MATERIAL BALANCE

5000 tpd of sugarcane are to be processed. Assuming that the factory operates for 20 hours per day. Thus we shall require processing 250 tons of sugarcane per hour.

Note: 1. All units where otherwise mentioned are in tons per hour.
2. The word 'analyses' wherever use implies particular materials following per hour in tons.

Basis: 250 tons per hour

Choosing standard Indian cane quality as below:

Water	70.0 %
Sucrose	14.0 %
Reducing sugars	0.5 %
Fibre	13.0 %
Ash and other impurities	2.5 %

Thus 250 tons cane feed per hour will contain:

Water	175.00
Sucrose	35.00
Reducing sugars	1.25
Fibre	32.50
Ash and other impurities	6.25
	250.00

Raw sugar manufacturing:

(1) Milling plant

Water used in milling operation is 25 – 30% of sugar cane.
Assume it as 25%.
Therefore imbition water used = $0.25 \times 250 = 62.5$
Assuming milling efficiency 95% i.e. 95% of sucrose goes into the juice.
Thus sucrose content in juice = $0.95 \times 35 = 33.25$
Unextracted sucrose = $0.05 \times 35 = 1.75$
The final bagasse from last mill contains the unextracted sucrose, woody fibre and 40 – 55% (assume 50%) water.
Thus water content in bagasse = $32.5 + 1.75 = 34.25$
Amount of bagasse = 32.5 fibre + 1.75 sucrose + 34.25 water = 68.5
Overall output of mill or juice entering the clarifier will have the following composition:

Water	= 175 + 62.5 – 34.25 = 203.25
Sucrose	= 33.25
Reducing sugars	= 1.25
Impurities	= 6.25
Thus total juice	= 244

(2) Clarifier

Reagent used: lime (0.5 kg lime/ton of sugar cane)
Thus lime to be added = 0.5 × 250 = 125 kg = 0.125 ton
Assume 96% efficiency of clarifier to remove impurities.
Therefore impurities to be removed = 0.96 × 6.25 = 6.00
Total sludge from clarifier = 0.125 + 6.0 = 6.125
Amount of clarified juice entering in the evaporator = 244 – 6.0 = 238
This clarified juice is fed to the first effect of the quadruple effect evaporator and analyses as follows:

Water	203.25
Sucrose	33.25
Impurities	0.25
Reducing sugars	1.25
Thus total juice	238.00

% of solids in this juice = {(33.25 + 0.25 + 1.25) × 100}/238 = 14.60

(3) Evaporator

Typical evaporator load = 75 – 80% of clarified juice
Assume 76% of clarified juice as evaporator load.
Thus evaporator load = 0.76 × 238 = 180.88
Input to the evaporator = (203.25 water + 33.25 sucrose + 0.25 impurities + 1.25 reducing Sugars)
= 238
Water removed in the evaporator = 180.88
Water remaining in the juice = 203.35 – 180.88 = 22.37

Hence output of evaporator analyses as follows:

Water	22.37
Sucrose	33.25
Impurities	0.25
Reducing sugars	1.25
Thus total solution	57.12

% of solids in this concentrated solution = {(33.25 + 0.25 + 1.25) × 100}/57.12 = 60.84

(4) Crystallizer 1

Crystallization of concentrated juice is done in a vacuum pan crystallizer. Crystallization is done at vacuum not exceeding 25 in (635mm).
Hence assume 580 mm Hg vacuum in crystallizer.
Therefore absolute pressure = 760 - 560
= 280 mmHg
= (280 × 1.013)/760 bar

= 0.2666 bar

Thus boiling point (from steam table) at this pressure = 61.42^0C

Boiling point rise = 4^0C

Solubility of sucrose in water is given by

$$Y = 68.18 + 0.1348 \times t + 0.000531 \times t$$

Where Y is % sucrose at saturation

t is temperature in ^{0}C

At 65.42^{o}C, Y becomes = 73.03%

Therefore sucrose per kg of water = Y/(100 – Y) = 73.03/(100 - 73.03)

= 2.71 kg Sucrose/ kg of water

But since impurities are present. Therefore purity can be calculated as

Purity = wt. of sucrose/ total wt. of solids

= 3.25/(33.25 + 0.25 + 1.25)

= 0.957 i.e. 95.7%

Hence the solubility is reduced by factor called solubility coefficient.

For purity of 95.7%, Solubility coefficient = 0.97

Thus effective solubility = 2.71 × 0.97

= 2.6287 kg of sucrose/kg of water

Input to crystallizer = (22.37 water + 33.25 sucrose + 1.25 reducing sugars + 0.25 impurities)

Assume 92% of sucrose recovery as crystal with respect to initial sucrose content in feed.

Weight of sucrose crystal formed = 0.92 × 33.25

= 30.59

Weight of reducing sugar crystals = 0.33 × 1.25

= 0.4125

Moisture associated with crystals = 1% of crystal weight

= 0.01 × 30.59 + 0.01 × 0.4125

= 0.3059 + 0.004125

= 0.3100

Sucrose in molasses = 33.25 - 30.59

= 2.66

Reducing sugar left in molasses = 1.25 – 0.4125 = 0.8375

Total sugar in molasses = 2.66 + 0.8375 = 3.4975

Water required to dissolve this = 3.4975/2.6287 = 1.331

Hence water to be evaporated = initial water – associated water – water in molasses

= 22.37 – 0.31 – 1.331

= 20.729

<u>Out put of crystallizer</u>:

(a) Solids: 31.4375

(30.59 sucrose + 0.3059 water) crystals +

(0.4125 reducing sugars + 0.004125 water) crystals +

0.125 impurities

(b) Molasses: 4.9535

(1.331 water + 2.66 sucrose + 0.8375 reducing sugar + 0.125 impurities)

(a) + (b) = Input to centrifuge = 31.4375 + 4.9535 = 36.3910

(5) Centrifuge

Assume 10% molasses adheres to the crystal.

Output of centrifuge

= (30.59 sucrose + 0.3059 H_2O) + (0.4125 reducing sugars + 0.004125 H_2O) + 0.125 impurities + 0.4954 molasses

= 31.9329

= input to affination step

<u>CANE SUGAR REFINING:</u>

(6) Affination

The first step in refining process is called affination or washing and consists of removing the adhering film molasses from the surface at the raw sugar crystal.

The separation process involves mingling the raw with a heavy syrup (about 75% solids) then purging the mixture in centrifugals and washing with hot water after the syrup has been spun off.

Best magma temperature is 43^0C.

Lyle warned "sugar loss in affination may be very large especially if the syrup is stored in tanks where it is heated".

Assuming 5% of sucrose is lost in affination along with molasses.

Output of affination step (i.e. washed sugar) analyses as follows:

Sucrose	= 30.59 – 0.05 × 30.59
	= 29.0605
Water	= 0.31
Reducing sugars	= 0.4135
Impurities	= 0.125
Total	= 29.909

(7) Melting or dissolving the washed sugar

The washed sugar is dissolved in about one-half its weight of water in a tank provided with mixing arms and called a melter, exhaust steam being applied from a perforated coil to aid solution.

Therefore water added for melting = 29.0605/2

= 14.5302

Therefore melt sugar analyses as follows:

Sucrose	= 29.0605
Water	= 0.31 + 14.5303

= 14.8403

Reducing sugars	= 0.4135
Impurities	= 0.125
Total	= 44.4393

(8) Defecation or clarification

(a) Prescreening of liquors - screening of melt liquors to remove strings, jute, twine and other coarse material has always been customarily but only during the past two decades has it become standard practice to subject liquors to fine screening.
But here assume that there is no such types of material in melt liquor.

(b) Lime – in the batch system, first a part of the lime was added, neat the required P_2O_5 then the remainder of the lime, to give a pH of 7.0 to 7.3 on the clarified liquor.
The amount of lime used ranges from 400 to 500 lb CaO per 10^6 lb melt, the average yearly figure for one refinery using Williamson clarification being 460 lb of CaO with 175 lb of P_2O_5 i.e. 635 ton per 10^6 ton melt.

Therefore lime to be added = $(44.4393 \times 635)/10^6$
= 0.0282 tons/hr
The reducing sugar does not dissolve in water and it goes along with sludge.
Assuming all impurities are removed and efficiency of the clarifier as 100%.
Thus the solution from clarifier contains sucrose and water & the sludge contains phosphate precipitate and reducing sugars.
The solution from this clarifier analyses as follows:

Water	14.8403
Sucrose	29.0605
Total	43.9008

(9) Decolourization

Assuming the colouring matter content in the solution from clarification as 2% of sucrose.
Therefore colouring matter = 0.02×29.0605
= 0.5812
Assume all colour is removed in the bone char bed decolourizer.
Thus colour removed = 0.5812
Solution from decolourizer analyses as follows:

Sucrose	= 29.0605 – 0.5812
	= 28.4793
Water	= 14.8403
Total	= 43.3196

(10) Crystallizer 2

Assuming same pressure as that of crystallizer 1.
Therefore solubility of sucrose in water as calculated before = 2.71 kg sucrose/kg water

Here no impurities are present, hence there is no need to consider solubility coefficient.
Assume 92% sucrose recovery as crystals with respect to initial sucrose content in feed.
Therefore weight of crystals formed = $0.92 \times 28.4793 = 26.2010$
Moisture associated = $0.01 \times 26.2010 = 0.26201$
Sucrose in molasses = $28.4793 - 26.2010$
$= 2.2783$
Therefore water in molasses = $2.2783 \div 2.71 = 0.8407$
Hence water to be evaporated = initial water – associated water – water in molasses
$= 14.8403 - 0.26201 - 0.8407$
$= 13.7376$
Assume 10% of molasses adheres to crystal in centrifuge.
Therefore molasses adhered = $0.10 \times (2.2783 + 0.8407)$
$= 0.10 \times 3.1190$
$= 0.3119$
Wet crystals from centrifuge analyses as follows:

Sucrose	$= 26.2010 + \{(0.3119 \times 2.2783)/3.119\}$
	$= 26.4288$
Water	$= 0.26201 + \{(0.3119 \times 0.8407)/3.119\}$
	$= 0.3461$
Total	$= 26.7749$

(11) Drying

The deterioration of sugar is retarded and the loss in test is reduced if the moisture content of the sugar is reduced. With a dryer, the moisture content may be reduced to between 0.2 and 0.5%.
Drying by contact with hot air involves heating the air, to increase the capacity for absorbing water and bringing it into intimate contact with the sugar from which it evaporates the moisture.

Assume that the final moisture content is 0.2%.

Weight of dry crystal is 26.4288 as calculated before.
Therefore final sugar produced = $26.4288 \div (1 - 0.002) = 26.4818$
Thus overall yield of refined sugar based on cane crushed = $(26.4818 \div 250) \times 100$
$= 10.59\%$
Thus moisture to be removed = m = $26.7749 - 26.4818$
$= 0.2931$ tons/hr
$= 293.1$ kg/hr
There are two possible methods of circulation of air and sugar.
i.e. parallel flow and countercurrent flow.
For safety, the calculation is based on most unfavourable condition, i.e. it is assumed that the ambient air is saturated. On the other hand, the air leaving a dryer is generally not saturated; it is assumed that in case of countercurrent flow, it has absorbed only two-

thirds of the quantity of water that it could have absorbed if it had left in a saturated condition.

We have then, in the case of countercurrent condition,

$$A = (100 \times m) \div \{(2 \div 3) \times (H_1 - H_0)\} = (1500 \times m) \div (H_1 - H_0)$$

Where A – weight of air to be passed through dryer (kg/hr)

m – moisture to be removed (kg/hr)

H_0 – weight of water vapour contained in saturated air at a temperature t_0 of entry air to the heater (ambient temperature) in kg/1000 kg

Taking ambient temperature as 30°C.

From fig. 36.3 (Hugot)

H_0 = 26 kg water/1000 kg saturated air

H_1 – weight of water vapour contained in saturated air at the temperature t_1 of exit From the dryer in kg/1000 kg

The temperature of air leaving the dryer is in between the 45 – 52°C.

Assuming it as 50°C.

From fig. 36.3 (Hugot)

H_1 = 85 kg water/1000 kg saturated air

Therefore A = (1500 × 293.1) ÷ (85 – 26) = 7451.69 kg/hr

Thus weight of air to be passed through the dryer = A = 7451.69 kg/hr

Hence volume of air required = V = A ÷ (a_0 + e_0)

From fig. 36.3 and 36.4 (Hugot)

a_0 = density of air at t_0 = 1.12 kg/m^3

e_0 = weight of vapour contained in saturated air at t_0 = 0.03 kg/m^3

Therefore V = 7451.69 ÷ (1.12 + 0.03) = 6479.73 m^3/hr