Falling-film evaporator plant for a cane sugar factory: Presentation of the concept and operating results*

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Abstract

In the cane sugar industry, Robert evaporators are generally considered the preferred evaporator design because of the issues associated with the scaling of heating surfaces. An evaporator set concept has been developed in collaboration with a supplier to utilise falling-film evaporators in the cane sugar industry in order to benefit from the numerous advantages of this technology. In 2011, a new 5-effect evaporator set composed entirely of falling-film evaporators was designed, supplied and commissioned for the Indian Cane Power Limited (ICPL), Uttur, a sugar cane factory located in the State of Karnataka, India. The design targets for this evaporator plant were smooth operation of falling-film evaporators in the cane sugar industry, considerable reduction of the steam consumption of the sugar factory and clear increase of power export to the local power supply network. The supplier BMA accompanied this project with the preparation of mass and energy balances, process flow diagrams and process layout concepts. BMA also assisted with commissioning and chemical cleaning of the plant.

Keywords: ***falling film evaporator, scaling, cleaning, non-condensables***

Introduction

Nowadays, cane sugar factories are not only companies that produce sugar from sugarcane, but are increasingly also defining themselves as sellers of by-products. One such by-product is the cogeneration and sale of surplus electricity

The cane sugar factory of Indian Cane Power Ltd (ICPL) in the federal state of Karnataka derives considerable economic benefits from feeding electrical power into the local grid, and the company is attempting to increase their co-generation proceeds by employing new technologies in sugar production and gaining surplus electricity from bagasse.

In order to increase their power yield, ICPL is trying to minimise the specific steam consumption in the sugar production process. In ICPL's original concept to increase cogeneration, the evaporation plant was equipped with Robert and falling-film evaporators, and used continuously operating vacuum pans in the sugar house.

Since the new concept proved to be promising, the capacity was, as a second step, increased with a new 5-effect evaporation plant in 2011. The evaporation plant now entirely consists of falling-film evaporators, and the steam requirements for sugar production have been further reduced by shifting the bleedings down to later evaporation effect and increasing the thick juice brix.

Falling-film evaporators allow advanced steam-saving concepts to be implemented for sugar production. This publication shares the experience and results of a full evaporator set with falling film evaporators in a cane sugar factory with particular view to scaling and non-condensable gases, which both have a distinct heat transfer reducing effect in falling-film evaporators.

Elements of the evaporation plant

The evaporation plant with all five falling-film evaporators is designed for 7000 tonnes of sugarcane per day, the 3rd vapour being used for crystallisation. Each of the first three effects have a surface area of 4000 m² (FFE1, FFE2, FFE3), while the last two effects have 1000 m² (FFE4, FFE5) (Figure 1). All evaporators are of BMA's 'Beta'evaporator design.

Additional equipment complements the plant. This equipment includes a central condensate tank for gradual condensate expansion. Pumps for clear juice, juice circulation and thick juice are installed.

Figure 1. New falling-film evaporators and condensate tank during installation at ICPL

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 heat exchangers 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 evaporation plant concept

ICPL conceived and implemented the new evaporation plant in collaboration with BMA. The basic conditions that had to be considered were defined by the classical front-end operations of a cane sugar factory, which include liming, clarification with the aid of flocculants, and subsequently clear juice sulfitation.

The modern steam bleeding system (Figure 2) is characterised by the fact that 3[rd] effect vapour is used for crystallisation. The raw juice is heated with 5th effect

Figure 2. New evaporation system of ICPL, with typical operating conditions

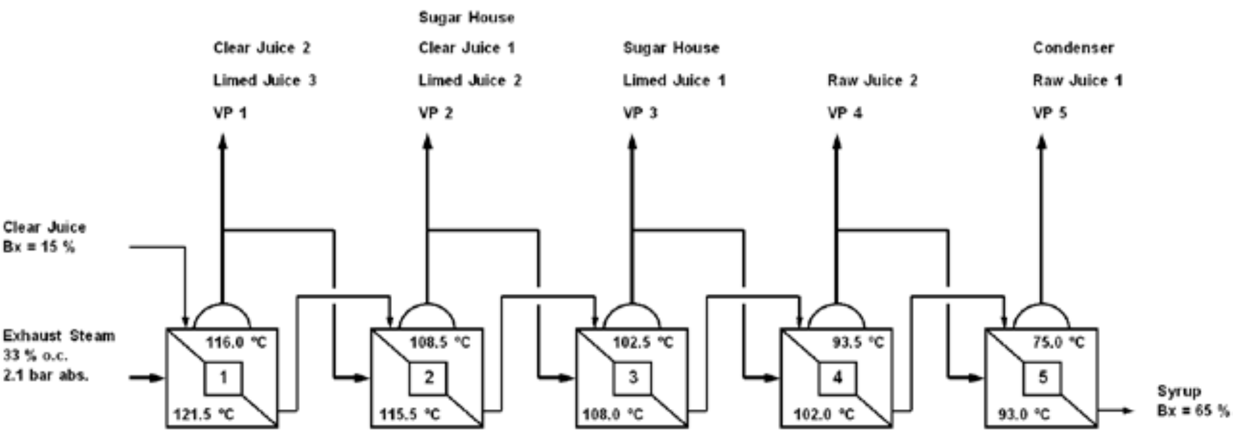
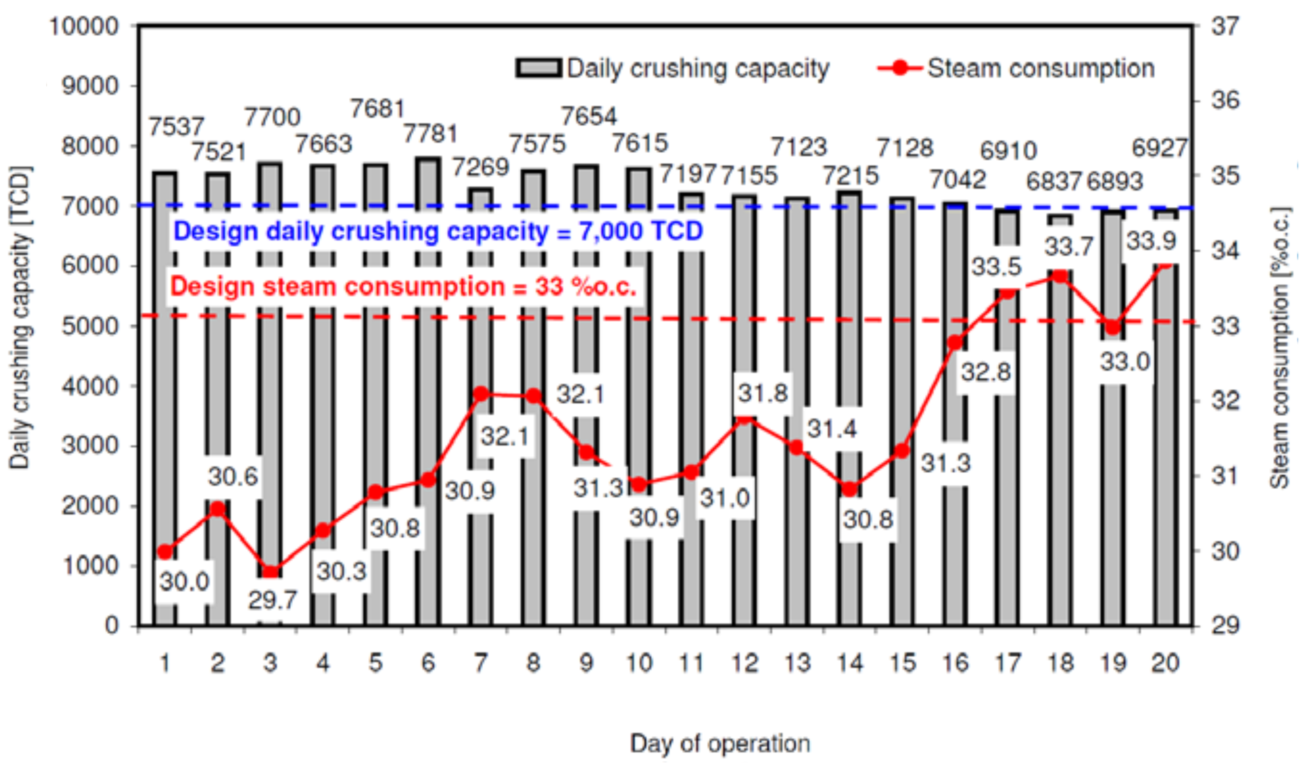


Figure 3. Daily crushing capacity and specific steam consumption



vapour and 4th effect vapour.

The 'Beta' type 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, mechanical cleaning with high-pressure water.

Achieved processing rate and specific steam requirements

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

The intended crushing rate of 7000 tonnes 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 10% lower than designed.

As the heating surfaces gradually become 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.

Scaling

A higher temperature gradient in the different evaporators is an indicator of increasing scaling during operation. The temperature gradient relative to the processing rate can serve as a simple measure of intensifying scaling.

As long as no changes are made in the heating system, this value reflects the development of the reciprocal heat transfer coefficient.

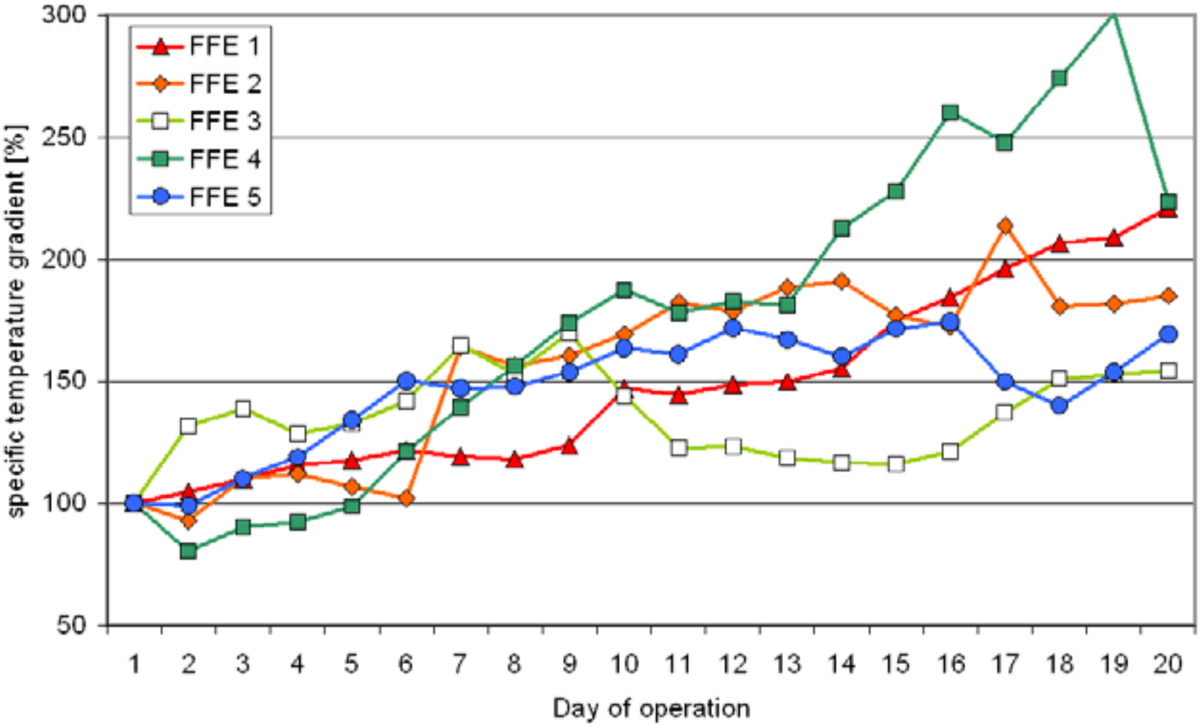
In Figure 4, specific temperature gradient is shown for each falling-film evaporator at ICPL for the first 21 days of evaporation plant operation. The curve for the 3rd evaporator effect clearly shows that, after day 10, the extent of vapour bleeding from this effect was reduced and extra bleeding shifted to the 2nd effect instead.

Since each evaporator effect is affected by scaling, the specific temperature gradient that is required for operation of the evaporation plant is on average twice as high after 21 days than that of the clean plant. This is particularly evident with the 1st, 2nd and 4th effects.

Scale on evaporator tubes is recognised as hampering the heat flow by a solid layer with low heat conductivity. Further, the heat transfer coefficient of clean tubes drops with rising dry substance content from the first to the last evaporator.

The operation figures show approximately the same increase of the specific temperature difference from clean to scaled tubes in all evaporators. This indicates that the scale thickness increases from the first to the last effect, comparable to the drop of heat transfer coefficients by rising dry substance content in

Figure 4. Development of the specific temperature gradient in the five falling-film evaporators as a measure of scaling, plotted against time



clean tubes.

The scales that formed in the different evaporator effects at ICPL were analysed. The main inorganic components in the scale are calcium carbonate, calcium phosphate, calcium sulfate, calcium sulfite and silicon compounds; how these are represented in the different evaporator effects is shown in Table 1.

The composition of the scale is typical of evaporators in the cane sugar industry, where phospho-defecation with clear juice sulfitation is used for juice cleaning; Dahi Ali (1986).

The raw material and operating conditions generally have an effect on the composition of the scale specifically:

- Composition of the processed cane, which is in its turn influenced by the soil and climatic conditions,
- pH value of the clear juice,
- Phospho-defecation for juice purification results in scale with a high phosphate content in the first effects,
- Sulfitation for juice purification results in a high sulfite content in the first effects.

Table 1 Scale from falling-film evaporators at ICPL: analysis of main inorganic components (February 2012)

Effect	FFE 1	FFE 2	FFE 3	FFE 4	FFE 5
Calcium carbonate	2.8 %	3.1 %	< 0.1 %	1.5 %	2.9 %
Calcium phosphate	42.8 %	6.6 %	3.5 %	3.0 %	1.4 %
Calcium sulphate	11.2 %	19.7 %	32.3 %	31.8 %	27.5 %
Calcium sulphite	0.1 %	14.4 %	< 0.1 %	1.8 %	< 0.1 %
Silicate	0.4 %	9.3 %	21.1 %	34.9 %	31.8 %
Scale samples					
Scale structure	Soft, thin layer. Can easily be scraped off.	Soft, thin layer. Can easily be scraped off.	Hard, thick layer. Difficult to remove mechanically.	Very hard, thin layer. Very difficult to remove mechanically.	Very hard and compact, thick layer. Very difficult to remove mechanically.

- Scales are, in addition, normally caused by the following factors:
- Dissolved salts, whose solubility goes down as temperatures and the sugar concentration go up, deposit on the heating surfaces,
- Suspended solids in the clear juice, which are not properly separated in the juice cleaning process, are caught on encrustations that have already been formed.

Chemical cleaning

Chemically cleaning the evaporators for removing scale is to regularly restore the original condition of the evaporators. Any remaining scale has to be removed with an additional mechanical

Table 2 Heating tubes in the different evaporator effects; before and after chemical cleaning

Effect	Before cleaning	After cleaning	Cleaning effect
FFE 1			Very good. Heating tubes are clean.
FFE 2			Very good. Heating tubes are clean.
FFE 3			Good. Heating tubes are largely clean.
FFE 4			Poor. Heating tubes still covered with considerable encrustations.
FFE 5			Poor. Heating tubes still covered with considerable encrustations.

process in which a high-pressure water jet is used.

Hugot (1972), and later also Rein (2007), provided a general description of the experience that has to be considered when cleaning evaporators:

- Calcium phosphate ($Ca_3(PO_4)_2$) primarily occurs in the first two evaporator effects; it forms soft scales that can fairly easily be removed in a chemical process with caustic soda solution and diluted sulfamic acid.
- Calcium sulfate ($CaSO_4$) forms in the last effects; it tends to form as a hard and compact scale that can only slowly be attacked with acids.
- Encrustations with silicon compounds in the last two effects are very hard and difficult to remove even in cleaning processes in which alkaline-acid methods are combined.

At ICPL, the evaporation plant was chemically cleaned not later than a 30 days operation period. Alkaline cleaning (a combination of a 6% caustic soda solution with 70% on solids of caustic soda NaOH and 30% on solids of sodium carbonate Na_2CO_3 as well as an EDTA-based scale softener) was followed by acid cleaning (formic acid with corrosion inhibitor), always at temperatures near 100 °C. The exposure time was always 8 h, the concentration of the cleaning solution being adapted to the scale thickness. Table 2 shows how successful cleaning was for the different evaporators.

While combined alkaline followed by acid cleaning produces satisfactory results in effects 1 to 3, the scale in effects 4 and 5 are much more difficult to remove because of the silicate content. When the plant was cleaned for the first time, the heating tubes were mechanically cleaned with high-pressure water. For the following cleaning periods, the chemical procedure was varied for the 4th and 5th effects in order to receive longer operation period between the cleaning cycles.

- Finally, the cleaning effectiveness of 4th and 5th effect remains at lower level compared to 1st, 2nd and 3rd effect and limits the operation period of both last evaporators. In order to ensure continuous operation of the cane sugar factory, the old evaporation set is operated during the cleaning cycle taking into account a break down in crushing capacity to 6000 tonnes of cane per day.

Removal of non-condensable gases from evaporator calandrias

To provide for an unobstructed heat transfer in evaporators, non-condensable gases have to be removed from the evaporator calandrias. Non-condensable gases reduce the condensation temperature of the heating steam.

The presence of these gases makes itself felt in particular in falling-film evaporators which, unlike Robert evaporators, are operated with a lower temperature gradient between heating steam and vapour. If the condensation temperature is not to be influenced by the non-condensable gases by more than 0.25 K, the concentration of these gases must remain below 1% (w/w).

The amount of non-condensable gases was determined for the calandrias of evaporator effects 1, 2 and 3 by measuring the quantity of non-condensables in the venting line of the evaporators:

- FFE1: No non-condensable gases were analysed for the 1st effect calandria, which is what had been expected. The turbine exhaust steam only contains traces of non-condensable gases that cannot be quantified in detail.
- FFE2: With the clear juice concentration in the 1st evaporator effect, dissolved gas is entrained into the calandria of the second evaporator together with the 1st vapour. The amount that has to be discharged is about 10 g of non-condensable gases per tonne of cane that is processed.
- FFE3: With the clear juice concentration in the 2nd evaporator effect, dissolved gas continues to be entrained into the calandria of the third evaporator with the 2nd vapour. The amount that has to be discharged is about 3 g of non-condensable gases per tonne of cane that is processed.

The non-condensable gases always collect in the calandrias at the bottom tube plate, from where they are discharged in a concentrated form. The reduced condensation temperature therefore only affects part of the evaporator heating area.

By defining that the concentration of non-condensable gases should not exceed 1% (w/w) at the discharge nozzle, steam losses of less than 0.1% o.c. can be adjusted for each evaporator.

Summary

In the cane sugar industry, too, falling-film evaporators allow steam-saving concepts to be implemented for sugar production. Because of the lower temperature gradient between heating steam and vapour, scaling and non-condensable gases have a distinct heat transfer reducing effect in falling-film evaporators.

Properly adapted cleaning procedures and adequate discharging of non-condensable gases allow falling-film evaporator plants to be operated with stable operation phases between cleaning intervals.

The specific steam consumption for sugar production is between 30 and 33% o.c., and helps maximise the electric power generation in comparison with concepts that have been in use so far.

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