SASTA CONGRESS 2008

Factory Workshop: The Future of Energy in a Cane Sugar Factory

MODERN SUGAR EQUIPMENT ASSISTING COGENERATION

by
Bruce Moor, Bosch Projects, South Africa

Abstract

The South African sugar industry has developed and/or perfected several innovative items of sugar manufacturing equipment in recent years. The installation of these has usually been justified on grounds of cost savings (particularly labour costs) and/or improved recoveries, often with little consideration of their energy characteristics.

With cogeneration, carbon credits and renewable fuels now suddenly assuming greatly heightened importance, it is appropriate to review the energy efficiency of these innovations.

As starting point, a typical efficient co-generating South African sugar factory of the 1980's is specified and modelled using the Bosch Projects Energy and Mass Balance (EMB). This 400 TCH factory is able to export **7.7 MW** of export power from its bagasse.

Standard modern equipment and technologies are then introduced:
- Upgraded steam conditions – pressure and temperature
- Continuous pan boiling for A, B and C strikes
- Diffusion instead of milling
- Recycling clarifier mud to the diffuser
- Electric shredder and VSD mill drives
- Boiler changes to improve efficiencies

The effect of each change is quantified using the EMB. Each new technology increases energy efficiency, enabling the co-generation to be increased to **35.4 MW** (460% of Base Case).

Technologies with smaller energy benefits but substantial other operational benefits are also described:
- Direct contact juice heaters
- Long tube climbing film evaporators

In addition to their energy benefits, electric drives, diffusion, mud recycling, continuous pans, direct contact heaters, long tube climbing film evaporators and pin-hole grates are all simpler to operate and require less maintenance than previous equipment. Most also improve sucrose recoveries.

1. Introduction

The South African sugar industry has developed and/or perfected several innovative items of sugar manufacturing equipment in recent years. The installation of these has usually been justified on grounds of cost savings (particularly labour costs) and/or improved recoveries, often with little consideration of their energy characteristics.

This reflects the traditional approach of designing sugar mills to burn all their bagasse as fuel and avoid any surplus disposal problem. However, in recent times, the world's energy crisis has changed objectives. Cogeneration, carbon credits and renewable fuels have assumed great importance and most South African mills are now seeking energy efficiency for co-generation or by-product manufacture. It is therefore appropriate to review the energy efficiency of the new equipment.

As starting Base Case, a typical South African efficient co-generating sugar factory of 1980's design was specified and modelled using the Bosch Projects Energy and Mass Balance (EMB). Modern equipment and technologies were then applied to enhance the energy efficiency of the plant. The benefit of each change was quantified using the EMB.

Key specifications for the Base Case factory were:

Factory description	Raw sugar factory, No refinery or by-products, Maximum co-generation of electricity from the available bagasse fuel.
Throughput	400 TCH
Cane quality	Pol 13.5% cane, Purity 84%, Fibre 15.0% cane
Preparation	Heavy duty shredding, PI > 90%
Pol extraction	97.7%
Bagasse moisture	50%
Evaporation	Quintuple effect
Pan boiling	Three boiling, A export, batch pans on V1
Steam conditions	17 Bar (1800 kPa abs), 360^{o}C
Boiler efficiency	80% on NCV
Turbo-alternators	Back pressure (80% efficiency) & Condensing (65% efficiency) sets, to optimise steam balance

2. Base case EMB

The EMB constructs a computer model of the factory including:

- All process mass flows,
- Fuel, steam & power.

The EMB starts by computing the Process (Exhaust) steam requirements. It then determines the HP steam balance, in this model using all available bagasse (after providing for stops, shuts and start ups). The process requirements are first satisfied from turbine exhausts and HP let down, whereafter any available HP is directed to condensing turbo-alternators to generate additional power.

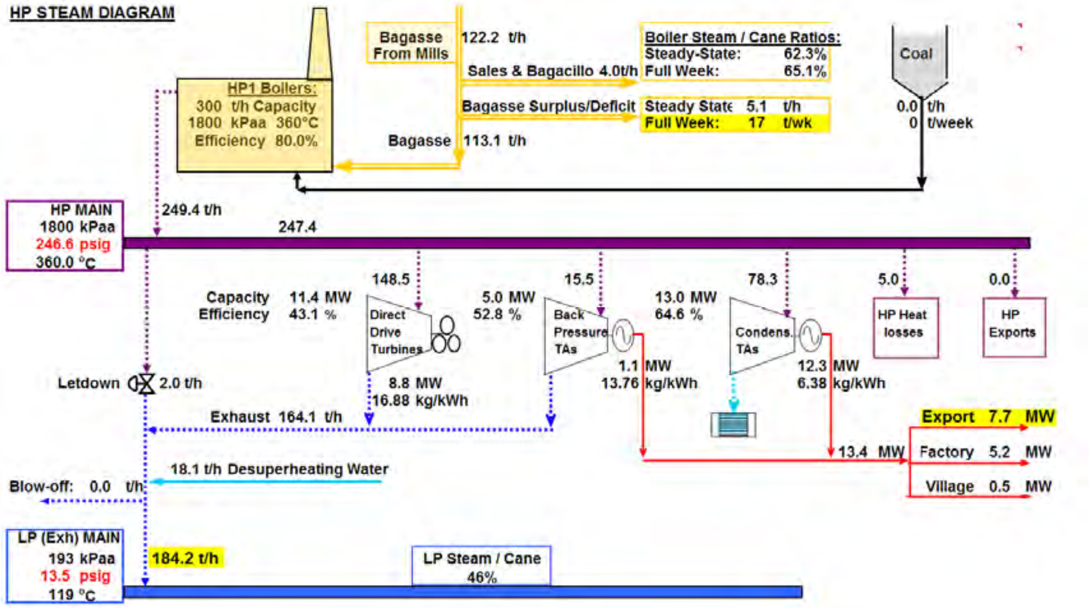


Figure 1. Base Case HP Steam and Power distribution

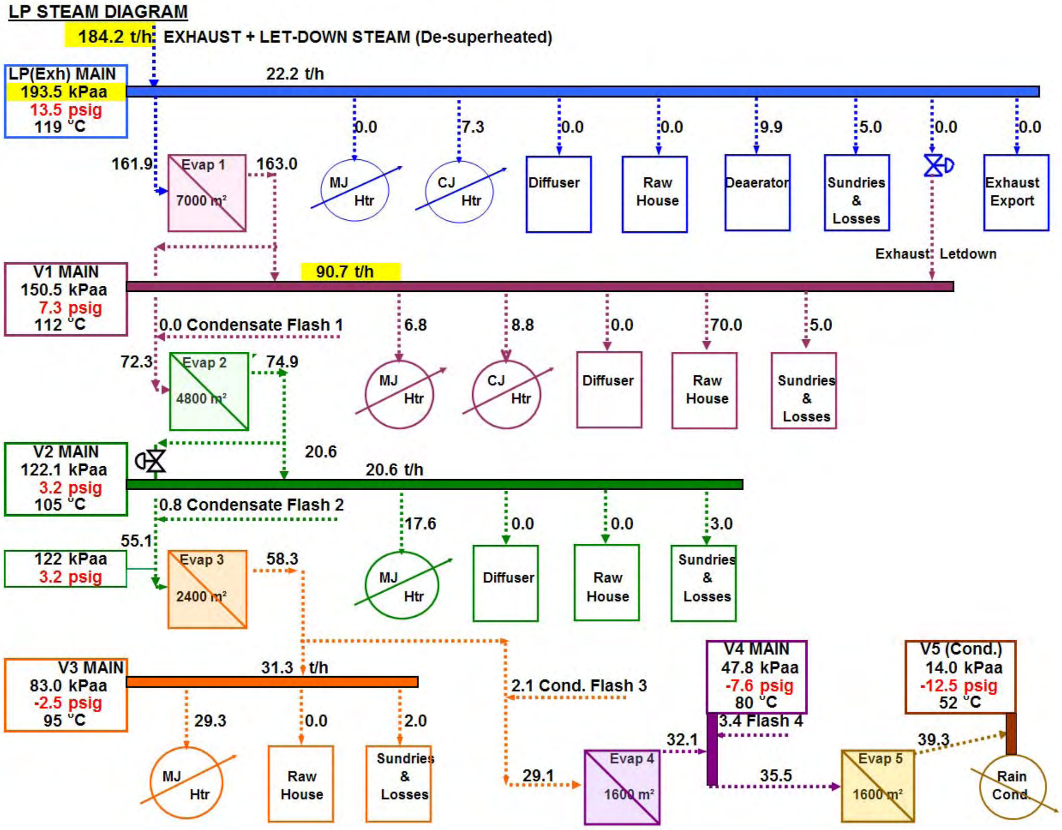


Figure 2. Base Case LP Steam and Vapour distribution to Process plant

Figures 1 and 2 above show the high pressure (HP) and process (LP) steam diagrams generated by the EMB for the Base Case “efficient 1980s factory”. It is seen that this factory is able to export **7.7 MW** of electrical power.

3. Steam conditions

As shown in the table below, less high grade steam is generated per ton of bagasse (because more enthalpy is required per ton steam), but more power is generated.

Steam pressure / Temperature	Tons steam / ton bagasse	Tons steam / MWh power	MWh power/ 100t bagasse
1800 kPa abs / 360°C	2.42	9.12	**24.0**
3100 kPa abs / 410°C	2.14	7.22	29.6
4500 kPa abs / 445°C	2.09	6.29	**33.3**

Table 1. Power from bagasse via 200 kPa abs back pressure TAs

For cogeneration, steam conditions are therefore increased to the 450 kPa abs, 445°C conditions which are still the South African maximum design conditions (Komati).

This increases the power available for export to **15.8 MW**.

4. Extraction plant

Whereas milling was the almost universal extraction technology till the 1980s, successful cane diffusion was then developed.

Milling: Milling extraction is high pressure (HP) steam intensive due to the power required for mill drives. We have used an imbibition rate of 280% fibre and six turbine-driven mills for the 97.7% extraction on 15% fibre cane.

Diffusion: Diffusion is process steam (LP) dependent due to the process steam required for the radiant heat losses from the diffuser, partly offset by less mixed juice heating (hot draught juice from the diffuser). The 97.7% extraction could probably be achieved at a lower imbibition rate, but we have used 320% to emphasise the benefits of diffusion even at high rates.

The choice of milling or diffusion will depend on various considerations for the particular factory, but the energy balance for our typical of factory example shows that diffusion is significantly better, even with the higher imbibition allowed.

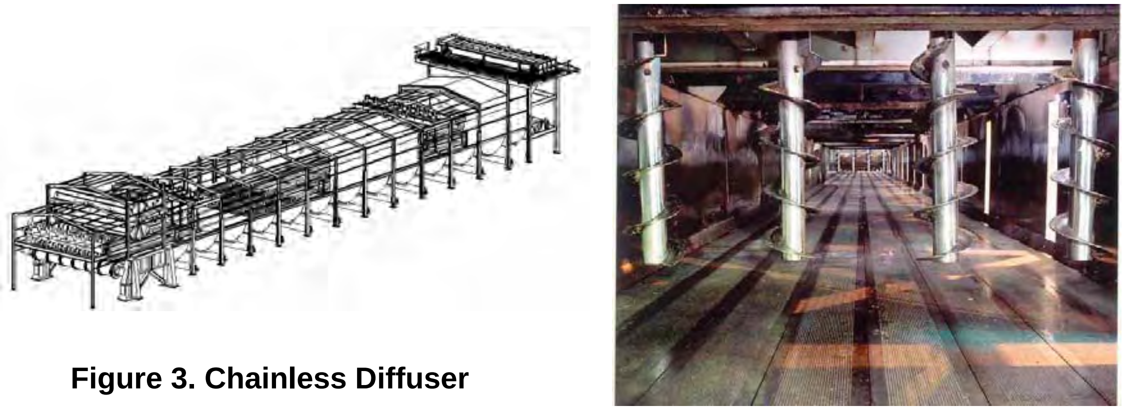


Figure 3. Chainless Diffuser

Switching to diffusion increases the available export power to **21.7 MW**.

Other benefits of diffusion are:

- Low maintenance costs
- Small operating staff
- High reliability

Diffusion with mud recycling: Since 1998, recycling of clarifier mud to diffusers has been practised successfully. This process greatly enhances the energy efficiency of diffusion:

- Evaporation load is reduced by having no filter wash water
- Heat losses from the filter station are eliminated
- Power for the filters and ancillary plant (vacuum system, bagacillo and mud mixing, filter cake disposal) is saved.
- The bagacillo provides additional fuel (about 4% for mills, 2% for diffusers).

By introducing mud recycling with the diffuser, additional steam is available and less exhaust required for process.

Comparing the EMBs of the three options:

Parameter	Units	Milling	Diffusion	Diff + Mud Recycle
Imbibition on fibre	%	300	320	320
Total boiler steam	t/h	237	237	250
Total process steam	t/h	183	196	194
Power exports	**MW**	**15.8**	**21.7**	**24.5**

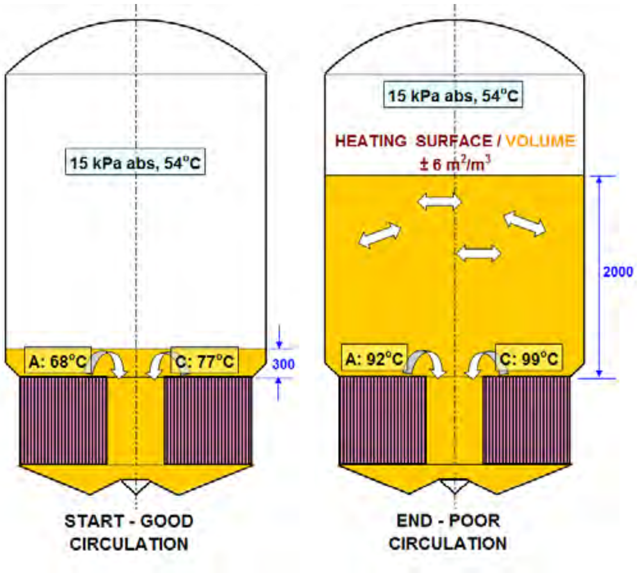
5. Continuous vacuum pans

The temperature of massecuite in pans is affected by the nature and quantity of the solids in solution and by the hydrostatic head. The effects on the boiling point of massecuite at the top of the calandria are illustrated below:

Batch pans

As pan level rises:

- Temperature needed for boiling increases.
- Heating surface / Volume ratio reduces.



Continuous pans

- Boiling temp. is constant.
- Constant HS / Volume ratio

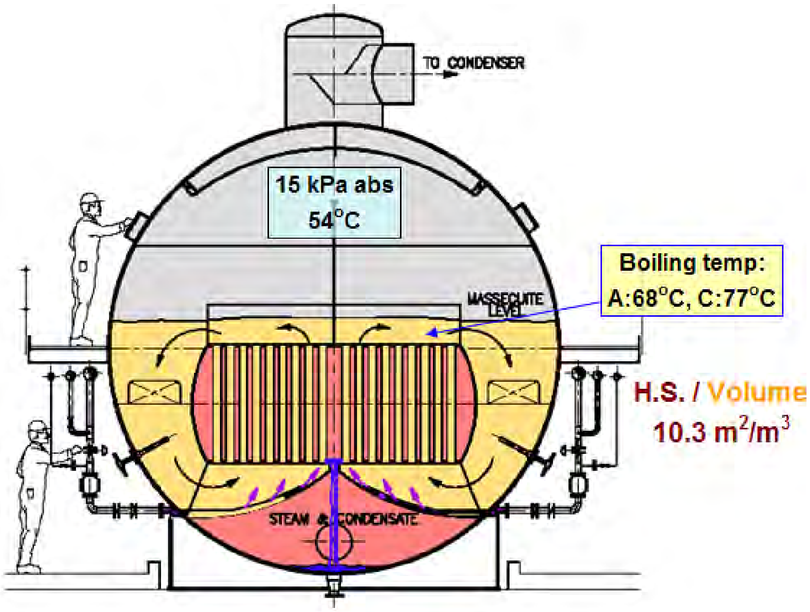


Figure 4. Effective massecuite boiling points at top of pan calandrias

Because of their low boiling head and high heating surface / volume ratios, CVPs are able to boil on low pressure vapours – typically V2 or V3 – whereas batch pans require exhaust steam or Vapour 1. This has obvious benefits for energy economy.

For assisting circulation, batch pans need mechanical stirrers or exhaust steam jiggers. Less circulation assistance is needed in CVPs, and if needed, it has been shown that incondensable gases can always be used for jigger steam in CVPs (but not in batch pans with their high head at the end of boilings). Incondensable jiggers have not been assumed in this paper.

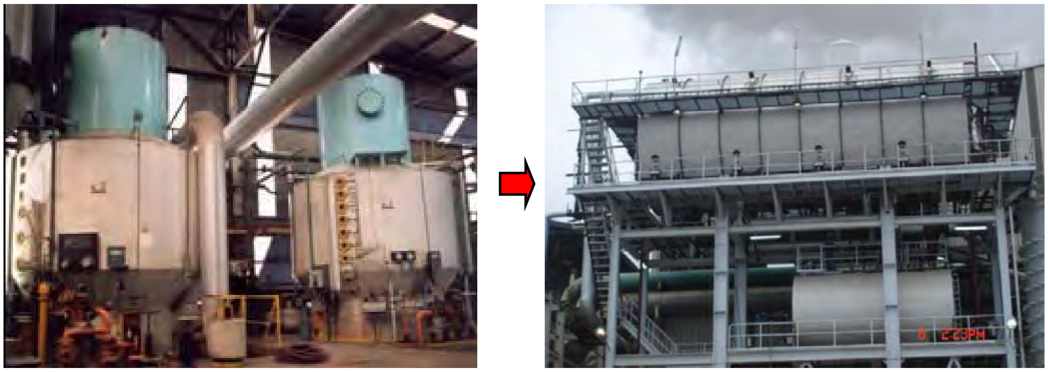


Figure 5. Convert strike pans to CVPs

Retaining batch pans on V1 for seed and introducing CVPs on V2 for A, B & C strikes gives the following changes:

Parameter	Units	Batch strike pans	Continuous strike pans
Total exhaust steam	t/h	195	183
Total V1 to Raw House	t/h	70	22
Total V2 to Raw House	t/h	0	46
Power exports	**MW**	**24.5**	**25.4**

Even greater benefits would be achieved by operating the CVPs on V3. However, for all further cases in this study, the continuous pans have been assumed on V2.

Other benefits of CVPs are well established, e.g.

- Easy automation
- Good exhaustions
- High time availability.

6. Electric mill & shredder drives

Mill and shredder drive turbines are usually single stage units with full load efficiencies of not more than 50% and < 40% at actual operating loads. This compares with the 80% efficiency of multi-stage power house turbo-alternators.

If co-generation is planned, efficient electric shredder drives and VSD mill drives are preferable to turbines. For this exercise, one VSD motor per mill has been assumed, although even better efficiencies would be achieved with individual shaft mounted VSDs on each roll. The benefit is obviously greater for a milling tandem than for a diffuser.

The benefits of electric drives depending on extraction process are:

Shredder & Mill Drives	Power Exports	Milling	Diffusion	Diff + Mud Recycle
Turbines	MW	16.3	22.3	25.4
Electric	MW	22.9	25.6	28.4
Difference	**MW**	**6.6**	**3.3**	**3.0**

A disadvantage of electric drives is their requirement for more power station capacity.

7. Boiler efficiency

It is often not appreciated that the easiest gains to be had are often from improving boiler efficiencies. In particular, improvements can often be effected in two areas: heat recovery and excess air control.

Heat recovery equipment

Many sugar boilers have been specified to burn all available bagasse rather than to maximise efficiency for co-generation or for by-product manufacture. Efficiencies can usually be increased by adding heat recovery equipment (economiser or more airheater surface).

Final gas temperature (into scrubber or ID fan if no scrubber) is an excellent indication of the potential for improvement. Bagasse boilers can operate without risk of corrosion at final gas temperatures of 160°C (lower with corrosion resistant materials). As a useful rule-of-thumb:

- ➢ *For every 10°C higher final gas temperature, the boiler will produce about 1% less steam per ton of bagasse.*

Excess air control

It is often possible to improve the efficiency of traditional bagasse boilers by controlling the amount and distribution of combustion air. In recent years, a number of improvements to bagasse boilers have helped in this regard:

- Pin-hole grates that precisely control undergrate air distribution and are low in maintenance
- Air-tight membrane furnace wall construction
- Improved bagasse feeders
- Improved furnace turbulence and combustion
- Automatic fuel/air ratio controls using zirconium oxygen meters or other gas quality measurement

These make it possible to achieve complete combustion with ± 27% excess air, thereby maintaining an O_2 level in flue gas at ± 4.0 %. Under these conditions, a boiler with 160°C final gas will be operating at > 85% LCV efficiency on bagasse of 50% moisture.

However, it is not uncommon to find boilers with excess air of 50% (or sometimes much higher!). A boiler at 55% excess air will produce about 2% less steam per ton of bagasse than at 27%. The useful rule-of-thumb:

- *For every 15 unit increase in % excess air, the boiler will produce 1% less steam per ton of bagasse.*

By increasing the LCV efficiency from 80% to 85%, export power is increased to **32.1 MW.**

8. Future steam conditions

For co-generation or if HP steam is the limiting factor in the energy balance, higher pressure steam is advantageous. This was clearly demonstrated by the earlier increase from 1800 kPaa to 4500 kPaa.

If the steam temperature is not sufficient in relation to the pressure, it will not be possible to use high efficiency turbo-alternators, as they will remove so much enthalpy (heat) from the steam that the exhaust is cooled to below saturation and wet steam droplets will damage the back end of the turbines. To permit reasonably efficient (≥ 80%) back pressure turbines exhausting to 200 kPa abs (1.0 bar gauge) the pressure / temperature combinations in the table below are recommended.

Pressure / Temperature conditions for efficient turbines

Steam pressure (kPa abs)	1800	3100	4500	6500	8500
Steam temperature (°C)	360	410	445	480	515

South African sugar engineers have not ventured above 4500 kPa abs steam, largely because of concerns that above this, feed water quality specifications are far more demanding, more exotic materials are required for the high steam temperatures and higher calibre boiler operators are probably needed. However, many sugar industries already regard 6500 kPaa boilers as the "standard" for new plant, a few operate 8500 kPaa boilers and some are considering pressures as high as 12000 kPaa.

With increased importance of energy efficiency, the next generation of boilers in South Africa will almost certainly be for 6500 kPaa / 480°C conditions or higher. With 600 kPa a steam, our factory can export **35.4 MW**.

The EMB steam diagrams for this modern efficient factory are shown in figures 6 and 7 below:

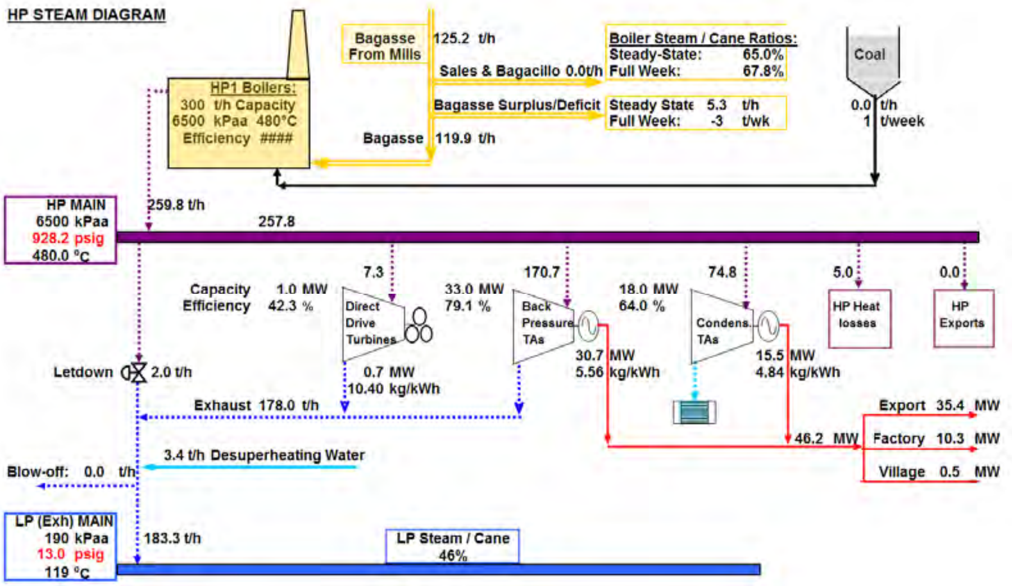


Figure 6. HP steam diagram for modern efficient factory

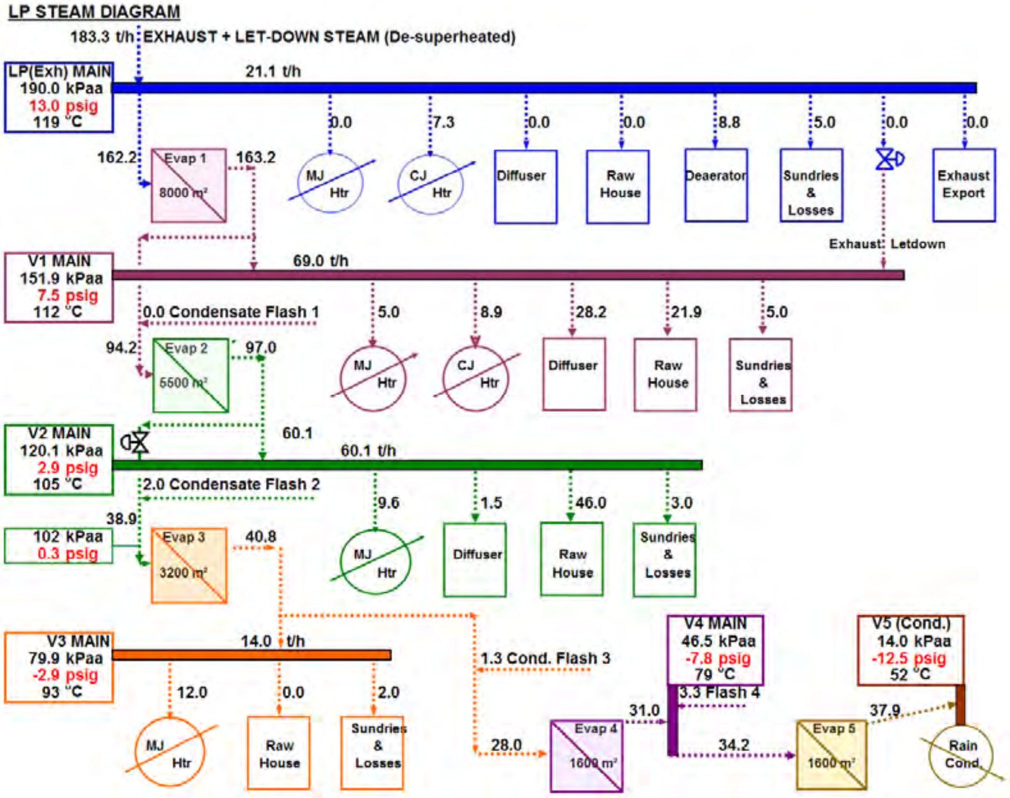


Figure 7. LP steam diagram for modern efficient factory

9. Summary of Energy Savings for a 400 TCH Factory

The progressive effects of the above innovations on the cogeneration capacity of a 400 TCH factory designed for 97.7% extraction, are shown from the EMBs to be as follows:

From Old	To New	Change (∆MW)	Total (MW)
	1980s Base Case factory	**-**	**7.7**
1800 kPa abs Steam	4500 kPa abs Steam	**8.1**	**15.8**
Milling extraction	Diffusion	**5.9**	**21.7**
Diffusion with filters	Diffusion + mud recycling	**2.8**	**24.5**
Batch pans	Continuous pans	**0.9**	**25.4**
Turbine shredder & mills	Electric drives	**3.0**	**28.4**
80% efficiency boilers	85% efficiency boilers	**3.7**	**32.1**
4500 kPa abs boilers	6500 kPa abs boilers	**3.3**	**35.4**

For the two factories, comparative performance figures are:

Parameter	Units	Base Case Factory	Efficient Factory
Total boiler steam	t/h	249	260
Total process steam	t/h	184	183
Power exports	**MW**	**7.7**	**35.4**

The available export power has been increased to 460% of original by the application of simple, proven technology.

Energy effects of some other novel equipment

Other recently introduced equipments that have small energy benefits but significant other benefits are Direct Contact Heaters and Long Tube Evaporators.

10. Direct contact (DC) juice heaters

Because the heating steam is condensed into the juice and has to be re-evaporated, DC heaters are widely believed to be energy inefficient. However, because of their low approach temperatures, lower grade vapour can be used and similar steam efficiencies usually achieved.

In the EMBs above, the mixed juice heating was performed by conventional shell-and-tube (S & T) heaters in three stages: primary on V3, secondary on V2 and final on V1. The size of heater required increases rapidly as ∆T is reduced, so in the 1st and 2nd stages, the juice was heated to 8°C below the relevant steam / vapour temperature. This is a typical ΔT, allowing for reasonable heater areas (a total on line of ± 2000 m^2 for this factory).

Alternatively, the same heating could be achieved using direct contact heaters, with ΔT approaches of 1.5K (which is typical for commercial DC heaters). This allows the heating stages to be on V4, V3 and V2.

The table below compares the two options for this factory, with the same exhaust pressure of 190 kPaa:

Steam	**Pressure**	**Temp**	**S&T Heaters**		**DC Heaters**	
	kPa abs	**°C**	**MJ out °C**	**t/h used**	**MJ out °C**	**t/h used**
Exhaust	190	118.6	102.5	**-**	102.5	**-**
V1	153	112.1	102.5	**5.1**	102.5	**-**
V2	118	104.6	96.6	**11.1**	102.5	**10.9**
V3	74	91.9	83.9	**10.3**	90.4	**11.2**
V4	45	79.2	72	**-**	77.7	**4.9**
V5	15	54.0	72	**-**	72.0	**-**
	Total steam:			**26.6**		**27.0**
	Exhaust for this heating			**8.9**		**7.4**

In this case, the DC heaters require ***1.5 t/h less*** total exhaust (process) steam than the S & T heaters. The DC heating would require an additional 250 m^2 heating surface in the 3rd effect evaporator and 400 m^2 more in the 4th effect, a total of 650 m^2. This compares with a saving of 2000 m^2 of juice heater surface!

(Note that with larger S & T heaters allowing a lower ΔT, the S & T balance could be improved to better than that of the DC heaters).

Direct contact juice heaters also save on mixed juice pumping power – for our 400 TCH factory, probably about 150 kW, depending on the type of heaters replaced.

Main benefits of DC heaters:

- Low capital cost
- Eliminate juice heater cleaning
- No extra vessels required for cleaning
- Reduced mixed juice pumping requirement
- Low maintenance
- Ease of control
- Permit intermediate liming without scaling problems

11. Long tube evaporators

In modern large factories with extensive vapour bleeding, large first and second effect evaporators are needed. For vessels of > 3,000 m^2 heating surface, Robert type vessels are cumbersome and costly. They also suffer from high retention times and significant sucrose destruction. Various falling film vessels with high volume recirculation pumps or Kestner rising film vessels with costly separation vessels have therefore been used.

For the final case factory modelled in this exercise, the 1st effect requirement is 8,000 m^2. In tubular falling film vessels on cane juice, recirculation needs to provide a minimum of 25 litres/cm of tube periphery for sufficient wetting. Adding the pumps into and from the evaporator, with the high pumping head involved, this would require about 250 kW of pumping power.

A simple, much lower cost long tube rising film design has recently been developed. This has all the advantages of Kestners at lower cost. The boiling action in these vessels effectively raises the juice by ± 5 m without any pumping. Some juice recirculation is incorporated (much less than for falling film), but this is effected without any mechanical pumping. Compared to falling film, these therefore provide a saving of ± 250 kW of pump power, as well as maintenance savings.

Main benefits of Long Tube Evaporators:

- Low capital cost – no support structure needed
- Small footprint
- Eliminate pumps
- Low juice retention time, minimise sucrose destruction
- Simple operation

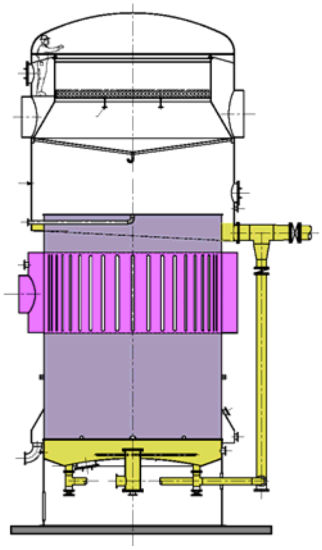


Figure 8. 6,000 m^2 L. T. climbing film evaporator with un-pumped recycle.

12. Conclusions

The sugar factory Energy and Mass Balance used is a powerful tool for evaluating the effects of alternative factory technologies and for optimising overall factory design.

The examples given demonstrate that substantial energy efficiency improvements are possible from the application of modern technology. These improvements need not be at the cost of simplicity; indeed, electric drives, diffusion, mud recycling, continuous pans, direct contact heaters, long tube rising film evaporators and pin-hole grates are all simpler to operate and require less maintenance than previous equipment.