FALLING FILM EVAPORATORS IN CANE SUGAR MILLS

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Abstract

THE TECHNOLOGY of the falling evaporator, tube or plate type, is now recognised as the best in the beet sugar industry. After many attempts, it still has not really succeeded in establishing itself in the cane sugar industry. We therefore sought to analyse the causes of the difficulties of introducing it to the cane industry and to try to solve them. After three years of experiments in cane sugar mills in Brazil, we carried out measurements of performance which give an excellent performance of heat exchange when the evaporator was clean. These measurements show also a linear degradation of these performances with time. Today, after many improvements, the falling film evaporator may, under certain conditions, be considered as an excellent solution in cane sugar mills.

Introduction

Our falling film evaporator, originally designed 25 years ago for the beet sugar industry, and improved year after year, operated well in beet sugar mills.

During the past 10 years, many people tried to introduce falling film evaporator technology to the cane sugar industry, with varied results (Bhagat, 1996; Morgenroth et al., 1997; Punter and Christopherson, 1992a, b; Tobe, 1992, 1996; Grant et al., 2001).

From our point of view, to bring this technology to the cane sugar industry, the design would require adaptation to suit differences in process: lower purity juices and more suspended matter in cane processing leading to faster clogging of the evaporator tubes and the need for more frequent cleaning.

Current situation

Beet juice evaporators

The Fives Cail falling film evaporator is characterised by 4 main points:

• A circumferential distribution of steam all around the calandria, with extraction of incondensible gases in the centre.
• A device for juice distribution above the top tubeplate.
• A centrifugal catchall.
• A static juice recirculation pattern to ensure optimum wetting of the tubes.

The calandria is not centred in the external shell, the incoming steam is distributed all around the calandria, and over all its height, before flowing between the tubes (see Figure 1). Extraction of the incondensible gases from the centre of the calandria ensures a systematic sweeping of the calandria.

The juice, which is fed to the top of the evaporator, is distributed between all the tubes of the calandria by a device in 3 stages (see Figure 2). The first stage consists of supplying a distribution tank in order to maintain a relatively stable and homogeneous juice level on its entire surface.

Secondly, this tank is emptied by bottom openings at a rate of 1 per 7 tubes of the calandria. This low number of holes allows a relatively significant diameter (15 to 25 mm) which minimises the risk of blocking.

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The third stage of distribution is ensured by ‘caps’ laid out above each tube of the calandria. The juice flows out of each hole in the tank and sprinkles the ‘cap’ laid out just below. Most of the juice splashes towards the 6 ‘caps’ which surround it, and a small amount of juice flows out around the tube of the calandria located below.

![Diagram of steam distribution](image1)

The centrifugal catchall (see Figure 3) ensures the separation of juice droplets from the vapour flow. The outgoing vapour from the calandria (a) is initially forced to flow up at a low velocity into a space (b) isolated from the juice flowing down.

It then enters an annular channel (c) surrounding the vessel, where its increased speed allows centrifugal separation of the transported droplets.

The droplets are collected on the external wall of the channel from where they are directed to the bottom of the evaporator. At the exit of this channel (d) the vapour leaves the vessel. For high vapour flows, this catchall is made up of 2 or 3 parallel channels in order to reduce their width and to optimise the effectiveness of separation.
An initial flash of the juice feed takes place in the bottom of the evaporator to reduce flow disturbance in the top distribution tank. Part of the outgoing juice is recirculated to a tray where it is mixed with the entering juice in order to have sufficient flow to the top tubeplate to ensure optimum wetting. In addition, a non-return valve on the recirculation line prevents by-passing of the entering juice.

**Adaptation of beet juice evaporators to cane**

The adaptation of beet technology to cane mills induces some constraints and/or obligations:

- The evaporator is clogged rather quickly; therefore, its design must not be very sensitive to blocking and mud deposits. That applies in particular to the juice distribution device.
- The evaporator must frequently be cleaned, sometimes mechanically; easy access to the top tubeplate is necessary.
- Our cane adaptation initially consisted in designing a device for juice distribution.
The Noryl® 'caps' used for beet applications cannot be used in cane because they are simply put on the tubes of the calandria. It would take too much time to remove them before cleaning and then to position them back.

We have instead used a new design of 'cap', the 'Brazilian', directly welded below the distribution tank, at a rate of 1 per hole in the base of the tank, that is 1 per 7 tubes of the calandria (see Figure 4). In all other respects, the distribution tank remains similar to the one used for beet.

The tank with its feeding pipes and its 'Brazilian' caps can, when the evaporator doesn't work, be lifted up from 1.5 to 1.8 m in the upper space of the evaporator in order to allow easy access to the top tubeplate for mechanical cleaning if required.

At the end of 2003, we had installed more than 55 000 m², mainly in Brazil, with 23 falling film evaporators, from 1st effect to 4th effect.

One of these factories (Paraiso) is fully equipped with 4 effects falling film evaporators. The installed surfaces vary from 1000 to 3750 m² with lengths of tubes ranging from 8 to 12 metres.

Cleaning of cane evaporators

For the cane evaporators installed in Brazil, two cleaning methods are used: chemical cleaning and mechanical cleaning.

For chemical cleaning, a caustic soda solution at 10–20%, and a temperature of approximately 90°C, circulates during 8 to 12 hours in the evaporator. On completion, the evaporator is rinsed with water.

Then, mud is collected at the bottom of the evaporator and is discharged before the next start-up of the evaporator. Depending on the factories, the frequency of cleaning can vary between 1 week and 1 month.

For mechanical cleaning (washing at high pressure), each tube of the calandria is individually cleaned by a spraying nozzle at 1000 bar (see Figures 5 and 6). Another special nozzle is used for blocked tubes.

Results in the cane industry.

In 2003, we made a detailed analysis of the thermal performances of the cane evaporators in the factory of Equipav, in Brazil, which has 2 evaporators of 3 000 m². These two evaporators operated in the first effect, with the same juice in parallel.

One evaporator is equipped with the distribution tank and its Brazilian 'caps', the other one is equipped with 7 spraying nozzles with full cone, instead of the distribution tank and its caps.

We carried out different measurements over a period of 9 days to establish thermal balances, and we followed the change in heat transfer coefficients versus the duration of cumulated work since the restarting of the evaporator after a cleaning. Figure 7 shows this change.
The evaporator called FF1 is the one equipped with spraying nozzles and the evaporator called FF2 is the one with the distribution tank and its Brazilian caps.

One notes a linear decrease in heat transfer coefficient with time. This decrease is due to the nature of the treated juices, which gradually clog the heat transfer surface.

It is also noted that, for a first effect evaporator, the heat transfer coefficients seem relatively low. It is important to explain this point:

- Firstly, there are various methods for calculation of the heat transfer coefficient. We always include in our calculations an arbitrary thermal loss of 1.5%.
- Secondly, there are various ways of considering the boiling point elevation. We considered a model based on beet processing. However, there is no substantial difference between cane and beet, when taking into account the levels of brix.
- Lastly, and mainly, the juice brix is already relatively high at the entrance of the evaporators (18 to 20 brix). Moreover, the high wettings required in operation (around 240 L/h.m tube, or 2300 L/h.m instead of 800 to 1200 L/h.m in beet industry) lead to significant rates of recirculation, and thus to rather high brix at the entry of calandria: 30 to 37 brix.

The calculated heat transfer coefficients do not tell us if the measured performances are correct or not.

For this reason, we compared the measured performances to a reference. We took as reference the best heat transfer coefficients that we have with beet and their relationship to the viscosity of the juices. Figure 8 illustrates this relationship.
Comment: how is it possible to affirm that these results are not in accordance with literature (and what literature?) when Y values are not indicated? It also exists different ways to calculate HEC, for example delta-T calculation based on outgoing juice leads to higher coefficients.

The viscosity of the juices on the x-axis of Figure 8 is the average viscosity of the juice between the entrance in the calandria and its exit from the calandria (this viscosity has been calculated). We have considered 2 types of data on this graph: on one hand, measured performances of Fives Cail beet falling film evaporators with tubes and, on the other hand, performances published for falling film evaporators with plates (Morgenroth et al., 1996, 1998). It appears that the performances of our falling film evaporators are similar to plate evaporators.

If one considers the curve of Figure 8 as being the optimal performance (100%), one can always express any other measurement of performance compared to this reference. It is what we did for the measured values plotted in Figure 7 (see Figure 9).
This new graph clearly shows the excellent performance of the FF2 evaporator (tank distribution and 'caps'), when it is clean, just after a cleaning operation, and its progressive and linear degradation with time.

The poorer performance of the FF1 evaporator, equipped with spraying nozzles, is due to a defect in the homogeneity of wetting of certain nozzles. This defect led to blockage of a considerable number of tubes. On the contrary, with a relatively significant wetting of tubes, FF2 evaporator does not suffer from any tube blockages even after 3.5 months of operation.

Taking into account the relatively fast clogging of the evaporators (see Figures 7 and 9) the frequency of cleaning is, on average, 7 days for the FF2 evaporator (maximum 14 days) and less than 6 days, on average, for the FF1 evaporator (maximum 10 days). In all cases, the evaporators are usually cleaned mechanically.

Advantages of the falling film evaporators

The falling film evaporators show numerous advantages compared to the traditional Robert evaporators, and to evaporators with cassettes of plate exchangers:

- Ease of installation: this type of evaporator does not require any supporting steelwork. It also has the advantage of a large heat transfer surface, up to 10 000 m², on a relatively small floor space.
- Compared to falling film plate evaporator, the Fives Cail falling film tube evaporator presents very similar performances (see Figure 8). In addition, tube plate falling film evaporator type is less sensitive to clogging and, above all, tubes can be unblocked when it is almost impossible with plate falling film.
- Excellent heat transfer. In falling flow, there is initially no hydrostatic head of the juice. Thin film evaporation leads to a high level of heat transfer. Finally, with a double pass of juice in one evaporator body, this provides a significant increase in performance (generally, about 1°C of ΔT total). It becomes easy to carry out evaporation in 5 or 6 effects. It results in a reduction of steam requirement. Tables 1 to 3 illustrate, for a sugar mill of 8000 tcd, the difference between an evaporator with traditional Robert vessels and with falling film vessels:

<table>
<thead>
<tr>
<th>Table 1—Performance of 4 effects Robert evaporators.</th>
<th>steam flow = 167.2 t/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect</td>
<td>effect 1</td>
</tr>
<tr>
<td>Calandria T° °C</td>
<td>120.0</td>
</tr>
<tr>
<td>Vapour space T° °C</td>
<td>109.2</td>
</tr>
<tr>
<td>Surface m²</td>
<td>3700</td>
</tr>
<tr>
<td>Total ΔT °C</td>
<td>10.8</td>
</tr>
<tr>
<td>BPE °C</td>
<td>0.3</td>
</tr>
<tr>
<td>Hydrot. ΔT °C</td>
<td>0.1</td>
</tr>
<tr>
<td>Net ΔT °C</td>
<td>10.3</td>
</tr>
</tbody>
</table>

| Table 2—Performance of 5 effects Robert evaporators. |
|-----------------------------------------------------|----------------------|
| Effect                                             | effect 1 | effect 2 | effect 3 | effect 4 | effect 5 | total |
| Calandria T° °C                                    | 124.8    | 114.0    | 106.2    | 99.2     | 90.7     |       |
| Vapour space T° °C                                 | 114.0    | 106.2    | 99.2     | 90.7     | 71.4     |       |
| Surface m²                                         | 3300     | 3300     | 3300     | 3300     | 3300     | 16500 |
| Total ΔT °C                                        | 10.8     | 7.8      | 7.0      | 8.5      | 19.3     | 53.4  |
| BPE °C                                             | 0.3      | 0.6      | 0.8      | 1.4      | 4.1      |       |
| Hydrot. ΔT °C                                      | 0.1      | 0.7      | 2.1      | 2.2      | 1.7      |       |
| Net ΔT °C                                          | 10.4     | 6.6      | 4.1      | 4.9      | 13.6     |       |
Table 3—Performance of 5 effects falling film evaporators.

<table>
<thead>
<tr>
<th>Effect</th>
<th>effect 1</th>
<th>effect 2</th>
<th>effect 3</th>
<th>effect 4 pass 1</th>
<th>effect 4 pass 2</th>
<th>effect 5 pass 1</th>
<th>effect 5 pass 2</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calandria T°C</td>
<td>120.0</td>
<td>108.9</td>
<td>101.6</td>
<td>94.5</td>
<td>88.0</td>
<td>88.0</td>
<td>88.0</td>
<td>15250</td>
</tr>
<tr>
<td>Vapour space T°C</td>
<td>108.9</td>
<td>101.6</td>
<td>94.5</td>
<td>88.0</td>
<td>71.5</td>
<td>71.5</td>
<td>71.5</td>
<td>1710</td>
</tr>
<tr>
<td>Surface m²</td>
<td>3050</td>
<td>3050</td>
<td>3050</td>
<td>1710</td>
<td>1340</td>
<td>1710</td>
<td>1340</td>
<td>15250</td>
</tr>
<tr>
<td>Total ΔT C</td>
<td>11.1</td>
<td>7.3</td>
<td>7.1</td>
<td>6.5</td>
<td>16.5</td>
<td>16.5</td>
<td>16.5</td>
<td>48.5</td>
</tr>
<tr>
<td>BPE °C</td>
<td>0.3</td>
<td>0.5</td>
<td>0.8</td>
<td>1.1</td>
<td>1.4</td>
<td>2.7</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Hydrost. ΔT °C</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Net ΔT °C</td>
<td>10.9</td>
<td>6.8</td>
<td>6.5</td>
<td>5.5</td>
<td>5.2</td>
<td>14.2</td>
<td>12.8</td>
<td>12.8</td>
</tr>
</tbody>
</table>

Note: these comparisons are done with the same conditions of operation in all cases.

It can be seen in Tables 1 and 2 that, when converting from a 4 to a 5 effect conventional Roberts evaporator system, there is an improvement in the steam flow rate, but the ΔT of the total evaporation increases from 48 to 53°C.

However, if you compare these figures with Table 3 of the 5 effects falling film evaporator, it shows that the ΔT is maintained at 48°C. It also has a low steam demand.

- The benefits of low juice retention reduce colour formation and sugar losses by inversion.
- More especially the Fives Cail designed tube bundle leads to a great reliability of the tube bundle, in particular by total absence of vibration of the tubes protected from a direct attack of high speed steam.
- It is relatively easy to clean evaporators.

Developments and prospects

The first seasons when the falling film evaporator was in operation were used to observe the different points and determine the changes required:

- To improve the effectiveness of the juice distribution, in term of homogeneity. That will also make chemical cleaning more efficient.
- To improve the centrifugal vapour catchall.
- To avoid blockages in the juice distributor during chemical cleaning.

Juice distribution

The initial system of juice distribution used in cane is not performing as well as the device used in beet with the following consequences:

- Poor distribution of juice. Some of the tubes on the calandria get insufficient wetting and become blocked.
- It is necessary to increase the flow of juice to achieve the correct juice flow number, for example 1200 to 1600 L/h.m.
- Correct wetting of the tubes with poor distribution during chemical cleaning results in incomplete cleaning.

To correct the defect of the initial juice distribution system, the distribution tank was replaced by a full cone spray nozzle system on certain evaporators. Different spray layouts were tried on different evaporators. They were either equipped with a single or a seven nozzles system. Figure 10 illustrates this system.

Taking into account the distribution pattern of the nozzles used, this system of distribution also requires a relatively high average wetting to obtain sufficient minimum local wetting. Finally, some of the customers were satisfied with this method of distribution, others less.

Comparative measurements were conducted on a small scale unit and with water with the Brazilian cap system and the Noryl ® caps used for beet. The results showed that the distribution coefficient of variation for the Brazilian cap is 65 to 70% compared with 30% or less for the Noryl ® system.
We therefore propose to use for cane a distribution system similar to that used for beet evaporators. To achieve this the caps used for the beet distributors are grouped in sets so that they can be easily handled for removal and replacement in a short time because the low number of sets compared to number of caps. This task will then take less than an hour. The plates, constituting the set of caps, can be either hung under the distributor tank, or put on the tubeplate itself, like the current Noryl® caps. Figure 11 illustrates the assembly of such a plate, put on the tubeplate with centering in the tubes of the calandria.

This plate is similar to 37 Noryl® beet caps. If an evaporator has 3500 tubes, it would be fitted with approximately 120 plates. Assuming it takes between 10 to 15 seconds to remove or replace a plate, to complete the task for a complete evaporator will take 20 to 30 minutes.

On the centre and on the major part of the tube plate, the hexagonal shaped plate is fitted entirely. On the edges of the tubeplate, hexagonal plates are profiled in order to follow the circular tubed periphery.

The cut out adjustments at the edges are made by cutting the connecting ligaments between the constituent discs of the hexagonal plate. Figure 12 illustrates an example of adjustment of the edges.
Entrainment separator

The centrifugal type catchall has proved to be very efficient in beet sugar factories. But it has been noticed that, in some cane sugar installations, they have not been effective.

In these factories, the channels in the centrifugal catchall have gradually built up with suspended matter of the juice which has settled to form what appears to be a sludge. Access to the centrifugal section for cleaning is difficult and was not considered in the original design.

A catchall with vane-type separator (see Figure 13) has two advantages: it is easily cleanable (which is not the case of the centrifugal catchall with 2 or 3 channels) and it is more flexible. We recommend this type of catchall for both the beet and cane installations. Figure 14 illustrates 2 ways it can be attached to the bottom of an evaporator.
The right hand design in Figure 14 is more compact, but the vapour flow entering the catchall is directly in the path of the juice raining down.

In addition, it is clear that, for other reasons, such as the need for external cleaning of the baffles for example, such a catchall cassette can also be installed on the vapour line outside the evaporator.

**Cleaning**

Suspended matter in cane juice gets trapped in various sections of an evaporator:
- Bottom of the distribution tank.
- Bottom of the effect.
- Catchall.

From our experience, different designs and operating considerations have to be given to falling film evaporators.

For example, if a tube is blocked during the season, it is not possible to clean it by chemical cleaning. Even with mechanical means, it normally requires special equipment and time to clean it. And time is not available during the harvest. It is therefore preferable to optimise the frequency of cleaning, to ensure the tube does not reach the point of blocking.

Chemical cleaning with caustic soda requires optimisation by adjusting the concentration and composition of additives (like wetting agent) to suit the local clogging specificities, which can also vary with each effect.

Due to the fact that the solution of caustic soda is constantly re-circulated toward the top of the evaporator, it is important to avoid re-circulation into the juice distributor of the suspended solids during cleaning. For this purpose we recommend the installation of a screening pot on the circulation line before the pump.

**Conclusions**

With some precautions in design and installation, operation of a falling film evaporator is an excellent alternative to the traditional Robert evaporator for cane factories.

The falling film evaporator offers different specific advantages such as the compactness and the facility of installation, the absence of hydrostatic head, good heat transfer coefficients, and relatively easy cleaning.

It also makes it possible to optimise the heat balances, in particular for cane mills with co-generation facilities.
It is planned to continue monitoring and improving the performances of the falling film evaporator with a pilot plant during 2004.

REFERENCES


EVAPORADORES DE PELÍCULA DESCENDENTE EN LOS MOLINOS DE CAÑA DE AZÚCAR

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PALABRAS CLAVE: Evaporador, Película Descendente, Coeficiente de Intercambio de Calor, Obstrucción, Limpieza.

Resumen

LA TECNOLOGÍA del evaporador descendente, de tipo tubular o de placa, se reconoce actualmente como la mejor en la industria del azúcar de remolacha. Después de múltiples intentos, ésta aún no se ha logrado establecer exitosamente en la industria de la caña de azúcar. Por tanto, buscamos analizar las causas de las dificultades para introducirla en la industria de la caña y tratar de resolverlas. Después de tres años de experimentos en los molinos de caña de azúcar en Brasil, llevamos a cabo mediciones de desempeño, las cuales muestran un excelente desempeño en el intercambio de calor cuando el evaporador estaba limpio. Estas mediciones muestran también una degradación lineal de dichos desempeños con el tiempo. Hoy en día, después de muchas mejoras, el evaporador de película descendente puede, bajo ciertas condiciones, considerarse como una excelente solución para los molinos de caña de azúcar.

Résumé

LA TECHNOLOGIE de l’évaporateur à flot tombant, à tubes ou à plaques, est maintenant reconnue comme la meilleure en sucrerie de betterave. Après de nombreuses tentatives elle n’a toujours pas réellement réussi à s’établir en sucrerie de canne. A notre tour nous avons cherché à analyser les causes des difficultés d’introduction en canne et à tenter de les résoudre. Après trois années d’expérience en sucrerie de canne au Brésil nous y avons réalisé des mesures de performances qui montrent une excellente performance d’échange thermique lorsque l’évaporateur est propre. Ces mesures montrent aussi une dégradation linéaire de ces performances avec le temps. Aujourd’hui, après de nombreuses améliorations, nous considérons que l’évaporateur à flot tombant peut, sous certaines conditions, constituer une excellente solution en sucrerie de canne.