

# Falling-film evaporator performance results from two Reunion Island factories

## Leistungsdaten von Fallfilmverdampfapparaten zweier Zuckerfabriken auf Réunion

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Following recent design improvements, and successful pilot plant testing, two new Fives Cail type falling-film evaporators were installed in the Bois Rouge and Le Gol cane sugar factories in Reunion Island in 2007, on 1<sup>st</sup> and 2<sup>nd</sup> effect duties respectively. A comprehensive evaluation of the operational results and performance has shown these units to be operating at a very good level of efficiency, particularly with respect to heat transfer coefficients, with average values exceeding 3,000 W/(m<sup>2</sup> · K). The performance of these units has enabled both factories to upgrade their evaporator stations from 5 to 6 effects and to achieve overall factory steam savings amounting to around 20%.

**Key words:** evaporation, falling-film evaporator, Reunion, Fives Cail

Basierend auf Konstruktionsverbesserungen und der erfolgreichen Testphase einer Pilotanlage wurden im Jahr 2007 zwei neue Fallfilmverdampfapparate der Fa. Fives Cail in den Rohrzuckerfabriken Bois Rouge and Le Gol auf Réunion als 1. bzw. 2. Verdampfungsstufe installiert. Eine umfangreiche Bewertung der Betriebsergebnisse und Leistungen dieser Apparate hat gezeigt, dass diese sehr effizient arbeiten, besonders hinsichtlich der Wärmedurchgangskoeffizienten, die im Durchschnitt über 3000 W/(m<sup>2</sup> · K) lagen. Die Leistung der Verdampfapparate ermöglichte beiden Zuckerfabriken, die Verdampfanlage von 5 auf 6 Stufen zu erweitern und insgesamt Energieeinsparungen von ca. 20 % zu erzielen.

**Stichwörter:** Verdampfung, Fallfilmverdampfapparate, Réunion, Fives Cail

### 1 Introduction

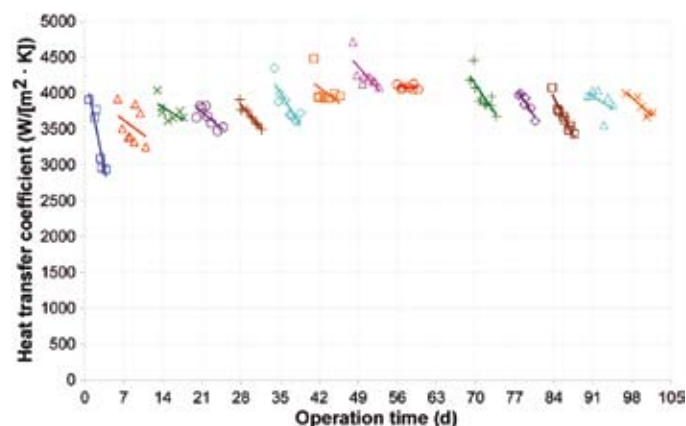
Fives Cail have designed and supplied falling-film evaporators to the beet sugar industry for over 30 years. In 2000, Fives Cail started to transfer this technology to the cane sugar industry. The design was adapted to take into account the specific quality of cane juice, i.e. cane juice purification not being as complete as that for beet juice purification. The heating surface is fouled more quickly and thus needs to be cleaned more often. After 5 years of development, Fives Cail finalized a reliable falling-film design for cane juice and two units were installed in Reunion Island in 2007, providing excellent performance.

### 2 Cane sugar falling-film evaporator developments

By the end of 2003, more than 55,000 m<sup>2</sup> of heating surface area was installed in Brazil by Fives Cail: comprising 23 evaporator vessels from effects 1 to 4, including a full falling-film evaporation station of 4 effects at Maracai sugar factory. The heating surface area of these evaporators was in the range from 1000 to 3750 m<sup>2</sup> and tube length ranges from 8 to 12 m. These early designs had several problems which were identified and have now been improved, including fouling of the juice distribution system, so that the beet design had to be adapted to limit deposits clogging the distribution. The evaporators had to be cleaned regularly, chemical cleaning was not fully effective and mechanical cleaning was required. The distribution system needed to be more accessible. The outlet centrifuge separator was easily fouled and some sugar was carried over into the vapor. Whereas the operation of these

early designs was not easy, their thermal performance was very promising. For example, the performance of a 3,000 m<sup>2</sup> evaporator (Equipav sugar factory) was measured in 2003 with the following results: the evaporator was fed with a juice of 30 to 35% dry substance content, the outlet juice dry substance content was 35 to 40%; the heat transfer coefficient achieved was around 2200 W/(m<sup>2</sup> · K) (90% of the expected performance) and decreased to 1100 W/(m<sup>2</sup> · K) after 10 days of operation without cleaning.

In 2004, Fives Cail worked on a 93 m<sup>2</sup> pilot evaporator in Reunion Island (Le Gol sugar factory). Trials took place on the juice distribution system testing different technologies, allowing to define a



**Fig. 1:** Evolution of the heat transfer coefficient during 14 weeks of operation

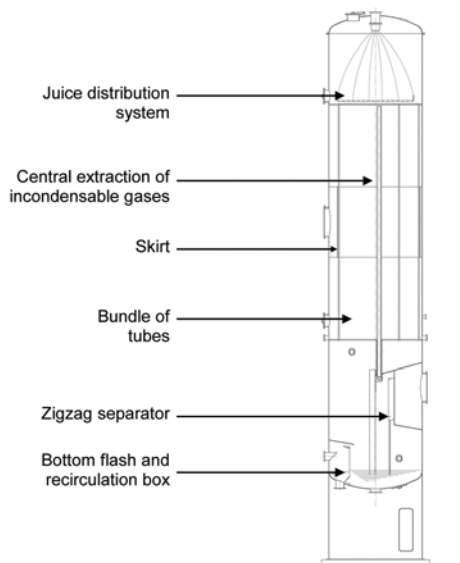
Average dry substance content: 27.7%. Average temperature difference: 5.2 K. Average evaporation rate: 28.4 kg/(h · m<sup>2</sup>)

suitable design for cane juice, including spray nozzles and a juice distribution tank with various designs of caps and plates. The evaporation trials confirmed a high heat transfer coefficient of around 3500 to 4000 W/(m<sup>2</sup> · K) was possible on a clean evaporator. The heat transfer coefficient decreased slowly after six days of operation, on the 7<sup>th</sup> day, the evaporator was cleaned using a chemical cleaning regime resulting in the initial heat transfer performances being recovered. After 14 weeks of operation it was demonstrated that this cleaning regime did not result in a cumulative effect of scaling or clogging (see Fig. 1). These trials resulted in Fives Cail being able to define a reliable design of falling-film evaporator for cane juice. This development work has been reviewed by *Journet* (2005).

### 3 Design features of Fives Cail falling-film evaporators for cane sugar mills

#### 3.1 Calandria design

Figure 2 gives a schematic illustration of the falling-film evaporators used in cane sugar applications. This illustrates the layout showing the top juice distribution section, the central section where the tube bundle is located, and the bottom section where vapor separation occurs and the juice collection box is located.

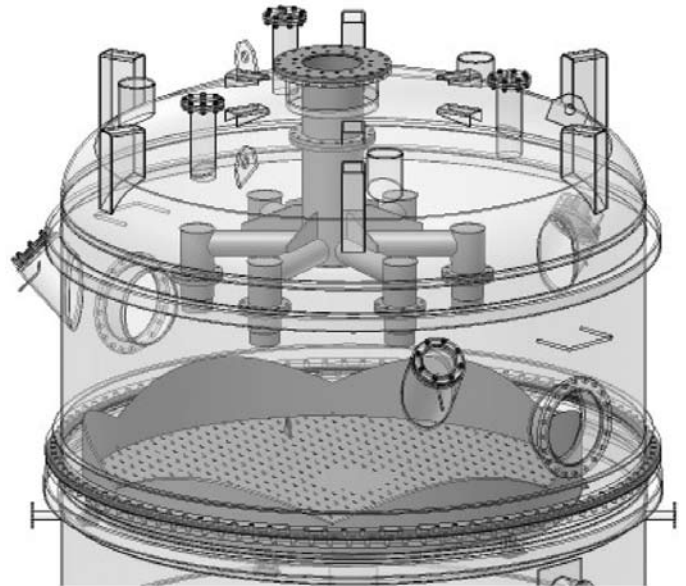


**Fig. 2:** Fives Cail falling-film evaporator for cane sugar mills

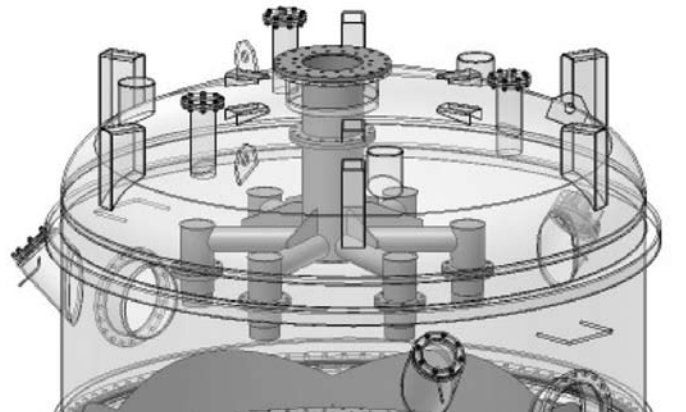
The vapor inlet is located in the middle of the bank of tubes, a skirt surrounds these tubes to reduce the vapor velocity and prevent vibration of the tubes, the vapor velocity has been calculated to be less than 2 m/s at the entry in to the tube bank. The incondensable gases are extracted by a single central pipe. Holes are drilled along the pipe; the quantity, location and the diameter of these holes are calculated to ensure the best extraction. This design gives a very good penetration of the vapor between all the tubes.

#### 3.2 The juice distribution system

The juice is pumped from the bottom of the evaporator to the top. The juice is distributed between all tubes in 3 steps (see Fig. 3). First step: The inlet pipe-work and nozzles distribute the juice into



**Fig. 3:** Three dimensional view of the Bois Rouge juice distribution system



**Fig. 4:** Cap-plates fitted under the juice distribution tank

distribution tank. The aim is to maintain a steady level of juice. Depending on the diameter of the distribution tank either a central nozzle or several nozzles are used.

Second step: The juice flows out the distribution tank to the tubes through adequately sized holes which prevent fouling.

Third step: Stainless steel cap-plates located under the juice distribution tank distributes the juice to the tubes (see Fig. 4).

The juice distribution tank and the cap-plates can be easily removed in case mechanical cleaning or inspection of the tubeplate is required. This simple juice distribution system is reliable and provides an even dispersion across the complete heating surface area.

#### 3.3 The zigzag separator

A zigzag separator is used to separate the juice droplets from the vapor (see Fig. 5). This type of separator is more efficient than a centrifugal separator, the pressure loss is reduced and it doesn't foul. This separator is cleaned by a water flush, the frequency of the cleaning is defined according to the experience of each installation.



**Fig. 5:** Zigzag separator scheme

### 3.4 Recirculation device

To ensure good operating conditions, the tubes need to be wetted at a minimum rate. Juice enters in the bottom of the calandria and flashes which avoids movement of the juice distribution system. The recirculation box allows mixing a fraction of the outlet juice with the inlet juice in order to have a sufficient flow rate of juice to wet the tubes. The check valve prevents by-passing of the inlet juice to the outlet.

### 3.5 Chemical cleaning

For operating with caustic soda solution, the caustic soda solution is prepared in a separate tank and pumped to the evaporator. The caustic soda solution uses the same circuit as the juice and therefore attains an even and thorough distribution across the heating surface area and optimizes the cleaning of the tubes. A screen on the circulation pipe prior to the pump retains any particles and avoids tube blockages.

## 4 Main characteristics of the falling-film evaporators in Reunion Island

Three falling-film evaporators were installed in 2007 in Le Gol and Bois Rouge sugar factories. The existing design of evaporators installed was a rising-film design. The addition of the falling-film evaporators allowed both sugar factories to improve their evaporation scheme to a 6-effects station. Both sugar factories are coupled to cogeneration plants using bagasse and coal. Table 1 summarizes the main characteristics of the evaporators. The falling-film evaporators are designed with built in skirts and therefore do not need

Factory	Le Gol	Bois Rouge
Evaporation Effect	6 effects	6 effects
Juice circulation	2A      2B 2 passages: juice in series, vapor in parallel	1
Heating area (m <sup>2</sup> )	2210	1790
Length of tube (m)	11.5	11.5
Outside Ø tube (mm)	35	35
Thickness (mm)	1.5	1.5
Vessel diameter (mm)	2700	2400
Tube material	AISI 439	AISI 439

any additional support structure. The three main parts of the evaporator are assembled on site using a crane.

The ratio heating surface/volume for the falling-film evaporators is 160 m<sup>2</sup>/m<sup>3</sup> (including the skirt). The ratio for classical rising film evaporators is around 40–50 m<sup>2</sup>/m<sup>3</sup> (Rein, 2007). With falling-film evaporators it is possible to erect large heating surface areas in a reasonable space, up to 10,000 m<sup>2</sup> in a single vessel. The classical rising-film evaporators are limited to 4,000–5,000 m<sup>2</sup> per vessel. The biggest new SRI design of Robert evaporator is 5,300 m<sup>2</sup> (Wright et al., 2003).

## 5 Performance results of the falling-film evaporators in Reunion Island

### 5.1 Heat transfer coefficient: results at Le Gol

Measurements were carried out at Le Gol sugar factory during the 2007 crop. Table 2 presents the measurements collected, measurements were taken throughout the crop period. The thermal balances were calculated during 3 h/d. Juice samples were collected continuously throughout this 3 h period, a cooling system was used to avoid flashing when taking samples of the juice. The pressure of the vapor on the juice side is measured on the 3<sup>rd</sup> effect. A pressure correction has been applied to take into account any pressure losses in the pipe between the 2<sup>nd</sup> and 3<sup>rd</sup> effects (10 mbar).

A thermal balance can be carried out between the inlet juice and inlet vapor and the outlet juice and outlet vapor for each evaporator. The inlet vapor flow rate can be deduced from this thermal balance. The heat transfer coefficient is calculated as

$$k = \Phi / (A \cdot \Delta T)$$

$\Phi$  Inlet vapor latent heat in W

$A$  Heating surface in m<sup>2</sup>

$\Delta T$  Difference between the inlet vapor temperature and the juice temperature in K

The heating surface area is calculated using only the heating tube inside diameter.

Measurement	Unit	Source
Flow rate: juice inlet – effect 2A and 2B; juice-circulation – effect 2A and 2B	m <sup>3</sup> /h	Average values collected in the control room
Temperature: juice inlet – effect 2A and 2B	°C	Calculated temperature using pressure
Dry substance content of juice inlet, juice outlet, juice circulation – effect 2A and 2B	%	Samples and measurement realized by the laboratory
Pressure on the tube side	bar abs	Average values collected in the control room
Pressure on the juice side	bar abs	Average values collected in the control room

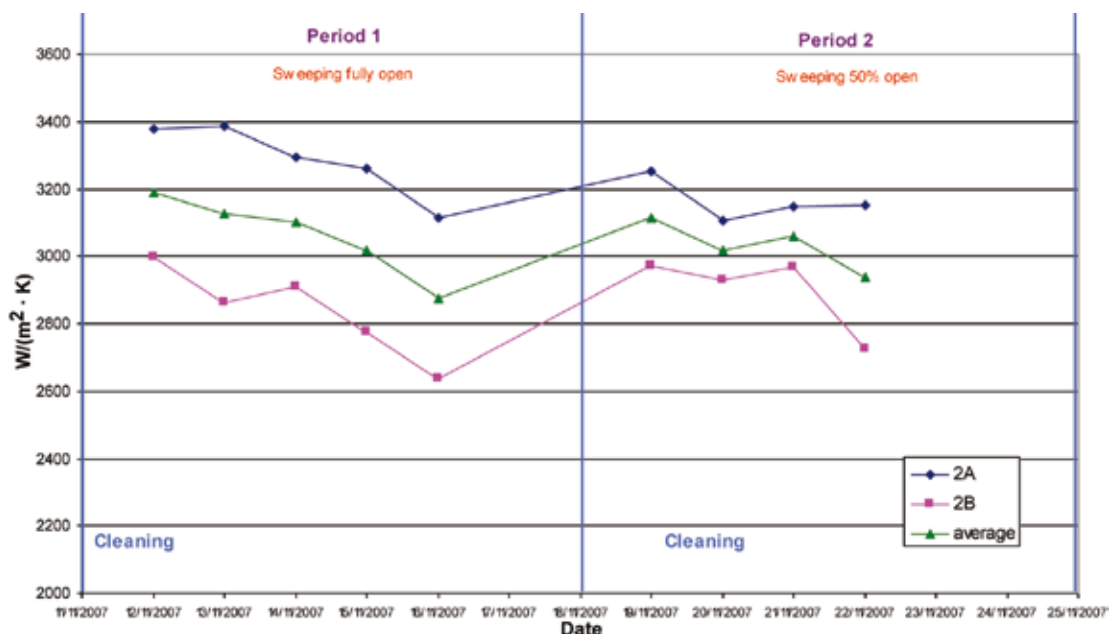


Fig. 6: Two weeks of measurements at Le Gol factory

The heat transfer coefficient was measured throughout the crop period. Figure 6 presents the heat transfer coefficient during 2 weeks of measurements for 2A, 2B effect evaporators and the average between the 2 evaporators. The factory stops every Sunday and the evaporators are cleaned. These cleanings are symbolized by the blue lines in Figure 6. The evaporators work for a 7 day period.

Incondensable gases are extracted by a single pipe located in the middle of the evaporator tube bundle. The incondensable gases are used to heat juice in separate heat exchangers, this type of extraction is called sweeping. The flow rate of vapor and incondensable gases extracted by the sweeping is regulated by a manual valve on the evaporators and the juice heat demand within the heat exchanger. The 2 different periods correspond to 2 different levels of incondensable gas extraction:

- Period 1: the sweeping is fully open on the juice heater.
- Period 2: The sweeping is 50% open on the juice heater.

The average heat transfer coefficients on the clean evaporators are respectively 3188 and 3113  $W/(m^2 \cdot K)$  for periods 1 and 2. The average heat transfer coefficient decreases during 7 days by 9.8% and 5.6% respectively for periods 1 and 2.

It can be seen from Figure 6 that the method of extraction of the incondensable gases impacts on the performance of evaporators. Fives Cail recommends extracting the incondensable gases through sweeping and this should represent at least 2.5% of the inlet vapor. In the first period, the sweeping was fully open and the heat transfer coefficient is greater than 3000  $W/(m^2 \cdot K)$  during 4 days operation. The average heat transfer coefficient during 5 days was 3061  $W/(m^2 \cdot K)$ . In the second period the sweeping manual valve was only 50% open and the performances were not as good as the first period.

The maximum sweeping measured (period 1) was 1.9%. This is below Fives Cail's recommendations due to the heat demand within the juice heat exchanger. The performances would certainly be even better if the 2.5% of extraction was achieved.

After the chemical cleaning, the initial performances were recovered, demonstrating that chemical cleaning is effective.

## 5.2 Heat transfer coefficient: results at Bois Rouge

Measurements were carried out at Bois Rouge sugar factory during the 2007 crop. The Bois Rouge results are not presented here, but the results are similar. The heat transfer coefficient was above 3000  $W/(m^2 \cdot K)$  when the evaporator was clean.

## 5.3 Heat transfer coefficient: comparison with literature

The heat transfer coefficient obtained for clean evaporators for both factories was above 3000  $W/(m^2 \cdot K)$ . This level of heat transfer coefficient is superior to other evaporation technologies (see Table 3).

Type of evaporators	1 <sup>st</sup> effect	2 <sup>nd</sup> effect
Robert*	2800–2500	1800–3000
Kestner*	2900	2100
Rising-film plates*	–	2500–3000
Falling-film plate*	2600–3000	–
Falling-film tube	> 3000	> 3000

\* Rein (2007)

During the 2007 crop it was shown that the Fives Cail design of falling-film evaporators did not become clogged during operation and the chemical cleaning with caustic soda was efficient, with the initial performance levels of the evaporators being recovered. After 2007 crop, Bois Rouge did an inspection of the tubes by endoscope, the tubes were found to be clean and without any incrustation build-up.

The Le Gol evaporator was designed with a double juice circulation whereas Bois Rouge only had a single juice circulation. The double juice circulation was designed at Le Gol to achieve the lowest possible recirculation. In the case of a single circulation, in order to maintain the minimum wetting rate there is an increase in the recirculation rate of juice and therefore this increases the circulation

juice dry substance content. With 2 passages, the recirculation of juice can be reduced and the first section of the evaporator operates with a lower dry substance content therefore resulting in a better heat transfer coefficient. The double circulation configuration of the evaporator allows the  $\Delta T$  of the evaporator to be reduced by 1 K.

#### 5.4 Very good thermal performances and 6 effects

The excellent thermal performances of the falling-film evaporators permitted both factories to extend their evaporation stations to 6 effects. The main equipment of the Le Gol factory are mills and pre-extractor, juice clarifier, continuous evaporating crystallizers for A and C sugar, and batch evaporating crystallizers (vacuum pans) for B sugar. The factory is coupled to a cogeneration plant using bagasse and coal.

The average steam (2.7 bar, 150 °C) consumption in the 2007 crop was 367 kg/t cane. This compares favorably with the average between the crops 2002–2006 of 410.5 kg/t cane resulting in an average saving of 43.5 kg/t cane (10.6%). These figures were also achieved in a year when the crop in Reunion Island was poor due to bad climatic conditions.

The average steam consumption in 2008 after 15 weeks of operation (70% of the cane crop processed) was 347.5 kg/t cane. Therefore again comparing with the average figure for the crops 2002–2006 (70% of crop processed) of 403 kg/t cane this shows a saving of 55.5 kg/t cane (13.7%).

Falling-film evaporators require a pump for the juice circulation and for the cleaning operation. Le Gol estimates that the energy consumption of the pump represents around 6% of steam energy savings.

With the new design of falling-film evaporators, Fives Cail has managed to overcome customary difficulties of the operation of the falling-film evaporator in cane sugar applications. This means falling-film evaporators can now be considered a very good alternative to the traditional *Robert* evaporators.

## 6 Conclusions

The development work carried out by Fives Cail in the last 5 years on the design of falling-film evaporators has overcome all the traditional problems associated with processing cane juice, in particular those to do with scaling and fouling of the juice distribution and heating surfaces have been successfully eliminated. With the two full-sized falling-film evaporator plant installations in Reunion, the designs have been proven to be successful under live operating conditions. The falling-film evaporators have the specific advantages

of compactness, easy erection and installation, no hydrostatic head elevation of the juice, minimum retention time, reducing color formation, a high heat transfer coefficient and low  $\Delta T$  and are easily chemically cleaned. However the overriding success of the falling-film evaporator technology is the ability to optimize the thermal balance of the cane sugar factory and to save energy consumption.

#### References

- Journet, G.; Rouanne, F.* (2005): Falling-film evaporators in cane sugar factories. *Zuckerind.* 130, 531–537  
*Rein, P.* (2007): Cane Sugar Engineering. Verlag Dr. A. Bartens, Berlin, 289–299  
*Wright, P.G.; Silva, T.; Pennisi, S.N.* (2003): The SRI evaporator – a new Roberts design. *Proc. Aust. Soc. Sugar Cane Technol.*, 25<sup>th</sup> Annual Conference

### Evaluation des performances d'évaporateurs à flot tombant installés dans deux sucreries à l'Île de la Réunion (Résumé)

Suite à des améliorations de conception et des tests concluant sur un pilote, 2 évaporateurs à flot tombant Fives Cail de nouvelles conceptions ont été installés en 2007 dans l'usine de Bois Rouge et du Gol à l'Île de la Réunion en respectivement, premier et deuxième effet. Une campagne de mesures a été menée de façon à mieux connaître les performances des caisses et à évaluer les résultats d'échange thermique. Cette campagne a montré des performances d'échange thermique d'un très bon niveau, supérieure à 3000 W/(m<sup>2</sup>.K) lorsque la caisse est propre. Ces très bonnes performances thermiques ont permis à chacune des usines de passer d'un schéma d'évaporation à 5 effets à un schéma d'évaporation à 6 effets et d'économiser de l'ordre de 20% de vapeur.

### Resultados del rendimiento de aparatos de evaporación de flujo descendente de dos fábricas de azúcar en Reunión (Resumen)

Después de algunas mejoras en el diseño y un período de ensayo eficaz se instalaron en 2007 dos aparatos nuevos de evaporación de flujo descendente de Fives Cail como 1ª y 2ª etapa de evaporación en las fábricas de azúcar crudo Bois Rouge y Le Gol en Reunión. Una evaluación amplia del rendimiento y de los resultados del servicio mostró que los aparatos de evaporación trabajan eficazmente, especialmente en lo que se refiere a los coeficientes de transmisión térmica media de 3000 W/(m<sup>2</sup> · K). El rendimiento alcanzado con los aparatos de evaporación permitió ampliar las plantas de evaporación en ambas fábricas de 5 a 6 etapas y ahorrar energía en total hasta un 20 %.

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