PLANT DESIGN FOR THE PRODUCTION OF SUGAR

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JULY 2021

PLANT DESIGN FOR THE MANUFACTURE OF SUGAR

EIGHTH SEMESTER B.E. PROJECT

Submitted in partial fulfilment of

The Requirements for the Degree of

BACHELOR OF ENGINEERING

In

CHEMICAL ENGINEERING

Of

ASSAM SCIENCE AND TECHNOLOGY UNIVERSITY

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This is to certify that Angita Roy (17/377), Arushmita Das (17/288), Bhuyashi Saikia (17/260) and Parinita Kalita (17/253) of B.E 8th Semester have jointly carried out the project entitled 'PLANT DESIGN FOR THE PRODUCTION OF SUGAR' under my supervision and submitted the report in partial fulfilment of the requirement for the Degree of Bachelor of Engineering in Chemical Engineering of Assam Engineering College, Jalukbari under Assam Science and Technology University, which may be accepted.

Date: 26/07/2021

(signature)

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ACKNOWLEDGEMENT

We take this opportunity to express our sincere and heartfelt gratitude to Dr. Bandana Chakrabarty, Professor, Department of Chemical Engineering, Assam Engineering College, Guwahati for her guidance and supervision throughout our project. We are highly indebted to her for her guidance and constant supervision as well as for providing necessary information regarding the project work. Working under her has indeed been a great experience and inspiration for us. We express our gratitude towards the fraternity of the Department of Chemical Engineering of Assam Engineering College, Guwahati.

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PROJECT AT A GLANCE

1.	Title	Production of Sugar
2.	Capacity	40000 ton/yr
3.	Process adopted	Common process for manufacture of sugar
4.	Equipment used	• Miller • Storage tank • Clarifier • Multiple effect Evaporator • Vacuum pan crystalliser • High speed centrifugal basket • Melter • Affinator • Decolouriser • Rotary drum filter
5.	Designed Equipment	• Storage tank • Multiple effect Evaporator
6.	Designed Specification	• MOC of storage tank = IS: 2002, 1962, Grade 2B quality steel • Length of storage tank = 8.232 m Diameter of storage tank = 13.105 m Height of storage tank= 10.484 m • Area of multiple effect evaporator = 253.3726 m^2
7.	Utilities	Steam
8.	Raw Material	Sugarcane juice
9.	Material Balance	Input = 62.808 ton/hr Output = 62.778 ton/hr
10.	Energy Balance	Input = 18746199.68 KJ/hr Output = 22939745.39 KJ/hr

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CHAPTER-1

INTRODUCTION

The project assigned to us from the Department of Chemical Engineering is ‘Production of Sugar’. The project work is about selecting the best process for manufacturing of Sugar. The project ‘Production of Sugar’ has been carried out with a view to carry out the following activities:

- Making a literature survey of Sugar: its properties, uses and market demand
- Making a comparative study of the various processes available for industrial manufacture of Sugar and selection of the best process among them
- Designing the selected process for a given output of Sugar, carrying out material and energy balances and designing two equipments of the process.

Firstly, a literature survey on Sugar is performed. In this section, the physical and chemical properties of Sugar, its uses, market on worldwide basis and various raw materials producing Sugar are analysed. Along with this, various manufacturing method for producing Sugar are also studied. These processes are compared on the basis of raw material, amount of sucrose produced, manufacturing method, extraction rate and yield of the product. At the end of the comparison, the production of sugar is decided to be done using sugarcane as its raw material, and accordingly its flow sheet is prepared.

Complete material balance is done on each equipment, keeping in mind that there is no loss of mass during the process. Taking 40000 ton/hour of capacity of plant and 330 working days (24 hours per day), a modified balance over the whole process and each equipment is then prepared. The energy balance over the equipments were then prepared keeping in mind that there is no accumulation of energy throughout the process. Two equipments from the process are selected for designing in proper and correct manner. The first is a storage tank, with an assumption of storage of feed for 2 days and on this basis, the volume, length and diameter of tank, number of stages in tank and width of each plate are calculated. The second equipment selected for designing is a three stage effect evaporator.

CHAPTER-2

LITERATURE SURVEY

2.1 History of Sugar Production:

Sugar is mainly produced commercially by using sugarcane, sugar beet, maple syrup, dates, etc. About 80% of the world's sugar is accounted by sugarcane, while 20% is produced from sugar beet. India and Brazil is the largest producer of sugar of the world, with Brazil producing around 25% of the world's sugar.

Sugar is available naturally as sucrose, glucose and fructose (in fruits and vegetables), as lactose and galactose (in milk and dairy) and maltose (in cereals). The sugar used domestically is basically sucrose which includes glucose and fructose.

Sucrose is mainly extracted from sugar cane and sugar beet with water. The extracted sugar juice is purified, filtered and concentrated and the sucrose is crystallised, dried and cooled. The molasses are the residual dark syrupy material. The crystallised sugar is not chemically altered or bleached. White sugar is available as granulated sugar while brown sugar retains some of the molasses. These molasses imparts characteristic flavours and colours.

2.2 Uses of Sugar:

Although sugar is widely used as a sweetening agent, it has many other functions in food technology. Important among these are the uses of sugar as fermentation substrate, preservative, flavouring and colouring agent, texture modifier, bulking agent. Apart from these, sugar also acts for the following-

Sugar adds viscosity: Viscosity is how thick, sticky, and semi-fluid a liquid is in terms of consistency. Sugar helps to provide a certain body or thickness in many types of drinks and in semi-liquid foods like syrups, chutneys and sweet sauces.

Sugar as an anticoagulant: When it's heated, sugar delays the coagulation of proteins (or the change to a more semi-solid state), which is useful for products such as baked custards and other desserts.

2.3 Chemistry of Sugar:

Sugar, chemically is a carbohydrate and consists of carbon (C), oxygen (O), and hydrogen (H) atoms. Broadly classified according to the arrangements of the atoms in the molecular structure, the main classifications include:

- **Monosaccharides** or simple sugars. For example, Dextrose (glucose), fructose and galactose.
- **Disaccharides** or complex sugars. For example, Sucrose, maltose, etc.
- **Polysaccharides**. Examples are dextrins, starches, and cellulose.

2.4. Refining of Sugar:

The crystallised sugar has to be refined before packaging. The sugar crystals are washed, boiled and filtered to remove any impurities present. It is then evaporated to achieve the desired crystal size under vacuum in order to avoid caramelisation. Then, it is centrifuged at high speed in which the crystals are separated from the fluid. The separate sugar crystals are dried and then sent for packaging.

CHAPTER – 3
PROCESS SELECTION AND DESCRIPTION

This chapter deals with the selection of the process for manufacture of sugar. As per literature survey we have found that sugar can be produced from many raw materials such as sugar beet, sugarcane, dates, maple syrup, etc. Although the sugar produced from sugarbeet has high sucrose content compared to that of sugarcane, we have confined our study to sugarcane because of its high availability in India. The properties of sugarcane are discussed in the following table:

Table 3.1: Properties of sugarcane

Sl. No.	Properties	Parameters
1.	Amount of Sucrose	(10-15)%
2.	By products obtained	Bagasse, Molasses, Filter cake
3.	Climatic condition required	Tropical and sub-tropical
4.	Processes involved	i. Milling ii. Extraction of juice iii.Clarification iv. Evaporation v. Crystallisation
5.	Yield of raw material	71 tons per hectare
6.	Yield of the process	120 kg of sugar per ton of sugarcane
7.	Extraction rate	(30-100)%
8.	Waste produce	5%
9.	Crop Length	12-18 months
10.	Energy Consumption	26-32 kWh/ton
11.	Availability in India	Available
12.	Total cost of the process	Low
13.	Water use	20 cubic metres per metric ton

3.2 Manufacture of sugar from sugarcane

After cutting, the sugarcanes are transported to the mills using trailers, trucks, railcars depending on the location of the mill. At the mill, after unloading, the sugarcanes are treated with water for cleaning purpose then these cleaned sugarcanes are sent to the millers where milling is carried out. The milling process is carried out in two stages, first stage is breaking the hard structure of the sugarcane and the second stage is grinding.

During the first stage, revolving knives, shredders, crushers, or a combination of these processes is used and for the grinding or milling of the crushed cane, multiple sets of three-roller mills are used and then conveyors transport the crushed cane from one mill to the next mill. Imbibition water is also added in the miller for imbibition process to be carried out, where extraction of sugar cane juice is occurring with the help of added water. From this stage we obtain a by-product called as bagasse which we can be used as a cattle feed and for manufacturing of disposable food containers.

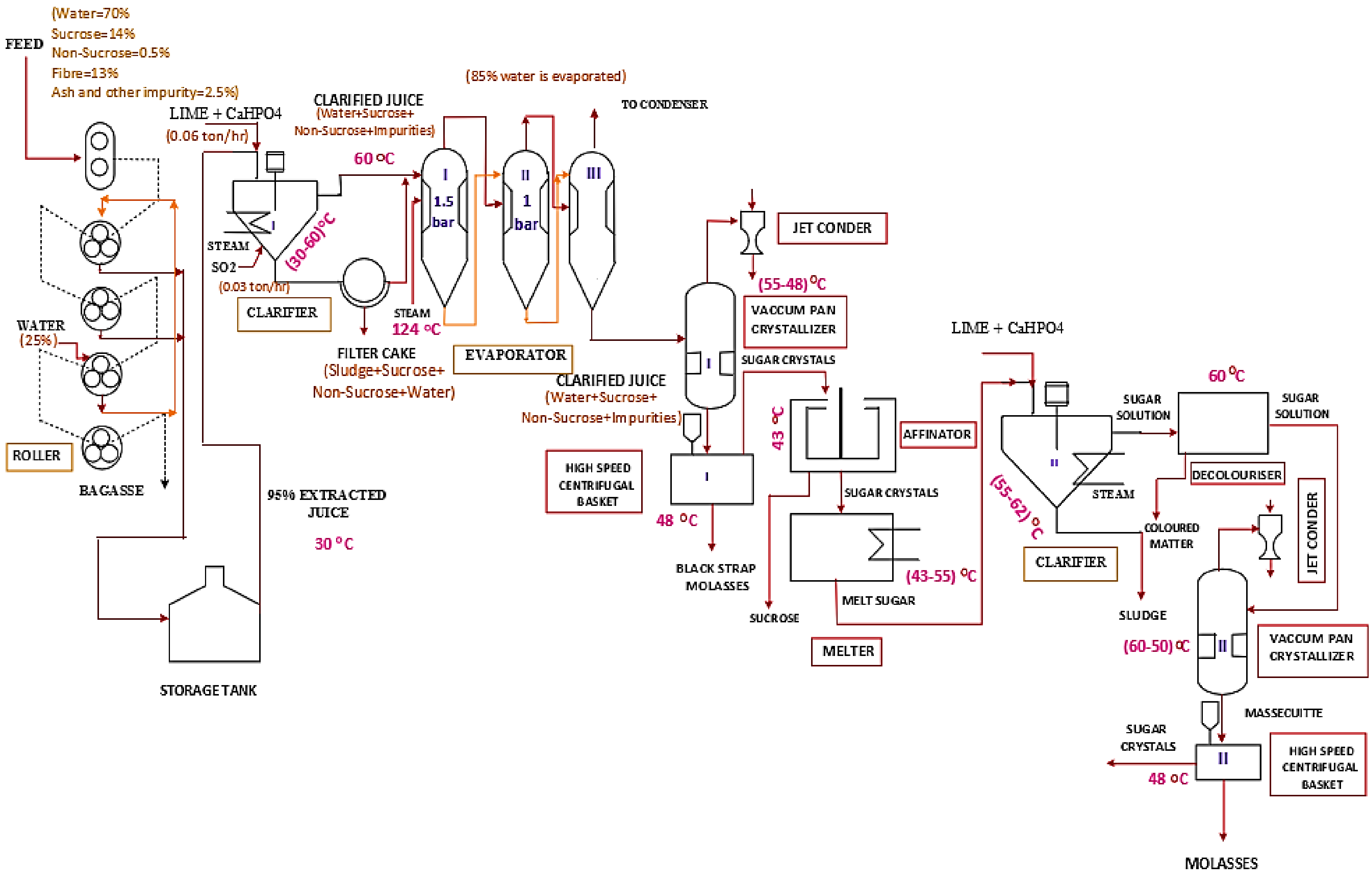
From the miller 95% juice is extracted and is sent to the clarifier and before this some pre-treatments are performed to remove large particles. In the clarifier, lime and little amount of soluble phosphate is added to maintain the pH and to remove impurities from the sugar solution. After this, temperature of the solution is raised and due to this heavy precipitation occurs and these are called as mud and it separated from the limed juice by gravity or centrifuge. From this we obtain a second by-product known as filter cake which is widely used as a fertilizer.

Clarified juice is then sent to the evaporators without any additional treatment. Evaporation process is carried out with the help of multiple effect evaporators and in this stage 85% of water is evaporated and then the concentrated sugar solution is sent to the vacuum pan crystallizer. In the evaporator, steam required is obtained from large boilers and the steam generated in the first effect is used in the second effect and the process continues and as the temperature decreases due to heat loss from evaporators, the pressure is also decreasing inside each evaporator and due to this the juice boils at lower temperatures in the subsequent evaporators.

The concentrated sugar solution from the evaporator now reaches the vacuum pan crystallizer where crystallisation of the solution takes place. In the crystallizer, the evaporation of sugar syrup is carried out until it reaches the super saturation stage. After this, the crystallization process is initiated by “seeding” the solution and when the volume of the mixture of liquor and crystals reaches the capacity of the pan then the evaporation is allowed to proceed until the final massecuite (mixture of liquor and crystal) is formed. After the formation of sugar crystals, the heavy syrup is sent to the centrifuge to separate the mother liquor and sugar crystals. From the centrifuge, the molasses obtained is discarded and the sugar crystals are sent to the affinator and from this refining of sugar begin.

The first equipment in the refining section is affinator, where washing and removing of adhering film molasses from the surface of sugar crystals are carried out. During this process, a very small amount of sucrose loss occurs, and then these washed crystals are sent to the melter. In the melter, water is added and temperature of the equipment is raised to dissolve the sugar crystals. After this, the melted sugar solution is sent to the clarifier to remove the remaining impurities and then sent to the decolourizer to remove the coloured matters. From the decolourizer, the solution is sent to the crystallizer where again crystallization process is carried out and finally in the centrifuge, the sugar crystals are separated from the molasses and then these pure refined sugar crystals are stored and sent for packaging.

Fig 3.1: Process flow sheet.



CHAPTER-4

MATERIAL BALANCE

BASIS = 100 ton/hr

4.1 Material balance over miller:

Assumptions:

a. Water content = 70%

b. Sucrose content = 14%

c. Non-sucrose = 0.5%

d. Fibre = 13%

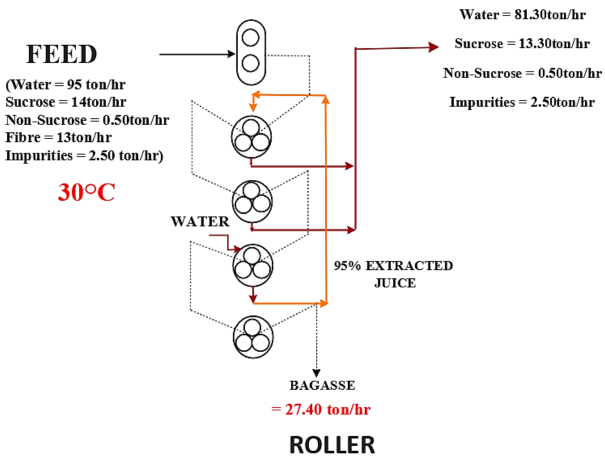
e. Ash and other impurities = 2.5%

f. Imbibition water = 25%

g. Bagasse moisture content = 50%

h. Extracted Sucrose = 95%

i. Operating temperature = 30º C



Input Streams:

Water content = (100 × 0.7) = 70 ton/hr.

Sucrose = (100 × 0.14) = 14 ton/hr.

Non-sucrose = (100 × 0.005) = 0.5 ton/hr.

Fibre = ((100 × 0.13) = 13 ton/hr.

Ash and other impurities = ((100 × 0.13) = 13 ton/hr

Imbibition water = ((100 × 0.25) = 25 ton/hr.

Output stream:

Sucrose extracted = (14 × 0.95) = 13.3 ton/hr

Unextracted sucrose = 14 – 13.3 = 0.7 ton/hr

Bagasse (Dry) = Fibre + Unextracted sucrose = 13 + 0.7 = 13.7 ton/hr

Total bagasse (Wet) = 13.7 + 13.7 = 27.4 ton/hr

Remaining water = Initial water content + imbibition water – water loss in bagasse

= 70 + 25 – 13.7 = 81.3 ton/hr

4.2. Material balance over clarifier 1:

Assumptions:

a. Lime = 15 kg/day per ton of feed = 0.625 kg/hr per ton of feed.

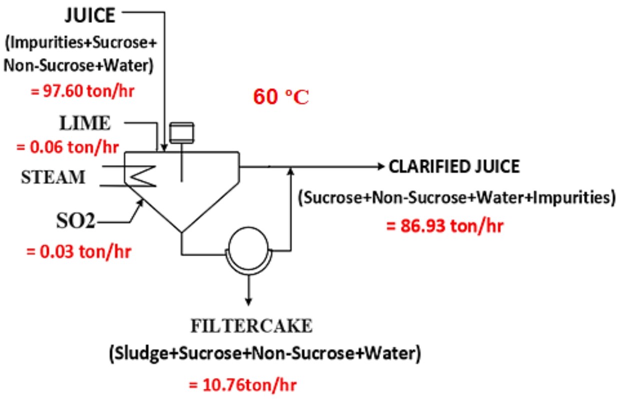
b. Sulphur = 8 kg/day per ton of feed = 0.33 kg/hr per ton of feed.

c. Efficiency of clarifier to remove impurities = 96%

d. Cake contains: 1% sucrose + 10% H_2O + 1% Non-Sucrose.

e. $CaHPO_4$ added = Negligible.

f. Operating temperature: (30 – 60) ° C



CLARIFIER

Input streams:

Remaining Water = 81.3 ton/hr

Lime = (100 x 0.625) = 62.5 kg/hr = 0.0625 ton/hr

Sulphur = (100 x 0.33) = 33 kg/hr = 0.033 ton/hr

Total Juice = Sucrose + Impurities + Water + Non-sucrose

= 13.3 + 2.5 + 81.30 +0.50 = 97.60 ton/hr

Output stream:

Sludge = (0.96 x Impurities) + Lime + Sulphur = (0.96 x 2.50) + 0.0625 + 0.033

= 2.49 ton/hr

Filter Cake = Sludge + Sucrose + Water +Non-Sucrose

= 2.49 + (0.01 x 13.3) + (0.1 x 81.3) + (0.01 x 0.5) = 10.76 ton/hr.

Remaining Sucrose = 13.30 - (0.01 x 13.3) = 13.16 ton/hr

Remaining Water = 81.30 - (0.1 x 81.30) = 73.17 ton/hr

Remaining Non-sucrose = 0.5 – (0.01 x 0.5) = 0.495 ton/hr

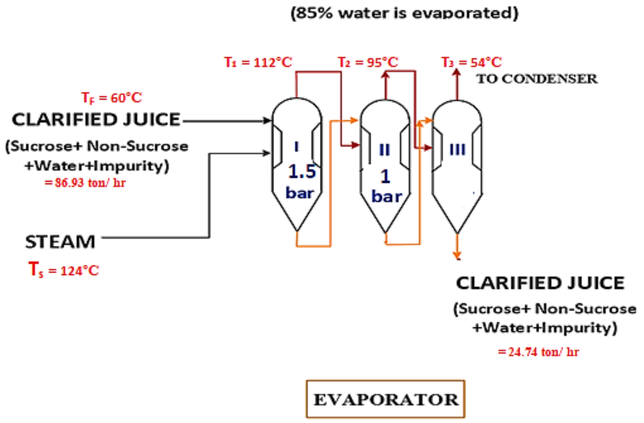
Clarified juice = Remaining (Impurities + Sucrose + Water + Non-sucrose)

= 0.1 + 13.167 + 73.17 + 0.495

= 86.932 ton/hr

4.3. Material balance over evaporator:

Assumptions:



a. Temperature of feed = 60º C

b. Pressure maintained at effect 1= 1.5 bar

c. Pressure maintained at effect 2= 1 bar

d. Output juice temperature = 54º C

<u>Effect 1</u>

Input streams:

Clarified juice = Remaining (Impurities + Sucrose + Water + Non-sucrose)

= 0.1 + 13.167 + 73.17 + 0.495 = 86.932 ton/hr

Output stream:

Evaporated water, E_1 = 0.7 × Remaining water = 0.7 × 73.17 = 51.219 ton/hr

Remaining water = 73.17 – E_1 = 21.951 ton/hr

Remaining clarified juice = 86.932 – 51.219 = 35.713 ton/hr

<u>Effect 2</u>

Input streams:

Clarified juice = Remaining (Impurities + Sucrose + Water + Non-sucrose)

$= 0.1 + 13.167 + 21.951 + 0.495 = 35.713$ ton/hr

Output streams:

Evaporated water, $E_2 = 0.3 \times$ Remaining water $= 0.3 \times 21.951 = 6.5853$ ton/hr

Remaining water $= 21.951 – E_2 = 15.3657$ ton/hr

Remaining clarified juice $= 35.713 – 6.5853 = 29.1277$ ton/hr

Effect 3

Input streams

Clarified juice = Remaining (Impurities + Sucrose + Water + Non-sucrose)

$= 0.1 + 13.167 + 15.3657 + 0.495 = 29.1277$ ton/hr

Output streams

Evaporated water, $E_3 = 0.28 \times 15.3657 = 4.3877$ ton/hr

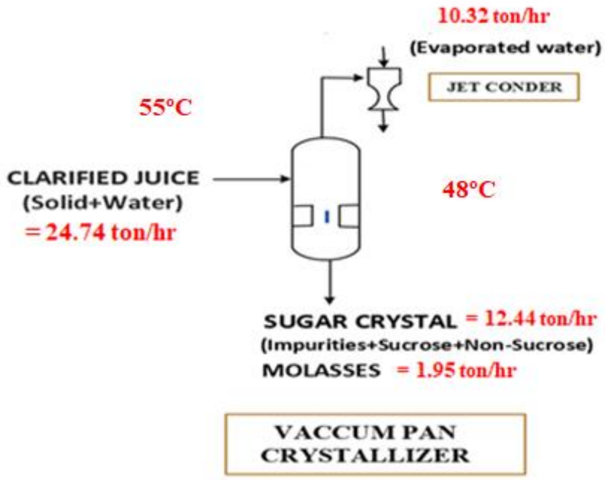
Remaining water $= 15.3657 – E_3 = 10.978$ ton/hr

Remaining clarified juice $= 29.1277 – 4.3877 = 24.74$ ton/hr

4.4. Material balance over crystallizer 1:

Assumptions:

a. Sucrose recovery = 92%



b. Non-sucrose recovery = 33%

c. Moisture associated with the crystal = 1% of crystal weight.

d. Solubility of Sucrose in H_2O at 55 ° C = 2.67 kg Sucrose per kg of water.

e. Operating temperature = (55 – 48) ° C

Input streams:

Clarified juice = Remaining (Impurities + Sucrose + Water + Non-sucrose)

= 0.1 + 13.167 + 10.978 + 0.495 = 24.74 ton/hr

Output streams:

Weight of sucrose crystal = 0.92 × Remaining sucrose = 0.92 × 13.167 = 12.113 ton/hr

Weight of non-sucrose crystal = 0.33 × Remaining non-sucrose = 0.33 × 13.167 = 0.163 ton/hr

Total sugar in molasses = (Remaining sucrose – weight of sucrose crystal) + (Remaining sucrose – weight of sucrose crystal)

= (13.167- 12.113) + (0.495 – 0.163) = 1.054 + 0.332 = 1.386 ton/hr

Water required to dissolve molasses = $\frac{Total\ sugar\ in\ molasses}{Solubility at\ 55^{o}C} = \frac{1.386}{2.67}$ = 0.519 ton/hr

Moisture associated with crystal = (0.01 × 12.113) + (0.01 × 0.163) = 0.12113 + 0.00163

= 0.123 ton/hr

Water evaporated = Remaining water – moisture with crystal – water required to dissolve molasses = 10.978 – 0.123 – 0.519 = 10.328 ton/hr

Total crystal = (Sucrose crystal + moisture) + (Non-sucrose crystal + moisture) + impurities

= (12.113 + 0.12113) + (0.163 + 0.00163) + 0.05 = 12.44 ton/hr

Molasses = Sugar in molasses + impurities + water required to dissolve molasses

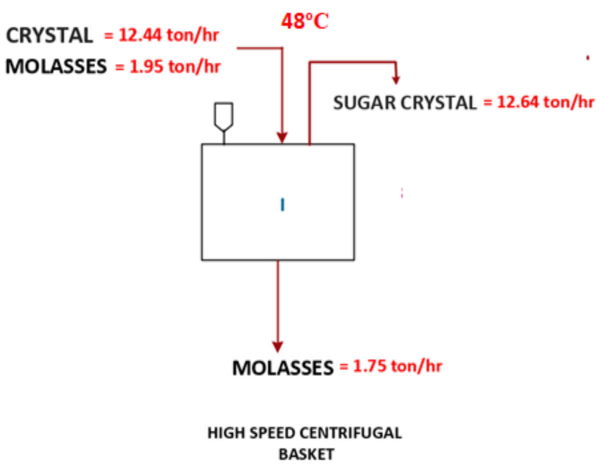
= 1.054 + 0.332 + 0.519 + 0.05 = 1.95 ton/hr

4.5. Material balance over centrifuge 1:

Assumptions:

a. Molasses associated with crystals = 10%

b. Operating temperature: 48° C



Input streams:

Total crystal = (Sucrose crystal + moisture) + (Non-sucrose crystal + moisture) + impurities

= (12.113 + 0.12113) + (0.163 + 0.00163) + 0.05

= 12.44 ton/hr

Molasses = Sugar in molasses + impurities + water required to dissolve molasses

= 1.054 + 0.332 + 0.519 + 0.05 = 1.95 ton/hr

Output streams:

Total sugar crystal = Sugar crystal + 10% of molasses weight

= 12.44 + (0.1 × 1.95) = 12.64 ton/hr

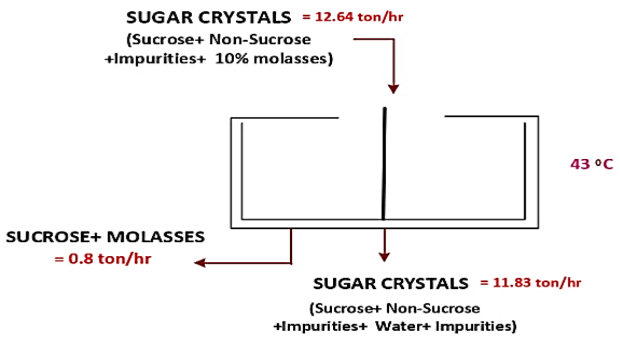
Remaining molasses = 1.95 – (0.1 × 1.95) = 1.75 ton/hr

4.6. Material balance over affinator:

Assumptions:

a. Sucrose loss with molasses film = 5%

b. Operating temperature: 43° C



AFFINATOR

Input streams:

Sugar crystal = (Sucrose crystal + moisture) + (Non-sucrose crystal + moisture) + impurities + 10% of molasses weight.

= (12.113 + 0.12113) + (0.163 + 0.00163) + 0.05 + 0.195 = 12.64 ton/hr

Output streams:

Sucrose loss with molasses = 0.05 × 12.113 = 0.605 ton/hr

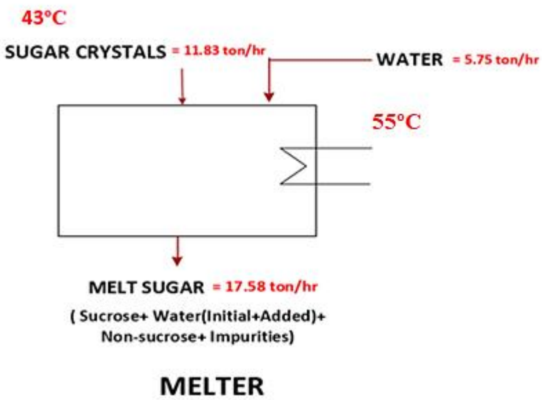
Remaining sucrose = 12.113 – 0.605 = 11.50 ton/hr

Moisture in crystal = (0.12113 + 0.00163) = 0.12 ton/hr

Total sugar crystal = (Sucrose crystal + moisture) + (Non-sucrose crystal + moisture) + impurities) = (11.50 + 0.12113) + (0.163 + 0.00163) + 0.05= 11.83 ton/hr

4.7. Material balance over melter:

Assumptions:



a. Sugar crystal is washed with water which is one-half of sucrose weight.

b. Operating temperature: (43-55) ° C

Input streams:

Sugar crystal = (Sucrose crystal + moisture) + (Non-sucrose crystal + moisture) + impurities)

= (11.50 + 0.12113) + (0.163 + 0.00163) + 0.05 = 11.83 ton/hr

Water added for melting = $\frac{11.50}{2}$ = 5.75 ton/hr

Output streams:

Melt sugar = (Sucrose + initial water + added water + Non-sucrose + impurities)

= (11.50 + 0.12 + 5.75 + 0.163 + 0.05)

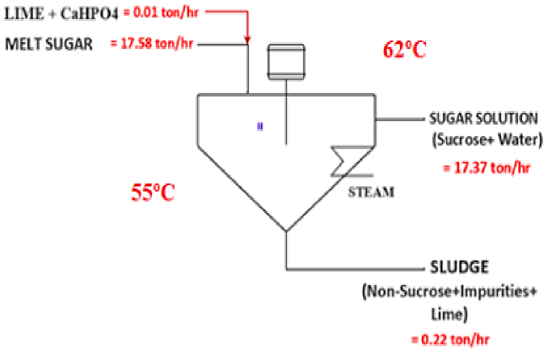
= 17.58 ton/hr

4.8. Material balance over clarifier 2:

Assumptions:

a. Lime = 15 kg/day of feed = 0.625 kg/hr

b. Efficiency of clarifier to remove impurities along with Non-sucrose as sludge = 100%



CLARIFIER

c. $CaHPO_4$ added = Negligible.

d. Operating temperature: (55-62) ° C

Input streams:

Melt sugar = (Sucrose + initial water + added water + Non-sucrose + impurities)

= 17.58 ton/hr

Lime = (0.625 × 17.58) = 10.98 ton/hr = 0.011 ton/hr

Output streams:

Sugar solution = (Sucrose + Water) = (11.50 + 0.12 + 5.75) = 17.37 ton/hr

Sludge = (Impurities + Non-sucrose + Lime) = (0.05 + 0.163 + 0.011) = 0.224 ton/hr

4.9. Material balance over decolourizer:

Assumptions:

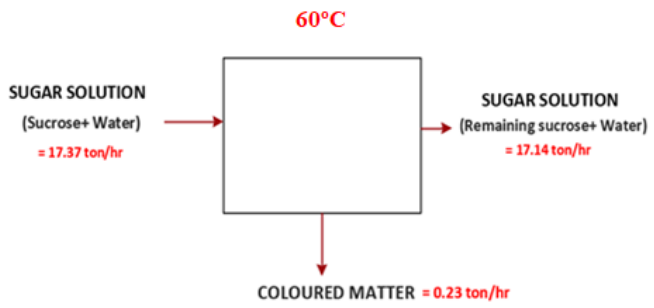
a. Colouring matter contains = 2% Sucrose

b. All colouring matters are removed.

c. Operating temperature: 60 ° C

Input streams:

Sugar solution = (Sucrose + Water) = 17.37 ton/hr



DECOLOURISER

Output streams:

Colouring matter removed = 2%

Sucrose = (0.02 × 11.50) = 0.23 ton/hr

Remaining sucrose = (11.50 – 0.23) = 11.27 ton/hr

Total sugar solution = (Sucrose + Water) = (11.27 + 5.87) = 17.14 ton/hr

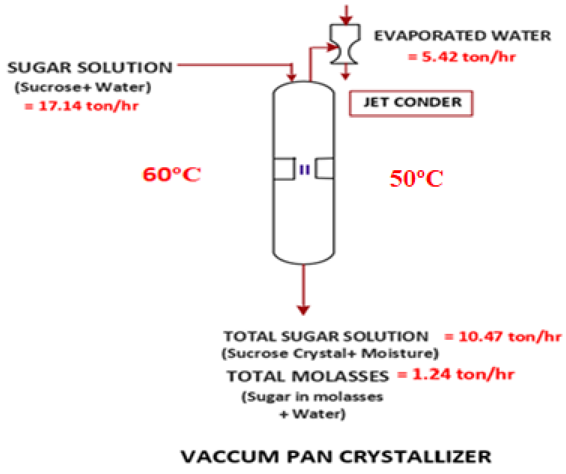
4.10. Material balance over crystallizer 2:

Assumptions:

a. Sucrose recovery = 92%

b. Moisture associated with the crystal = 1% of crystal weight.

c. Solubility of Sucrose in H_2O at 60ºC = 2.67 kg Sucrose per kg of water.



d. Operating temperature = (60-50) º C

Input streams:

Sugar solution = (Sucrose + Water) = 17.14 ton/hr

Output streams:

Weight of sucrose crystal = 0.92 × Remaining sucrose

= 0.92 × 11.27= 10.37 ton/hr

Total sucrose in molasses = (Remaining sucrose – weight of sucrose crystal)

= (11.27 - 10.37) = 0.9 ton/hr

Water required to dissolve molasses = $\frac{Totalsugarinmolasses}{Solubility\ at\ 60^{\circ}C}$

$= \frac{0.9}{2.67} = 0.34\ \text{ton/hr}$

Moisture associated with crystal = (0.01 × 10.37) = $0.1037\ \text{ton/hr}$

Water evaporated = Remaining water – moisture with crystal – water required to dissolve molasses = 5.87- 0.1037 – 0.34= 5.42 ton/hr

Total crystal = (Sucrose crystal + moisture) = 10.37 + 0.1037= 10.47 ton/hr

Molasses = Sugar in molasses + water required to dissolve molasses

= 0.9 + 0.34 = 1.24 ton/hr

4.11. Material balance over centrifuge 2:

Assumptions:

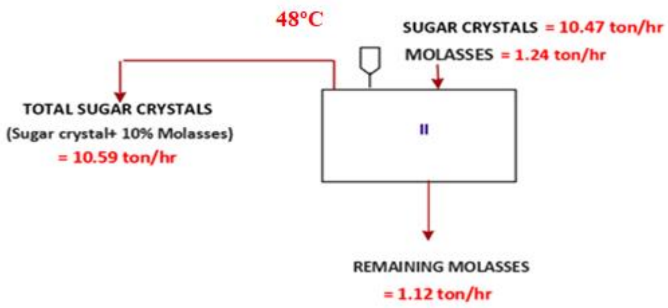
a. Molasses associated with crystals = 10%

b. Operating temperature: 48 ° C

Input streams:

Sugar crystal = (Sucrose crystal + moisture) = 10.47 ton/hr

Molasses = Sugar in molasses + water required to dissolve molasses = 1.24 ton/hr



HIGH SPEED CENTRIFUGAL BASKET

Output streams:

Total sugar crystal = (Sucrose crystal + moisture) + 10% molasses

= 10.47 + (0.1 × 1.24)

= 10.59 ton/hr

Molasses = 1.24 – (0.1× 1.24) = 1.12 ton/hr.

OVERALL MATERIAL BALANCE

Table 4.1: Overall material balance

Input streams	Compositions (ton/hr)	Output streams	Compositions (ton/hr)
Milling (Feed)	60	Milling (Bagasse)	13.152
Clarifier 1 (Lime + Sulphur)	0.0432	Clarifier 1 (Filter cake)	5.1648
Melter (Added water)	2.76	Evaporator (Evaporated Water)	29.8464
Clarifier 2 (Lime)	0.0048	Crystallizer 1 (Evaporated Water)	4.953
		Centrifuge 1 (Molasses)	0.84
		Affinator (Sucrose loss)	0.384
		Clarifier 2 (Sludge)	0.1056
		Decolourizer (Colouring matter)	0.1104
		Crystallizer 2 (Evaporated water)	2.6016
		Centrifuge 2	5.62
Total input	62.808	Total output	62.778

CHAPTER-5

MODIFIED MATERIAL BALANCE

Plant capacity = 40000 ton/yr

Considering 330 working days per year and 24 working hours per day, for (330 × 24) = 7920 operating hours per year –

$$\frac{40000}{330 \times 24} = 5.05 \text{ ton/hr}$$

From calculation on previous basis –

100 ton/hr of feed gives 10.59 ton/hr of sugar crystal.

Therefore, multiplying factor = $\frac{5.05}{10.59}$ = 0.48

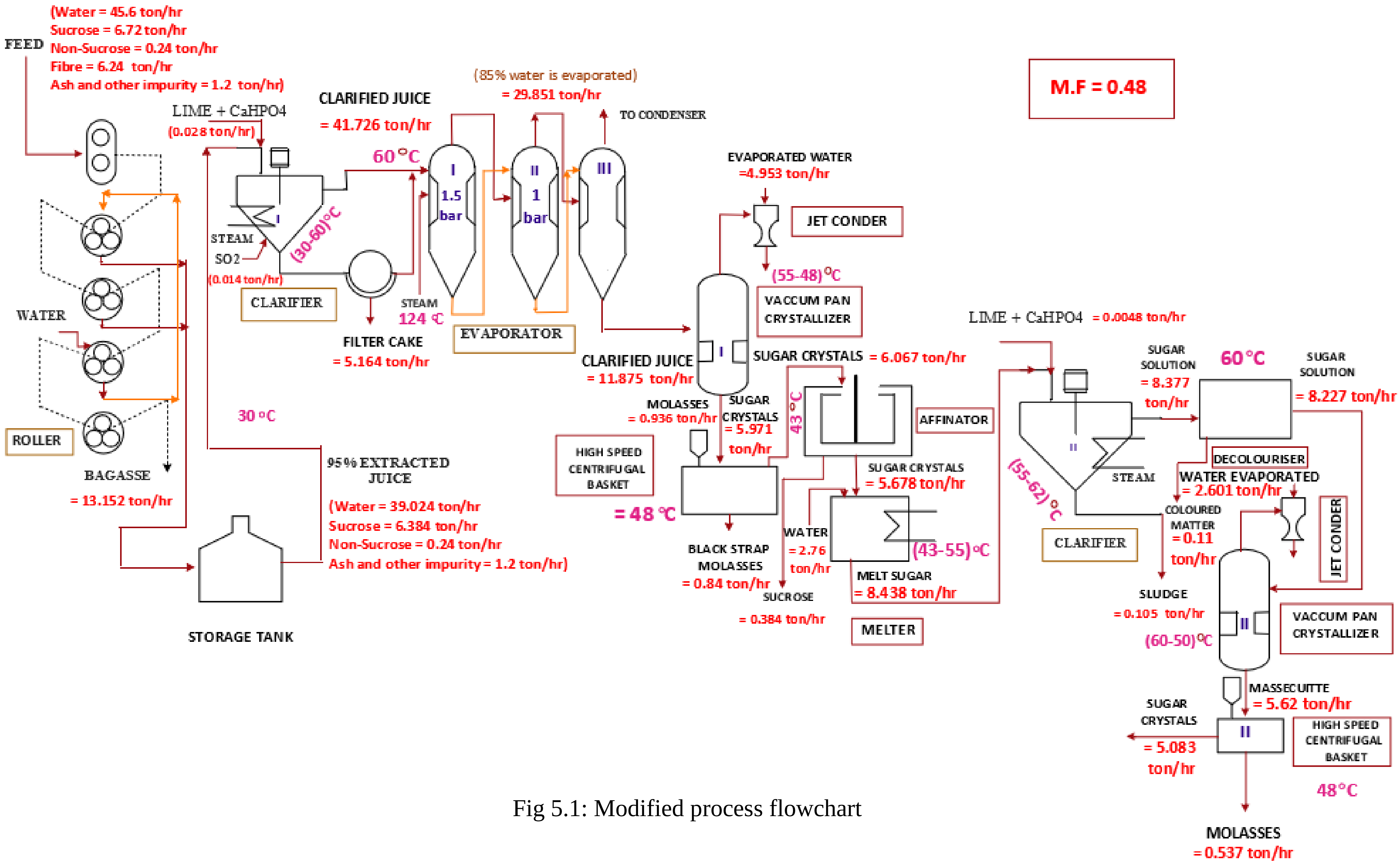


Fig 5.1: Modified process flowchart

Table 5.1: Modified material balance on miller

Equipment	Input Streams	Compositions (ton/hr)	Modified Compositions (ton/hr)	Output Streams	Compositions (ton/hr)	Modified Compositions (ton/hr)
MILLER	Water content + Imbibition water	95	45.6	Remaining water (Water content + Imbibition water)	81.30	39.024
	Sucrose	14	6.72	Sucrose Extracted	13.30	6.384
	Non-sucrose	0.50	0.24	Non-Sucrose	0.50	0.24
	Fibre	13	6.24	Bagasse (Extracted sucrose + Fibre + water)	27.40	13.152
	Ash & other impurities	2.50	1.2	Ash & other impurities	2.50	1.2

Table 5.2: Modified material balance on clarifier 1

Equipment	Input Streams	Compositions (ton/hr)	Modified composition (ton/hr)	Output streams	Compositions (ton/hr)	Modified compositions (ton/hr)
CLARIFIER 1	Total Juice (Water + sucrose + impurities)	97.10	46.608	Total Clarified Juice (Remaining impurities + Remaining sucrose + Remaining Water + Remaining Non-sucrose)	86.93	41.726
	Lime	0.06	0.028	Filter Cake (Sludge + Sucrose + Water + Non-Sucrose)	10.76	5.164
	Sulphur	0.03	0.014			
	Non-Sucrose	0.50	0.24			

Table 5.3: Modified material balance on evaporator

Equipment		Input Streams	Composition (ton/hr)	Modified compositions (ton/hr)	Output streams (ton/hr)	Compositions (ton/hr)	Modified compositions (ton/hr)
EVAPORATOR	Effect 1	Clarified juice	86.93	41.726	Remaining clarified juice	35.71	17.141
					Evaporated water	51.22	24.585
	Effect 2	Clarified juice	35.71	17.14	Remaining clarified juice	29.12	13.977
					Evaporated water	6.58	3.158
	Effect 3	Clarified juice	29.12	13.977	Remaining clarified juice	24.74	11.875
					Evaporated water	4.38	2.102

Table 5.4: Modified material balance on crystalliser 1

Equipment	Input streams	Compositions (ton/hr)	Modified compositions (ton/hr)	Output streams	Compositions (ton/hr)	Modified compositions (ton/hr)
CRYSTALLIZER 1	Total clarified juice (Impurities + sucrose + Non-sucrose + Water)	24.74	11.875	Total sugar crystal (Sucrose + Non-sucrose + Impurities + moisture)	12.44	5.971
				Total molasses	1.95	0.936
				Evaporated water	10.32	4.953

Table 5.5: Modified material balance on centrifuge 1

Equipment	Input streams	Compositions (ton/hr)	Modified compositions (ton/hr)	Output streams	Compositions (ton/hr)	Modified compositions (ton/hr)
CENTRIFUGE 1	Sugar crystal	12.44	5.971	Total sugar crystal	12.64	6.067
	Molasses (Sugar in molasses + impurities + water)	1.95	0.936	Total molasses	1.75	0.84

Table 5.6: Modified material balance on affinator

Equipment	**Input streams**	**Compositions (ton/hr)**	**Modified compositions (ton/hr)**	**Output streams**	**Compositions (ton/hr)**	**Modified compositions (ton/hr)**
AFFINATOR	Sugar crystal	12.64	6.067	Total sugar crystal (Remaining sucrose + water + impurities + non-sucrose)	11.83	5.678
				Sucrose loss + molasses	0.8	0.384

Equipment	**Input streams**	**Compositions (ton/hr)**	**Modified compositions (ton/hr)**	**Output streams**	**Compositions (ton/hr)**	**Modified compositions (ton/hr)**
MELTER	Sugar Crystal	11.83	5.678	Melt sugar (Sucrose + Water + Non-sucrose + impurities)	17.58	8.438
	Water added for melting	5.75	2.76			

Table 5.7: Modified material balance on melter

Equipment	Input streams	Compositions (ton/hr)	Modified compositions (ton/hr)	Output streams	Compositions (ton/hr)	Modified compositions (ton/hr)
CLARIFIER 2	Melt Sugar	17.58	8.438	Sugar solution	17.37	8.337
	Lime	0.01	0.0048	Sludge	0.22	0.105

Table 5.8: Modified material balance of clarifier 2

Equipment	Input streams	Compositions (ton/hr)	Modified compositions (ton/hr)	Output streams	Compositions (ton/hr)	Modified compositions (ton/hr)
DECOLOURIZER	Sugar solution	17.37	8.337	Total sugar solution	17.14	8.227
				Coloured material	0.23	0.11

Table 5.9: Material balance of decolourizer

Table 5.10: Modified balance on crystalliser 2

Equipment	Input streams	Compositions (ton/hr)	Modified compositions (ton/hr)	Output streams	Compositions (ton/hr)	Modified compositions (ton/hr)
CRYSTALLIZER 2	Sugar Solution	17.14	8.227	Total sugar crystal	10.47	5.025
				Total molasses	1.24	0.595
				Evaporated water	5.42	2.601

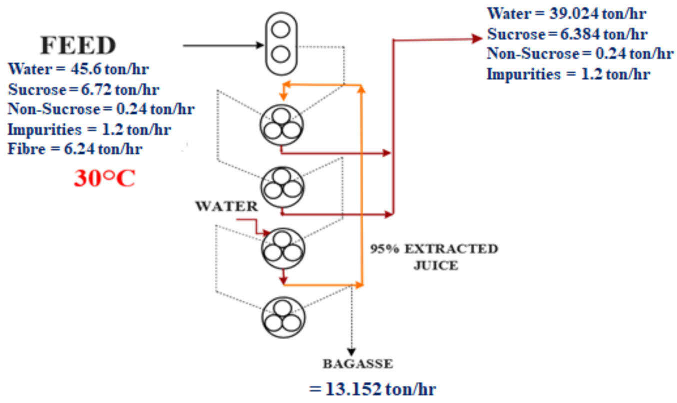
Equipment	Input streams	Compositions (ton/hr)	Modified compositions (ton/hr)	Output streams	Compositions (ton/hr)	Modified compositions (ton/hr)
CENTRIFUGE 2	Sugar crystal	10.47	5.025	Total sugar crystal	10.59	5.083
	Molasses	1.24	0.595	Remaining molasses	1.12	0.537

Table 5.10: Modified balance on centrifuge 2

CHAPTER-6

ENERGY BALANCE

6.1. Energy balance over miller:



ROLLER

Assumptions:

i. Operating temperature: 30° C

Sl. No	Input Streams	Composition (Tons/hr)	Sl. No	Output Streams	Composition (Tons/hr)
1.	Feed (Water:33.6 ton/hr+ Sucrose: 6.72ton/hr+ Non-Sucrose: 0.24ton/hr+ Fibre: 6.24ton/hr+ Impurities: 1.2ton/hr)	48	1.	Extracted Juice (Water:39.024ton/hr+ Sucrose: 6.384ton/hr+ Non-Sucrose: 0.24ton/hr+ Impurities: 1.2ton/hr)	46.848
2.	Imbibition Water	12	2.	Bagasse (Unextracted Sucrose:0.336ton/hr+ Fibre: 6.32ton/hr + Water: 6.576 ton/hr)	13.232

Table 6.1: Composition balance on miller

Input Streams:

1. C_p (Feed) = 3.30380 KJ/Kg.ºC

2. $\Delta H_{\text{In}} = \Delta H_{\text{feed}} + \Delta H_{\text{imbibed water}}$

$= \{48\times1000\times3.30380 \times (30\text{-}25)\} + \{12\times 1000 \times 4.18 \times (30\text{-}25)\}$

= 1043712 KJ/hr.

Output Streams:

1. C_p (Juice) = 3.68148 KJ/Kg.ºC

2. C_p (Bagasse) = 2.741294KJ/Kg.ºC

3. $\Delta H_{\text{Out}} = \Delta H_{\text{Juice}} + \Delta H_{\text{Bagasse}}$

$= \{46.848\times1000\times3.68148 \times(30\text{-}25)\} + \{13.232\times1000\times 2.741294 \times (30\text{-}25)\}$

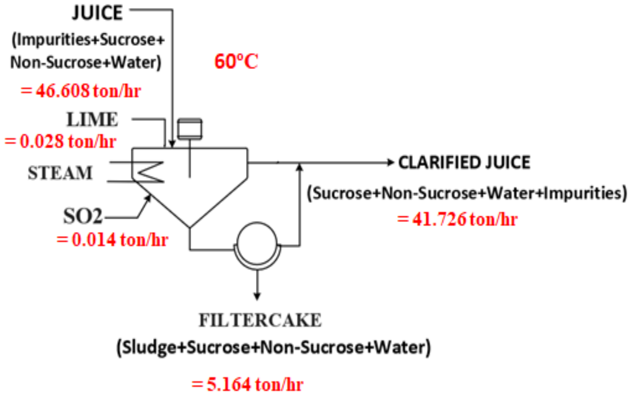
= 1043713.886 KJ/hr.

6.2. Energy balance over clarifier 1:

Assumptions

i. Steam input Pressure = 1 bar.

ii. Operating temperature = (30-60) º C



CLARIFIER

Sl. No	Input Streams	Compositions (Ton/hr)	Sl. No	Output Streams	Compositions (Ton/hr)
1.	Juice (Water:39.024ton/hr+ Sucrose: 6.384ton/hr+ Non-Sucrose: 0.24ton/hr+ Impurities: 1.2ton/hr)	46.848	1.	Clarified juice (Sucrose: 6.32ton/hr+ Water: 35.121ton/hr+ Non-sucrose: 0.237ton/hr + Impurities: 0.048ton/hr)	41.726
2.	Lime	0.028	2.	Filter Cake {Sludge (impurities:1.152 ton/hr+ lime:0.028ton/hr+ Sulphur: 0.014ton/hr) +Sucrose:0.064ton/hr+ Water: 3.902ton/hr+ Non-Sucrose:0.0024ton/hr}	5.162
3.	Sulphur	0.014			

Table 6.2: Composition balance on clarifier 1

Steam requirement:

$m_{juice.}C_{p.}dT + m_{lime.}C_{p.}dT + m_{Sulphur.}C_{p.}dT = m_{steam}.\lambda$

[λ= 2256.99 KJ/Kg at 1 bar; Ref: Steam Table]

= {46.848 x 1000 x 3.68148 x (60-30)} + {0.028 x 1000x 1.208 x (60-30)} + {0.014 x 1000 x 0.642 x (60-30)} =m_{steam} × (2256.99)

m_{steam} = 2293.046762kg/hr

Input streams:

1. Cp (Juice) =3.68148 KJ/Kg.ºC

2. Enthalpy of input steam, H_g = 2675.84 KJ/Kg. [Ref: Steam Table]

3. $\Delta H_{In} = \Delta H_{juice} + \Delta H_{lime} + \Delta H_{Sulphur} + m_{steam}.H_g$

= {46.848 x 1000x 3.68148 x (30-25)} + {0.028 x 1000 x1.208 x (30-25)} + {0.014 x 1000 x 0.642 x (30-25)} + {2293.046762 x 2675.84}

= 6998390.183 KJ/hr.

Output streams:

1. C_p of clarified juice = 3.716338 KJ/Kg.ºC

2. C_p of filter cake = 3.37950KJ/Kg.ºC

3. Enthalpy of output steam, H_l = 418.849 KJ/Kg [Ref: Steam Table]

4. $\Delta H_{Out} = \Delta H_{juice} + \Delta H_{filter\ cake} + m_{steam}.H_l$

= {41.726 × 1000 × 3.716338 × (60-25)} + {5.162 × 1000 × 3.37950 × (60-25)} + {2293.046762 × 418.849}

= 6998391.787 KJ/hr

6.3. Energy balance over evaporator:

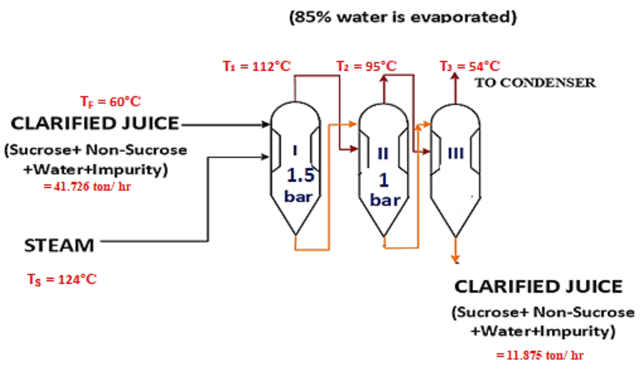
Assumptions:

i. Steam input pressure = 2.25 bar

ii. Feed temperature = 60°C

iii. Pressure maintain at effect 2 = 1 bar.

1st effect,



EVAPORATOR

Steam requirement:

$m_{juice}.C_p.dT = m_{steam}.\lambda$ [λ = 2191.06 KJ/Kg at 2.25 bar; Ref: Steam Table]

= {41.726 x 1000 x 3.716338 x (112-60)} = m_{steam} x 2191.06

m_{steam} = 3680.196712 kg/hr

Input streams:

1. Cp of clarified juice = 3.716338 KJ/Kg.ºC

2. Enthalpy of input steam, H_g = 2711.52 KJ/Kg. [Ref: Steam Table]

3. $\Delta H_{In} = \Delta H_{juice} + m_{steam}.H_g$

= {41.726 x 1000 x 3.716338 x (60-25)} + {3680.196712 x 2711.52}

= 15406304.17 KJ/hr

Output streams:

1. C_p of clarified juice = 3.051317 KJ/Kg.ºC

2. Enthalpy of output steam, H_l = 520.46 KJ/Kg [Ref: Steam Table]

3. $\Delta H_{Out} = \Delta H_{juice} + \Delta H_{evaporated\ water} + m_{steam}.H_l$

= {17.141 x 1000 x 3.051317 x (112-25)} + {24.585 x 1000 x 4.18 x (112-25)} + {3680.196712 x 520.46}.

= 15406304.63 KJ/hr

2^{nd} effect,

Input streams:

1. Cp of clarified juice = 3.051317 KJ/Kg.ºC

2. $\Delta H_{In} = \Delta H_{juice} + \Delta H_{evaporated\ water} + \Delta H_{steam\ chest}$

$= \{17.141 \times 1000 \times 3.051317 \times (112-25)\} + \{24.585 \times 1000 \times 4.18 \times (112-25)\}$

= 13490909.45 KJ/hr

Output streams:

1. C_p of clarified juice =2.819726 KJ/Kg.ºC

2. $\Delta H_{out} = \Delta H_{juice} + \Delta H_{evaporated\ water} + \Delta H_{steam\ chest}$

$= \{13.977 \times 1000 \times 2.819726 \times (95-25)\} + \{3.158 \times 1000 \times 4.18 \times (95-25)\} + \{24.585 \times 1000 \times 4.18 \times (95-25)\}$

= 13490909.11KJ/hr.

3^{rd} effect,

Input streams:

1. C_p of clarified juice = 2.81972 KJ/Kg.ºC

2. $\Delta H_{In} = \Delta H_{juice} + \Delta H_{evaporated\ water}$

$= \{13.977 \times 1000 \times 2.819726 \times (95-25)\} + \{3.158 \times 1000 \times 4.18 \times (95-25)\}$

= 3682822.52 KJ/hr

Output streams:

1. C_p of clarified juice = 2.577901516 KJ/Kg.ºC

2. $\Delta H_{out} = \Delta H_{juice} + \Delta H_{evaporated\ water} + \Delta H_{steam\ chest}$

$= \{11.875 \times 1000 \times 2.577901516 \times (54-25)\} + \{2.102 \times 1000 \times 4.18 \times (54-25)\} + \{3.158 \times 1000 \times 4.18 \times (54-25)\}$

= 3682822.15 KJ/hr

6.4. Energy balance over crystallizer 1:

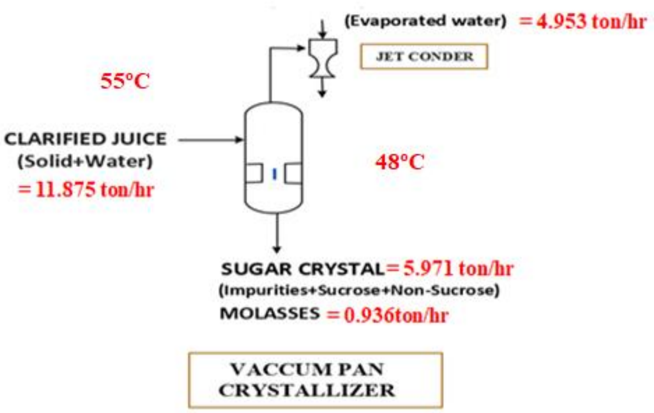
Assumptions:

i. Operating temperature = (54 - 48) ºC

<table>
<tr><th>Sl. No</th><th>Input Streams</th><th>Compositions (Tons/hr)</th><th>Sl. No</th><th>Output Streams</th><th>Compositions (Tons/hr)</th></tr>
<tr><td rowspan="3">1.</td><td rowspan="3">Clarified juice (Sucrose: 6.32ton/hr+ Water: 5.265ton/hr+ Non-sucrose: 0.237ton/hr+ Impurities: 0.048ton/hr)</td><td rowspan="3">11.87</td><td>1.</td><td>Total sugar crystal (Sucrose: 5.814ton/hr+ Non-sucrose: 0.078ton/hr+ Impurities: 0.024ton/hr+ moisture: 0.059ton/hr)</td><td>5.975</td></tr>
<tr><td>2.</td><td>Total molasses (Sucrose: 0.506ton/hr+ Non-sucrose: 0.159 ton/hr+ Water: 0.249 ton/hr+ Impurities: 0.024ton/hr)</td><td>0.938</td></tr>
<tr><td>3.</td><td>Evaporated Water</td><td>4.953</td></tr>
</table>

Table 6.3: Composition balance on crystallizer 1

Steam requirement:



$m_{juice}.C_p.dT = m_{steam}.\lambda$ [λ= 2173.80 KJ/Kg at 2.7 bar; Ref: Steam Table]

= {11.87 x 1000 x 2.577901516 x (54-48)} = m_{steam} x 2173.80

m_{steam} = 84.45953904 kg/hr

Input streams:

1. C_p of clarified juice = 2.577901516 KJ/Kg.ºC

2. Enthalpy of input steam, H_g = 2719.86 KJ/Kg. [Ref: Steam Table]

3. $\Delta H_{In} = \Delta H_{juice} + m_{steam}.H_g$

= {11.87 x 1000 x 2.5777901516 x (54 -25)} + {84.45953904 x 2719.86}

= 1117109.161 KJ/hr

Output streams:

1. C_p of sugar crystal = 3.8516 KJ/Kg.ºC

2. C_p of molasses = 3.0362 KJ/Kg.ºC

3. Enthalpy of output steam, H_l = 546.058 KJ/Kg [Ref: Steam Table]

4. $\Delta H_{Out} = \Delta H_{crystal} + \Delta H_{molasses} + \Delta H_{evaporated\ water} + m_{steam}.H_l$

= {5.975 x 1000 x 3.8516 x (48-25)} + {0.938 x 1000 x 3.0362 x (48-25)} + {4.953 x 1000 x 4.18 x (48-25)} + {84.45953904 x 546.058}

= 1117110.336 KJ/hr.

6.5. Energy balance over centrifuge 1:

Assumptions:

i. Operating temperature = 48 º C

Sl. No	Input Streams	Composition (Ton/hr)	Sl. No	Output Streams	Composition (Ton/hr)
1.	Total sugar crystal (Sucrose: 5.814 ton/hr+ Non-sucrose: 0.078 ton/hr+ Impurities: 0.024 ton/hr+ moisture: 0.059 ton/hr)	5.975	1.	Total sugar crystal (Sucrose:5.864 ton/hr+ Non-sucrose:0.11 ton/hr+ Impurities: 0.026 ton/hr+ moisture:0.084 ton/hr)	6.084
2.	Total molasses (Sucrose: 0.506 ton/hr+ Non-sucrose: 0.159 ton/hr + Water: 0.249 ton/hr + Impurities: 0.024 ton/hr)	0.938	2.	Total molasses (Sucrose: 0.455 ton/hr+ Non-sucrose: 0.143 ton/hr+ Water: 0.224 ton/hr+ Impurities: 0.021 ton/hr)	0.843

Table 6.4: Composition balance on centrifuge 1

Input streams:

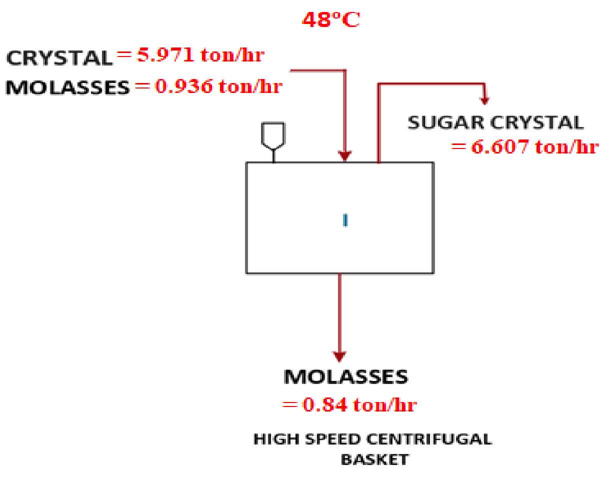
1. Cp of sugar crystal = 3.8516 KJ/Kg.ºC

2. C_p of molasses = 3.0362 KJ/Kg.ºC

3. $\Delta H_{\text{In}} = \Delta H_{\text{crystal}} + \Delta H_{\text{molasses}}$

= {5.975 x 1000 x 3.8516 x (48-25)} + {0.938 x 1000 x 3.0362 x (48-25)}

= 594809.1088 KJ/hr.



Output streams:

1. C_p of sugar crystal = 3.8316 KJ/Kg.ºC

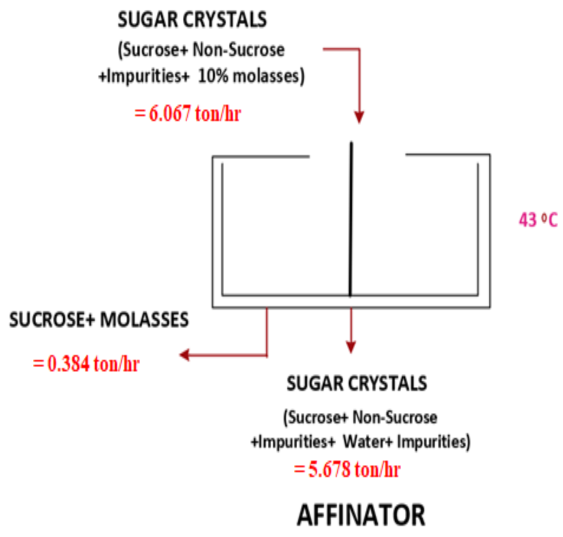
2. C_p of molasses = 3.0247 KJ/Kg.ºC

3. $\Delta H_{\text{Out}} = \Delta H_{\text{crystal}} + \Delta H_{\text{molasses}}$

= {6.084 x 1000 x 3.8316 x (48-25)} + {0.843 x 1000 x 3.0247 x (48-25)}

= 594809.3595 KJ/hr.

6.6. Energy balance over affinator:



Assumptions:

i. Operating temperature = 43 º C

Sl. No	Input Streams	Composition (Ton/hr)	Sl. No	Output Streams	Composition (Ton/hr)
1.	Total sugar crystal (Sucrose: 5.864ton/hr + Non-sucrose: 0.11ton/hr + Impurities: 0.026ton/hr + moisture: 0.084ton/hr)	6.084	1.	Total sugar crystal (Sucrose: 5.52ton/hr + Non-sucrose: 0.07824ton/hr + Impurities: 0.024ton/hr + moisture: 0.0576ton/hr)	5.679
			2.	Sucrose loss: 0.34ton/hr + Molasses film (Non-sucrose: 0.016ton/hr + impurities: 0.0024ton/hr + water: 0.025ton/hr}	0.383

Table 6.5: Composition balance on affinator

Input streams:

1. C_p of sugar crystal = 3.8316 KJ/Kg.ºC

2. $\Delta H_{\text{in}} = \Delta H_{\text{crystal}}$= {5.975 x 1000 x 3.8316 x (43-25)} = 412088.58 KJ/hr

Output streams:

1. C_p of sugar crystal = 3.8275 KJ/Kg.ºC

2. C_p of losses = 3.02199 KJ/Kg.ºC

3. $\Delta H_{\text{Out}} = \Delta H_{\text{crystal}} + \Delta H_{\text{losses}}$

= {5.679 x 1000 x 3.8275 x (43-25)} + {0.383 x 1000 x 3.02199 x (43-25)}

= 412088.3041 KJ/hr

6.7. Energy balance over melter:

Assumptions:

i. Steam input Pressure = 1 bar.

ii. Operating temperature = (43-55) ^{o} C

Sl. No	Input Streams	Compositions (Ton/hr)	Sl. No	Output Streams	Compositions (Tons/hr)
1.	Total sugar crystal (Sucrose: 5.52ton/hr + Non-sucrose: 0.07824ton/hr + Impurities: 0.024ton/hr + moisture: 0.0576ton/hr)	6.084	1.	Melt Sugar (Sucrose: 5.52ton/hr + Non-sucrose: 0.07824ton/hr + Impurities: 0.024ton/hr + moisture: 2.817ton/hr)	8.439
2.	Added water	2.76			

Table 6.6: Composition balance on melter

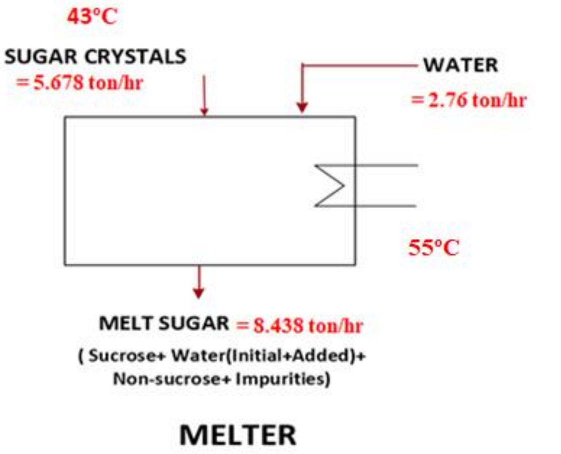
Steam requirement:

$m_{juice.}C_{p.}dT + m_{added\ water.}C_{p.}dT = m_{steam}.\ \lambda$ [λ = 2256.99 KJ/Kg at 1 bar; Ref: Steam Table]

= {6.084 x 1000 x 3.8275 x (55-43)} + {2.76 x 1000 x 4.18 x (55-43)} = m x (2256.99)

m_{steam} = 185.1491234 kg/hr

Input streams:



1. C_p of sugar crystal = 3.8275 KJ/Kg.ºC

2. Enthalpy of input steam, H_g = 2675.84 KJ/Kg. [Ref: Steam Table]

3. $\Delta H_{In} = \Delta H_{crystal} + \Delta H_{added\ water} + m_{steam}.H_g$

= {6.084 x 1000 x 3.32882 x (43-25)} + {2.76 x 1000 x 4.18 x (43-25)} + {185.1491234 x 2675.84}

= 1122249.01 KJ/hr

Output streams:

1. C_p of melt sugar = 3.80619 KJ/Kg.ºC

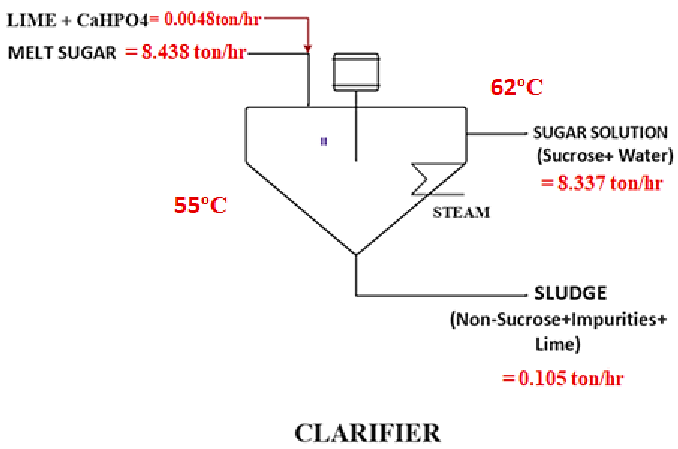
2. Enthalpy of output steam, H_l = 418.849 KJ/Kg [Ref: Steam Table]

3. $\Delta H_{Out} = \Delta H_{melt\ sugar} + m_{steam}.H_l$

= {8.439 x 1000 x 3.80619 x (55-25)} + {185.1491234 x 418.849}

= 1122249.92 KJ/hr

6.8. Energy balance over clarifier 2:



Assumptions:

i. Operating temperature = (55-62) º C

ii. Steam input at 1 bar.

Sl. No	Input Streams	Composition (Ton/hr)	Sl. No	Output Streams	Composition (ton/hr)
1.	Melt Sugar (Sucrose: 5.52ton/hr + Non-sucrose: 0.07824ton/hr + Impurities: 0.024ton/hr + moisture: 2.817ton/hr)	8.439	1	Sugar solution (Sucrose: 5.52ton/hr + water: 2.817ton/hr)	8.337
2	Lime	0.0048	2	Sludge (Impurities: 0.024ton/hr + Non-sucrose: 0.078ton/hr + lime: 0.00528ton/hr)	0.107

Table 6.7: Composition balance on clarifier 2

Steam requirement:

$m_{juice}.C_p.dT + m_{lime}.C_p.dT = m_{steam}.\ \lambda$[$\lambda$ = 2256.99 KJ/Kg at 1 bar; Ref: Steam Table]

= {8.439 x 1000 x 3.80619 x (62-55)} + {0.0048 x 1000 x 1.208 x (62-55)} =

m_{steam} x (2256.99)

m_{steam} = 99.60277762 kg/hr

Input streams:

1. Cp of melt sugar = 3.80619 KJ/Kg.ºC

2. Enthalpy of input steam, H_g = 2675.84 KJ/Kg. [Ref: Steam Table]

3. $\Delta H_{In} = \Delta H_{melt\ sugar} + \Delta H_{lime} + m_{steam}.H_g$

= {8.439 x 1000 x 3.80619 x (55-25)} + {0.0048 x 1000 x 1.208 x (55-25)} + {99.60277762 x 2675.84}

= 1230308.17 KJ/hr

Output streams:

1. Cp of sugar solution = 3.804528 KJ/Kg.ºC

2. Cp of sludge = 3.7916 KJ/Kg.ºC

3. Enthalpy of output steam, H_l = 418.849 KJ/Kg [Ref: Steam Table]

3. $\Delta H_{Out} = \Delta H_{sugar\ solution} + \Delta H_{sludge} + m_{steam}.H_l$

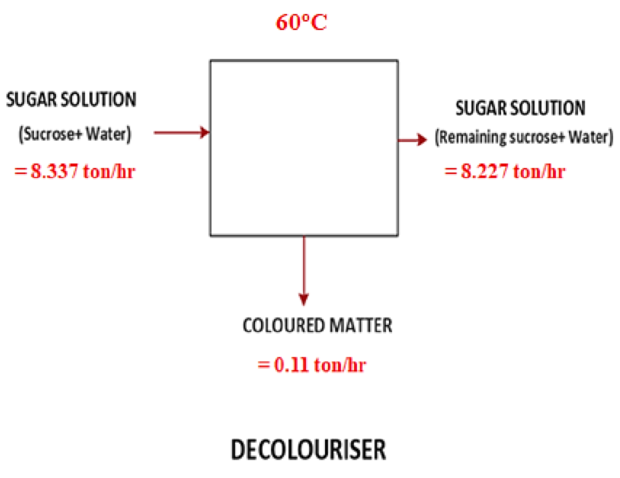
= {8.337 x 1000 x 3.804528 x (62-25)} + {0.107 x 1000 x 3.7916 x (62-25)} + {99.60277762 x 418.849}

= 1230308.416 KJ/hr

6.9. Energy balance over decolouriser:

Assumptions:

i. Operating temperature = 60ºC



Sl. No	Input Streams	Compositions (Ton/hr)	Sl. No	Output Streams	Compositions (Ton/hr)
1	Sugar solution (Sucrose: 5.52ton/hr + water: 2.8176ton/hr)	8.3376	1	Sugar solution (Sucrose: 5.4096ton/hr + water: 2.8176ton/hr)	8.2272
			2.	Coloured matter	0.1104

Table 6.8: Composition balance on decolouriser

Input streams:

1. Cpof sugar solution = 3.804528 KJ/Kg.ºC

2. $\Delta H_{\mathrm{In}} = \Delta H_{\mathrm{sugar\ solution}}$= {8.3376 x 1000 x 3.804528 x (60-25)} = 1110222.143 KJ/hr

Output streams:

1. Cp of sugar solution = 3.838673 KJ/Kg.ºC

2. Cp of coloured matter = 1.26 KJ/Kg.ºC

3. $\Delta H_{\mathrm{Out}} = \Delta H_{\mathrm{sugar\ solution}} + \Delta H_{\mathrm{coloured\ matter}}$

= {8.2272 x 1000 x 3.838673 x (60-25)} + {0.1104 x 1000 x 1.26 x (60-25)}

= 1110222.208 KJ/hr

6.10. Energy balance over crystallizer 2:

Assumptions:

i. Operating temperature = (60-50) º C

Sl. No	Input Streams	Composition (Ton/hr)	Sl. No	Output Streams	Composition (Ton/hr)
1	Sugar solution (Sucrose: 5.4096ton/hr + water: 2.8176ton/hr)	8.2272	1.	Sugar crystal (Sucrose: 4.9776ton/hr + water: 0.0497ton/hr)	5.0273
			2.	Molasses (Sucrose: 0.432ton/hr + water: 0.1632 ton/hr)	0.5952
			3.	Evaporated water	2.6016

Table 6.9: Composition balance on crystalliser 2

Steam requirement:

$m_{juice.}C_{p.}dT = m_{steam}.\lambda$ [λ = 2202.35 KJ/Kg at 1.98 bar; Ref: Steam Table]

= {8.2272 x 1000 x 3.838673 x (60-50)} = m_{steam} x 2202.35

m_{steam} = 143.3992349 kg/hr

Input streams:

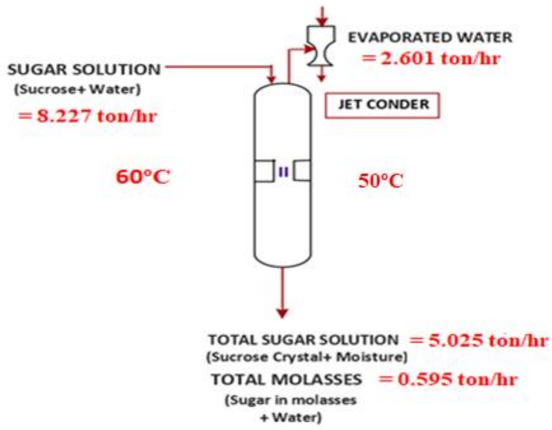
1. Cp of sugar solution = 3.838673 KJ/Kg. ºC

2. Enthalpy of input steam, H_g = 2705.84 KJ/Kg. [Ref: Steam Table]

3. $\Delta H_{In} = \Delta H_{sugar\ solution} + m_{steam}.H_g$

= {8.2272 x 1000 x 3.838673 x (60-25)} + {143.3992349 x 2705.84}

= 1493368.953 KJ/hr



VACCUM PAN CRYSTALLIZER

Output streams:

1. Cp of sugar crystal = 3.82998 KJ/Kg. ºC

2. C_p of molasses = 3.52990 KJ/Kg. ºC

3. Enthalpy of output steam, H_l = 503.493 KJ/Kg [Ref: Steam Table]

4. $\Delta H_{Out} = \Delta H_{crystal} + \Delta H_{molasses} + \Delta H_{evaporated\ water} + m_{steam}.H_l$

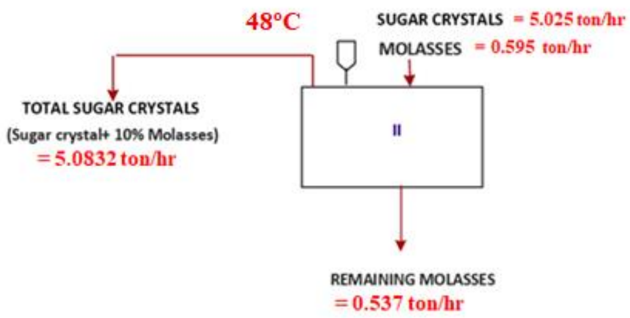
= {5.0273 x 1000 x 3.82998 x (50-25)} + {0.5952 x 1000 x 3.52990 x (50-25)} + {2.6016 x 1000 x 4.18 x (50-25)} + {143.3992349 x 503.493}

= 1493367.96 KJ/hr.

6.11. Energy balance over centrifuge 2:

Assumptions:

i. Operating temperature = 48 º C



HIGH SPEED CENTRIFUGAL BASKET

Table 6.10: Composition balance on centrifuge 2

Sl. No	Input Streams	Compositions (Ton/hr)	Sl. No	Output Streams	Compositions (Ton/hr)
1.	Sugar crystal (Sucrose: 4.9776ton/hr + water: 0.0497ton/hr)	5.0273	1.	Total sugar crystal (Sucrose: 5.0208ton/hr + moisture: 0.00657ton/hr)	5.0273
2.	Molasses (Sucrose: 0.432ton/hr + water: 0.1632ton/hr)	0.5952	2.	Total molasses (Sucrose: 0.3888ton/hr + Water: 0.1468ton/hr)	0.5356

Input streams:

1. Cp of sugar crystal = 3.82998 KJ/Kg. ºC

2. C_p of molasses = 3.52990 KJ/Kg. ºC

3. $\Delta H_{\text{in}} = \Delta H_{\text{crystal}} + \Delta H_{\text{molasses}}$

= {5.0273 x 1000 x 3.82998 x (48-25)} + {0.5952 x 1000 x 3.52990 x (48-25)}

= 491175.4635 KJ/hr.

Output streams:

1. C_p of sugar crystal = 3.85866 KJ/Kg. ºC

2. C_p of molasses = 3.65342 KJ/Kg. ºC

3. $\Delta H_{\text{Out}} = \Delta H_{\text{crystal}} + \Delta H_{\text{molasses}}$

= {5.0273 x 1000 x 3.85866 x (48-25)} + {0.5356 x 1000 x 3.65342 x (48-25)}

= 491175.5029 KJ/hr.

OVERALL ENERGY BALANCE

Table 6.11: Overall energy balance

ΔH_{Input}	Values (KJ/hr)	$\Delta H_{\text{Out put}}$	Values (KJ/hr)
Milling (Feed)	1043712	Milling (Bagasse)	181364.01
Clarifier 1 (Steam)	6135826.248	Clarifier 1 (Filter Cake)	610574.265
		Clarifier 1 (Steam Condensate)	960440.3432
Clarifier (Lime + Sulphur)	214.06	Evaporator (Evaporated water)	10119416.34
		Evaporator (Steam condensate)	9491778.941
Evaporator (Steam)	9978926.989	Crystallizer 1 (Evaporated water)	476181.42
		Crystallizer 1 (Steam condensate)	46119.806
Crystallizer 1 (Steam)	229718.122	Centrifuge 1 (Molasses)	58645.908
Melter (Added water)	207662.4	Affinator (Sucrose loss)	20833.599
		Melter (Steam condensate)	77549.525

Melter (Steam)	495429.430	Clarifier 2 (Sludge)	15010.944
Clarifier 2 (Lime)	173.952	Decolourizer (Colouring matter)	4868.640
Clarifier 2 (Steam)	266521.096	Crystallizer 2 (Evaporated water)	271867.2
		Clarifier 2 (Steam condensate)	41718.523
Crystallizer 2 (Steam)	388015.3858	Crystallizer 2 (Steam condensate)	72200.510
		Centrifuge 2	491175.502
Total input	18746199.68	Total Output	22939745.39

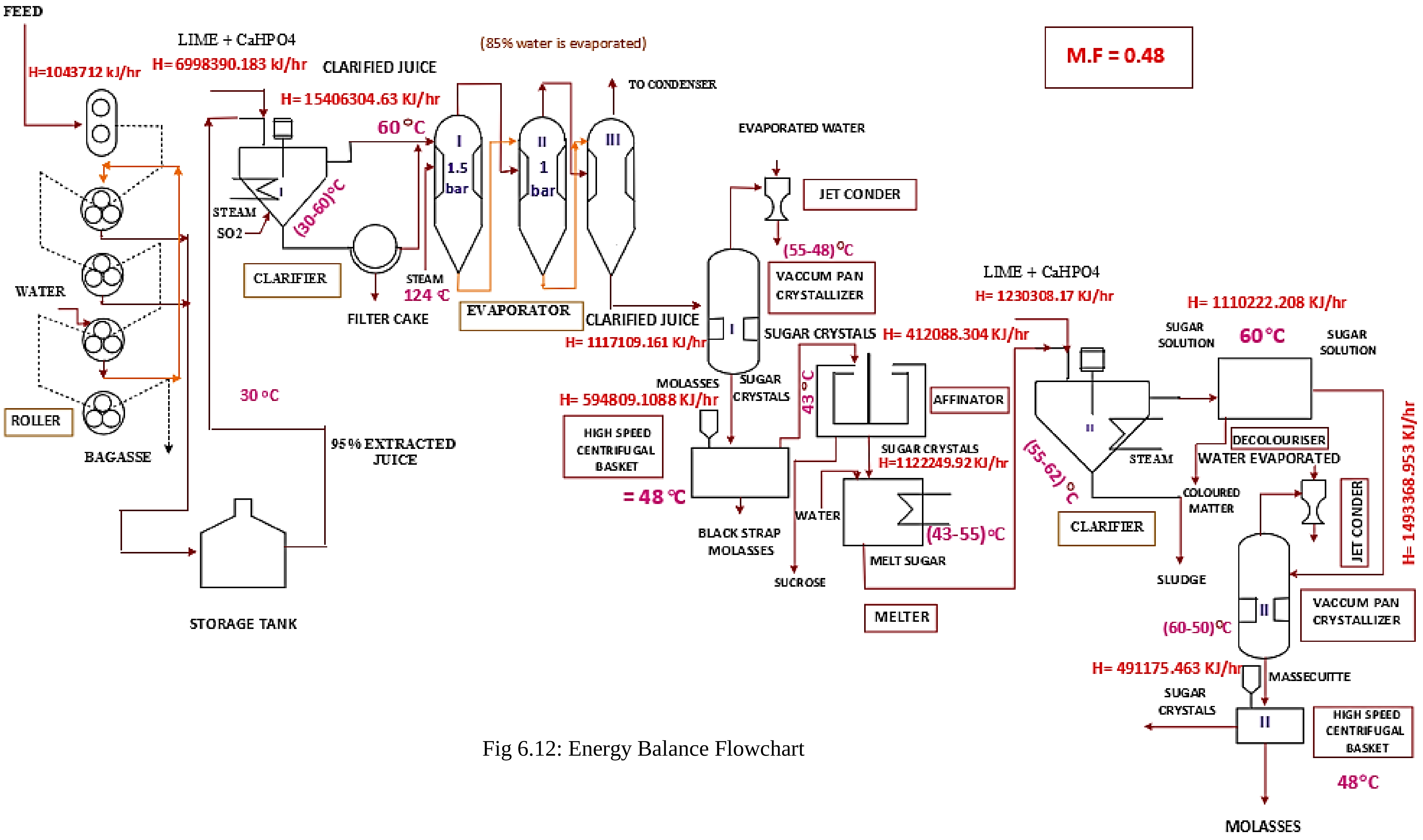


Fig 6.12: Energy Balance Flowchart

CHAPTER-7

DESIGN OF STORAGE TANK

From material balance it is found that for 1 hour operation,

Cane Juice extracted = 46.848 ton = 46848 kg

Therefore, in 2 days the amount of cane sugar extracted = (46848 ×24 × 2) kg

= 2248704 kg.

Volume of juice = (mass/density)

= (2248704 / 1590) m^3

= 1414.28 m^3.

<u>Assumptions</u>:

1. The annual per unit cost of fabrication of the tank per unit area is 2 times the annual cost of fabrication of bottom per unit area.

i.e, $C_1 = 2\ C_2$

2. The annual cost of fabricated roof per unit area is 1.8 times the annual cost of fabrication of bottom per unit area.

i.e, $C_3 = 1.8\ C_2$

3. The annual cost of foundation and land taken together per unit area of the tank bottom is 0.4 times the annual cost of fabrication per unit area.

i.e, $C_4 + C_5 = 0.4\ C_2$

Determination of diameter and height

Assuming a small tank,

The optimum tank proportion is-

$\frac{D}{H} = \frac{2\ C1}{C2 +\ C3 +\ C4 +\ C5}$

$= \frac{2(C1)}{C2 + 1.8\ C2 + 0.4\ C2}$

$= \frac{4\ C2}{3.2\ C2}$

= 1.25

D = 1.25 H

Now, $V = \frac{\pi}{4} D^2 H$

Or, $1414.28 = \frac{\pi}{4} (1.25H)^2 H$

Or, $1414.28 \times 4 = \pi \times (1.25)^2 \times H^3$

Or, H = 10.484 m. (= 34.396 ft)

So, D = 1.25 × 10.484 = 13.105 m. (= 42.995 ft)

Assuming double welded butt joint, condition for small tank is-

$$D (H-1) \leq 1720$$

Now, D (H-1) = 42.995 (34.396 – 1)

= 1435.86 ft.

Our assumption of small tank is correct.

Hence,

Diameter of the tank, D= 13.105 m

Height of the tank, H = 10.484 m

Joint efficiency factor, E = 0.85

Specific gravity of the juice, G = 1

Allowable stress, S = 12.1 kgf/mm^2 = 1210 kgf/cm^2 (IS: 2002, 1962, Grade 2B quality steel).

<u>Determination of number of plates & thickness section</u>:

Circumference of the tank = π × D = π × 13.105 = 41.17 m.

Effective circumference = (41.17 – 2 x n x 10^{-3}), where n = Number of plates.

Length of each plate, L = $\frac{(41.17 - 2 \text{ x n x } 10-3)}{n}$

Assume, n = 5; L = 8.232 m < 10 m.

n = 4; L = 10.290 m >10 m.

Therefore, assuming n = 5, then length of each plate, L = 8.232 m.

According to Indian standard, number of thickness section to be taken in case of storage tank design is generally equal to the number of plates used.

∴ Number of thickness section = 5

Width of each plate, W = H / n

= 10.848/5 = 2.1696 m = 2169.6 mm.

Available width, W = 2200 mm. [Ref: Appendix B]

Thickness calculation of each section:

$$t_1 = \frac{50\ X\ (H-0.3)\ X\ D\ X\ G}{S\ X\ E}$$

$$= \frac{50\ X\ (10.484-0.3)\ X\ 13.105\ X\ 1}{1210\ X\ 0.85}$$

= 6.48 mm

$\therefore$ t_1 (standard) = 7 mm.

$$t_2 = \frac{50\ X\ (8.284-0.3)\ X\ 13.105\ X\ 1}{1210\ X\ 0.85}$$

= 5.08 mm.

$\therefore$ t_2 (standard) = 5.5 mm.

$$t_3 = \frac{50\ X\ (6.084-0.3)\ X\ 13.105\ X\ 1}{1210\ X\ 0.85}$$

= 3.68 mm.

$\therefore$ t_3 (standard) = 5 mm.

$$t_4 = \frac{50\ X\ (3.884-0.3)\ X\ 13.105\ X\ 1}{1210\ X\ 0.85}$$

= 2.28 mm.

$\therefore$ t_4 (standard) = 5 mm.

$$t_5 = \frac{50\ X\ (1.684-0.3)\ X\ 13.105\ X\ 1}{1210\ X\ 0.85}$$

= 0.88 mm.

$\therefore$ t_5 (standard) = 5 mm.

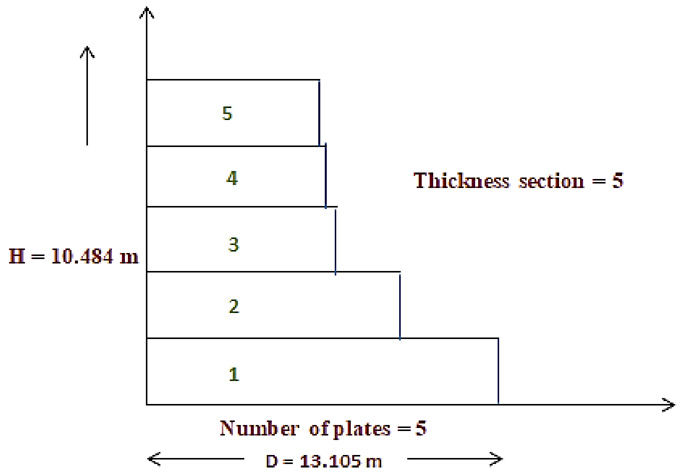


Fig 7.1: Thickness section of storage tank

According to Clause 6.3.3.2 IS: 803-1976, minimum thickness for nominal tank diameter less than 15 m is 5 mm.

Thickness section	Height , H (m)	Minimum thickness (mm)	Standard and final thickness (mm) [Appendix B]
1	10.484	6.48	7
2	8.284	5.08	5.5
3	6.084	3.68	5
4	3.884	2.28	5
5	1.684	0.88	5

Table 7.1: Data table for storage tank

CHAPTER-8

DESIGN OF MULTI EFFECT EVAPORATOR

<ins>Assumptions:</ins>

1. Temperature of feed, T_f = 60°C

2. Steam is entering at a pressure,

P_s = 2.25 bar

3. Pressure maintained at the 2nd effect, P_2 = 1bar

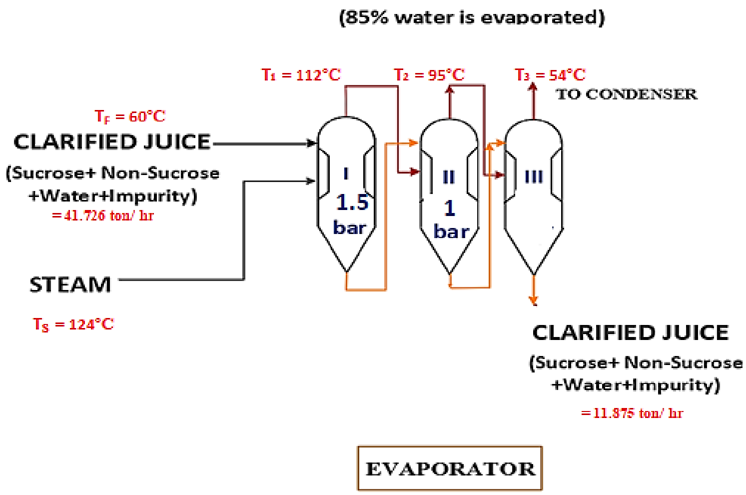
4. Coefficient of heat transfer is assumed as,

U_1 = 4600 KJ/hr.m^2°C,

U_2 = 2500 KJ/hr.m^2°C,

U_3 = 1200 KJ/hr.m^2°C for effects 1, 2, 3 respectively.

5. Negligible BPR.



From material balance calculations,

Feed flow rate to evaporator = 41.726 ton/hr

Due to this large flow rate and to decrease the load on it, the feed is divided into two parts and it is allowed to flow through two lines of parallelly connected three evaporator in series.

Therefore, Feed, F = 41.726/2 ton/hr = 20863 kg/hr

Let, V_1, V_2 and V_3 are the flow rates of the evaporated water, and

L_1, L_2 and L_3 are the flow rates of juice in the outlet of effects 1, 2 and 3 respectively.

Weight fraction of sucrose in the feed, $x_f = \frac{6.32016}{41.726} = 0.1514632126$

Weight fraction of sucrose in the product, $x_{L3} = \frac{6.32016}{11.8752} = 0.5322150364$

By solid balance,

$Fx_f = L_1 x_{L1} = L_2 x_{L2} = L_3 x_{L3}$

Total product, $L_3 = \frac{F \times xf}{x3} = \frac{20863 \times 0.1514632126}{0.5322150364} = 5937.406477$ Kg/hr

Material Balance:

On 1st effect:

$F = V_1 + L_1$

On 2nd effect:

$L_1 = V_2 + L_2$

On 3rd effect:

$L_2 = V_3 + L_3$

Therefore, overall material balance, $F - L_3 = V_1 + V_2 + V_3$

$V_1 + V_2 + V_3 = 20881 - 5937.406477 = 14925.59352$ Kg/hr

Assuming equal heat transfer surface area, the difference in pressure in each effect will be nearly equal, Average pressure difference $= \frac{Ps - P3}{3} = \frac{2.25 - 0.15}{3}$ = 0.7 bar per effect

Table 8.1: Data table for Evaporator

Effect	Pressure, bar	Pressure difference	Steam/ vapour temperature , °C	λ, Latent heat KJ/Kg
Steam chest 1st effect	2.25		T_s = 123.99	λ_s = 2191.06
2nd effect	1.55	0.7	T_1 = 112.308	λ_1=2223.702
3rd effect	0.85	0.7	T_2 = 95.15	λ_2 = 2269.8
Vapour to condenser	0.15	0.7	T_3 = 54	λ_3 = 2373.51

(Temperatures and latent heat values are from steam table)

Energy balance calculations,

1st effect,

$S\lambda s + FC_f\ (T_f - T_1) = V_1\lambda_1$

$(2191.06 \times S) + [20863 \times 3.716338 \times (60-112.308)] = V_1 \times 2223.702$

$(2191.06 \times S) - (V_1 \times 2223.702) = 4055646.364$

2nd effect,

$V_1\lambda_1 + (F - V_1)\ C1\ (T_1 - T_2) = V_2\lambda_2$

$(2223.702 \times V_1) + [(20863 - V_1) \times 3.07055372 \times (112.308 - 95.15)] = 2269.8 \times V_2$

$(2171.017439 \times V_1) - (2269.8 \times V_2) = -1099157.99$

3^{rd} effect,

$V_2\lambda_2 + (F-V_1-V_2)\ C2\ (T_2-T_3) = V_3\lambda_3$

$(2269.8\times V_2) - [(20863-V_1-V_2)\times 2.819725931\times (95.51-54)] = 2373.51\times V_3$

$(2153.768278\times V_2) - (116.0317221\times V_1) - (2373.51\times V_3) = -2420769.817$

(Here C_f, C1, C2, C3 are specific heats of juice in feed and effects 1, 2, 3)

Solving energy balance and overall material balance equations,

S = 6598.001712 Kg/hr

V_1 = 4677.322441 Kg/hr

V_2 = 4958.01682 Kg/hr

V_3 = 5290.254259 Kg/hr

Area calculations,

$$A_1 = \frac{S\times\lambda s}{U1\times(Ts-T1)} = \frac{6598.00712\times 2191.06}{4600\times(123.99-112.308)} = 269.0243934\ m^2$$

$$A_2 = \frac{V1\lambda 1}{U2\times(T1-T2)} = \frac{4677.322441\times 2223.702}{2500\times(112.308-95.15)} = 242.4751432\ m^2$$

$$A_3 = \frac{V2\lambda 2}{U3\times(T2-T3)} = \frac{4958.01682\times 2269.8}{1100\times(85.96-54)} = 248.618283\ m^2$$

$$\text{Mean Area} = \frac{A1+A2+A3}{3} = \frac{269.0243934+242.4751432+248.618283}{3} = 253.3726065\ m^2$$

Deviations of area are:

Deviation in 1st effect = $\pm \frac{Am-A1}{Am} = \frac{253.3726065 - 269.0243934}{253.3726065} \times 100$ = 6.18 %

Deviation in 2nd effect = $\pm \frac{Am-A2}{Am} = \frac{253.3726065 - 242.4751432}{253.3726065} \times 100$ = 4.3 %

Deviation in 3rd effect = $\pm \frac{Am-A3}{Am} = \frac{253.3726065 - 248.618283}{253.3726065} \times 100$ = 1.88 %

Deviations are less than 10%. Therefore,

S = 6598.001712 Kg/hr

V_1 = 4677.322441 Kg/hr

V_2 = 4958.01682 Kg/hr

V_3 = 5290.254259 Kg/hr

CONCLUSION

Sugar is an important chemical compound from economical point of view. During this project our job was to study the development and designing of the complete process and also the equipment used. Proper raw material, optimum efficiency, safety and economy of the plant have also been looked into.

In course of our project, we have studied starting from the various available process factors like raw materials, economy, efficiency etc. A suitable process was selected to serve our desired purpose in an economical way. A complete material balance and energy balance of the whole process and in each of the equipment is done in a comprehensive manner.

The project has helped us in great way in acquiring good knowledge of the practical problems that a chemical engineer must face while designing a practical plant.

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APPENDICES

1. Solubility calculation:

Crystallization is performed at vacuum (0.15 bar). The boiling point at this pressure is 54º C. Neglecting boiling point rise, solubility of sucrose in water is given by –

$$Y = 68.18 + (0.1348 \times T) + (0.000531 \times T)$$

Where, T = Temperature in º C.

Y = Percentage sucrose at saturation.

At 54 º C, Y = 75.48%

Therefore, sucrose per kg of water = Y/ (100-Y) = 75.48/ (100-75.48)

= 3.07 Kg sucrose per kg water.

Purity of the sucrose = weight of sucrose / weight of total solids

= 13.167/ (13.167+ 0.1 + 0.495)

= 0.9567

= 95.67%

Solubility coefficient for 95.67% pure sucrose solution = 0.87

Therefore, effective solubility = (3.07 × 0.87) = 2.67 kg of sucrose /kg of water.

2. For a tank of a particular nominal diameter, the minimum thickness of the plates to be followed is given by Clause 6.3.3.2 of Codebook IS: 803-1976.

6.3.3.2 In no case shall the nominal thickness of shell plates (including shell extensions for floating roof) be less than the following:

Nominal Tank Diameter m	*Minimum Nominal Thickness* mm
Less than 15	5·0
Over 15 up to and including 36	6·0
Over 36 up to and including 60	8·0
Over 60	10·0

3. Overall heat transfer coefficient,U of sugar solution used in designing of multiple effect evaporator is obtained from Perry’s handbook. (Table 11-2 , Page 11-21).

TABLE 11-2 Overall Heat-Transfer Coefficients for Coils Immersed in Liquids

U Expressed as Btu/(h · ft^2 · °F)

Substance inside coil	Substance outside coil	Coil material	Agitation	*U*
Steam	Water	Lead	Agitated	70
Steam	Sugar and molasses solutions	Copper	None	50–240
Steam	Boiling aqueous solution			600
Cold water	Dilute organic dye intermediate	Lead	Turboagitator at 95 r.p.m.	300
Cold water	Warm water	Wrought iron	Air bubbled into water surrounding coil	150–300
Cold water	Hot water	Lead	0.40 r.p.m. paddle stirrer	90–360
Brine	Amino acids		30 r.p.m.	100
Cold water	25% oleum at 60°C.	Wrought iron	Agitated	20
Water	Aqueous solution	Lead	500 r.p.m. sleeve propeller	250
Water	8% NaOH		22 r.p.m.	155
Steam	Fatty acid	Copper (pancake)	None	96–100
Milk	Water		Agitation	300
Cold water	Hot water	Copper	None	105–180
60°F. water	50% aqueous sugar solution	Lead	Mild	50–60
Steam and hydrogen at 1500 lb./sq. in.	60°F. water	Steel		100–165
Steam 110–146 lb./sq. in. gage	Vegetable oil	Steel	None	23–29
Steam	Vegetable oil	Steel	Various	39–72
Cold water	Vegetable oil	Steel	Various	29–72

4. Evaluation of steam pressure and temperature for input to various equipments from Steam Table:

T C	P_{sat} kPa	v_f m3/kg	v_g m3/kg	v_{fg} m3/kg	h_f kJ/kg	h_g kJ/kg	h_{fg} kJ/kg	u_f kJ/kg	u_g kJ/kg	u_{fg} kJ/kg	s_f kJ/kg K	s_g kJ/kg K	s_{fg} kJ/kg K
54	14.999	0.001014	10.02	10.02	225.848	2599.36	2373.51	225.833	2449.04	2223.21	0.7543	8.0091	7.2547
56	16.507	0.001015	9.159	9.158	234.202	2602.85	2368.65	234.185	2451.66	2217.48	0.7798	7.9757	7.1959
58	18.143	0.001016	8.381	8.380	242.558	2606.34	2363.78	242.540	2454.27	2211.73	0.8051	7.9428	7.1377
60	19.916	0.001017	7.679	7.678	250.918	2609.80	2358.89	250.898	2456.87	2205.97	0.8302	7.9104	7.0802
62	21.834	0.001018	7.044	7.043	259.281	2613.26	2353.98	259.259	2459.46	2200.20	0.8552	7.8786	7.0234
64	23.906	0.001019	6.470	6.469	267.647	2616.70	2349.05	267.623	2462.04	2194.41	0.8801	7.8472	6.9671
66	26.144	0.001020	5.949	5.948	276.016	2620.13	2344.11	275.990	2464.61	2188.62	0.9048	7.8163	6.9115
68	28.557	0.001021	5.476	5.475	284.389	2623.54	2339.15	284.360	2467.16	2182.80	0.9294	7.7859	6.8564
70	31.156	0.001023	5.047	5.046	292.765	2626.94	2334.18	292.733	2469.71	2176.97	0.9539	7.7559	6.8020
72	33.952	0.001024	4.656	4.655	301.144	2630.32	2329.18	301.109	2472.24	2171.13	0.9782	7.7263	6.7481
74	36.957	0.001025	4.300	4.299	309.527	2633.69	2324.16	309.489	2474.76	2165.27	1.0024	7.6972	6.6948
76	40.184	0.001026	3.976	3.975	317.913	2637.04	2319.13	317.872	2477.27	2159.40	1.0265	7.6686	6.6421
78	43.645	0.001028	3.680	3.679	326.303	2640.37	2314.07	326.258	2479.76	2153.51	1.0505	7.6403	6.5899
80	47.353	0.001029	3.409	3.408	334.696	2643.69	2308.99	334.648	2482.25	2147.60	1.0743	7.6125	6.5382
82	51.322	0.001030	3.162	3.161	343.093	2646.99	2303.90	343.040	2484.72	2141.68	1.0980	7.5850	6.4870
84	55.567	0.001032	2.935	2.934	351.494	2650.27	2298.78	351.437	2487.17	2135.74	1.1216	7.5579	6.4364
86	60.102	0.001033	2.727	2.726	359.899	2653.53	2293.64	359.837	2489.62	2129.78	1.1450	7.5313	6.3862
88	64.942	0.001034	2.537	2.536	368.308	2656.78	2288.47	368.240	2492.04	2123.80	1.1684	7.5050	6.3366
90	70.104	0.001036	2.361	2.360	376.720	2660.01	2283.29	376.648	2494.46	2117.81	1.1916	7.4790	6.2874
92	75.603	0.001037	2.200	2.199	385.137	2663.21	2278.08	385.059	2496.86	2111.80	1.2147	7.4534	6.2387
94	81.457	0.001039	2.052	2.051	393.558	2666.40	2272.84	393.474	2499.25	2105.77	1.2377	7.4282	6.1905
96	87.683	0.001040	1.915	1.914	401.984	2669.57	2267.58	401.893	2501.62	2099.73	1.2606	7.4033	6.1427
98	94.299	0.001042	1.789	1.788	410.414	2672.72	2262.30	410.316	2503.98	2093.66	1.2833	7.3787	6.0954
100	101.325	0.001043	1.673	1.672	418.849	2675.84	2256.99	418.743	2506.32	2087.57	1.3060	7.3545	6.0485
102	108.778	0.001045	1.566	1.565	427.289	2678.95	2251.66	427.175	2508.64	2081.47	1.3285	7.3306	6.0020
104	116.678	0.001046	1.466	1.465	435.733	2682.03	2246.30	435.611	2510.95	2075.34	1.3510	7.3070	5.9560
106	125.047	0.001048	1.374	1.373	444.183	2685.09	2240.91	444.052	2513.25	2069.19	1.3733	7.2837	5.9103
108	133.905	0.001050	1.289	1.288	452.638	2688.13	2235.49	452.498	2515.52	2063.03	1.3955	7.2606	5.8651
110	143.273	0.001051	1.210	1.209	461.099	2691.14	2230.04	460.948	2517.78	2056.83	1.4177	7.2379	5.8203

T C	P_{sat} kPa	v_f m3/kg	v_g m3/kg	v_{fg} m3/kg	h_f kJ/kg	h_g kJ/kg	h_{fg} kJ/kg	u_f kJ/kg	u_g kJ/kg	u_{fg} kJ/kg	s_f kJ/kg K	s_g kJ/kg K	s_{fg} kJ/kg K
112	153.173	0.001053	1.137	1.136	469.565	2694.13	2224.57	469.404	2520.03	2050.62	1.4397	7.2155	5.7758
114	163.628	0.001055	1.069	1.068	478.038	2697.10	2219.06	477.865	2522.25	2044.38	1.4616	7.1933	5.7318
116	174.662	0.001057	1.005	1.004	486.516	2700.04	2213.52	486.332	2524.46	2038.12	1.4834	7.1715	5.6880
118	186.297	0.001058	0.946389	0.945331	495.001	2702.95	2207.95	494.804	2526.64	2031.84	1.5051	7.1498	5.6447
120	198.559	0.001060	0.891572	0.890512	503.493	2705.84	2202.35	503.282	2528.81	2025.53	1.5267	7.1285	5.6017
122	211.472	0.001062	0.840500	0.839438	511.991	2708.70	2196.71	511.766	2530.96	2019.19	1.5483	7.1074	5.5591
124	225.062	0.001064	0.792881	0.791817	520.496	2711.53	2191.04	520.257	2533.09	2012.83	1.5697	7.0865	5.5168
126	239.354	0.001066	0.748448	0.747382	529.009	2714.34	2185.33	528.754	2535.19	2006.44	1.5910	7.0659	5.4749
128	254.377	0.001068	0.706958	0.705890	537.530	2717.11	2179.58	537.258	2537.28	2000.02	1.6123	7.0455	5.4332
130	270.156	0.001070	0.668188	0.667118	546.058	2719.86	2173.80	545.769	2539.34	1993.57	1.6334	7.0254	5.3919
132	286.720	0.001072	0.631933	0.630861	554.595	2722.57	2167.98	554.287	2541.38	1987.09	1.6545	7.0054	5.3510
134	304.097	0.001074	0.598007	0.596933	563.140	2725.25	2162.11	562.813	2543.40	1980.59	1.6754	6.9857	5.3103
136	322.317	0.001076	0.566238	0.565162	571.693	2727.90	2156.21	571.347	2545.39	1974.05	1.6963	6.9662	5.2699
138	341.408	0.001078	0.536469	0.535391	580.256	2730.52	2150.26	579.888	2547.36	1967.47	1.7171	6.9469	5.2298
140	361.402	0.001080	0.508556	0.507476	588.828	2733.10	2144.27	588.438	2549.31	1960.87	1.7378	6.9279	5.1900
142	382.328	0.001082	0.482365	0.481283	597.410	2735.65	2138.24	596.996	2551.23	1954.23	1.7585	6.9090	5.1505
144	404.219	0.001084	0.457774	0.456690	606.002	2738.16	2132.16	605.564	2553.12	1947.55	1.7790	6.8903	5.1113
146	427.106	0.001086	0.434672	0.433585	614.604	2740.64	2126.03	614.140	2554.98	1940.84	1.7995	6.8718	5.0723
148	451.022	0.001089	0.412954	0.411865	623.217	2743.07	2119.86	622.726	2556.82	1934.10	1.8199	6.8535	5.0336
150	476.000	0.001091	0.392524	0.391433	631.841	2745.47	2113.63	631.322	2558.63	1927.31	1.8402	6.8353	4.9952
152	502.073	0.001093	0.373295	0.372202	640.477	2747.84	2107.36	639.928	2560.41	1920.49	1.8604	6.8174	4.9570
154	529.277	0.001095	0.355186	0.354090	649.124	2750.16	2101.04	648.544	2562.17	1913.62	1.8806	6.7996	4.9190
156	557.644	0.001098	0.338120	0.337023	657.783	2752.44	2094.66	657.170	2563.89	1906.72	1.9006	6.7819	4.8813
158	587.212	0.001100	0.322029	0.320930	666.454	2754.68	2088.23	665.808	2565.58	1899.77	1.9206	6.7645	4.8438
160	618.016	0.001102	0.306849	0.305747	675.138	2756.88	2081.74	674.457	2567.24	1892.79	1.9406	6.7472	4.8066
162	650.092	0.001105	0.292519	0.291414	683.836	2759.04	2075.20	683.117	2568.87	1885.75	1.9604	6.7300	4.7696
164	683.477	0.001107	0.278985	0.277878	692.546	2761.15	2068.60	691.790	2570.47	1878.68	1.9802	6.7130	4.7328
166	718.210	0.001110	0.266195	0.265085	701.271	2763.22	2061.95	700.474	2572.03	1871.56	2.0000	6.6961	4.6962
168	754.328	0.001112	0.254102	0.252990	710.010	2765.24	2055.23	709.171	2573.56	1864.39	2.0196	6.6794	4.6598

5. Allowable stress data for determination of thickness of each plate in designing storage tank obtained from Appendix A of codebook IS: 2825-1969.

APPENDIX A

(*Clause* 2.2.1.1)

ALLOWABLE STRESS VALUES FOR FERROUS AND NON-FERROUS MATERIAL

A-1. STRESS VALUES

A-1.1 The allowable stress values for carbon and low alloy steels are given in Table A.1 as determined from the criteria given in Table 2.1 and Appendix B.

TABLE A.1 ALLOWABLE STRESS VALUES FOR CARBON AND LOW ALLOY STEEL IN TENSION

Material Specification	Grade or Designation	Mechanical Properties			Allowable Stress Values in kgf/mm² at Design Temperature °C												
		Tensile Strength *Min* kgf/mm² R_{20}	Yield Stress *Min* kgf/mm² E_{20}	Percentage Elongation *Min* on Gauge Length $=5{\cdot}65\sqrt{S_0}$	Up to 250	Up to 300	Up to 350	Up to 375	Up to 400	Up to 425	Up to 450	Up to 475	Up to 500	Up to 525	Up to 550	Up to 575	Up to 600
				Plates													
IS : 2002-1962	I	37	0·55 R_{20}	26	9·5	8·7	7·8	7·5	7·2	5·9	4·3	3·6	—	—	—	—	—
IS : 2002-1962	2A	42	0·50 R_{20}	25	9·8	9·0	8·1	7·7	7·4	5·9	4·3	3·6	—	—	—	—	—
IS : 2002-1962	2B	52	0·50 R_{20}	20	12·1	11·1	10·0	9·5	8·3	5·9	4·3	3·6	—	—	—	—	—
IS : 2041-1962	20Mo55	48	28	20	14·3	13·2	12·3	11·9	11·5	11·2	10·8	7·7	5·6	3·7	—	—	—
IS : 2041-1962	20Mn2	52	30	20	14·0	12·8	11·6	11·0	8·3	5·9	4·3	3·6	—	—	—	—	—
IS : 1570-1961	15Cr90Mo55	50	30	20	16·0	15·2	14·4	13·8	13·4	13·0	12·6	11·7	8·6	5·8	3·5	—	—
IS : 1570-1961	C15Mn75	42	23	25	10·7	9·8	8·9	8·4	8·1	5·9	4·3	3·6	—	—	—	—	—
				Forgings													
IS : 2004-1962	Class 1	37	0·50 R_{20}	—	8·6	7·9	7·1	6·8	6·5	5·9	4·3	3·6	—	—	—	—	—
IS : 2004-1962	Class 2	44	0·50 R_{20}	15	10·2	9·3	8·5	8·0	7·7	5·9	4·3	3·6	—	—	—	—	—
IS : 2004-1962	Class 3	50	0·50 R_{20}	21	11·7	10·7	9·6	9·1	8·3	5·9	4·3	3·6	—	—	—	—	—
IS : 2004-1962	Class 4	63	0·50 R_{20}	15	14·7	13·4	12·2	11·5	8·3	5·9	4·3	3·6	—	—	—	—	—
IS : 1570-1961	20Mo55	48	28	20	14·3	13·2	12·3	11·9	11·5	11·2	10·8	7·7	5·6	3·7	—	—	—
IS : 2611-1964	15Cr90Mo55	50	30	20	16·0	15·2	14·4	13·8	13·4	13·0	12·6	11·7	8·6	5·8	3·5	—	—
IS : 1570-1961	10Cr2Mo1	50	32	20	17·9	17·3	16·4	16·1	15·8	15·3	14·9	12·7	9·6	7·0	4·9	3·2	2·3

(*Continued*)