Enhancing Plant Efficiency and Profitability through Energy Saving

Abdul Aziz Tahir, Technical Director, Ranipur Sugar Mills, Sindh

Workshop Review:

Pakistan Sugar Industry is facing local challenges to compete the word Sugar Market. Survival of Sugar Industrydemands second line of revenue generation. This is possible only when energy cost per ton of sugar production and sugar production per ton of cane willbecome compatible with the world Sugar leaders. Need of the hour is to save I kg bagasse to produce 0.44KW Electric Power for national grid. The workshop presentations will review the important aspects of energy conservation for the enhancement of the Plant efficiency and profitability. This presentation will elaborate the respective focal points.

1-Selection of Cane Preparation Devices

Target: ***+90 Preparation Index with minimum energy consumption***

a. Preparation index or % open cell of prepared cane is directly related to the performance, capacity crushing and energy consumption ofmilling train.

b. Edward suggested a***0.1 % increase in extraction(of 1st Mill) per 1 % increase in Preparation Index.***

c. Comparison of Cane preparatory devices

Basis:

Crushing Rate:7000 TCD / 291.7 TCH

Fiber % cane: 14.0 %

Fiber rate: 40.84 Tons/hr

i.**General Description:**

Sr.NO.	Machine Type	Dia x Rotor length	RPM	Tip Speed (M/Sec.)	Preparation Index (%)	Remarks
1	Unigrator	1727 x 1800	850	76.90	+/- 86 %	
2	Shredder	1525 x1980	1200	95.85	+ 90.00	
3	Fiberizer (in line Shredder)	1680 x 1800	1000	88.00	+ 90.00	

ii.**Comparison of Installed Power(KW)**

Machine Type	Total Installed Power	1st Cane Carrier	2nd Cane Carrier	1st Cutter	2nd Cutter	Feeding Kicker	Carding Drum	Feeding Drum	Rotor	Kicker after Fiberizer
Unigrator	Kw/t.fr/ hr.	1.35	1.90	11.0	14.0	-	-	-	35	
	2605KW	55	75	450	575	N/A	N/A	N/A	1450	N/A
Shredder	Kw/t.fr/ hr.	1.35	1.90	11.0	14.0	-	-	-	50	
	3240Kw	55	75	450	575	35	N/A	N/A	2050	N/A
Fiberizer	Kw/t.fr/ hr.	1.90	-	-	-	-	-	-	50	-
	2280KW	75	-	-	-	-	75	50	2050	30

iii.**Saving with Fiberizer as compared with Shredder**

Machine Type	Installed Power(KW)	Absorbed Power(@ 85% of installed Power)	Energy Saving per day (KWhr)	Energy saving KWhr per campaign (110 days)	Financial Gain (@Rs.15/kwhr)
Shredder	3240	2754	-	-	-
Fiberizer	2280	1938	19,584	21,54,240	Rs. 32.31 Millions

d. General Arrangement of In line Shredder(Fiberizer)

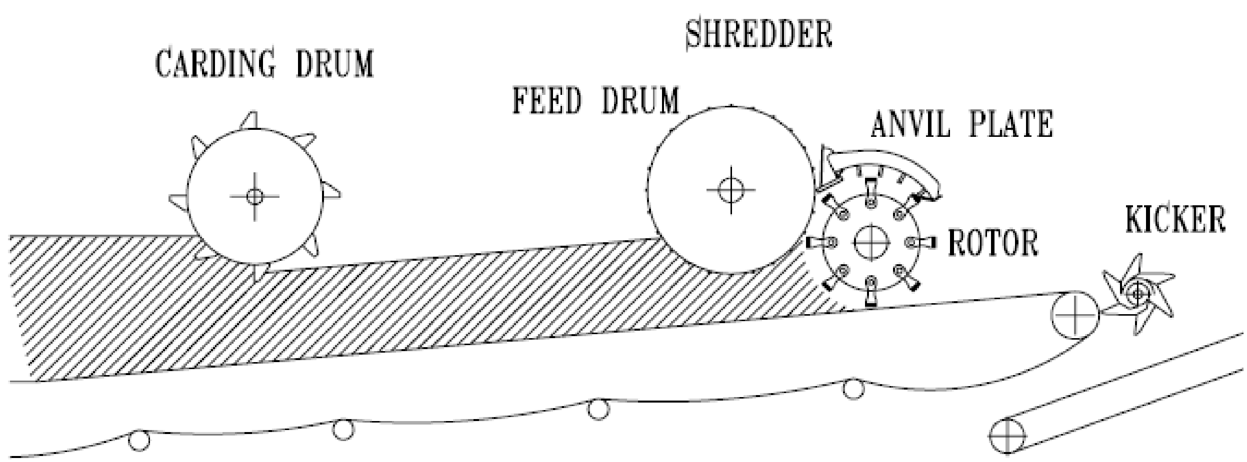


Fig. 4—A typical in-line shredder installation.

e.**Comments:**

i.Less capital, operation and maintenance cost of Fiberizer as compared with Shredder withequal P.I Index.

ii.Wearing of Fiberizer Hammers head is fast but now this is no more issue after the use ofreplaceable carbide tips at hammer heads.

iii.Fiberizer is operated without the allied preparatory equipments, so it cannot by pass in case of any type of stoppage.

iv.Main fault which can occur occasionally with Fiberizer is breakage of its Rotor Shaft. As machineblessed with gigantic momentary gain , one spare rotor without hammers can be abetter solution.

f. **Performance monitoring of Preparatory devices**

i.Weekly Preparation Index test for 2^{nd} cutter and main machine is necessary.

ii.Maintain P.I 65 % after 2^{nd} cutter and recommended P.I after main machine, otherwise take a stop to replace cutter knife edges and hammer tip sides of the main machine.

2. **Milling Review**

Target: ***96 % Mill Extraction with optimum energy consumption***

a. The three roller mill with forced feeder is a common practice in Pakistan Sugar Industry

b. The application of 2 roll mill without trash plate as 1st mill of milling tandem is passing through experienceof the Pakistan Sugar Industry.

c. Shaft Power distribution at conventional three roller mills

Sr.#	Description	% Power Consumption	Remarks
1	Compression of Bagasse	64.0	can be reduced with better P.I and making top and feed roller as lotus
2	Metal Bearing Loss	15.0	Can be minimized with application of anti-friction roller Bearings
3	Trash Plate	14.0	Can be reduced with better mill setting, polishing surface of trash plate and 100 % eliminated by replacing 3 roller mills with 2 roller mills.
4	Scrapper	2.0	Standard loss with all mills
5	Pinion Loss	5.0	Standard loss with all mills

d. Performance evaluation of 2 Roller mills as 1st Mill

Target: ***+ 70.0 % Mill Extraction and 55% Moisture content in bagasse***

HMC Pakistan claims:

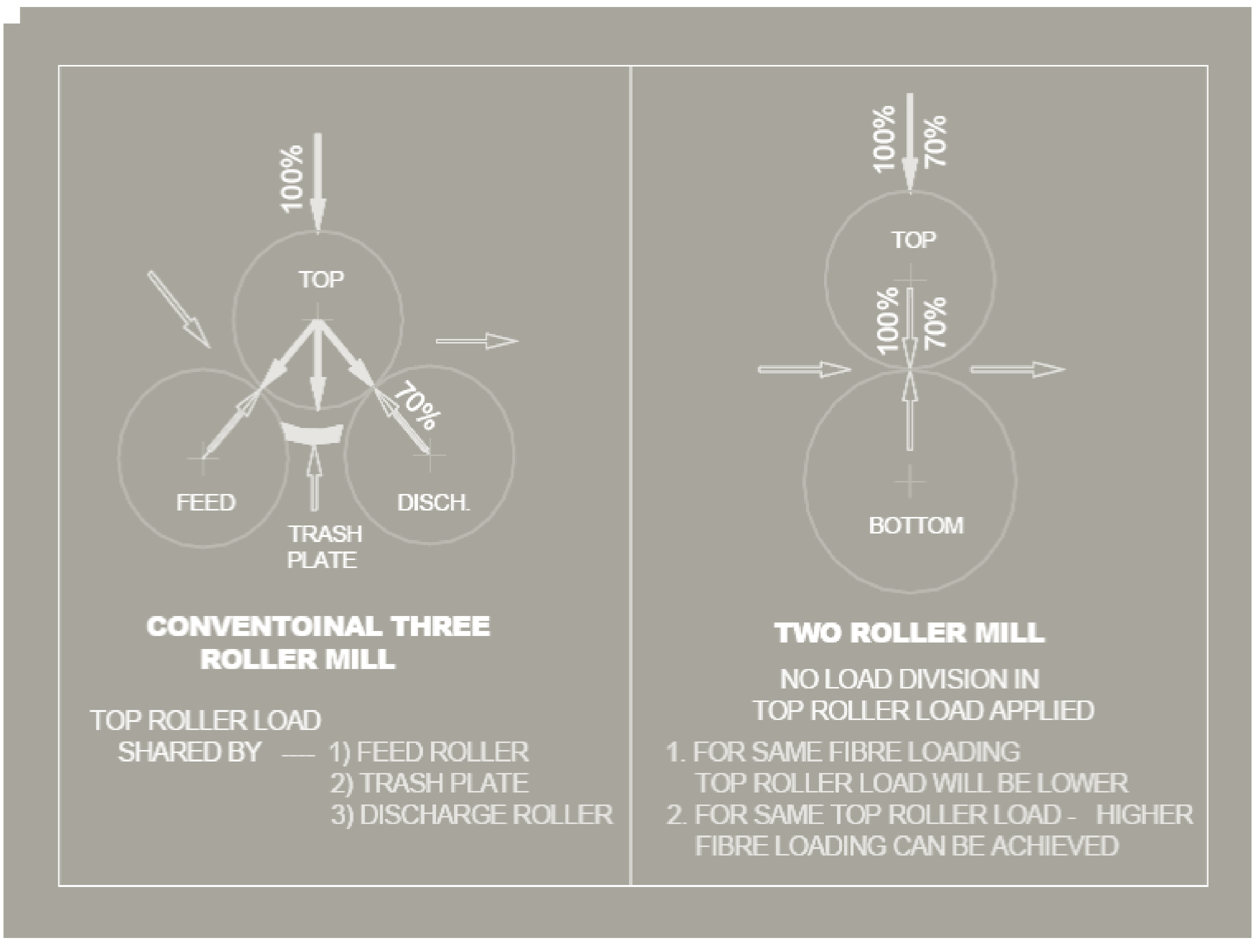
30 % less power consumption with 2 roller mills with equal mill performance of three roller mills.

70 % Mill extraction and 60% Moisture content in bagasse is reported as feedback from client.

e. Comparison of 2 roller mills of different makes:

Sr.#	Description	HMC, Pakistan	ULKA, India
1	Mill Type	2 roll with Single Feeder	Compact Muti – Roller Mills(CMR)
	Hydraulic load	Top Roller	Top Roller
	Mill Drive with	Fixed Bottom Roller	Fixed Bottom Roller
	Top Roller	Lotus Type	Lotus Type
	Feeding Roller	Single	Double
	Mill Extraction(%)(Client Feedback)	68 to 77	75 to 78
	Moisture % Bagasse(Client Feedback)	60 to 62	52 to 54

f. Shaft Load Shearing by 3 rollers and 2 Roller Mills



g. **Benefits of 2 Roller Mills**

i. Less Shaft Power due to bottom roller drive, no trash plate.

ii. All hydraulic load is available for Bagasse compression whichis 30 % less than 3 roller Mills

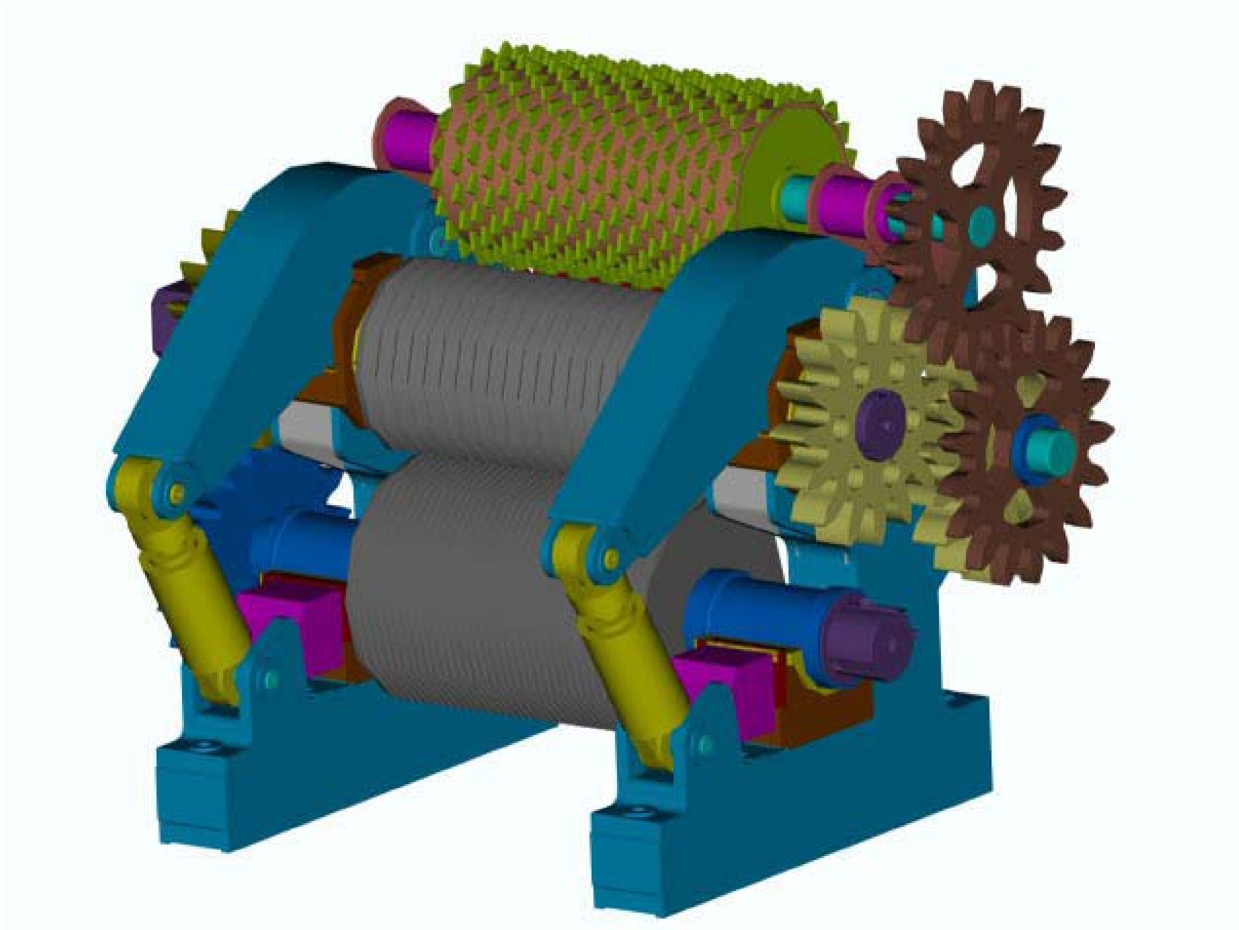
iii. Less capital Cost than same size 3roller mills.

iv. Less Operation and Maintenance Cost.

v. Better extraction due to reduction in reabsorption factor with the help of top lotus roller and better juice drainage arrangement with bottom roller.

h. General arrangement of HMC and ULKA CMR Mill is shown below:

HMC 2 ROLL MILLS WITH SINGLE FEED ROLLER



ULKA CMR MILLS WITH 2 FEED ROLLERS

3. **Replacing Steam Turbines with Electric Drives at Milling Tandem**

Target: ***Production of surplus ElectricPower of +19 Kw/ton cane crushed***

Comparison of 5 mills tandem equipped with 750 Kw Steam turbines for 8000 TCD Plant.

Sr.#	Description	Single stage B.P Steam Turbine	Induction Motor
1	Energy Requirement of 5 Mills	3750 Kw.hr	3750 Kw.hr
2	H.P (60 Bars) Steam consumption	131,000 pounds/hr (@35lbs/kw)	47,625 pounds /hr (@12.7lbs/Kw)
3	Steam Saving with Induction Motors	-	83,375 pounds/hr
4	Surplus Energy Production	-	6565 kw.hr
5	Surplus Energy Production per Ton Cane		19.695Kw/Ton cane crushed
6	Saving with 110 crop day(Rs.15/Kw.hr)		Rs.259.97 Million

4. **Recommended IEC Classes Electric Mill Drives**

a. **Table for Classes Description**

Sr.#	Description	Class IV	Class V
	Continuous Rating	100 %	100 %
	Overload running-1	125 % for 2 Hrs	150 % for 2 Hrs.
	Overload running-2	200 % for 10 second	200 % for 60 seconds

b. **Other benefits of Induction Drives**

i. VFD control drive

ii. Low starting torque

iii. Low maintenance cost

iv. Reduced noise

v.Faster return (Payback within one season)

vi. Excellent overload protection

vii.Easy and faster start and stop

5. Heat Loss saving in Flue gases at 1 % moisture drop in Bagasse through Bagasse Dryer

Bagasse moisture	51	%
HV of Bagasse at 51 % Moisture	7400	KJ/kg
Water vapour in 1 kg Bagasse	0.51	Kg
Cp of Water	78.63	$KJ/Kg.^0C$
Bagasse Temperature	50	^0C
Heat of 51 % moisture in Bagasse at 50 ^0C	2005	KJ
Flue gases temperature	200	^0C
Heat loss in flue gases due to 51% Bagasse moisture	6015	KJ

<u>Heat Saving with Bagasse Dryer</u>

Bagasse Moisture after bagasse dryer	50	%
Water vapour in 1 kg bagasse	0.5	Kg
Bagasse Temperature	50	^0C
Heat loss in flue gases due to 50% bagasse moisture	5897	KJ
Heat saving in Flue gases after 1 degree drop in Bagasse moisture	117.9	KJ
% Heat saving in Flue gases after 1 degree drop in bagasse moisture	1.594	%

1 % drop in moisture in bagasse saves 1.6 % heat losses in Flue Gases

6. **Selection of Efficiency based process house Equipments**

a. **Vacuum Filters**

R & D was done at Ranipur Sugar Mills in off season2010 atFCB made 9 x 18 ft Vacuum Filter to increase mud cake loading and discharging rate . From season 2010-11 to 2013-14, there remained one Vacuum Filter in operation to carry the mud load of average 5.25 tons per hr with optimum Mud Pol of 1.9 % and moisture content of 77.5 %. Before modification Ranipur operated 2 units of same size with 2 Vacuum pumps for same mud loading . Modified Vacuum Filter was operated with single Vacuum pump. There was saving of 75 Kw motor installed at 2^{nd} Vacuum Pump.

Saving with 110 Crop day season

Electric Energy: 75 x 24x110 = 198000 KWHrs

Financial Gain : 198000 x 15 = Rs. 2.97 Million per annum

Same designed Vacuum Filter is now available in local market of Pakistan

b. **Juice and Melt Heating**

Target: ***Heating the process liquid with Heater of highest HTC with the application of condensate or downstream vapours.***

i. Selection of Heater Type

Sr.#	Process Liquid	Shell and Tube Heater	Wide gape Plate Type Heater with reverse flow	Direct Contact Heater
1	Primary juice	B	A	N
	Defecated Juice	A	B	N
	Clear Juice	B	A	N
	Melt Heating	C	B	A
	Condensate	B	A	N

A: 1ST Choice

B: 2nd Choice

C: 3rd Choice

N: Not recommended

ii. **Heat Transfer Coefficient (HTC) and Pressure drop**

HTC is proportional to Fluid velocity (V) and pressure drop is proportional to Square of Fluid velocity (V^2), So Selection of Velocity is very critical to maintain fast flow through heater tubes or plates, normal recommended velocity range for condensate and juices is 1.5 to 2 m/sec. and for Syrup and Melt 1 to 1.5 m/sec.

In all cases of Fluid flow,***HTC of Plate type Heater is 1.5 to 3 times higher than tubular Heater***.(Cane Sugar Engineering, page210)

During selection the heating surface of the heater , HTC of heating media must be considered to avoid any practical implication. Following is the Table for HTC ($W/m^2.K$) for Heating media:

Sr.#	Heating Media	HTC ($W/m^2.K$)
1	Exhaust Steam	260 – 1310
2	1st vapours	250 - 1260
	2nd Vapours	230 - 730
	3rd Vapours	150 – 710
	4th/last effect vapours	320 - 600

Source: Energy Manual for Sugar Factories(2nd edition), page 82

c. **Evaporators**

Evaporator station is the biggest thermal energy consumer station of the Sugar Factory. It consumes about 90 % of the total steam production of the boilers.

i. Falling Film Long tube Evaporator (FFE)

In Pakistan Sugar Industry, trend to install Falling Film Evaporator (FFE) as 1st effect is encouraging. Many Sugar Factories have successfully trialed the operation. No doubt FFE is the best option as 1st effect in evaporator station due to its built in features.

It offers;

i.iHigh Heat transfer Coefficient

i.iiTemperature difference in heating steam to evaporating vapours is minimum (5 degree)

i.iiiIt can operate with higher temperature of Steam up to 130 - 135 ^{0}C without risk of sugarinversion.

i.ivIt produced high temperature 1st vapours and steam condensate for best condensate andflash heat recovery .

i.vWorking as 1st effect , Refine massecuite Pans can also operate on 2nd vapours of 105 ^{0}C. Thusit offers best heat economy by utilizing down side vapours for heating to other stations.

i.vi Its Heating Surface to Volume Ratio is as highest as 240 m^2/m^3.

i.viiIt requires less space for installation, single evaporator of heating surface of 6000 Sq.mhave been installed.

i.viiiShort residence juice time reduced sugar inversion and colour formation.

i.ixIt requires no steel structure and can be build out side of the process house building.

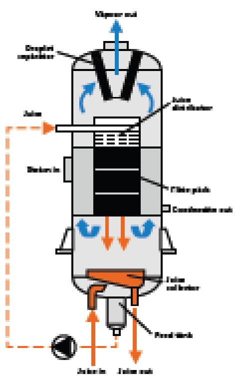
i.xIt is very sensitive to operate , must require automation for wetting the tube surfaces andprécised distribution of juice in juice distribution box.

Hugot(1986) quotes "***the use of FFE as 1st effect of the evaporating station, equipped with vapour recompression together with the use of hot condensate for juice heating may reduce the steam requirement to 35 % on Cane"***.

ii. **Plate Falling Film Evaporator(EVAPplus FFE)**

It is the combination of tube and plate evaporators. It offers highest overall HTC than FFE. Operation required automation for insuring the wetting plate and tube surfaces. Fig. A given below describe the operation pattern of the evaporator.

Fig. B gives comparison of HTC of FFE evaporator and EVAPplus FFE Evaporator.



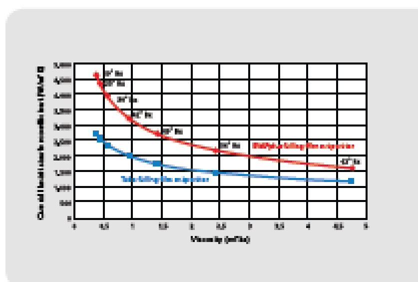
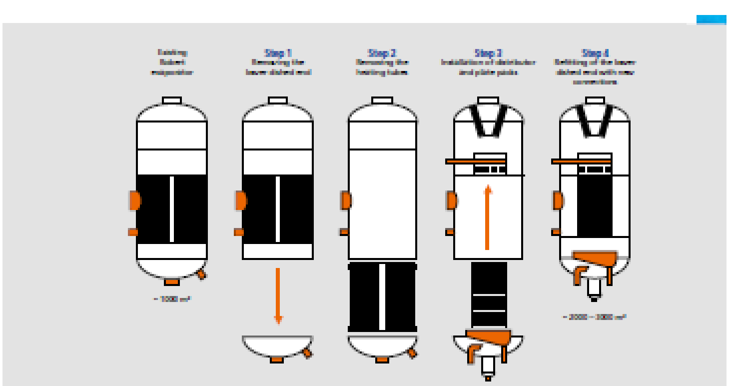


Fig.a Fig.b

ii.iConversion of Robert Type evaporator to EVAPplus plate pack Evaporator

The calandria is removed and replaced with EVAPplus plate pack and the respective distributor. With the minimum expenditure the heating surface are and the system efficiency is considerably increased. Conversion steps are shown below in the Fig.c



d.Energy Balance of Process House with FFE as 1st Effect

Basis: Cane Crushing: 1000 TCD

Pol % Cane: 14.0 %

Fiber % cane: 14.0 %

Imb. % Fiber: 250 %

i. Evaporator Set Up

1st Effect(FFE)	2nd Effect(Robert)	3rd Effect(Robert)	4th Effect(Robert)
(Sq.M)	(Sq.M)	(Sq.M)	(Sq.M)
6000.0	6000.0	1000.0	800.0

ii. Vapour Bleeding Arrangement

Heating Station	Heating Media
Primary Juice Heating-I(30 – 45 ^{0}C)	4th vap. through 2 VLJH of 500 + 500Sq.m
Primary Juice Heating-II(45 – 48 ^{0}C)	3rd vapours
Sec. Heating-I (65 – 95 ^{0}C)	2nd vapours
Sec. Heating-II (95 – 103 C)	1st Vapours
Pre-Heating-I (98 – 103 C)	1st vapours
Pre-Heating-II (103 – 110)	Exhaust Steam
Melt Heating at Talo Refinery (60 - 90 C)	1st Vapours
Pan, Molasses tank, Mass. Pumps, Raw Centrifugal washing	1st Vapours
B and C Graining	1st Vapours
Raw and Refine Pans(A+B+C Conti Pans and Ref. Batch Pans)	2nd Vapours of 105 C

iii. Steam Requirement of Process House

Evaporators	177.32 Tons/hr	42.56 % Cane
Juice Preheating-II	8.32 Tons/hr	2.00 % Cane
Washing Steam for Ref.M and Dryer	9.95 Tons/hr	2.39 %Cane
Total Steam Requirement	195.59 Tons/hr	46.94 % cane

e. Continuous Pan Boiling

Benefits of continuous Pan boiling are no more hidden in Pakistan Sugar Industry. Considering all good features of the Continuous pan boiling for raw massecuite, it is very much essential for heat economy to utilize right size of pan (H.S/V ratio not less than 9.0) for right type and quantity of boiling massecuite.Fletcher & Stewart recommended the Typical T-H Continuous Pan Sizes as given below:

e.i**A Massecuite**

Massecuite Flow Rate(Cu.m/Hr.)	24	30	36	42	48	54	60	
Conti Pan Size(Cu.m)	60	70	80	100	100	120	2 x70	

e.ii**B Massecuite**

Massecuite Flow Rate(Cu.m/Hr.)	14	17.5	21	24.5	28	31.5	35	
Conti Pan Size(Cu.m)	60	70	90	100	120	2x60	2 x70	

e.iii**C Massecuite**

Massecuite Flow Rate(Cu.m/Hr.)	8	10	12	14	16	18	20	
Conti Pan Size(Cu.m)	50	60	70	80	100	100	120	

d. Single Entry Vapour Condensers

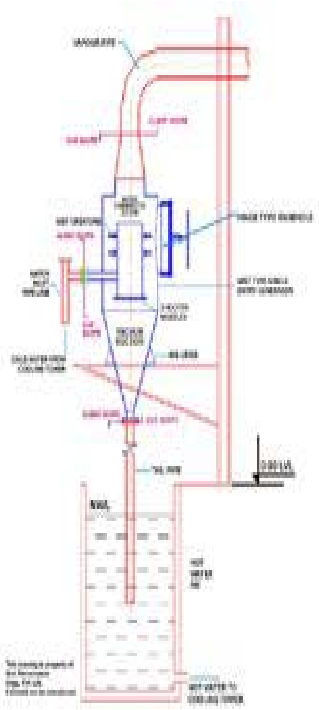
Target: ***Reduction in tons of water required to condense ton of vapours***

Inefficient Multi jet condensers are being replaced with efficient vapor condenser of many makes and types. One type is Mist type S.S single entry condenser. Block Diagram is shown below:

f.iComparison of MREPL(Indian) make Mist Type Single entry condenser and Multi jet Condenser

Sr.#	Description	Multi jet Condenser	Mist Type Single Entry Condenser
1	Vapour s to condensed	45 Tons per hr	45 Tons per hr
2	Condenser approach	15 ^{0}C	8 ^{0}C
3	Condenser efficiency	40 to 50 %	80 %
4	Water to Vapour Ratio	65 to 70	40 to 45
5	Injection water flow (M3/Hr.)	3150	1800-2000
6	Power consumed at injection Station	195 Kw/Hr	115 Kwhr.
7	Power saved at Injection station	-	80 Kwhr.
8	Power Saving at Spray station	-	80 Kwhr.
9	Total Power Saving in system	-	16o Kwhr.

f.IISketch of Mist Type Single Entry Condenser



g. Selection of Raw Centrifugal Machines

Target: ***Operating Machines at full rated capacity with good quality output Sugar***

g.I**Selection Criteria**

Massecuite Type	Mass. Feeding Temperature(^{0}C)	Basket Angle/RPM	Specific Power load (Kw/ton Mass cured)
A	60	30/(1400 – 1600)	3.0
B	55	34/(1600 – 1800)	4.5
C	52-54	34/ (1800 -2000)	4.6

This is experienced that at crushing rate of 4000 TCD, one machine of Type "1250" is enough on each station for pre massecuite curing.

7.**Bagasse fired Boilers**

In Pakistan Sugar Industry induction trend of High pressure Boilers of Ranging pressure from 60 to 100 Bar is encouraging. High Pressure boileroffersmany advantages over low pressure boiler as listed below:

a. It produces more Kcal per ton of output steam for converting it to electrical energy through H.P Turbines.

b. Generally for 62 Bar pressure , 1 kg of Bagasse produce 2.2 kg high pressure steam and 4.5 Kg steam is required to generate 1 kw power at extraction cum condensing turbine.

c. Fuel consumption per Kcal of steam production is low due to high degree of control and breakage of thermal bounding of water molecules at high pressure and temperature.

d. It requires high purity feed water of following characteristic(900 Psi Boilers)

Sr.No	Description	Values	Units
1	Dissolved O_2	7	Ppb
2	PH	8.5 to 9.0	
3	Iron	Less than 0.02	Ppm
4	Copper	Less than 0.015	Ppm
5	Silica	Less than 20	Ppm
6	Total alkalinity	Less than 150	Ppm
7	Conductivity	Less than 1200	Micro ppm

e. Recommended limits of gasescontents and temperature in Flue gases

Sr.No.	Gas Type	Recommended Limits	Remarks
1	O_2	Not more than 8.0 %	Higher O_2 percentage promotes loss of heat many folds through flue gases as 1 part of O_2 will carry 3.3 parts of N_2 by weight and 1 kg of air will carry 0.5 kg water content through moisture
2	CO_2	10 -12 %	CO_2 presence indicates the combustion of fuel, Higher CO_2 level indicates higher Degree of Combustion
	CO	Less than 100 ppm	CO presence indicates incomplete combustion of fuel, Higher CO level indicates higher degree of Combustion loss
	Temperature	Less than 200 ^0C	

f. Factors effecting Boiler Efficiency

f.i**Moisture contents of Bagasse**

f.i.i50% water content in Bagasse takes away 5900 KJ heat per kg bagasse while leaving withfluegases , which is a main reason of lower combustion efficiency of bagasse fired boilers.

f.i.i***1% drop in Moisture through milling control or by bagasse dryer reduces 1.6% heat losses inFlue gasses.***

f.i.iii***1% decrease in Moisture in bagasse increase boiler efficiency by 0.8 %***

f.II**Excess Air**

Bagasse contains 22% O_2 in it by birth. TheoreticallyIt requires 3.2 kg air per kg bagasse for combustion but practically it requires 25 – 30 % excess air for good combustion.

1% reduction in excess air improves 0.6 % boiler efficiency.

f.iii**Flue gas temperature:**

22 ^{0}C rise in flue gasses temperature decreases thermal efficiency by 1 %.

f.iv**O_2 level in Flue Gases**

f.iv.iMonitoring O_2 level in flue gases is the best indicator for air fuel ratio control for efficientcombustion .

f.iv.ii***3 % decrease of O2 in flue gases promote fuel saving of 2%.***

f.v**Feed Water Temperature**

15 ^{0}C rise in feed water temperature rises thermal efficiency by 3 %.

f.iv**Combustion Air Preheating**

20 ^{0}C rise in combustion air rises thermal efficiency by 1 %.

f.v**Boiler water tube sooting and scaling**

f.v.i***3 mm thick soot layer on external surface boiler tube can cause an increase in 2.5 % in fuelcombustion.***

f.v.ii***3 mm scale deposit inside boiler tube can cause an increase in 8 % fuel combustion.***

8. **Electrical Motors**

a.**Power loss in Motors**

Indicated in fig and table below:

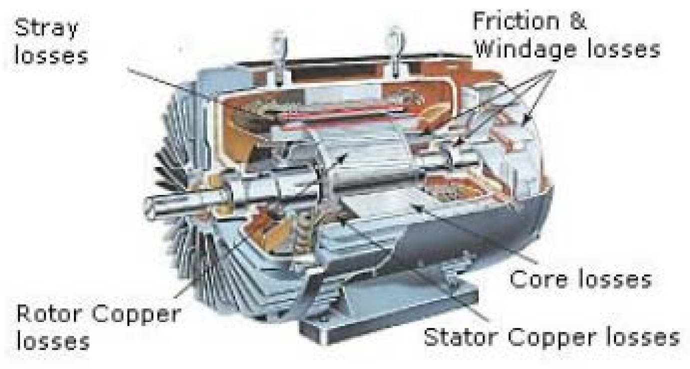


Table: Electrical Losses in the Motor

Losses Type	2-Pol Average	4-Pol Average	Factors Effecting Losses
Core Losses	19 %	21%	Electrical steel, air gap. Saturation
Friction and winding Losses	25 %	10%	Fan Efficiency, Lubrication, Bearings
Stator Copper Losses	26 %	34 %	Conductor Area, mean length of turn, heat dissipation
Rotor Copper Losses	19 %	21 %	Bar and end ring area and material
Stray Load Losses	11 %	14 %	Manufacturing process, slot Design, air Gap

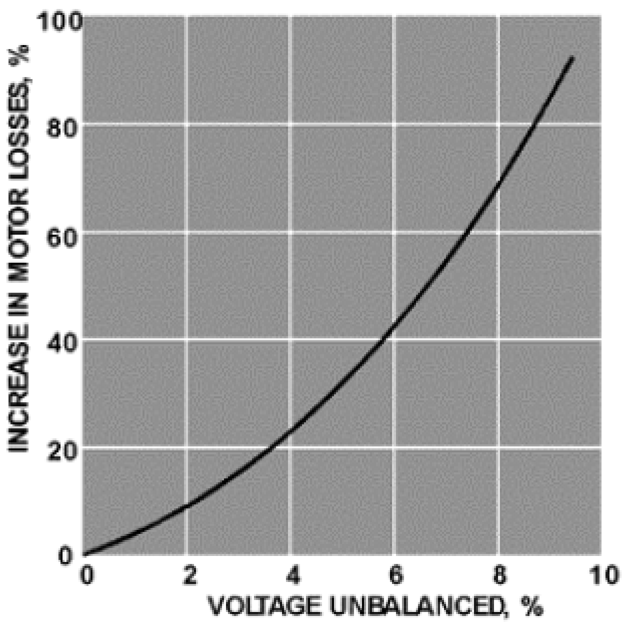
b. **Effect of Voltage unbalance on Motor Losses**

If the measured voltage are 420, 430 and 440V, the average is 430V and the deviation is 10V.

The % Voltage Unbalance will be = 10V x100/430 = 2.3 %

1% Voltage unbalance will increase the motor losses by 5 %.

Under given graph shows the increase in motor losses due to voltage unbalance:



c. **Importance of Motor running Cost – Life Cycle Cost**

Motors can be considered as consumable items not a Capital items considering the current energy prices. Importance of the running cost can be seen from the Table given below:

Motor Rating(KW)	7.5	7.5	37	37
Efficiency(%)	86	88	92	93
Power input(Kw)	8.72	8.52	40.22	39.78
Running Hours	6000	6000	6000	6000
Energy Input(Kw/Yr.)	52320	51120	241320	238680
Running Cost(@ Rs.15/Kw.hr)	784800	766800	3619800	3580200
Running Cost for 10 Years	7848000	7668000	36198000	35802000
Difference	180,000	-	396,000	-
First Cost(Rs.)	15000	18000	80000	96000
First Cost as % of running cost for 10 years	0.20	0.23	0.22	0.27

c.iRemarks:

c.i.i7.5 Kw motor of 86 % efficiency consumes extra electricity of Rs.180,000/- in its life cycle whichis 12 times higher than its purchased cost as compared with same rated motor of 88% efficiency.

c.i.ii 37 Kw motor of 92 % efficiency consumes extra electricity of Rs.396,000/-in its life cyclewhich is 4.95 time higher than its Purchased cost as compared with same rated motor of 92% efficiency.

d. Increased cost due to Oversized Motor

Motor Load Requirement	KW	15	15	15
Motor Rating	KW	15	30	55
Motor eff. at Operating Load	(%)	89	89	84
Input Power	Kw	16.85	16.85	17.85
Total Kwhrs(6000 hrs/year)	Kwhrs.	101100	101100	107100
Input Energy Cost/year (Rs.15/Kw.hr)	Rs.	1516500	1516500	1606500
Motor Power Factor		0.89	0.75	0.50
Input KVA		18.93	22.44	35.70
Energy Difference	Kwhrs	-	-	6000
Motor Purchased cost	(Rs.)	250000	55000	95000
Increase in investment	Rs.	-	30000	70000
Increase in running cost per year	Rs.	-	-	90000

Remarks: 44 kw oversized motor than required Kw motor cost extra Rs.70,000/- in purchased price and Rs.90,000/- in running cost per annum.

9. **Soft Starters and Variable Frequency Drives(VFD).**

a. **Soft Starters**

Soft starter is a solid state device that protects AC electric motors from damage caused by sudden influxes of power by limiting the large initial inrush of current associated motor start up . They provide a gentle ramp up to full speed and used only at startup.

Soft Starters are used where speed and torque control are required only at start up. Application is sugar industry at the startup of cane cutter, Raw Centrifugal Machines, ID Fan Motors and heavy duty Feed water pumps.

b. **Variable Frequency Drives**

The VFD is motor control device that protects and controls speed of an AC induction motor during start up, stop and running cycle.

b.i. **Energy saving with VFD**

VFDs offer greatest energy saving for fans and pumps. It regulates the speed of the mechanical equipment to control the flow by adjusting the driving motor speed. Energy saving with VFD is based on affinity law which states "***Flow changes linear with speed , Pressure is proportional to the Square of speed and power is proportional to the cube of the speed***". It means, if we drop the speed of pump to 80% of its rated speed to control the flow rate the power will reduced to the half of its rated power. $(0.8)^3$=.512= 51.2 percent.

For energy saving , throttling the output valve for centrifugal pumps and regulating pressure relief valve for high pressure Boiler water feed pumps to control flow and damping control to regulate boiler furnace pressure is not a solution but control of speed of pump or fan through VFD .

Application places in sugar industry where flow or pressure regulating is required, like Centrifugal pumps, ID, FD Fans, Injection pumps and Boiler Feed pumps etc.