_r}^{T_o}\left(a_3 + b_3\cdot T + c_3\cdot T^2 + d_3\cdot T^3\right)dT\right] + m`_{o_4}\cdot\left[\int_{T_r}^{T_o}\left(a_4 + b_4\cdot T + c_4\cdot T^2 + d_4\cdot T^3\right)dT\right]\ldots$$
$$+ m`_{o_5}\cdot\left[\int_{T_r}^{T_o}\left(a_5 + b_5\cdot T + c_5\cdot T^2 + d_5\cdot T^3\right)dT\right] + m`_{o_6}\cdot\left[\int_{T_r}^{T_o}\left(a_6 + b_6\cdot T + c_6\cdot T^2 + d_6\cdot T^3\right)dT\right]\ldots$$
$$+ m`_{o_7}\cdot\int_{T_r}^{T_o}\left(a_7 + b_7\cdot T + c_7\cdot T^2 + d_7\cdot T^3\right)dT + m`_{o_8}\cdot\int_{T_r}^{T_o}\left(a_8 + b_8\cdot T + c_8\cdot T^2 + d_8\cdot T^3\right)dT\ldots$$
$$+ m`_{o_9}\cdot\left[\int_{T_r}^{T_o}\left(a_9 + b_9\cdot T + c_9\cdot T^2 + d_9\cdot T^3\right)dT\right]$$

$$\Delta H_o = 6.691\times 10^5\,\frac{kJ}{day}$$

Total energy out: $\Delta H_{out} := \Delta H_l + \Delta H_o$

$$\Delta H_{out} = 6.691\times 10^5\,\frac{kJ}{day}$$

Heat load: $\Delta H_4 := \Delta H_{out} - \Delta H_{in}$

$$\Delta H_4 = 2.425\times 10^5\,\frac{kJ}{day}$$

4.5 Energy Balances on Mixer 1

Material flows of the mixer 1 **Temperature**

$$m` := \begin{pmatrix} 7361.84 & 0.00 & 0.00 & 7361.84 \\ 1149.95 & 0.00 & 0.00 & 1149.95 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 77.82 & 0.00 & 0.00 & 77.82 \\ 0.00 & 257.69 & 0.00 & 257.69 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \end{pmatrix}\cdot\frac{kg}{day} \qquad \begin{pmatrix} T_i \\ T_a \\ T_l \\ T_o \end{pmatrix} := \begin{pmatrix} 319 \\ 303 \\ 0 \\ 325 \end{pmatrix}\cdot K$$

$m`_i := m`^{\langle 1\rangle}$ $m`_a := m`^{\langle 2\rangle}$ $m`_l := m`^{\langle 3\rangle}$ $m`_o := m`^{\langle 4\rangle}$

$T_i = 319\,K$ $T_a = 303\,K$ $T_l = 0\,K$ $T_o = 325\,K$

Energy In

Energy of input

$$\Delta H_i := m`_{i_1} \cdot \left[\int_{T_r}^{T_i} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT\right] + m`_{i_2} \cdot \left[\int_{T_r}^{T_i} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT\right] ...$$
$$+ m`_{i_3} \cdot \left[\int_{T_r}^{T_i} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT\right] + m`_{i_4} \cdot \left[\int_{T_r}^{T_i} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT\right] ...$$
$$+ m`_{i_5} \cdot \left[\int_{T_r}^{T_i} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT\right] + m`_{i_6} \cdot \left[\int_{T_r}^{T_i} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT\right] ...$$
$$+ m`_{i_7} \cdot \int_{T_r}^{T_i} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + m`_{i_8} \cdot \int_{T_r}^{T_i} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT ...$$
$$+ m`_{i_9} \cdot \left[\int_{T_r}^{T_i} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT\right]$$

$$\Delta H_i = 6.691 \times 10^5 \frac{kJ}{day}$$

Energy of addition

$T_a = 303\ K$

$$\Delta H_a := m`_{a_1} \cdot \left[\int_{T_r}^{T_a} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT\right] + m`_{a_2} \cdot \left[\int_{T_r}^{T_a} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT\right] ...$$
$$+ m`_{a_3} \cdot \left[\int_{T_r}^{T_a} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT\right] + m`_{a_4} \cdot \left[\int_{T_r}^{T_a} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT\right] ...$$
$$+ m`_{a_5} \cdot \left[\int_{T_r}^{T_a} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT\right] + m`_{a_6} \cdot \left[\int_{T_r}^{T_a} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT\right] ...$$
$$+ m`_{a_7} \cdot \int_{T_r}^{T_a} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + m`_{a_8} \cdot \int_{T_r}^{T_a} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT ...$$
$$+ m`_{a_9} \cdot \left[\int_{T_r}^{T_a} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT\right]$$

$$\Delta H_a = -9.391 \times 10^{11} \frac{kJ}{day}$$

Total energy in: $\Delta H_{in} := \Delta H_i + \Delta H_a$

$$\Delta H_{in} = -9.391 \times 10^{11} \frac{kJ}{day}$$

Energy Out

Energy of Output

$T_o = 325\,K$

$$\Delta H_o := m'_{o_1} \cdot \left[\int_{T_r}^{T_o} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT\right] + m'_{o_2} \cdot \left[\int_{T_r}^{T_o} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{o_3} \cdot \left[\int_{T_r}^{T_o} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT\right] + m'_{o_4} \cdot \left[\int_{T_r}^{T_o} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{o_5} \cdot \left[\int_{T_r}^{T_o} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT\right] + m'_{o_6} \cdot \left[\int_{T_r}^{T_o} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{o_7} \cdot \int_{T_r}^{T_o} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + m'_{o_8} \cdot \int_{T_r}^{T_o} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \ldots$$
$$+ m'_{o_9} \cdot \left[\int_{T_r}^{T_o} \left(a_9 + b_9' \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT\right]$$

$$\Delta H_o = -5.453 \times 10^{12} \frac{kJ}{day}$$

Total energy out: $\Delta H_{out} := \Delta H_o$

$$\Delta H_{out} = -5.453 \times 10^{12} \frac{kJ}{day}$$

Heat load: $\Delta H_5 := \Delta H_{out} - \Delta H_{in}$

$$\Delta H_5 = -4.513 \times 10^{12} \frac{kJ}{day}$$

4.6 Energy Balances on Boiler

Material flows of the boiler **Temperature**

$$m' := \begin{pmatrix} 7361.84 & 0.00 & 0.00 & 7361.84 \\ 1149.95 & 0.00 & 0.00 & 1149.95 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 77.82 & 0.00 & 0.00 & 77.82 \\ 257.69 & 0.00 & 0.00 & 257.69 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \end{pmatrix} \cdot \frac{kg}{day} \qquad \begin{pmatrix} T_i \\ T_a \\ T_l \\ T_o \end{pmatrix} := \begin{pmatrix} 325 \\ 0 \\ 0 \\ 365 \end{pmatrix} \cdot K$$

$m'_i := m'^{\langle 1 \rangle}$ $m'_a := m'^{\langle 2 \rangle}$ $m'_l := m'^{\langle 3 \rangle}$ $m'_o := m'^{\langle 4 \rangle}$

$T_i = 325\,K$ $T_a = 0\,K$ $T_l = 0\,K$ $T_o = 365\,K$

Energy In

Energy of input

$$\Delta H_i := m`_{i_1} \cdot \left[\int_{T_r}^{T_i} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT\right] + m`_{i_2} \cdot \left[\int_{T_r}^{T_i} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT\right] \ldots$$
$$+ m`_{i_3} \cdot \left[\int_{T_r}^{T_i} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT\right] + m`_{i_4} \cdot \left[\int_{T_r}^{T_i} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT\right] \ldots$$
$$+ m`_{i_5} \cdot \left[\int_{T_r}^{T_i} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT\right] + m`_{i_6} \cdot \left[\int_{T_r}^{T_i} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT\right] \ldots$$
$$+ m`_{i_7} \cdot \int_{T_r}^{T_i} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + m`_{i_8} \cdot \int_{T_r}^{T_i} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \ldots$$
$$+ m`_{i_9} \cdot \left[\int_{T_r}^{T_i} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT\right]$$

$$\Delta H_i = -5.453 \times 10^{12} \frac{kJ}{day}$$

Total energy in: $\Delta H_{in} := \Delta H_i$

$$\Delta H_{in} = -5.453 \times 10^{12} \frac{kJ}{day}$$

Energy Out

Energy of Output

$T_o = 365\ K$

$$\Delta H_o := m`_{o_1} \cdot \left[\int_{T_r}^{T_o} \left(a_1 + b_1 \cdot T + o_1 \cdot T^2 + d_1 \cdot T^3\right) dT\right] + m`_{o_2} \cdot \left[\int_{T_r}^{T_o} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT\right] \ldots$$
$$+ m`_{o_3} \cdot \left[\int_{T_r}^{T_o} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT\right] + m`_{o_4} \cdot \left[\int_{T_r}^{T_o} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT\right] \ldots$$
$$+ m`_{o_5} \cdot \left[\int_{T_r}^{T_o} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT\right] + m`_{o_6} \cdot \left[\int_{T_r}^{T_o} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT\right] \ldots$$
$$+ m`_{o_7} \cdot \int_{T_r}^{T_o} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + m`_{o_8} \cdot \int_{T_r}^{T_o} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \ldots$$
$$+ m`_{o_9} \cdot \left[\int_{T_r}^{T_o} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT\right]$$

$$\Delta H_o = -1.537 \times 10^{13} \frac{kJ}{day}$$

Total energy out: $\Delta H_{out} := \Delta H_l + \Delta H_o$

$$\Delta H_{out} = -1.537 \times 10^{13} \frac{kJ}{day}$$

Heat load: $\Delta H_6 := \Delta H_{out} - \Delta H_{in}$

$$\Delta H_6 = -9.914 \times 10^{12} \frac{kJ}{day}$$

4.7 Energy Balances on Mixer 2

Material flows of the mixer 2 **Temperature**

$$m` := \begin{pmatrix} 7361.84 & 0.00 & 0.00 & 7361.84 \\ 1149.95 & 0.00 & 0.00 & 1149.95 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 77.82 & 0.00 & 0.00 & 77.82 \\ 257.69 & 0.00 & 0.00 & 257.69 \\ 0.00 & 132.71 & 0.00 & 132.71 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \end{pmatrix} \cdot \frac{kg}{day} \qquad \begin{pmatrix} T_i \\ T_a \\ T_l \\ T_o \end{pmatrix} := \begin{pmatrix} 365 \\ 303 \\ 0 \\ 369 \end{pmatrix} \cdot K$$

$m`_i := m`^{\langle 1 \rangle}$ $m`_a := m`^{\langle 2 \rangle}$ $m`_l := m`^{\langle 3 \rangle}$ $m`_o := m`^{\langle 4 \rangle}$

$T_i = 365\,K$ $T_a = 303\,K$ $T_l = 0\,K$ $T_o = 369\,K$

Energy In

Energy of input

$$\Delta H_i := m`_{i_1} \cdot \left[\int_{T_r}^{T_i} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT\right] + m`_{i_2} \cdot \left[\int_{T_r}^{T_i} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT\right] \ldots$$
$$+ m`_{i_3} \cdot \left[\int_{T_r}^{T_i} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT\right] + m`_{i_4} \cdot \left[\int_{T_r}^{T_i} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT\right] \ldots$$
$$+ m`_{i_5} \cdot \left[\int_{T_r}^{T_i} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT\right] + m`_{i_6} \cdot \left[\int_{T_r}^{T_i} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT\right] \ldots$$
$$+ m`_{i_7} \cdot \int_{T_r}^{T_i} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + m`_{i_8} \cdot \int_{T_r}^{T_i} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \ldots$$
$$+ m`_{i_9} \cdot \left[\int_{T_r}^{T_i} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT\right]$$

$$\Delta H_i = -1.537 \times 10^{13} \frac{kJ}{day}$$

Energy of addition

$T_a = 303\,K$

$$\Delta H_a := m'_{a_1} \cdot \left[\int_{T_r}^{T_a} (a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3)\,dT\right] + m'_{a_2} \cdot \left[\int_{T_r}^{T_a} (a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3)\,dT\right] ...$$
$$+ m'_{a_3} \cdot \left[\int_{T_r}^{T_a} (a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3)\,dT\right] + m'_{a_4} \cdot \left[\int_{T_r}^{T_a} (a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3)\,dT\right] ...$$
$$+ m'_{a_5} \cdot \left[\int_{T_r}^{T_a} (a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3)\,dT\right] + m'_{a_6} \cdot \left[\int_{T_r}^{T_a} (a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3)\,dT\right] ...$$
$$+ m'_{a_7} \cdot \int_{T_r}^{T_a} (a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3)\,dT + m'_{a_8} \cdot \int_{T_r}^{T_a} (a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3)\,dT ...$$
$$+ m'_{a_9} \cdot \left[\int_{T_r}^{T_a} (a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3)\,dT\right]$$

$$\Delta H_a = 498.324\,\frac{kJ}{day}$$

Total energy in: $\Delta H_{in} := \Delta H_i + \Delta H_a$

$$\Delta H_{in} = -1.537 \times 10^{13}\,\frac{kJ}{day}$$

Energy Out

Energy of Output

$T_o = 369\,K$

$$\Delta H_o := m'_{o_1} \cdot \left[\int_{T_r}^{T_o} (a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3)\,dT\right] + m'_{o_2} \cdot \left[\int_{T_r}^{T_o} (a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3)\,dT\right] ...$$
$$+ m'_{o_3} \cdot \left[\int_{T_r}^{T_o} (a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3)\,dT\right] + m'_{o_4} \cdot \left[\int_{T_r}^{T_o} (a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3)\,dT\right] ...$$
$$+ m'_{o_5} \cdot \left[\int_{T_r}^{T_o} (a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3)\,dT\right] + m'_{o_6} \cdot \left[\int_{T_r}^{T_o} (a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3)\,dT\right] ...$$
$$+ m'_{o_7} \cdot \int_{T_r}^{T_o} (a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3)\,dT + m'_{o_8} \cdot \int_{T_r}^{T_o} (a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3)\,dT ...$$
$$+ m'_{o_9} \cdot \left[\int_{T_r}^{T_o} (a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3)\,dT\right]$$

$$\Delta H_o = -1.649 \times 10^{13}\,\frac{kJ}{day}$$

Total energy out: $\Delta H_{out} := \Delta H_o$

$$\Delta H_{out} = -1.649 \times 10^{13}\,\frac{kJ}{day}$$

Heat load: $\Delta H_7 := \Delta H_{out} - \Delta H_{in}$

$$\Delta H_7 = -1.121 \times 10^{12}\,\frac{kJ}{day}$$

4.8 Energy Balances on Clarifier

Material flows of the clarifier

$$m' := \begin{pmatrix} 7361.84 & 0.00 & 0.00 & 7361.84 \\ 1149.95 & 0.00 & 0.00 & 1149.95 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 77.82 & 0.00 & 0.00 & 77.82 \\ 257.69 & 0.00 & 0.00 & 257.69 \\ 132.71 & 0.00 & 0.00 & 132.71 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \end{pmatrix} \cdot \frac{kg}{day}$$

Temperature

$$\begin{pmatrix} T_i \\ T_a \\ T_l \\ T_o \end{pmatrix} := \begin{pmatrix} 369 \\ 0 \\ 0 \\ 350 \end{pmatrix} \cdot K$$

$m'_i := m'^{\langle 1 \rangle}$ $\quad m'_a := m'^{\langle 2 \rangle}$ $\quad m'_l := m'^{\langle 3 \rangle}$ $\quad m'_o := m'^{\langle 4 \rangle}$

$T_i = 369\,K$ $\quad T_a = 0\,K$ $\quad T_l = 0\,K$ $\quad T_o = 350\,K$

Energy In

Energy of input

$$\Delta H_i := m'_{i_1} \cdot \left[\int_{T_r}^{T_i} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT\right] + m'_{i_2} \cdot \left[\int_{T_r}^{T_i} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{i_3} \cdot \left[\int_{T_r}^{T_i} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT\right] + m'_{i_4} \cdot \left[\int_{T_r}^{T_i} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{i_5} \cdot \left[\int_{T_r}^{T_i} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT\right] + m'_{i_6} \cdot \left[\int_{T_r}^{T_i} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{i_7} \cdot \int_{T_r}^{T_l} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + m'_{i_8} \cdot \int_{T_r}^{T_i} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \ldots$$
$$+ m'_{i_9} \cdot \left[\int_{T_r}^{T_i} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT\right]$$

$$\Delta H_i = -1.649 \times 10^{13} \frac{kJ}{day}$$

Total energy in: $\Delta H_{in} := \Delta H_i$

$$\Delta H_{in} = -1.649 \times 10^{13} \frac{kJ}{day}$$

Energy Out

Energy of Output

$T_o = 350\,K$

$$\Delta H_o := m'_{o_1} \cdot \left[\int_{T_r}^{T_o} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT\right] + m'_{o_2} \cdot \left[\int_{T_r}^{T_o} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{o_3} \cdot \left[\int_{T_r}^{T_o} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT\right] + m'_{o_4} \cdot \left[\int_{T_r}^{T_o} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{o_5} \cdot \left[\int_{T_r}^{T_o} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT\right] + m'_{o_6} \cdot \left[\int_{T_r}^{T_o} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{o_7} \cdot \int_{T_r}^{T_o} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + m'_{o_8} \cdot \int_{T_r}^{T_o} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \ldots$$
$$+ m'_{o_9} \cdot \left[\int_{T_r}^{T_o} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT\right]$$

$$\Delta H_o = -1.138 \times 10^{13} \frac{kJ}{day}$$

Total energy out: $\Delta H_{out} := \Delta H_o$

$$\Delta H_{out} = -1.138 \times 10^{13} \frac{kJ}{day}$$

Heat load: $\Delta H_8 := \Delta H_{out}' - \Delta H_{in}$

$$\Delta H_8 = 5.109 \times 10^{12} \frac{kJ}{day}$$

4.9 Energy Balances on Filter

Material flows of the filter **Temperature**

$$m' := \begin{pmatrix} 7361.84 & 0.00 & 0.00 & 7361.84 \\ 1149.95 & 0.00 & 0.00 & 1149.95 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 77.82 & 0.00 & 77.82 & 0.00 \\ 257.69 & 0.00 & 257.69 & 0.00 \\ 132.71 & 0.00 & 132.71 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \end{pmatrix} \cdot \frac{kg}{day} \qquad \begin{pmatrix} T_i \\ T_a \\ T_l \\ T_o \end{pmatrix} := \begin{pmatrix} 369 \\ 0 \\ 370 \\ 370 \end{pmatrix} \cdot K$$

$m'_i := m'^{\langle 1 \rangle}$ $m'_a := m'^{\langle 2 \rangle}$ $m'_l := m'^{\langle 3 \rangle}$ $m'_o := m'^{\langle 4 \rangle}$

$T_i = 369\,K$ $T_a = 0\,K$ $T_l = 370\,K$ $T_o = 370\,K$

Energy In

Energy of input

$$\Delta H_i := m'_{i_1}\cdot\left[\int_{T_r}^{T_i}\left(a_1 + b_1\cdot T + c_1\cdot T^2 + d_1\cdot T^3\right)dT\right] + m'_{i_2}\cdot\left[\int_{T_r}^{T_i}\left(a_2 + b_2\cdot T + c_2\cdot T^2 + d_2\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{i_3}\cdot\left[\int_{T_r}^{T_i}\left(a_3 + b_3\cdot T + c_3\cdot T^2 + d_3\cdot T^3\right)dT\right] + m'_{i_4}\cdot\left[\int_{T_r}^{T_i}\left(a_4 + b_4\cdot T + c_4\cdot T^2 + d_4\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{i_5}\cdot\left[\int_{T_r}^{T_i}\left(a_5 + b_5\cdot T + c_5\cdot T^2 + d_5\cdot T^3\right)dT\right] + m'_{i_6}\cdot\left[\int_{T_r}^{T_i}\left(a_6 + b_6\cdot T + c_6\cdot T^2 + d_6\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{i_7}\cdot\int_{T_r}^{T_i}\left(a_7 + b_7\cdot T + c_7\cdot T^2 + d_7\cdot T^3\right)dT + m'_{i_8}\cdot\int_{T_r}^{T_i}\left(a_8 + b_8\cdot T + c_8\cdot T^2 + d_8\cdot T^3\right)dT\ldots$$
$$+ m'_{i_9}\cdot\left[\int_{T_r}^{T_i}\left(a_9 + b_9\cdot T + c_9\cdot T^2 + d_9\cdot T^3\right)dT\right]$$

$$\Delta H_i = -1.649\times 10^{13}\,\frac{kJ}{day}$$

Total energy in: $\Delta H_{in} := \Delta H_i$

$$\Delta H_{in} = -1.649\times 10^{13}\,\frac{kJ}{day}$$

Energy Out

Energy of Loss

$T_l = 370\ K$

$$\Delta H_l := m'_{l_1}\cdot\left[\int_{T_r}^{T_l}\left(a_1 + b_1\cdot T + c_1\cdot T^2 + d_1\cdot T^3\right)dT\right] + m'_{l_2}\cdot\left[\int_{T_r}^{T_l}\left(a_2 + b_2\cdot T + c_2\cdot T^2 + d_2\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{l_3}\cdot\left[\int_{T_r}^{T_l}\left(a_3 + b_3\cdot T + c_3\cdot T^2 + d_3\cdot T^3\right)dT\right] + m'_{l_4}\cdot\left[\int_{T_r}^{T_l}\left(a_4 + b_4\cdot T + c_4\cdot T^2 + d_4\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{l_5}\cdot\left[\int_{T_r}^{T_l}\left(a_5 + b_5\cdot T + c_5\cdot T^2 + d_5\cdot T^3\right)dT\right] + m'_{l_6}\cdot\left[\int_{T_r}^{T_l}\left(a_6 + b_6\cdot T + c_6\cdot T^2 + d_6\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{l_7}\cdot\int_{T_r}^{T_l}\left(a_7 + b_7\cdot T + c_7\cdot T^2 + d_7\cdot T^3\right)dT + m'_{l_8}\cdot\int_{T_r}^{T_l}\left(a_8 + b_8\cdot T + c_8\cdot T^2 + d_8\cdot T^3\right)dT\ldots$$
$$+ m'_{l_9}\cdot\left[\int_{T_r}^{T_l}\left(a_9 + b_9\cdot T + c_9\cdot T^2 + d_9\cdot T^3\right)dT\right]$$

$$\Delta H_l = -1.677\times 10^{13}\,\frac{kJ}{day}$$

Energy of Output

$T_o = 370\,K$

$$\Delta H_o := m'_{o_1} \cdot \left[\int_{T_r}^{T_o} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT\right] + m'_{o_2} \cdot \left[\int_{T_r}^{T_o} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{o_3} \cdot \left[\int_{T_r}^{T_o} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT\right] + m'_{o_4} \cdot \left[\int_{T_r}^{T_o} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{o_5} \cdot \left[\int_{T_r}^{T_o} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT\right] + m'_{o_6} \cdot \left[\int_{T_r}^{T_o} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{o_7} \cdot \int_{T_r}^{T_o} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + m'_{o_8} \cdot \int_{T_r}^{T_o} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \ldots$$
$$+ m'_{o_9} \cdot \left[\int_{T_r}^{T_o} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT\right]$$

$\Delta H_o = 2.313 \times 10^6 \frac{kJ}{day}$

Total energy out: $\Delta H_{out} := \Delta H_l + \Delta H_o$ $\qquad \Delta H_{out} = -1.677 \times 10^{13} \frac{kJ}{day}$

Heat load: $\Delta H_9 := \Delta H_{out} - \Delta H_{in}$ $\qquad \Delta H_9 = -2.84 \times 10^{11} \frac{kJ}{day}$

4.10 Energy Balances on Evaporator

Material flows of the evaporator **Temperature**

$$m' := \begin{pmatrix} 7361.84 & 0.00 & 6257.57 & 1104.28 \\ 1149.95 & 0.00 & 0.00 & 1149.95 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \end{pmatrix} \cdot \frac{kg}{day} \qquad \begin{pmatrix} T_i \\ T_a \\ T_l \\ T_o \end{pmatrix} := \begin{pmatrix} 369 \\ 0 \\ 373 \\ 373 \end{pmatrix} \cdot K$$

$m'_i := m'^{\langle 1 \rangle}$ $\qquad m'_a := m'^{\langle 2 \rangle}$ $\qquad m'_l := m'^{\langle 3 \rangle}$ $\qquad m'_o := m'^{\langle 4 \rangle}$

$T_i = 369\,K$ $\qquad T_a = 0\,K$ $\qquad T_l = 373\,K$ $\qquad T_o = 373\,K$

$\Delta T_{10} := T_o - T_i$ $\qquad \Delta T_{10} = 4\,K$

Energy In

Energy of input

$$\Delta H_i := m'_{i_1}\cdot\left[\int_{T_r}^{T_i}\left(a_1 + b_1\cdot T + c_1\cdot T^2 + d_1\cdot T^3\right)dT + H_{v_1}\right] + m'_{i_2}\cdot\left[\int_{T_r}^{T_i}\left(a_2 + b_2\cdot T + c_2\cdot T^2 + d_2\cdot T^3\right)dT + H_{v_2}\right]\ldots$$
$$+ m'_{i_3}\cdot\left[\int_{T_r}^{T_i}\left(a_3 + b_3\cdot T + c_3\cdot T^2 + d_3\cdot T^3\right)dT + H_{v_3}\right] + m'_{i_4}\cdot\left[\int_{T_r}^{T_i}\left(a_4 + b_4\cdot T + c_4\cdot T^2 + d_4\cdot T^3\right)dT + H_{v_4}\right]\ldots$$
$$+ m'_{i_5}\cdot\left[\int_{T_r}^{T_i}\left(a_5 + b_5\cdot T + c_5\cdot T^2 + d_5\cdot T^3\right)dT + H_{v_5}\right] + m'_{i_6}\cdot\left[\int_{T_r}^{T_i}\left(a_6 + b_6\cdot T + c_6\cdot T^2 + d_6\cdot T^3\right)dT + H_{v_6}\right]\ldots$$
$$+ m'_{i_7}\cdot\left[\int_{T_r}^{T_i}\left(a_7 + b_7\cdot T + c_7\cdot T^2 + d_7\cdot T^3\right)dT + H_{v_7}\right] + m'_{i_8}\cdot\left[\int_{T_r}^{T_i}\left(a_8 + b_8\cdot T + c_8\cdot T^2 + d_8\cdot T^3\right)dT + H_{v_8}\right]\ldots$$
$$+ m'_{i_9}\cdot\left[\int_{T_r}^{T_i}\left(a_9 + b_9\cdot T + c_9\cdot T^2 + d_9\cdot T^3\right)dT + H_{v_9}\right]$$

$$\Delta H_i = 1.908\times 10^7\,\frac{kJ}{day}$$

Total energy in: $\Delta H_{in} := \Delta H_i$

$$\Delta H_{in} = 1.908\times 10^7\,\frac{kJ}{day}$$

Energy Out

Energy of Loss

$T_l = 373\,K$

$$\Delta H_i := m'_{i_1}\cdot\left[\int_{T_r}^{T_i}\left(a_1 + b_1\cdot T + c_1\cdot T^2 + d_1\cdot T^3\right)dT + H_{v_1}\right] + m'_{i_2}\cdot\left[\int_{T_r}^{T_i}\left(a_2 + b_2\cdot T + c_2\cdot T^2 + d_2\cdot T^3\right)dT + H_{v_2}\right]$$
$$+ m'_{i_3}\cdot\left[\int_{T_r}^{T_i}\left(a_3 + b_3\cdot T + c_3\cdot T^2 + d_3\cdot T^3\right)dT + H_{v_3}\right] + m'_{i_4}\cdot\left[\int_{T_r}^{T_i}\left(a_4 + b_4\cdot T + c_4\cdot T^2 + d_4\cdot T^3\right)dT + H_{v_4}\right]$$
$$+ m'_{i_5}\cdot\left[\int_{T_r}^{T_i}\left(a_5 + b_5\cdot T + c_5\cdot T^2 + d_5\cdot T^3\right)dT + H_{v_5}\right] + m'_{i_6}\cdot\left[\int_{T_r}^{T_i}\left(a_6 + b_6\cdot T + c_6\cdot T^2 + d_6\cdot T^3\right)dT + H_{v_6}\right]$$
$$+ m'_{i_7}\cdot\left[\int_{T_r}^{T_i}\left(a_7 + b_7\cdot T + c_7\cdot T^2 + d_7\cdot T^3\right)dT + H_{v_7}\right] + m'_{i_8}\cdot\left[\int_{T_r}^{T_i}\left(a_8 + b_8\cdot T + c_8\cdot T^2 + d_8\cdot T^3\right)dT + H_{v_8}\right]$$
$$+ m'_{i_9}\cdot\left[\int_{T_r}^{T_i}\left(a_9 + b_9\cdot T + c_9\cdot T^2 + d_9\cdot T^3\right)dT + H_{v_9}\right]$$

$$\Delta H_l = -1.677\times 10^{13}\,\frac{kJ}{day}$$

Energy of Output

$T_o = 373\,K$

$$\Delta H_i := m'_{i_1} \cdot \left[\int_{T_r}^{T_i} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT + H_{v_1}\right] + m'_{i_2} \cdot \left[\int_{T_r}^{T_i} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT + H_{v_2}\right] \ldots$$
$$+ m'_{i_3} \cdot \left[\int_{T_r}^{T_i} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT + H_{v_1}\right] + m'_{i_4} \cdot \left[\int_{T_r}^{T_i} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT + H_{v_3}\right]$$
$$+ m'_{i_5} \cdot \left[\int_{T_r}^{T_i} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT + H_{v_5}\right] + m'_{i_6} \cdot \left[\int_{T_r}^{T_i} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT + H_{v_6}\right]$$
$$+ m'_{i_7} \cdot \left[\int_{T_r}^{T_i} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + H_{v_7}\right] + m'_{i_8} \cdot \left[\int_{T_r}^{T_i} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT + H_{v_8}\right]$$
$$+ m'_{i_9} \cdot \left[\int_{T_r}^{T_i} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT + H_{v_9}\right]$$

$\Delta H_o = 2.313 \times 10^6 \frac{kJ}{day}$

Total energy out: $\Delta H_{out} := \Delta H_l + \Delta H_o$

$\Delta H_{out} = -1.677 \times 10^{13} \frac{kJ}{day}$

Heat load: $\Delta H_{10} := \Delta H_{out} - \Delta H_{in}$

$\Delta H_{10} = -1.677 \times 10^{13} \frac{kJ}{day}$

4.11 Energy Balances on Crystallizer

Material flows of the crystallizer **Temperature**

$$m' := \begin{pmatrix} 1104.28 & 0.00 & 0.00 & 938.64 \\ 1149.95 & 22.54 & 0.00 & 1000.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 338.13 \end{pmatrix} \cdot \frac{kg}{day} \qquad \begin{pmatrix} T_i \\ T_a \\ T_l \\ T_o \end{pmatrix} := \begin{pmatrix} 373 \\ 0 \\ 303 \\ 385 \end{pmatrix} \cdot K$$

$m'_i := m'^{\langle 1 \rangle}$ $\quad m'_a := m'^{\langle 2 \rangle}$ $\quad m'_l := m'^{\langle 3 \rangle}$ $\quad m'_o := m'^{\langle 4 \rangle}$

$T_i = 373\,K$ $\quad T_a = 0\,K$ $\quad T_l = 303\,K$ $\quad T_o = 385\,K$

$\Delta T_{11} := T_o - T_i$

$\Delta T_{11} = 12\,K$

Energy In

Energy of input

$$\Delta H_i := m'_{i_1} \cdot \left[\int_{T_r}^{T_i} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT\right] + m'_{i_2} \cdot \left[\int_{T_r}^{T_i} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{i_3} \cdot \left[\int_{T_r}^{T_i} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT\right] + m'_{i_4} \cdot \left[\int_{T_r}^{T_i} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{i_5} \cdot \left[\int_{T_r}^{T_i} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT\right] + m'_{i_6} \cdot \left[\int_{T_r}^{T_i} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{i_7} \cdot \int_{T_r}^{T_i} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + m'_{i_8} \cdot \int_{T_r}^{T_i} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \ldots$$
$$+ m'_{i_9} \cdot \left[\int_{T_r}^{T_i} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT\right]$$

$$\Delta H_i = 4.476 \times 10^5 \frac{kJ}{day}$$

Energy of addition

$T_a = 0\ K$

$$\Delta H_a := m'_{a_1} \cdot \left[\int_{T_r}^{T_a} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT\right] + m'_{a_2} \cdot \left[\int_{T_r}^{T_a} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{a_3} \cdot \left[\int_{T_r}^{T_a} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT\right] + m'_{a_4} \cdot \left[\int_{T_r}^{T_a} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{a_5} \cdot \left[\int_{T_r}^{T_a} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT\right] + m'_{a_6} \cdot \left[\int_{T_r}^{T_a} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{a_7} \cdot \int_{T_r}^{T_a} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + m'_{a_8} \cdot \int_{T_r}^{T_a} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \ldots$$
$$+ m'_{a_9} \cdot \left[\int_{T_r}^{T_a} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT\right]$$

$$\Delta H_a = -3.277 \times 10^3 \frac{kJ}{day}$$

Total energy in: $\Delta H_{in} := \Delta H_i + \Delta H_a$

$$\Delta H_{in} = 4.443 \times 10^5 \frac{kJ}{day}$$

Energy Out

Energy of Output

$T_o = 385\,K$

$$\Delta H_o := m'_{o_1} \cdot \left[\int_{T_r}^{T_o} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT\right] + m'_{o_2} \cdot \left[\int_{T_r}^{T_o} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{o_3} \cdot \left[\int_{T_r}^{T_o} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT\right] + m'_{o_4} \cdot \left[\int_{T_r}^{T_o} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{o_5} \cdot \left[\int_{T_r}^{T_o} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT\right] + m'_{o_6} \cdot \left[\int_{T_r}^{T_o} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{o_7} \cdot \int_{T_r}^{T_o} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + m'_{o_8} \cdot \int_{T_r}^{T_o} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \ldots$$
$$+ m'_{o_9} \cdot \left[\int_{T_r}^{T_o} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT\right]$$

$$\Delta H_o = 4.457 \times 10^5 \frac{kJ}{day}$$

Total energy out: $\Delta H_{out} := \Delta H_l + \Delta H_o$

$$\Delta H_{out} = -1.677 \times 10^{13} \frac{kJ}{day}$$

Heat load: $\Delta H_{11} := \Delta H_{out} - \Delta H_{in}$

$$\Delta H_{11} = -1.677 \times 10^{13} \frac{kJ}{day}$$

4.12 Energy Balances on Centrifuge

Material flows of the centrifuge **Temperature**

$$m' := \begin{pmatrix} 938.64 & 0.00 & 0.00 & 938.64 \\ 1000.00 & 0.00 & 0.00 & 1000.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 338.13 & 0.00 & 338.13 & 0.00 \end{pmatrix} \cdot \frac{kg}{day} \qquad \begin{pmatrix} T_i \\ T_a \\ T_l \\ T_o \end{pmatrix} := \begin{pmatrix} 383 \\ 0 \\ 385 \\ 385 \end{pmatrix} \cdot K$$

$m'_i := m'^{\langle 1 \rangle}$ $m'_a := m'^{\langle 2 \rangle}$ $m'_l := m'^{\langle 3 \rangle}$ $m'_o := m'^{\langle 4 \rangle}$

$T_i = 383\,K$ $T_a = 0\,K$ $T_l = 385\,K$ $T_o = 385\,K$

- **Energy In**

Energy of input

$$\Delta H_i := m'_{i_1}\cdot\left[\int_{T_r}^{T_i}\left(a_1 + b_1\cdot T + c_1\cdot T^2 + d_1\cdot T^3\right)dT\right] + m'_{i_2}\cdot\left[\int_{T_r}^{T_i}\left(a_2 + b_2\cdot T + c_2\cdot T^2 + d_2\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{i_3}\cdot\left[\int_{T_r}^{T_i}\left(a_3 + b_3\cdot T + c_3\cdot T^2 + d_3\cdot T^3\right)dT\right] + m'_{i_4}\cdot\left[\int_{T_r}^{T_i}\left(a_4 + b_4\cdot T + c_4\cdot T^2 + d_4\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{i_5}\cdot\left[\int_{T_r}^{T_i}\left(a_5 + b_5\cdot T + c_5\cdot T^2 + d_5\cdot T^3\right)dT\right] + m'_{i_6}\cdot\left[\int_{T_r}^{T_i}\left(a_6 + b_6\cdot T + c_6\cdot T^2 + d_6\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{i_7}\cdot\int_{T_r}^{T_i}\left(a_7 + b_7\cdot T + c_7\cdot T^2 + d_7\cdot T^3\right)dT + m'_{i_8}\cdot\int_{T_r}^{T_i}\left(a_8 + b_8\cdot T + c_8\cdot T^2 + d_8\cdot T^3\right)dT\ldots$$
$$+ m'_{i_9}\cdot\left[\int_{T_r}^{T_i}\left(a_9 + b_9\cdot T + c_9\cdot T^2 + d_9\cdot T^3\right)dT\right]$$

$$\Delta H_i = 4.351\times 10^5\,\frac{kJ}{day}$$

Total energy in: $\Delta H_{in} := \Delta H_i + \Delta H_a$

$$\Delta H_{in} = 4.318\times 10^5\,\frac{kJ}{day}$$

Energy Out

Energy of Loss

$T_l = 385\ K$

$$\Delta H_l := m'_{l_1}\cdot\left[\int_{T_r}^{T_l}\left(a_1 + b_1\cdot T + c_1\cdot T^2 + d_1\cdot T^3\right)dT\right] + m'_{l_2}\cdot\left[\int_{T_r}^{T_l}\left(a_2 + b_2\cdot T + c_2\cdot T^2 + d_2\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{l_3}\cdot\left[\int_{T_r}^{T_l}\left(a_3 + b_3\cdot T + c_3\cdot T^2 + d_3\cdot T^3\right)dT\right] + m'_{l_4}\cdot\left[\int_{T_r}^{T_l}\left(a_4 + b_4\cdot T + c_4\cdot T^2 + d_4\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{l_5}\cdot\left[\int_{T_r}^{T_l}\left(a_5 + b_5\cdot T + c_5\cdot T^2 + d_5\cdot T^3\right)dT\right] + m'_{l_6}\cdot\left[\int_{T_r}^{T_l}\left(a_6 + b_6\cdot T + c_6\cdot T^2 + d_6\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{l_7}\cdot\int_{T_r}^{T_l}\left(a_7 + b_7\cdot T + c_7\cdot T^2 + d_7\cdot T^3\right)dT + m'_{l_8}\cdot\int_{T_r}^{T_l}\left(a_8 + b_8\cdot T + c_8\cdot T^2 + d_8\cdot T^3\right)dT\ldots$$
$$+ m'_{l_9}\cdot\left[\int_{T_r}^{T_l}\left(a_9 + b_9\cdot T + c_9\cdot T^2 + d_9\cdot T^3\right)dT\right]$$

$$\Delta H_l = 0.163\,\frac{kJ}{day}$$

Energy of Output

$T_o = 385\,K$

$$\Delta H_o := m'_{o_1}\cdot\left[\int_{T_r}^{T_o}\left(a_1 + b_1\cdot T + c_1\cdot T^2 + d_1\cdot T^3\right)dT\right] + m'_{o_2}\cdot\left[\int_{T_r}^{T_o}\left(a_2 + b_2\cdot T + c_2\cdot T^2 + d_2\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{o_3}\cdot\left[\int_{T_r}^{T_o}\left(a_3 + b_3\cdot T + c_3\cdot T^2 + d_3\cdot T^3\right)dT\right] + m'_{o_4}\cdot\left[\int_{T_r}^{T_o}\left(a_4 + b_4\cdot T + c_4\cdot T^2 + d_4\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{o_5}\cdot\left[\int_{T_r}^{T_o}\left(a_5 + b_5\cdot T + c_5\cdot T^2 + d_5\cdot T^3\right)dT\right] + m'_{o_6}\cdot\left[\int_{T_r}^{T_o}\left(a_6 + b_6\cdot T + c_6\cdot T^2 + d_6\cdot T^3\right)dT\right]\ldots$$
$$+ m'_{o_7}\cdot\int_{T_r}^{T_o}\left(a_7 + b_7\cdot T + c_7\cdot T^2 + d_7\cdot T^3\right)dT + m'_{o_8}\cdot\int_{T_r}^{T_o}\left(a_8 + b_8\cdot T + c_8\cdot T^2 + d_8\cdot T^3\right)dT\ldots$$
$$+ m'_{o_9}\cdot\left[\int_{T_r}^{T_o}\left(a_9 + b_9\cdot T + c_9\cdot T^2 + d_9\cdot T^3\right)dT\right]$$

$$\Delta H_o = 4.457\times 10^5\,\frac{kJ}{day}$$

Total energy out: $\Delta H_{out} := \Delta H_l + \Delta H_o$

$$\Delta H_{out} = 4.457\times 10^5\,\frac{kJ}{day}$$

Heat load: $\Delta H_{12} := \Delta H_{out} - \Delta H_{in}$

$$\Delta H_{12} = 1.385\times 10^4\,\frac{kJ}{day}$$

4.13 Energy Balances on Dryer

Material flows of the dryer

$$m' := \begin{pmatrix} 938.64 & 0.00 & 938.64 & 0.00 \\ 1000.00 & 0.00 & 0.00 & 1000.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 \end{pmatrix}\cdot\frac{kg}{day}$$

Temperature

$$\begin{pmatrix} T_i \\ T_a \\ T_l \\ T_o \end{pmatrix} := \begin{pmatrix} 385 \\ 0 \\ 400 \\ 400 \end{pmatrix}\cdot K$$

$m'_i := m'^{\langle 1\rangle}$ $\quad m'_a := m'^{\langle 2\rangle}$ $\quad m'_l := m'^{\langle 3\rangle}$ $\quad m'_o := m'^{\langle 4\rangle}$

$T_i = 385\,K$ $\quad T_a = 0\,K$ $\quad T_l = 400\,K$ $\quad T_o = 400\,K$

Energy In

Energy of input

$$\Delta H_i := m`_{i_1} \cdot \left[\int_{T_r}^{T_i} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT\right] + m`_{i_2} \cdot \left[\int_{T_r}^{T_i} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT\right] ...$$
$$+ m`_{i_3} \cdot \left[\int_{T_r}^{T_i} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT\right] + m`_{i_4} \cdot \left[\int_{T_r}^{T_i} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT\right] ...$$
$$+ m`_{i_5} \cdot \left[\int_{T_r}^{T_i} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT\right] + m`_{i_6} \cdot \left[\int_{T_r}^{T_i} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT\right] ...$$
$$+ m`_{i_7} \cdot \int_{T_r}^{T_i} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + m`_{i_8} \cdot \int_{T_r}^{T_i} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT ...$$
$$+ m`_{i_9} \cdot \left[\int_{T_r}^{T_i} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT\right]$$

$$\Delta H_i = 4.457 \times 10^5 \frac{kJ}{day}$$

Total energy in: $\Delta H_{in} := \Delta H_i + \Delta H_a$

$$\Delta H_{in} = 4.424 \times 10^5 \frac{kJ}{day}$$

Energy Out

Energy of Loss

$T_l = 400\,K$

$$\Delta H_l := m`_{l_1} \cdot \left[\int_{T_r}^{T_l} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT\right] + m`_{l_2} \cdot \left[\int_{T_r}^{T_l} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT\right] ...$$
$$+ m`_{l_3} \cdot \left[\int_{T_r}^{T_l} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT\right] + m`_{l_4} \cdot \left[\int_{T_r}^{T_l} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT\right] ...$$
$$+ m`_{l_5} \cdot \left[\int_{T_r}^{T_l} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT\right] + m`_{l_6} \cdot \left[\int_{T_r}^{T_l} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT\right] ...$$
$$+ m`_{l_7} \cdot \int_{T_r}^{T_l} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + m`_{l_8} \cdot \int_{T_r}^{T_l} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT ...$$
$$+ m`_{l_9} \cdot \left[\int_{T_r}^{T_l} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT\right]$$

$$\Delta H_l = 4.017 \times 10^5 \frac{kJ}{day}$$

CHAPTER SIX

6.0 DESIGN OF EQUIPMENT

Given that the densitites of the components are:

$$\rho := \begin{pmatrix} 1.00 \cdot 10^3 \\ 1.59 \cdot 10^3 \\ 2250 \\ 1050 \\ 1562 \\ 2620 \\ 2264 \\ 1562 \\ 1562 \end{pmatrix} \cdot \frac{kg}{m^3}$$

6.1 Design of Crystallizer

Calculation of Area

The area of an crystallizer is given by the relationship

$$Q = U \cdot A \cdot \Delta T$$

where

Q = "heat load on the crystallizer"

U = "heat transfer coefficient of the crystallizer"

A = "Area of the crystallizer"

ΔT = "temperature difference on the crystallizer"

From the equation above, making A the subject of the formula,

$$A = \frac{Q}{U \cdot \Delta T}$$

From the energy balances

$$Q := \Delta H_{11}$$

$$\Delta T := \Delta T_{11}$$

For the crystallizer caustic potash concentration,

$$U := 1000 \cdot \frac{W}{m^2 \cdot K}$$

So, the area of the crystallizer is then calculated to be

$$A_{crystallizer} := \frac{|Q|}{U \cdot \Delta T} \qquad A_{crystallizer} = 1.618 \times 10^7 \, m^2$$

Energy of Output

$T_o = 400\,K$

$$\Delta H_o := m'_{o_1} \cdot \left[\int_{T_r}^{T_o} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT\right] + m'_{o_2} \cdot \left[\int_{T_r}^{T_o} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{o_3} \cdot \left[\int_{T_r}^{T_o} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT\right] + m'_{o_4} \cdot \left[\int_{T_r}^{T_o} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{o_5} \cdot \left[\int_{T_r}^{T_o} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT\right] + m'_{o_6} \cdot \left[\int_{T_r}^{T_o} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT\right] \ldots$$
$$+ m'_{o_7} \cdot \int_{T_r}^{T_o} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT + m'_{o_8} \cdot \int_{T_r}^{T_o} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \ldots$$
$$+ m'_{o_9} \cdot \left[\int_{T_r}^{T_o} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT\right]$$

$$\Delta H_o = 1.238 \times 10^5 \frac{kJ}{day}$$

Total energy out: $\Delta H_{out} := \Delta H_I + \Delta H_o$

$$\Delta H_{out} = 5.255 \times 10^5 \frac{kJ}{day}$$

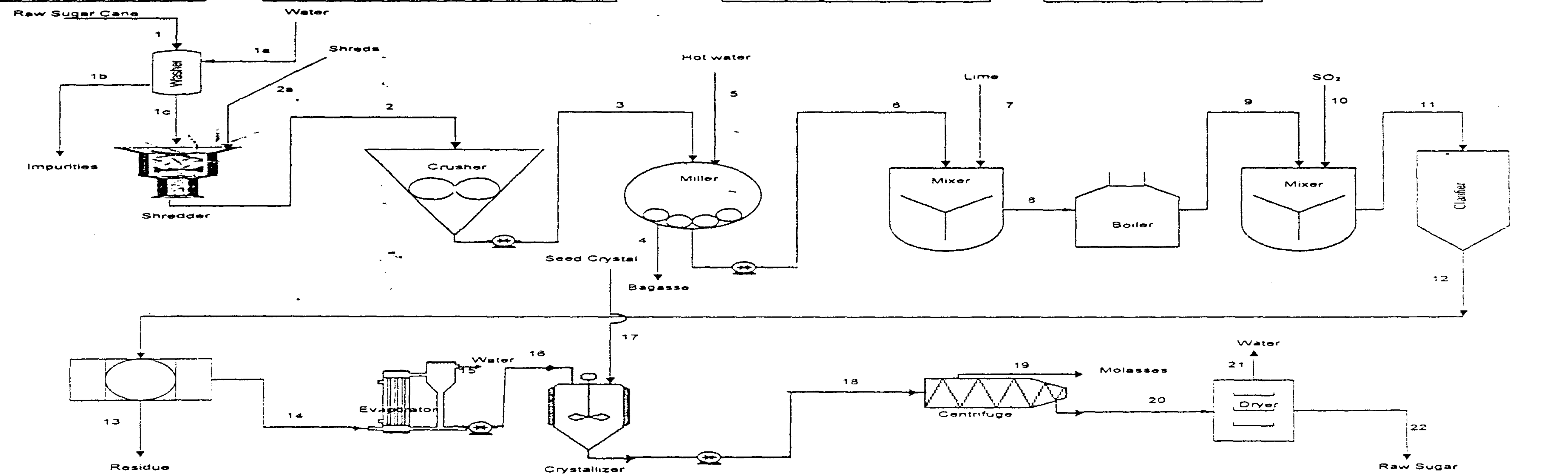
Heat load: $\Delta H_{13} := \Delta H_{out} - \Delta H_{in}$

$$\Delta H_{13} = 8.312 \times 10^4 \frac{kJ}{day}$$

5.0 FLOW SHEET/DIAGRAM

5.1 FLOWSHEETING

GROUP G PLANT DESIGN	Title: Sugar Production Client: Chemical Engineering Department, FUT, Minna	Drawn By: Group G Members Checked By: Emgr. Abubakar Garba Isah	Date: 19th November, 2006



Flow No.	1	1a	1b	1c	2a	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Component	Flows (kg/day)																									
Water	6052.37	864.62	778.16	6138.83	0.00	6138.83	6138.83	0.00	1223.01	7361.84	0.00	7361.84	7361.84	0.00	7361.84	7361.84	0.00	7361.84	6257.57	1104.28	0.00	938.64	0.00	938.64	938.64	0.00
Saccharose	1149.95	0.00	0.00	1149.95	0.00	1149.95	1149.95	0.00	0.00	1149.95	0.00	1149.95	1149.95	0.00	1149.95	1149.95	0.00	1149.95	0.00	1149.95	22.54	1000.00	0.00	1000.00	0.00	1000.00
Impurities	233.45	0.00	233.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shreds	345.85	0.00	0.00	345.85	345.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bagasse	864.62	0.00	0.00	864.62	0.00	864.62	864.62	786.81	0.00	77.82	0.00	77.82	77.32	0.00	77.82	77.82	77.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	257.69	257.69	257.69	0.00	257.69	257.69	257.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	132.71	132.71	132.71	132.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Residue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Molasses	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	338.13	0.00	0.00	0.00
Total	8646.24	864.62	1011.61	8499.26	345.85	8153.41	8153.41	786.81	1223.01	8589.61	257.69	8847.30	8847.30	132.71	8980.01	8980.01	468.21	8511.79	6257.57	2254.23	22.54	1938.64	338.13	1938.64	938.64	1000

CHAPTER SEVEN

7.1 EQUIPMENT OPTIMIZATION

The optimisation of the equipment means the ways of maximising the performance of the equipment. Equipment optimisation was achieved by the method of heat integration.

In an attempt to reduce the utility costs, that is, to optimize the performance of the equipments, engineers try to find a way of increasing the output from the various equipments and the available raw materials. The recycling process, in the case of material balance, and, in energy balance, can achieve this; this can be carried out by what is called heat integration.

Heat integration is done to the entire process to determine the net amount of heat to supply to or remove the system. The concept of heat integration examines the possibility of utilizing the heat from one part of the process and applying it to another part of the system so that one does not always look to utilities to supply the energy.

CHAPTER EIGHT

8.0 SAFETY AND QUALITY CONTROL

8.1 Safety

Safety is an area of engineering and public health that deals with the protection of workers' health, through control of the work environment to reduce or eliminate hazards. Industrial accidents and unsafe working conditions can result in temporary or permanent injury, illness, or even death. They also take a toll in reduced efficiency and loss of productivity. (Encarta, 2004)

8.1.1 General Safety Rules

Follow relevant instructions

a) Before attempting to operate the plant, all relevant manufacturers' instructions and local regulations should be understood and implemented.

b) It is irresponsible and dangerous to misuse equipment or ignore instructions, regulations or warnings.

c) The specified maximum operating conditions must not be exceeded. (Odigure, 1998)

Operation

a) It must be ensured that all staff must be fully aware of the potential hazards when the plant is being operated.

b) Serious injury can result from touching apparently stationary equipment or rotating belt.

c) No metallic object should be allowed into the plant. Otherwise, the gear motor of the affected conveyor must be set in the reverse direction and the entrained materials should be discharged. (Odigure, 1998)

Maintenance

a) A badly maintained plant is a potential hazard. It must be ensured that competent members of staff is responsible for organizing maintenance and repairs on a planned basis.

b) Faulty equipment must be permitted to be operated. Repairs must be carried out competently and the operation must be checked. (Odigure, 1998)

Using electricity

a) At least once a month, the electrical cables should be checked to ensure that they are operating normally.

b) Electricity is the commonest cause of accidents in the factory, it must be respected.

c) It must be ensured that electricity supply has been disconnected from the equipment before attempting repairs or adjustment.

d) It must be known that water and electricity are not compatible and can cause serious injury if they come into contact.

e) The plant must always be disconnected from electricity when not in use. (Odigure, 1998)

Avoiding fire or explosion

a) It must be ensured that the factory is provided with adequate fire extinguishers appropriate to the potential dangers.

b) It must be known that empty vessels having inflammable liquids can contain vapours and explode if ignited.

Handling poisons or toxic materials

a) Food must not be allowed to be brought into or consumed in the factory.

b) Smoking should not be allowed in the factory premises. Notices should be so displayed and enforced. (Odigure, 1998)

Avoiding cuts and burns

a) Care must be taken when handling sharp edged components. Undue force must not be exerted on glass or fragile items.

b) Hot surfaces cannot, in most cases, be totally shielded and can produce severe burns even when not "visibly hot". Common sense must be used always!

Eye protection

a) Facilities for eye irritation should always be available

Ear protection

a) Ear protectors must be worn when operating the plant.

Guard and safety devices

a) Guards and safety devices must be installed on the plant to protect the operators. The equipment must not be operated with such devices removed.

b) Safety gauges, cut-out and other safety devices must be set to protect the equipment. Interference with these devices may create a potential hazard.

c) It is impossible to guard the operator against all contingencies. Common sense musc be used.

d) Before starting a machine, it must be ensured that the members of staff are aware of how it (the machine) should be stopped in an emergency. (Odigure, 1998)

First aid

a) It is essential that first aid equipment is available and that the supervisor knows how to use it.

b) A notice giving details of a proficient first aider should be prominently displayed. (Odigure, 1998)

8.2 Quality Control

Quality simply means "fitness for use". But, according to the International Standard Organisation (ISO), quality is defined as the totality of the characteristics of an entity that bear on its ability to satisfy stated and intended needs. It is more costly to exceed a specification than to meet it. Therefore, there is the need to get quality goal or target for effective quality control.

Maintaining product quality in accordance with acceptable standard has been a major role for industrial instrumentation since its inception decades ago. With the ever-increasing interest in speeding up production, one becomes aware of the fact that rejectable as well as acceptable products can be produced at high rates.

8.2.1 Quality assurance

Quality assurance is defined by ISO as all the planned and systematic activities implemented within the quality system and demonstration is needed to provide adequate confidence on entity will fulfil requirement for quality.

8.2.1.1 Principles of quality assurance

The principles of quality assurance include the following:

i. Management involvements and objective (management) involvement is very essential to ensure quality.
ii. Programming and planning.
iii. Application of quality control principles.
iv. Design and specification control.
v. Purchasing control and vendor appraisal.
vi. Production control.
vii. Marketing and service quality functions.
viii. Proper documentation.
ix. Non-conformance control.
x. Remedial action.
xi. Defect and failure analysis.

8.2.1.2 Quality management

Quality management involves all activities of the overall management functions that determine the quality policy, objective and responsibilities and implement then by means, such as quality planning control assurance and improvement within the quality system. Responsibility of quality lies at all level of all. To successfully implement quality management, the organisation structure, procedure process and resources are requisite.

CHAPTER NINE

9.0 PROCESS CONTROL AND INSTRUMENTATION

It is proposed that most of the plant equipments in this plant are to be operated using automatic control with the indicating instruments being located in a control room. This is the general practice for a plant of this type which is not labour intensive. With the exception of the reactor system, the plant operates at atmospheric pressure and therefore the process control and instrumentation will be based upon temperature, flow and level measurements. Measurements of these parameters will be made using thermocouples, orifice plates and float type indicators respectively. (Austin & Jeffrey, 1991)

9.1 Types of control instruments

The control instruments are of four major categories

a) Temperature controllers (TC)

b) Pressure controller (PC)

c) Flow controller (FC)

d) Level controller (LC)

9.2 Control Mechanism

The pneumatic control hardware is recommended for this process it will be powered by instrument air supplies.

The control mechanism for this process consist of a sensor to detect the process variables; a transmitter to convert the sensor into an equivalent "signal" a controller that compares this process signal with a desired set point value and produces an appropriate controller output signal and a final control element (pneumatic activator) tat changes the manipulated variable with the use of a mechanical action.

9.3 Control Sensors

The devices to be used for the on-line measurement of the process variables are:

1) Flow sensor: The orifice meter can be employed in the process since it is simple and of low cost.

2) Temperature sensor: The recommended temperature sensors are resistance thermometer detectors (RTDS) and Thermocouples. The 100v pt (-2000C to 850C) and type N (0-13000) are both sufficient for RTDS and thermocouples respectively.

3) Pressure sensors: Bourdon – Tube pressure gauge can be used.

4) Level sensor: float activated devices are sufficient.

Alarms are to be employed to alert the process operator to a process that requires immediate action and attention. Instead of individually issuing point alarms, all alarms associated with a certain aspect of the process are to be simply wired to give a single trouble alarm.

9.4 Transmitters, Controllers and Control Valves

The transmitter is the inter-phase between the process and it's control system. The transmitter converts the sensors signal into a control signal. The pilot – acting controllers should be employed in the process. The pilot – acting controllers are capable of greater degree of sensitivity since they eliminate of the lags which would be inherent in sel – acting mechanism activated by the force of a large volume of fluid. The fluid control element is an automatic control which throttles the flow of the manipulated variable.

CHAPTER TEN

10.0 ENVIRONMENTAL ACCEPTABILITY

Any new project or technology involving hazardous materials requires a rational approach of assessing the suitability and acceptability to the environment and man .

Various legislations govern the emission of pollutants into the environment. The environmental friendliness of the process choice adopted from the design process is of utmost importance to the relevant government agencies responsible for environmental protection. Awareness of the relevant federal regulations is an essential component of a legally acceptable plant design .

10.1 Identification of All Possible Pollutants

Particulate matter (PM), combustion products, and volatile organic compounds (VOC) are the primary pollutants emitted from the sugarcane processing industry. Combustion products include nitrogen oxides (NO_x), carbon monoxide (CO), CO_2, and sulfur oxides (SO_x). Potential emission sources include the sugar granulators, sugar conveying and packaging equipment, bulk load out operations, boilers, granular carbon and char regeneration kilns, regenerated adsorbent transport systems, lime kilns and handling equipment (at some facilities), carbonation tanks, multi-effect evaporator stations, and vacuum boiling pans.

Potential sources of PM emissions include the granular carbon and char regeneration kilns, regenerated adsorbent transporting systems, sugar granulators, granulated sugar transport systems, and sugar packaging operations. The multi-effect evaporators and vacuum boiling pans are a potential source of VOC emissions from the juice. However, only the first three of five evaporators (in a typical five-stage evaporator) release exhaust gases and the gases are used as a heat source for various process heaters before release to the atmosphere. Emissions from the carbonation tanks are primarily water vapor but may contain small quantities of VOC and may also include CO_2 and other combustion gases from the boilers (Chen and Chou, 1993).

10.2 Suggestions on the Treatment of the Pollutants

The exhaust from granulators typically is vented to cyclones to remove large PM and is then passed through a wet cyclone system (e. g., Rotoclone) to remove smaller particles. Fabric filters are sometimes used to control PM emissions from sugar handling operations and from fluidized bed drying and cooling systems. Particulate matter emissions from boilers typically are controlled with cyclones. Wet scrubbers are sometimes used as primary or secondary control devices for boilers. Some natural gas-fired boilers are not equipped with controls. Emissions from the carbonation tanks, evaporators, and vacuum boiling typically are not controlled (Chen and Chou, 1993).

CHAPTER ELEVEN

11.0 START UP AND SHUT DOWN PROCEDURE

Start up time may be defined as the time span between end of construction and the beginning of normal operations. Start up and shut down procedure must proceed safely and be flexible enough to be carried out in various ways. In other words, the start up and shut down of the plant should be such that it can be easily and safely operated. The operating limits of the plant should not be exceeded and dangerous mixtures must not be formed as a result of abnormal states of concentration, composition, temperature, phase, pressure, reactants and products.

It should be noted that some items of actions must be completed before even the start up of the plant in order to prepare the plant for the start up operation. The items of actions are:

i. All scaffolds and temporary piping and supports should be removed.

ii. Lines and equipment should be flushed out.

iii. Pumps, motors/turbines and compressors should be run.

iv. Hydrostatic or pneumatic lines and equipment should be tested.

v. Laboratory and sampling schedule should be prepared.

vi. All instruments should be inspected and tested.

11.1 Start Up Procedures

For the plant designed, the following are the start up procedures:

i. The heat exchanger should be started up using auxiliary fuel to begin steam production.

ii. The reactors should be heated up and maintained at their operating temperatures and pressures.

iii. The inlet and outlet valves of the reactors should be opened up.

iv. The compressor valve to supply air at a regulated pressure should be opened.

v. All the inlet and outlet valves to the reactor should be shut as soon as the feed enters the reactor in order to achieve maximum conversion.

vi. The outlet value of the reactor should be opened for the evacuation of the reactor contents.

vii. The outlet valve of the reactor should be locked before opening the inlet valve before further entering of the feed into the reactor.

11.2 Shut Down Procedures

The shut down procedures for the plant are as outlined below

i. The supply of sugar cane into the washer should be stopped

ii. The supply of the steam to the heat exchanger should be cut off.

iii. The hot water supply into the miller should also be terminated.

iv. All the purge valves should be opened to discharge unconverted reactants

CHAPTER TWELVE

12.0 SITE FOR PLANT LOCATION

The location of the plant can have a crucial effect on the profitability of the sugar production project and the scope for future expansion. Many factors must be considered when selecting a suitable site, and they are as outlined below:

i. Location, with respect to the marketing area.

ii. Raw materials supply.

iii. Transport facilities.

iv. Availability of labour.

v. Availability of utilities.

vi. Availability of suitable land.

vii. Environmental impact and effluent disposal.

viii. Local community considerations.

ix. Climate.

x. Political and strategic considerations.

12.1 Factors Considered for Site and Plant Location

The factors considered for site and plant location are as described thus.

12.1.1 Location, with respect to the marketing area

For a material produced in bulk quantities such as the sugar where the cost of the product per tonne is relatively low and the cost of transport is a significant fraction of the sales price, the plant should be located close to the primary market.

12.1.2 Raw materials

The availability and price of suitable raw materials will often determine the site location. Plants producing material such as the sugar plant are best located close to the source of the major raw materials where this is also close to the marketing area.

12.1.3 Transport

The transport of materials and products to and from the plant will be an overriding consideration for site selection.

If practicable, a site should be selected that is close to at least two major forms of transport: road, rail, waterway (canal or river), or a sea port. Road transport is being increasingly used, and is suitable for local distribution from a central warehouse. Rail transport will be cheaper for the long-distance transport of bulk chemicals.

Air transport is convenient and efficient for the movement of personnel and essential equipment and supplies, and the proximity of the site to a major airport should be considered.

12.1.4 Availability of labour

Labour will be needed for construction of the plant and its operation. Skilled construction workers will usually be brought in from outside the site area, but there should be an adequate pool of unskilled labour available locally; and labour suitable for training to operate the plant. Skilled tradesmen will be needed for plant maintenance. Local trade union customs and restrictive practices will have to be considered when assessing the availability and suitability of the local labour for recruitment and training.

12.1.5 Utilities (Services)

Chemical processes invariably require large quantities of water for cooling and general process use, and the plant must be located near a source of water of suitable quality. Process water may be drawn from a river, from wells, or purchased from a local authority.

At some sites, the cooling water required can be taken from a river or lake, or from the sea; at other locations cooling towers will be needed. Electrical power will be needed at all sites.

12.1.6 Environmental impact and effluent disposal

All industrial processes produce waste products, and full consideration must be given to the difficulties and coat of their disposal. The disposal of toxic and harmful effluents will be covered by local regulations, and the appropriate authorities must be consulted during the initial site survey to determine the standards that must be met.

12.1.7 Local community considerations

The proposed plant must be fit in with and be acceptable to the local community. Full consideration must be given to the safe location of the plant so that it does not impose a significant additional risk to the community..

On a new site, the local community must be able to provide adequate facilities for the plant personnel: schools, banks, housing, and recreational and cultural facilities.

12.1.8 Availability of suitable land

Sufficient suitable land must be available for the proposed plant and for future expansion. The land should be ideally flat, well drained and have suitable load bearing capacity. A full site evaluation should be made to determine the need for pining or other special foundations. It should also be available at low cost.

12.1.9 Climate

Adverse climatic conditions at a site will increase costs. Abnormally low temperatures will require the provision of additional insulation & special heating for equipment & pipe runs. Stronger structures will be needed at locations subject to high winds or earthquakes.

12.1.10 Political and strategic consideration

Capital grants, tax concessions and other incentives provided by governments to direct new investment to preferred locations, such as areas of high un-employment should be the overriding considerations in the site selection.

12.2 Selection of Site

Careful consideration of the factors for the site selection outlined above reveals that the best site for this project is the Minna, Niger State, Nigeria

12.3 Justification of the Selected Site

Actually, the site selected based on the fact that it satisfied more than 75% of the factors considered. For instance, it is close to the source of raw materials apart from the fact that there is market for the product (sugar) there.

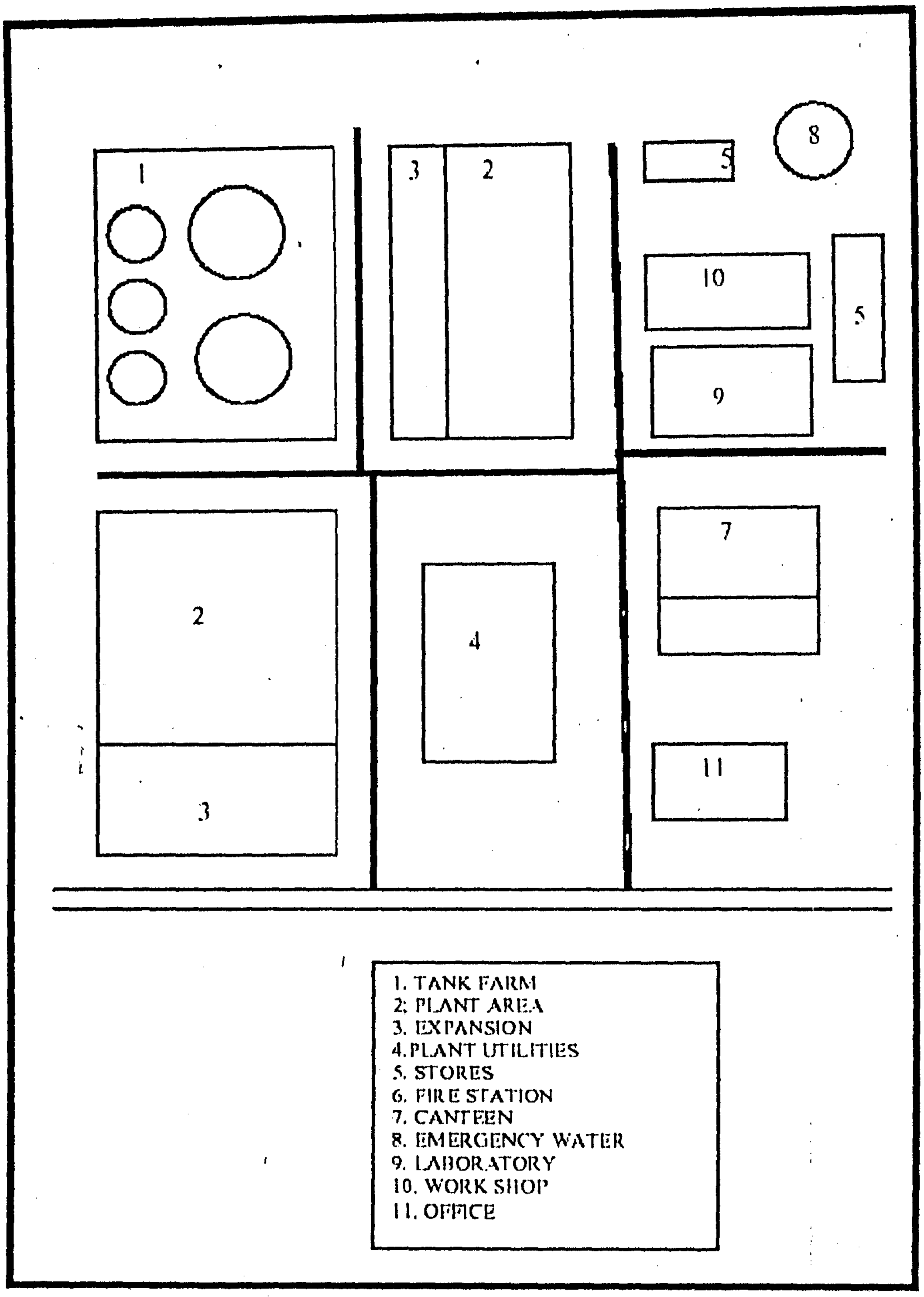


Fig. 12.1: Plant layout

CHAPTER THIRTEEN

13.0 ECONOMIC ANALYSIS

13.1 Purchased Equipment Cost

13.1.1 Purchased equipment cost of washer

Given that,

$M\_S := 1100 \quad F_m := 1.00 \quad F_p := 1.00 \quad F_c := F_m \cdot F_p$

$$PC_{washer} := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{D_{washer}}{ft}\right)^{1.066} \cdot \left(\frac{H_{washer}}{ft}\right)^{0.802} \cdot F_c\right] \cdot er \cdot Naira$$

$PC_{washer} = 2.786 \times 10^6 \, Naira$

13.1.2 Purchased equipment cost of shredder

Given that,

$M\_S := 1100 \quad F_m := 1.00 \quad F_p := 1.00 \quad F_c := F_m \cdot F_p$

$$PC_{shredder} := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{D_{shredder}}{ft}\right)^{1.066} \cdot \left(\frac{H_{shredder}}{ft}\right)^{0.802} \cdot F_c\right] \cdot er \cdot Naira$$

$PC_{shredder} = 2.62 \times 10^6 \, Naira$

13.1.3 Purchased equipment cost of crusher

Given that,

$M\_S := 1100 \quad F_m := 1.00 \quad F_p := 1.00 \quad F_c := F_m \cdot F_p$

$$PC_{crusher} := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{d_{crusher}}{ft}\right)^{1.066} \cdot \left(\frac{h_{crusher}}{ft}\right)^{0.802} \cdot F_c\right] \cdot er \cdot Naira$$

$PC_{crusher} = 2.532 \times 10^6 \, Naira$

13.1.4 Purchased equipment cost of miller

Given that,

$M\_S := 1100 \quad F_m := 1.00 \quad F_p := 1.00 \quad F_c := F_m \cdot F_p$

$$PC_{miller} := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{D_{miller}}{ft}\right)^{1.066} \cdot \left(\frac{H_{miller}}{ft}\right)^{0.802} \cdot F_c\right] \cdot er \cdot Naira$$

$PC_{miller} = 2.48 \times 10^6 \, Naira$

13.1.5 Purchased equipment cost of mixer 1

Given that,

$M\_S := 1100 \qquad F_m := 1.00 \qquad F_p := 1.00 \qquad F_c := F_m \cdot F_p$

$$PC_{mixer\_1} := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{d_{mixer\_1}}{ft}\right)^{1.066} \cdot \left(\frac{h_{mixer\_1}}{ft}\right)^{0.802} \cdot F_c\right] \cdot er \cdot Naira$$

$PC_{mixer\_1} = 5.355 \times 10^6 Naira$

13.1.6 Purchased equipment cost of boiler

Given that,

$M\_S := 1100 \qquad F_m := 0.00 \qquad F_p := 0.00 \qquad F_c := 1.00 + F_m + F_p$

$$PC_{boiler} := \left(\frac{M\_S}{280}\right) \cdot \left[5520 \cdot \left[\frac{|Q_{boiler}|}{\left(10^6 \cdot \frac{BTU}{hr}\right)}\right]^{0.83} \cdot F_c\right] \cdot er \cdot Naira$$

$PC_{boiler} = 1.426 \times 10^{11} Naira$

13.1.7 Purchased equipment cost of mixer 2

Given that,

$M\_S := 1100 \qquad F_m := 1.00 \qquad F_p := 1.00 \qquad F_c := F_m \cdot F_p$

$$PC_{mixer\_2} := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{d_{mixer\_2}}{ft}\right)^{1.066} \cdot \left(\frac{h_{mixer\_2}}{ft}\right)^{0.802} \cdot F_c\right] \cdot er \cdot Naira$$

$PC_{mixer\_2} = 5.355 \times 10^6 Naira$

13.1.8 Purchased equipment cost of clarifier

Given that,

$M\_S := 1100 \qquad F_m := 1.00 \qquad F_p := 1.00 \qquad F_c := F_m \cdot F_p$

$$PC_{clarifier} := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{D_{clarifier}}{ft}\right)^{1.066} \cdot \left(\frac{H_{clarifier}}{ft}\right)^{0.802} \cdot F_c\right] \cdot er \cdot Naira$$

$$PC_{clarifier} = 2.781 \times 10^{6}\,Naira$$

13.1.9 Purchased equipment cost of filter

Given that,

$M\_S := 1100 \qquad F_m := 1.00 \qquad F_p := 1.00 \qquad F_c := F_m \cdot F_p$

$$PC_{filter} := \left(\frac{M\_S}{280}\right) \cdot \left[101.3 \cdot \left(\frac{A_{filter}}{ft^2}\right)^{0.65} \cdot F_c\right] \cdot er \cdot Naira$$

$$PC_{filter} = 1.104 \times 10^{6}\,Naira$$

13.1.10 Purchased equipment cost of evaporator

Given that,

$M\_S := 1100 \qquad F_m := 0.00 \qquad F_p := 0.00 \qquad F_c := 1.00 + F_m + F_p$

$$PC_{evaporator} := \left(\frac{M\_S}{280}\right) \cdot \left[5520 \cdot \left[\frac{Q_{evaporator}}{\left(10^6 \cdot \frac{BTU}{hr}\right)}\right]^{0.83} \cdot F_c\right] \cdot er \cdot Naira$$

$$PC_{evaporator} = 2.207 \times 10^{11}\,Naira$$

13.1.11 Purchased equipment cost of crystallizer

Given that,

$M\_S := 1100 \qquad F_m := 1.00 \qquad F_p := 1.00 \qquad F_c := F_m \cdot F_p$

$$PC_{crystallizer} := \left(\frac{M\_S}{280}\right) \cdot \left[101.3 \cdot \left(\frac{A_{crystallizer}}{ft^2}\right)^{0.65} \cdot F_c\right] \cdot er \cdot Naira$$

$$PC_{crystallizer} = 1.357 \times 10^{10}\,Naira$$

13.1.12 Purchase cost of centrifuge

For this unit,

$C_{centfiuge} := 58000 \qquad S_{centrifuge} := \frac{D_{centrifuge}}{m} \qquad n_{centrifuge} := 1.3$

$$PC_{centrifuge} := C_{centfiuge} \cdot S_{centrifuge}^{n_{centrifuge}} \cdot er \cdot Naira$$

$$PC_{centrifuge} = 9.373 \times 10^{6} Naira$$

13.1.13 Purchased equipment cost of dryer

Given that,

$M\_S := 1100 \quad F_m := 1.00 \quad F_p := 1.00 \quad F_c := F_m \cdot F_p$

$$PC_{dryer} := \left(\frac{M\_S}{280}\right) \cdot \left[101.3 \cdot \left(\frac{A_{dryer}}{ft^2}\right)^{0.65} \cdot F_c\right] \cdot er \cdot Naira$$

$$PC_{dryer} = 2.178 \times 10^{4} Naira$$

Total purchase cost of equipment:

$$PC_{total} := \left(PC_{washer} + PC_{shredder} + PC_{crusher} + PC_{miller} + PC_{mixer\_1} + PC_{boiler} + PC_{mixer\_2}\right) \dots + PC_{clarifier} + PC_{filter} + PC_{evaporator} + PC_{crystallizer} + PC_{centrifuge} + PC_{dryer}$$

$$PC_{total} = 3.769 \times 10^{11} Naira$$

Estimation of Total Capital Investment

I. Direct Costs

A. Equipment + installation + instrumentation + piping + electrical + insulation + painting

1. **Purchased equipment cost (PEC),** 15-40% of fixed capital investment

As calculated, $PEC := PC_{total}$ $\quad PEC = 3.769 \times 10^{11} Naira$

2. **Installation, including insulation and painting,** 25-55% of purchased equipment cost

Assuming $Insta := 40\% \cdot PEC$ $\quad Insta = 1.508 \times 10^{11} Naira$

3. **Instrumentation and controls, installed,** 6-30% of purchased equipment cost

Assume $Instr := 11\% \cdot PEC$ $\quad Instr = 4.146 \times 10^{10} Naira$

4. **Piping installed,** 10-80% of purchased equipment cost

Assume $Pip := 30\% \cdot PEC$ $\quad Pip = 1.131 \times 10^{11} Naira$

5. Electrical, installed, 10-40% of purchased equipment cost

Assume $Elect := 15\% \cdot PEC$ $Elect = 5.654 \times 10^{10}$ Naira

So, the cost of equipment, installation, instrumentation, piping, electrical, insulation and painting is given as

$CA := PEC + Insta + Instr + Pip + Elect$ $CA = 7.388 \times 10^{11}$ Naira

B. Buildings, process and auxiliary, 10-70% of purchased equipment cost

Assume $Build := 20\% \cdot PEC$ $Build = 7.538 \times 10^{10}$ Naira

C. Service facilities and yard improvements, 40-100% of purchased equipment cost

Assuming $Servi := 50\% \cdot PEC$ $Servi = 1.885 \times 10^{11}$ Naira

D. Land, 1-2% of fixed capital investment or 4-8% of purchased equipment cost)

Assuming $Lan := 5\% \cdot PEC$ $Lan = 1.885 \times 10^{10}$ Naira

Thus, the direct cost is equal to

$Direct\_Cost := CA + Build + Servi + Lan$ $Direct\_Cost = 1.021 \times 10^{12}$ Naira

II. Indirect costs: expenses which are not directly involved with material and labour of

actual installation of complete facility (15-30% of fixed capital investment)

A. Engineering and supervision, 5-30% of direct cost

Assuming $Engin := 13\% \cdot Direct\_Cost$ $Engin = 1.328 \times 10^{11}$ Naira

B. Construction expense and contractor's fee, 6-30% of direct cost

Assuming $Const := 15\% \cdot Direct\_Cost$ $Const = 1.532 \times 10^{11}$ Naira

C. Contingency, 5-15% of direct cost

Assuming $Conti := 7\% \cdot Direct\_Cost$ $Conti = 7.15 \times 10^{10}$ Naira

Thus, indirect cost is equal to

$Indirect\_Cost := Engin + Const + Conti$ $Indirect\_Cost = 3.575 \times 10^{11}$ Naira

III. Fixed Capital Investment:

Fixed capital investment = Direct cost + Indirect cost

$$Fixed\_CI := Direct\_Cost + Indirect\_Cost \qquad Fixed\_CI = 1.379 \times 10^{12}\,Naira$$

IV. Working Capital, 11-20% of fixed capital investment

Assuming $Working\_C := 11\% \cdot Fixed\_CI \qquad Working\_C = 1.517 \times 10^{11}\,Naira$

13.1 V. Total Capital Investment (TCI):

Total capital investment to be Fixed capital investment + Working capital

Assuming $TCI := Fixed\_CI + Working\_C \qquad TCI = 1.531 \times 10^{12}\,Naira$

Estimation of Total Product Cost:

I. Manufacturing Cost = Direct production cost + Fixed charges + Plant overhead cost

A. Fixed Charges, 10-20% of total product cost)

i. Depreciation, This depends on life period, salvage value and method of calculation

- about 13% of FCI for machinery and equiupment and 2-3% of building value for

buildings Assuming $Depre := 10\% \cdot Fixed\_CI + 3\% \cdot Build \qquad Depre = 1.402 \times 10^{11}\,Naira$

ii. Local Taxes, 1-4% of fixed capital investment

Assuming $Tax := 3.5\% \cdot Fixed\_CI \qquad Tax = 4.826 \times 10^{10}\,Naira$

iii. Insurance, 0.4-1% of fixed capital investment)

Assuming $Insur := 0.6\% \cdot Fixed\_CI \qquad Insur = 8.274 \times 10^{9}\,Naira$

iv. Rent, 8-12% of value of fixed capital investment

Assuming $Ren := 10\% \cdot Fixed\_CI \qquad Ren = 1.379 \times 10^{11}\,Naira$

Thus, fixed charges is given as

$$Fixed\_Charges := Depre + Tax + Insur + Ren \qquad Fixed\_Charges = 3.346 \times 10^{11}\,Naira$$

13.2 B. Direct Production Cost (Operating Cost):

Fixed charges is 10-20% of total product cost

Assuming $Fixed\_Charges = 15\% \cdot TPC$

making total product cost, TPC, the subject of the formula,

$$TPC = \frac{FC}{15\%}$$

$$TPC := \frac{Fixed\_Charges}{15\%}$$ $$TPC = 2.231 \times 10^{12} Naira$$

i. **Raw materials,** 10-50% of total product cost)

Assuming

$Raw\_mat := 15\% \cdot TPC$

$Raw\_mat = 3.346 \times 10^{11} Naira$

ii. **Operating Labour (OL),** 10-20% of total product cost

Assuming $OperL := 10\% \cdot TPC$ $OperL = 2.231 \times 10^{11} Naira$

iii. **Direct Supervisory and Clerical Labour (DS & CL),** 10-25% of OL

Assuming $DireS := 15\% \cdot OperL$

$DireS = 3.346 \times 10^{10} Naira$

iv. **Utilities,** 10-20% of total product cost

Assuming $Util := 12.5\% \cdot TPC$ $Util = 2.788 \times 10^{11} Naira$

v. **Maintenance and repairs (M & R),** 2-10% of fixed capital investment

Assuming $Maint := 3.7\% \cdot Fixed\_CI$ $Maint = 5.102 \times 10^{10} Naira$

vi. **Operating Supplies,** 10-20% of M & R or 0.5-1% of FCI

Assuming $OperS := 17\% \cdot Maint$ $OperS = 8.674 \times 10^{9} Naira$

vii. **Laboratory Charges,** 10-20% of OL

Assuming $Lab := 15\% \cdot OperS$ $Lab = 1.301 \times 10^{9} Naira$

viii. **Patent and Royalties,** 0-6% of total product cost

Assuming $Paten := 4.5\% \cdot TPC$ $Paten = 1.004 \times 10^{11} Naira$

Thus, direct production cost is

$$DPC := Raw\_mat + OperL + DireS + Util + Maint + OperS + Lab + Paten$$

$$DPC = 1.031 \times 10^{12} Naira$$

C. **Plant Overhead Costs,** 50-70% of operating labour, supervision, and maintenance or

5-15% of total product cost); includes for the following: general plant upkeep and overhead,

payroll overhead, packaging, medical services, safety and protection, restaurants, salvage,

laboratories, and storage facilities.

Considering the plant overhead cost to be 55% of OL, DS & CL and M & R

Therefore,

$$Plant\_Overhead := 55\% \cdot (OperL + DireS + Maint)$$

$$Plant\_Overhead = 1.691 \times 10^{11} \text{Naira}$$

Manufacture cost = Direct production cost + Fixed charges + Plant overhead cost

$$Manuf := DPC + Fixed\_Charges + Plant\_Overhead \qquad Manuf = 1.535 \times 10^{12} \text{Naira}$$

II. General Expenses = Administrative costs + distribution and selling costs + research

and development costs

A. **Administrative costs,** 2-6% of total product cost

Assuming $Admin := 3\% \cdot TPC$ $\qquad Admin = 6.692 \times 10^{10} \text{Naira}$

B. **Distribution and Selling Costs,** 2-20% of total product cost; includes costs for

sales offices, salesmen, shipping, and advertising.

Assuming $Distr := 11\% \cdot TPC$ $\qquad Distr = 2.454 \times 10^{11} \text{Naira}$

C. **Research and Development Costs,** about 5% of total product cost

Assuming $Resea := 5\% \cdot TPC$

$$Resea = 1.115 \times 10^{11} \text{Naira}$$

D. **Financing (Interest),** 0 - 10% of total capital investment

Assuming $Interest := 5\% \cdot TCI$ $\qquad Interest = 7.653 \times 10^{10} \text{Naira}$

Thus, general expenses,

$$Gener := Admin + Distr + Resea + Interest \qquad Gener = 5.003 \times 10^{11} \text{Naira}$$

III. Total Product Cost = Manufacture Cost + General Expenses

$$TProdC := Manuf + Gener$$

$$TProdC = 2.035 \times 10^{12} \text{Naira}$$

13.3 V. Gross Earnings/Income (Revenue Expectations):

The selling price of the product is

$$Selling\_price := 350 \cdot \frac{Naira}{kg}$$

$$Quantity\_Produced := 22000000.00 \cdot \frac{kg}{day}$$

Assuming that the attainment is $Attainment := 331 \cdot day$

Total income = Selling price x quantity of product manufactured

Assume $Total\_income := Selling\_price \cdot Quantity\_Produced \cdot Attainment$

$$Total\_income = 2.549 \times 10^{12} Naira$$

Gross income = Total income - Total Product Cost

That is, $Gross\_income := Total\_income - TPC$

$$Gross\_income = 3.181 \times 10^{11} Naira$$

Tax rate, $Tax\_rate := 1\%$

$Taxes := Tax\_rate \cdot Gross\_income$ $\qquad Taxes = 3.181 \times 10^{9} Naira$

Net profit = Gross income - Taxes

$Net\_profit := Gross\_income - Taxes$

$$Net\_profit = 3.149 \times 10^{11} Naira$$

Calculation of Rate of Return:

$$Rate\_of\_return = \frac{Net\_profit}{Total\_CI} \cdot 100$$

Therefore,

$$Rate\_of\_return := \frac{Net\_profit}{TCI} \cdot 100\% \qquad Rate\_of\_return = 20.576\%$$

13.4 Cash Flow

Cash flow is the difference between the amount earned and the amount expended.

$Cash\_Flow := Total\_income - TProdC$ $\qquad Cash\_Flow = 5.133 \times 10^{11} Naira$

13.5 Pay-Back Period

The pay-back period is calculated as the reciprocal of the rate of return.

Therefore,

$$Pay\_back\_period := \frac{1}{Rate\_of\_return} \cdot yr \qquad Pay\_back\_period = 4.86\,yr$$

13.6 Discounted Cash Flow Rate or Return

The discounted cash flow is the interest rate that will make the condition given as

$$DCF = \sum_{i=1}^{n} \frac{Cash\_Flow}{(1+r)^n} = 0$$

Using trial-and-error calculations as suggested by Sinnot R. K. (Coulson and Richardson's

Chemical Engineering, 3rd Edition, pg 277,

$$r := 53 \cdot \% \qquad n := 61 \qquad DCFRR := r$$

$$DCF := \sum_{i=1}^{n} \frac{Cash\_Flow}{(1+r)^n} \qquad DCF = 170$$

Therefore, the Discounted Cash Flow Rate of Return (DCFRR) is equal to $DCFRR = 53\%$.

13.7 Return on Investment

This is calculated as given thus.

Return on investment (ROI) is given by the expression,

$$ROI = \frac{Total\_profit\_less\_depreciation}{Total\_investment}$$

That is,

$$ROI := \frac{Total\_income - Depre}{Total\_income} \cdot 100\% \qquad ROI = 94.501\,\%$$

13.4 Cash Flow

Cash flow is the difference between the amount earned and the amount expended.

$Cash\_Flow := |Total\_income - TProdC|$

$Cash\_Flow = 3.219\times 10^{7}$ Naira

13.5 Pay-Back Period

The pay-back period is calculated as the reciprocal of the rate of return.

Therefore,

$$Pay\_back\_period := \frac{1}{Rate\_of\_return} \cdot yr$$

$Pay\_back\_period = 4.1yr$

13.6 Discounted Cash Flow Rate or Return

The discounted cash flow is the interest rate that will make the condition given as

$$DCF = \sum_{i=1}^{n} \frac{Cash\_Flow}{(1+r)^{n}} = 0$$

Using trial-and-error calculations as suggested by Sinnot R. K. (Coulson and

Richardson's

Chemical Engineering, 3rd Edition, pg 277,

$r := 53 \cdot \%$

$n := 61$

$DCFRR := r$

CHAPTER FOURTEEN

14.0 RECOMMENDATIONS TO THE INDUSTRIALIST

14.1 General Recommendations

Based on the design work carried out, the following recommendations are made to the industrialists to be noted during the construction, start-up and operating phases of the work:

i. The safety of workers, equipments and infrastructures should be highly evaluated during the design implementation stage of the design.

ii. Adequate data and technological parameters should be at the possession of the plant operations at all time to forestall any unwanted accident.

iii. Routine turn around plant maintenance should be of paramount importance in the design. An articulate and organised maintenance team should safeguard quick plant shut down and ensure equipment salvage value. This will also take care of schedule, slippage, cost over-run and possible re-work.

iv. Personnel should undergo routine training about new work ethic and equipments to improve their knowledge of the plant operation and increase overall plant productivity.

v. Procurement of raw materials and equipments should be based on strict regulation of specification and maximum quality.

vi. Plant should not be operated above the design specification to avoid abnormal conditions and explosions.

vii. The implementation of this design work must be adequately supervised by the experts.

viii. The plant should be sited close to the source of raw materials.

ix. Alternative sources of energy should be available at all times to avoid plant failure and possible sources of failure.

x. The water and air around the plant should be monitored regularly to ensure compliance with the Environmental Protection Agency Standards.

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