

Further reduction of steam demand at modern cane sugar mills*

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Abstract

More and more cane sugar factories are closely monitoring their energy consumption figures and trying to reduce their steam demand to a minimum by investing in equipment and process optimisation. The new global tendency to install cogeneration plants is the main reason for the cane sugar factories to monitor not only the daily quantity of sugar produced, but also the amount of bagasse quantity that is saved each day. The bagasse saved serves as an energy source after crushing to produce electric power that is then fed into the local mains. Modern cane sugar factories achieve steam consumption values of 30% on cane (in cane sugar factories with plantation-white production) and 40% on cane (in cane sugar factories with a back-end refinery) and can thus store 50% / 35% of the bagasse produced. Operating results from cane sugar factories in India and Pakistan point to clearly enhanced processing performance and reduced steam demand thanks to the installation of falling-film evaporators as well as modifications of the heating scheme and the pan-boiling process. However, it has to be determined that reducing the steam consumption by optimisation of the factory's heating scheme will be useful only if the heat/power equilibrium remains effective in spite of the steam savings.

Keywords: heating scheme, steam demand, equilibrium heat/power, cogeneration, falling-film evaporator

Introduction

In the cane sugar industry, the Robert evaporator is currently the most common type of evaporator. This is not only a question of costs, but it can also be explained by the fact that cleaning of the heating tube is a simple mechanical process. However, Robert evaporators need a higher temperature difference in the different evaporator effects, due to the hydrostatic pressure that is produced by the high juice level. This restricts the possibility of using vapour from the last effects for heating purposes, and consequently increases the factory's steam consumption.

We have developed the concept that allows falling-film evaporators to be used in the cane sugar industry, so the benefits of this technology, which has been applied in the beet sugar industry for decades with great success, can also be put to use for the production of cane sugar.

In 2011, a five-effect evaporation plant with falling-film evaporators was installed and commissioned for Indian Cane Power Limited (ICPL), which is a 6,000 tonnes of cane per day (tcd) plantation-white cane sugar factory without a refinery. In 2012, two additional falling-film evaporators were installed as standby units for effects 3 and 4.

In 2014, two-falling-film evaporators were installed and commissioned at Ghotki Sugar Mill (GSM) in Pakistan. GSM is a 12,000 tcd cane sugar factory with an attached refinery.

Table 1 summarises key operating data of both factories. Both projects have the same objectives:

- Stable operation of the evaporation plant;
- Larger capacity;
- Reduced steam consumption; and
- Larger amount of bagasse saved and therefore more exported electric power.

Table 1: Operating features of the mills at Indian Cane Power Ltd (ICPL) and Ghotki Sugar Mill (GSM)

Parameter	ICPL	GSM
Initial crushing capacity tcd	6,000	12,000
Intended crushing capacity tcd	7,000	13,000
Reached crushing capacity tcd	9,000	14,700
Final product	Plantation white	Refined sugar
Operation with refinery	No	Yes
Mill tandem / diffuser	Mill tandem	Mill tandem
Cogeneration	Yes	Yes
Juice purification system	Phospho-defecation + double sulphitation	Phospho-defecation
Existing evaporation station	Quintuple effect FFEs + Roberts	Quintuple effect FFEs + Roberts
Improved evaporation station	Quintuple effect only FFEs (new)	Quintuple effect FFEs + Roberts (extended)
Initial steam consumption % on cane	36	46
Current steam consumption % on cane	30	40

In parallel with the two projects, heating system concepts were developed, from preparing the mass and heat balances to the process and instrumentation diagrams, including the arrangement plans. Assistance with the projects also comprised plant commissioning and development of effective cleaning practices.

Falling-film evaporators allow advanced steam saving concepts to be implemented for sugar production. This paper shares the experience and results of evaporator plants including falling-film evaporators in cane sugar factories with a particular view to the operating particularities of cane sugar mills with and without refineries.

Results

Project 1: ICPL (plantation-white sugar mill without a refinery)

Elements of the evaporation plant

The new evaporation plant (Figure 1) was designed for a capacity of 7000 tcd. It consists of five falling-film evaporators with a specific heating surface of 2.0 m²/tcd that is distributed as: 4,000 m² in each of effects 1-3; 1000 m² in each of effects 4-5.

Additional equipment to complement the plant includes a central condensate tank for gradual condensate expansion. Pumps

Figure 1: New falling-film evaporation station during installation at ICPL



for clear juice, juice circulation and thick juice are also installed. These pumps ensure that the evaporators are supplied with the required amount of juice for concentration. For better heat

utilisation, the clear juice is gradually heated in heaters before it enters the first evaporator. Storage tanks and feed tanks, as well as separate pumps, are available for chemical cleaning. Measuring and control equipment and a central process-control system provide for easy control of the complete system.

Special features of the heating system concept (ICPL)

The heating system concept for ICPL (Figure 2) is based on making maximum use of the vapour from the last effects for heating purposes. What is particularly decisive is the utilisation of VP 3 for crystallisation (Lehnberger et al. 2013). Details of the heating system include:

- Heating of primary juice (PJ) with VP 5, condensate and VP 4;
- Heating of limed juice (LJ) with VP 3, VP 2 and VP 1;
- Heating of clear juice (CJ) with VP 2 and VP 1; and
- Crystallisation with VP 2 and VP 3.

The falling-film evaporators operate with an independent juice circulation system. Even if the clear juice feed rate should fluctuate, correct operation of the different evaporators is always maintained, because wetting of the heating tubes with circulating juice is independent of the amount of clear juice that

enters the system. The heating tubes of the evaporators are easily accessible from the upper tube plate to provide for easy inspection and, if necessary, cleaning with high-pressure water (hydrojet).

Processing rate achieved and specific steam requirements (ICPL)

The evaporation plant was supplied and commissioned in January 2012. Figure 3 gives an overview of the crushing capacity and specific steam consumption values that were recorded during a period of 3 weeks.

The intended crushing rate of 7,000 t of cane per day at 33% steam on cane was maintained without any interruptions. As long as the evaporation plant was clean (the first 10 days of operation), the recorded capacity was almost 10% higher than the design value, with a specific steam consumption 6.5% lower than designed. As the heating surfaces became gradually scaled, i.e. after the 18th day of operation, the capacity and specific steam consumption values remained slightly below the rated values. After day 21, the evaporators were cleaned (Lehnberger et al. 2013).

Figure 2: Heating-system concept of ICPL with typical operating conditions (Step 1)

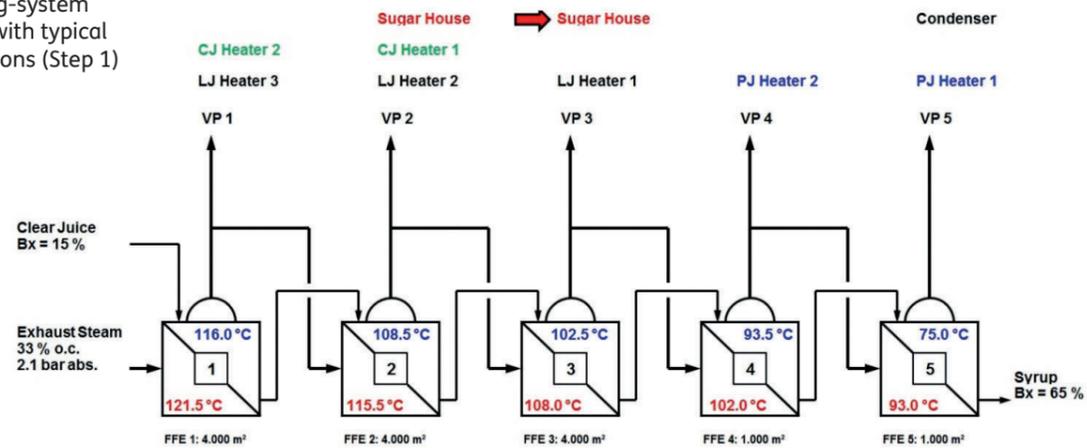
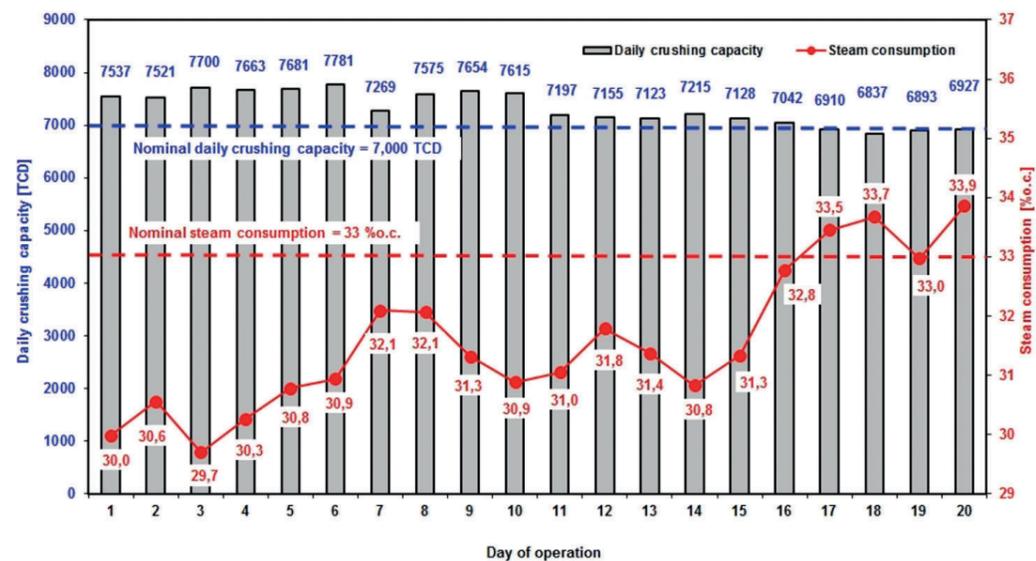


Figure 3: Daily crushing capacity and specific steam consumption at ICPL (Step 1)



In 2012, two further falling-film evaporators were installed (Figure 4), replacing effects 3 and 4 and increased the heating surface of effect 4 to 4000 m². The original effect 4, with a heating surface of 1000 m², was then used as a standby evaporator for effect 5. After this modification, the heating surfaces were distributed as 4,000 m² in each of effects 1-4; 1000 m² in effect 5.

Figure 4: Extension of falling-film evaporation station at ICPL



With this upgrade of the evaporation plant, together with optimisation measures in the sugar house, even VP 4 could be used for crystallisation (Figure 5). This raised the factory's processing capacity to 9,000 tcd, and steam consumption was reduced to 28% on cane (without accounting for downtimes) (Figure 6).

Project 2: GSM (cane sugar mill with a refinery) Elements of the evaporation plant (GSM)

The original evaporation plant at GSM combines falling-film evaporators as effect 1 with Robert evaporators as effects 2, 3, 4 and 5, with a specific heating surface of 1.5 m²/tcd. To upgrade the evaporation plant, two new falling-film evaporators were installed with a heating surface of 5000 m² each in effect

Figure 5: Heating-system concept of ICPL with typical operating conditions (Step 2).

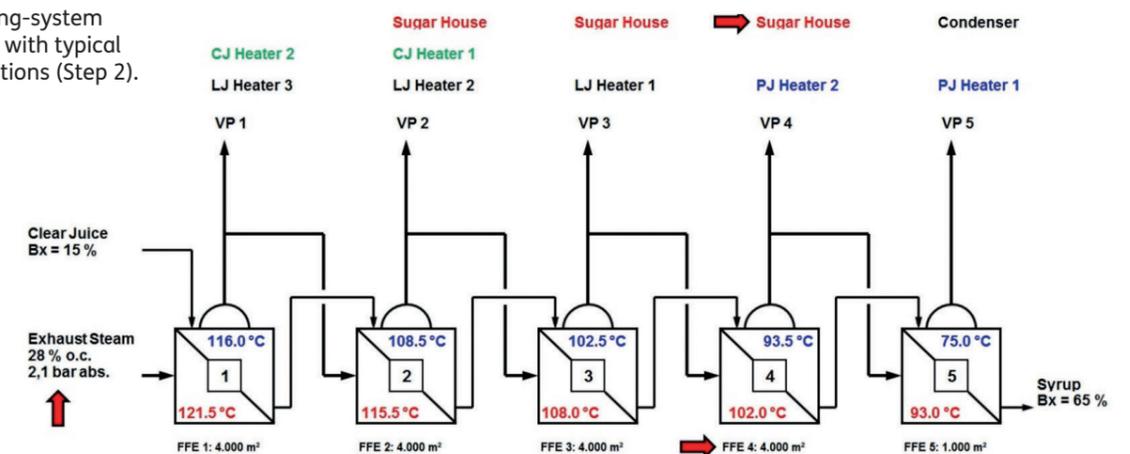
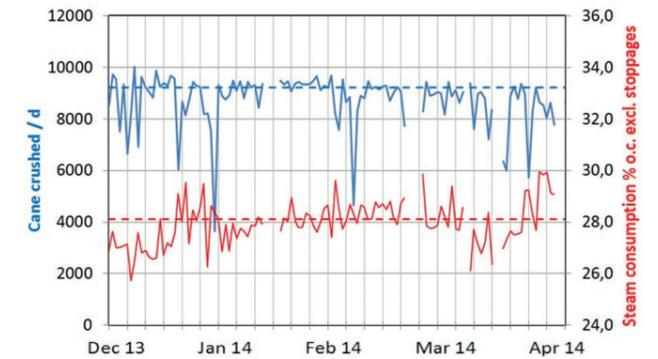


Figure 6: Daily crushing capacity and specific steam consumption at ICPL (Step 2)



1 (Figure 7). The existing evaporators were then distributed to the remaining effects. The two new evaporators increased the specific heating surface to 2.0 m²/tcd. Since each effect now has its own standby evaporator, evaporator switching for cleaning purposes is much easier than previously, and there is also more flexibility in operation (Table 2) (Brahim et al. 2015).

Figure 7: New falling-film evaporators for effect 1 at GSM



Table 2: Old and new evaporator setup at GSM

Evaporators	Existing setup	Standby	Extended setup	Standby
1st Effect	3500 m ² + 3500 m ²	3000 m ²	5000 m ² + 5000 m ² (new)	3500 m ²
2nd Effect	2500m ² + 2500 m ² + 2100 m ²		3500 m ² + 3000 m ²	2500 m ²
3rd Effect	1800 m ²	1800 m ²	2500 m ² + 2100 m ²	1800 m ²
4th Effect	1500 m ²		1800 m ²	1500 m ²
5th Effect	900 m ²	900 m ²	900 m ²	900 m ²

Table 3: Old and new (intermediate step) heater setup at GSM

Heaters	Existing setup (12,000 tcd)		Future setup (13,000 tcd - Intermediate step)	
	In operation	Standby	In operation	Standby
Vapour line heaters	1 x 350 m ²	1 x 350 m ²	2 x 350 m ² (VP 5)	1 x 450 m ² (VP 5)
Primary juice heaters	2 x 350 m ²	1 x 350 m ²	1 x 450 m ² (Condensate) 1 x 450 m ² (VP 4 / VP 3)	1 x 450 m ² (VP 4 / VP 3)
Limed juice heaters	3 x 350 m ²	1 x 350 m ²	2 x 350 m ² (VP 2) 2 x 350 m ² (VP 1)	2 x 350 m ² (VP 1 / VP 2)
Clear juice heaters			1 x 350 m ² (VP 1)	
Total	9 x 350 m²		9 x 350 m² (Existing); 4 x 450 m² (New)	

Four new shell and tube heaters for raw juice with a heating surface of 450 m² each were installed during the 2014/2015 harvest in addition to the two falling-film evaporators. The old and the new heater setups are shown in Table 3.

As a further and final step, four additional shell-and-tube

heaters for limed juice and clear juice, with a heating surface of 450 m² each, were installed during the 2015/2016 crushing to further improve vapour bleeding and decrease steam consumption (Table 4).

Table 4: Old and new (final step) heater setup at GSM

Heaters	Existing setup (12,000 tcd)		Future setup (13,000 tcd - Final step)	
	In operation	Standby	In operation	Standby
Vapour line heaters	1 x 350 m ²	1 x 350 m ²	2 x 350 m ² (VP 5)	1 x 450 m ² (VP 5)
Primary juice heaters	2 x 350 m ²	1 x 350 m ²	1 x 450 m ² (Condensate) 1 x 450 m ² (VP 4 / VP 3)	1 x 450 m ² (VP 4 / VP 3)
Limed juice heaters	3 x 350 m ²	1 x 350 m ²	1 x 450 m ² (Condensate) 1 x 450 m ² (VP 3) 2 x 350 m ² (VP 2) 2 x 350 m ² (VP 1)	1 x 450 m ² (VP 3) 2 x 350 m ² (VP 1 / VP 2)
Clear juice heaters			1 x 450 m ² (VP 2) 1 x 350 m ² (VP 1)	
Total	9 x 350 m²		9 x 350 m² (Existing); 8 x 450 m² (New)	

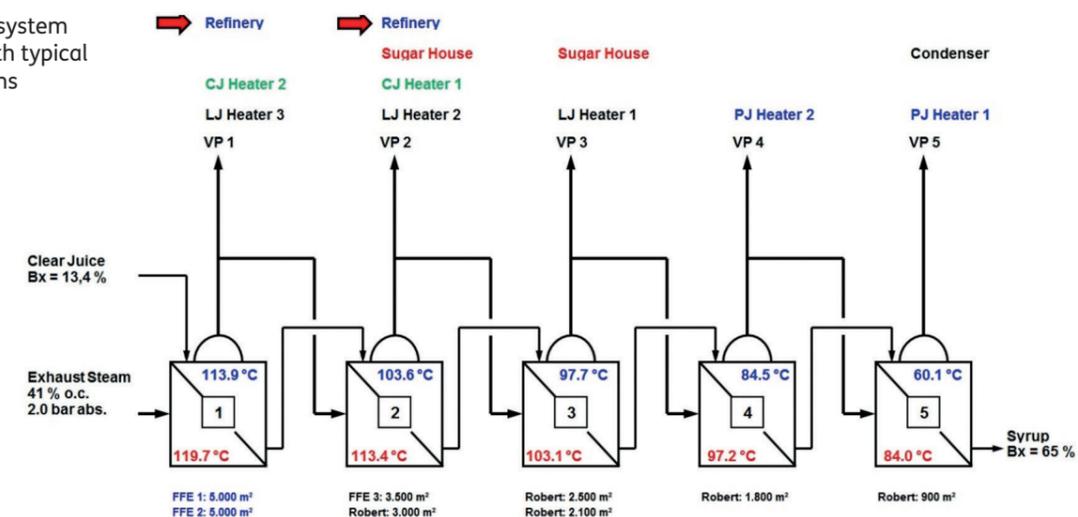
Special features of the heating system concept (GSM)

Operation at GSM differs from ICPL in that GSM has an attached refinery with an additional steam consumption of approximately 10% on cane for which VP 1 (2% on cane) and VP 2 (8% on cane) are used. For the sugar house, only VP 2 and VP 3 are used. The heater setup is similar to that at ICPL except that during the 2014/2015 harvest first limed juice heating with condensate and VP 3 and first clear juice heating with VP 2 were not available. This has nothing to do with the planned heating system concept, but it was a decision taken because of the very tight time

schedule for project implementation. The missing four heaters with a heating surface of 450 m² each were then installed during the 2015/2016 harvest. The final heating system concept for GSM was (Figure 8):

- Heating of primary juice (PJ) with VP 5, condensate and VP 4;
- Heating of limed juice (LJ) with condensate, VP 3, VP 2 and VP 1;
- Heating of clear juice (CJ) with VP 2 and VP 1;
- Raw pans with VP 2 and VP 3; and
- Refinery pans with VP 2 and VP 1.

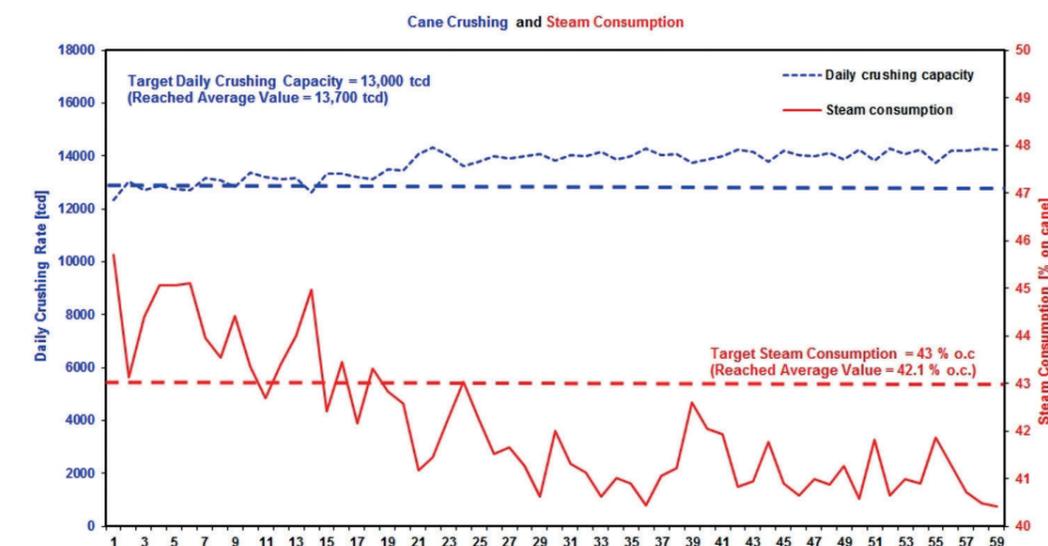
Figure 8: Heating system concept of GSM with typical operating conditions



Operational results (GSM)

The targeted crushing rate of 13,000 tcd was not only achieved, it was even exceeded. The average crushing rate was 13,700 tcd, which is 5% higher than the rated value (Figure 9).

Figure 9: Daily crushing capacity and specific steam consumption in GSM (2014/2015)



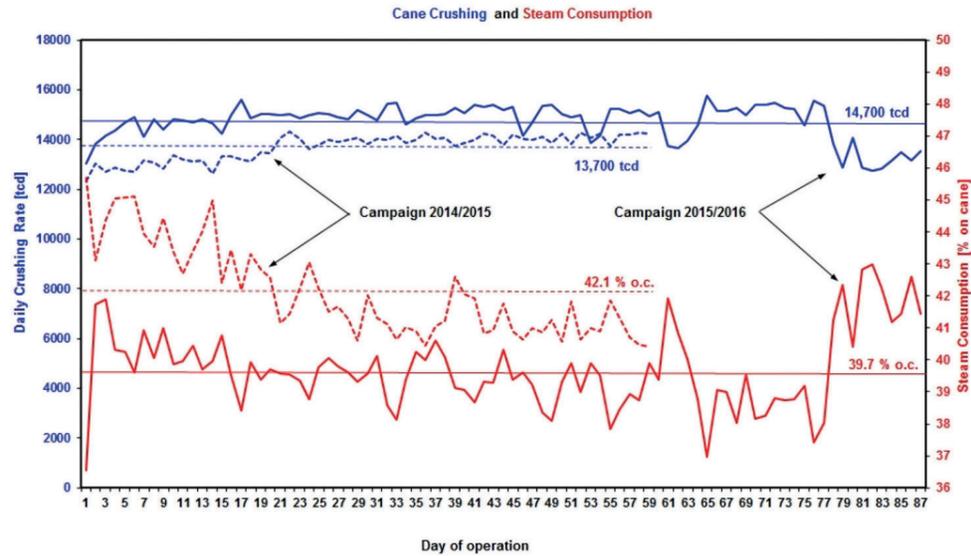
The high steam consumption during the first 2 weeks can be explained by the fact that the new installations had not been insulated during the first 2 weeks (new falling-film evaporators, new heaters, juice and steam piping). When the insulation for the equipment was completed (20 days after commissioning), the specific heat consumption dropped to 40-43% on cane. The mean specific steam consumption determined for the entire period of data recording was 42.1% on cane. For the period after completion of insulation, the average steam consumption was 41% on cane, which is 2% on cane lower than the rated value (43% on cane).

During the 2015/2016 harvest, the remaining four tube bundle heaters for heating limed juice and clear juice were

installed. In this way, vapour bleeding from effects 2 and 3 could be increased and the utilisation of condensate exhaust heat could be intensified. The effect of this heating scheme optimisation on the processing rate and the steam consumption can be clearly seen in Figure 10. This figure shows a comparison of the measured values for processing rate and specific steam consumption from the harvests in 2014/2015 and 2015/2016.

Thanks to the newly installed heaters, the processing rate could be raised to 14,700 tcd, which is 1,000 tcd more than the previous year. At the same time, the specific steam consumption decreased to 39.7% on cane, which is 1.3% on cane less than the steam consumption value achieved in the previous harvest (Figure 10).

Figure 10: Daily crushing capacity and specific steam consumption in GSM (2015/2016)



Heat/power equilibrium

The ICPL and GSM projects clearly show that the steam consumption of a cane sugar factory can be reduced to 30% on cane (without a refinery) and 40% on cane (with a refinery), when the heating scheme of the factory has been optimised. However, this can only be achieved, if simultaneously with the reduced steam consumption, sufficient power is generated for operating the whole factory, which is not always to be taken for granted. Especially in sugar factories with low-pressure boilers, it is difficult to achieve the above values. Steam-driven units for the so-called prime movers, such as mills, shredder, cane cutter, FWP and fans, complicate things due to the higher specific steam consumption of those steam turbines compared with power generation turbines.

Project 3: Matiari Sugar Mill (MSM) (cane sugar mill with a refinery)

Consideration of the Matiari Sugar Mill (MSM) in Pakistan clearly demonstrates the limiting effect of low pressure boilers combined with steam driven prime movers on the reduction of steam consumption. This cane sugar factory, with a backend refinery and

processing 4000 tcd, had a specific steam consumption of 55% on cane and wanted to increase crushing capacity to 6,000 tcd by reducing steam consumption to a minimum. The specific power consumption of the factory is currently 20 kWh/tc.

Factory heating scheme currently applied

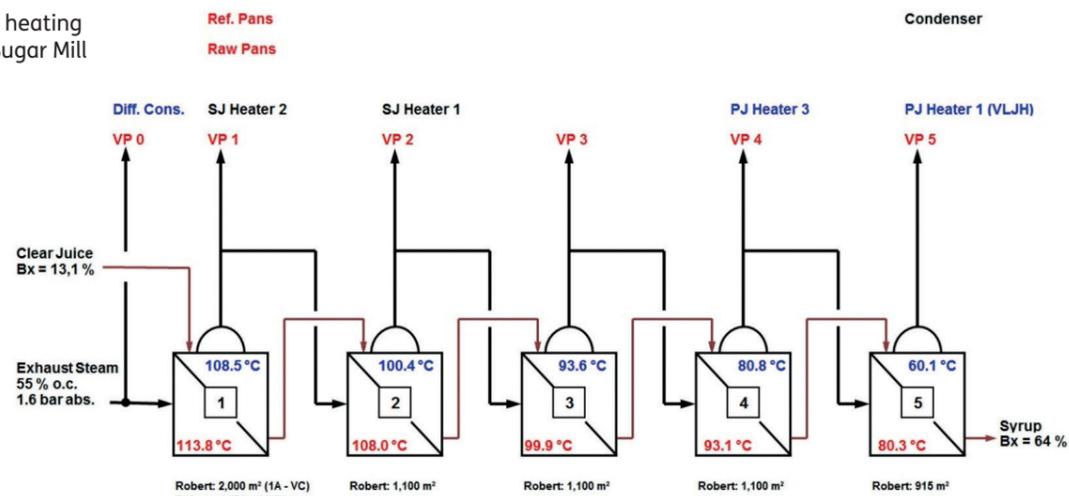
Figure 11 shows the current heating scheme of MSM. All pans for raw and refined sugar are heated with VP 1. Clear juice is not heated and there is no bleeding from the 3rd effect.

At first sight, it appears that the current high steam consumption of 55% on cane has process-related reasons and is caused only by a bad factory heating scheme. However, the bad heating scheme is due to a high steam consumption of the prime movers, and some use of reduced 6 bar live steam for various heating purposes, as well as a relatively high specific power consumption of the factory combined with low pressure boilers and turbines.

The current steam consumption of 55% on cane is composed as:

- Live steam to prime movers = 29.9% on cane.
- Live steam for power production = 21.5% on cane.
- Live steam through reducing station (bypass turbine) = 2.5% on cane.

Figure 11: Current heating system of Matiari Sugar Mill (MSM)



- Live steam (reduced to 6 bar) to different consumers = 1.2% on cane.

An optimisation of the heating scheme alone would reduce the steam consumption of the process, but not the total steam consumption of the factory. A steam on cane of 55% would still be needed, but could not be consumed completely by the process. Part of it would have to be blown off into the atmosphere in order to keep the heat/power equilibrium and avoid power input from the local mains.

Case study: Optimisation of steam/power balance

Optimising the factory operation focuses on the reduction of steam consumption to a minimum while retaining the existing low pressure boilers and turbines. To achieve this, the drive units of some prime movers have to be modernised by replacing the existing steam turbines with electric motors. Another important change applies to the use of reduced live steam, which has to be stopped completely. Exhaust steam from the turbo-generators shall be utilised instead. This offers the advantage that live steam from the boiler is used twice, i.e. first for power generation in the turbo-generators and then for various steam consumers in the form of exhaust steam as heat transfer medium.

Although the replacement of the steam drives of some prime movers by electric motors helps reduce the steam consumption, the specific power consumption increases, which in turn raises the necessary steam volume by the turbo-generators. Taken as a whole, however, and due to the higher efficiency of the turbo-

generators compared to the steam turbines of the prime movers, steam consumption decreases (Rein 2007).

Table 5 shows a list of the specific values to be expected for power and steam consumption for five scenarios:

- Scenario 0: Situation now (2015/2016 harvest).
- Scenario 1: Without reduced 6 bar steam usage.
- Scenario 2: Scenario 1 + Feed water pumps electrically driven.
- Scenario 3: Scenario 2 + Fibrizer electrically driven.
- Scenario 4: Scenario 3 + Mills electrically driven.

The objective of drive modernisation for the prime movers is to reduce the factory's overall steam consumption to a value below 50% on cane. A limiting factor is the power generation capacity installed in the factory which is a maximum 36 kWh/tc (9,000 kW for 6,000 tcd). These two values clearly limit the feasibility of the above scenarios (Figure 12).

Only scenario 3 is useful for this project, i.e. only the FWP and the Fibrizer drives will be modernised; the drives of the mills remain unchanged. This helps reduce the specific steam consumption to 49.4% on cane. Although the factory's specific power consumption increases to 29.5 kWh/tc, it clearly remains below the maximum limit of 36 kWh/tc.

The drive modernisation for some prime movers and the removal of reduced live 6 bar steam usage are indeed two important steps to reduce steam consumption, but they have to be accompanied by process optimisation and an improvement of the factory's heating scheme. This can be achieved by implementation of the following optimisation measures (Figure 13):

Table 5: Increase in specific power consumption and decrease in specific steam consumption for the different scenarios

Scenario	Type of change	Specific power consumption of the mill. kWh/tc	Necessary steam flow through turbo-generator power turbines % o.c.	Necessary steam flow to prime movers turbines % o.c.	6 bar steam % o.c.	Total steam % o.c.
0	Situation now	20.0	24.5	29.9	1.2	55.6
1	Without live steam usage	20.0	24.5	29.9	0.0	54.4
2	Scenario 1 + FWP elec. driven	20.6	25.2	27.6	0.0	52.7
3	Scenario 2 + Fibrizer elec. driven	29.5	36.1	13.3	0.0	49.4
4	Scenario 3 + Mills elec. driven	39.1	49.2	0.0	0.0	49.2

Figure 12: Advisable scenarios based on specific steam consumption of < 50% on cane and specific power consumption of < 36 kWh/tc

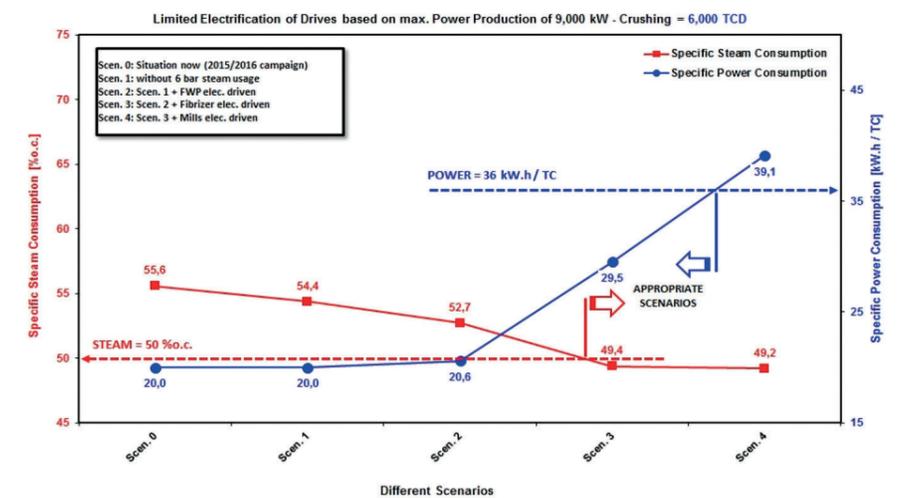
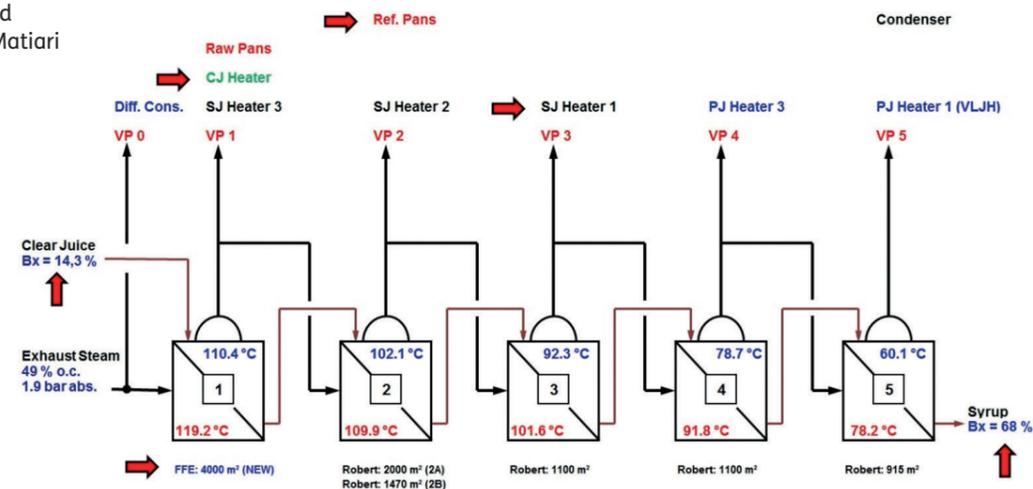


Figure 13: Optimised heating system for Matiari Sugar Mill (MSM)



- Reduction of imbibition water from 49 to 40% on cane;
- Increasing syrup Bx from 64% to 68%;
- Heating all refinery pans with VP 2 instead of VP 1;
- Heating SJ with VP 3, VP 2 and VP 1 instead of only VP 2 and VP 1; and
- Heating CJ with VP 1.

The following new equipment items need to be installed to be able to increase capacity and optimise the heating scheme:

- 1 x new FFE (4000 m²) as new 1st effect (the existing Robert evaporators are used in effects 2 to 5);
- 1 x new VKT (4.4 m diameter) for A product (usage of all existing pans in raw sugar house for A1-, B- and C-products);
- 1 x new BVP (60 m³) for R1 product (usage of all existing pans in refinery sugar house for R2- and R3-products); and
- 6 x new juice heaters (350 m² each) to improve vapour bleeding for juice heating.

By comparing the steam consumption scheduled in this case study (49% on cane) with the steam consumption achieved at GSM (40% on cane), a difference of 9% on cane results. This shows clearly that it is only possible to achieve a steam consumption of 40% on cane in a cane sugar factory with backend refinery if the factory is equipped with a high-pressure boiler, which allows, together with a high-pressure turbine, generation of sufficient power at simultaneously low steam consumption.

It has to be examined separately on a case-by-case basis, how the use of steam-driven prime movers limits the reduction of the factory overall steam consumption, since it strongly depends on the efficiency of the steam turbines. Two-step steam turbines are clearly more efficient than one-step turbines, but they are more expensive (Hugot 1972). It can generally be said though that electric motors are to be preferred for prime movers, when the focus is on very low steam consumption for the factory.

Conclusions

Falling-film evaporators have proved to be excellent performers in the beet sugar industry. Thanks to a carefully conceived cleaning process and adequate discharge of non-condensable gases, they can also be used with great success in the cane sugar industry.

Since these evaporators require a lower temperature gradient than Robert evaporators, and since the residence time is low, the

temperature level in the last effects of the evaporation plant can be increased. Vapour from effects 3 and even 4 can therefore be used for crystallisation, which allows for an optimisation of the heating system in cane sugar factories.

When combining falling-film evaporators with well-organised sugar house operation (continuous boiling, batch pans with stirrers, controlled water application), specific steam consumption values of 30% on cane can be continuously achieved in cane sugar factories without a refinery, and 40% on cane in cane sugar factories with a refinery.

A prerequisite, however, is that in spite of the reduced steam consumption, sufficient power can be generated for the entire factory. The simplest way to achieve this is if the factory is equipped with high-pressure boilers and turbines as well as electric drives for the prime movers.

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