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Evaporator station
Exopolysaccharides

Verdampfanlage
Exopolysaccharide

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Less steam for more: Hybrid tubular plate heat exchangers the cleverer heating elements for falling film evaporators

Weniger Dampf für mehr: Hybrid-Tubular-Plattenwärmeübertrager – die cleveren Heizelemente für Fallfilmverdampfapparate

1 Introduction

The evaporation process with its upstream and downstream thermal processes is very energy-intensive. According to a study by the Munich-based management consultancy Future Camp, which specializes in climate protection, sustainability, energy efficiency, environmental management and innovation, the total energy demand of the German sugar industry in 2019 was around 7.9 TWh. Around 58% of this was covered by natural gas, a total of 29% was lignite and hard coal. All energy sources result in emissions of around 2.1 mn t of CO_2 annually, with hard coal and lignite being responsible for around 40% of emissions.

In order to achieve the climate protection goals and considering the approaching phase-out of hard coal and lignite, the sugar industry is investing in the conversion from hard coal and lignite, which should be completed by 2030. Additional costs arise by increasing energy costs and taxes on CO_2 emissions. Furthermore, profits are falling due to the abolition of the EU quota system.

Since energy costs account for almost 20% of total production costs, low-carbon fuels and more efficient production systems ensure long-term competitiveness. In the case of energy-intensive evaporation in particular, the use of several evaporators connected in series, but above all the use of hybrid tubular plate heat exchangers, can reduce costs.

2 Energy savings and cost reductions

Evaporators have a major influence on the heat management of the factory and on increase energy efficiency in upstream and downstream process stages. Savings in steam usage reduce the primary energy consumption and lead to an effective reduction in energy costs.

In multi-effect evaporators the vapor produced in the first effect is used to heat following effects. The amount of steam required roughly corresponds to the total amount of evaporated water divided by the number of effects. Since hybrid tubular plate heat exchangers are operated at lower temperature differences, the evaporation station can be expanded by additional effects, which lowers operating costs.

Further potential energy savings result from the use of falling film evaporators with hybrid tubular plate heat exchangers instead of e.g. natural circulation evaporators or falling film evaporators with tube bundles.

In sugar factories, the thin juice having a dry substance (DS) content of approximately 17% is heated to the temperature level of the turbine bleed steam and thickened in co-current with or without a separate pre-evaporator. The dry substance content in the first effect or in the pre-evaporator is between 17% and 18% DS. In the mostly 5- to 6-effect systems, the juice reaches a DS of 68% to 75% at the end of the evaporator system before it is sent to the crystallization or the thick juice tank.

The vapors generated by thickening are required as heating steam for the subsequent evaporator effects, pulp drying, juice preheating, extraction, juice purification and crystallization.

3 A comparison: why classic is not always better

In order to maintain a high product quality, the juice must be gently thickened. That means: The thin juice is to be guided through the process with an appropriate covering (wetting rate) on the heating surface, within a certain residence time and within a precisely defined temperature range.

In the beet sugar industry until the early 1980s classic *Robert* evaporators were used, which operate as natural circulation evaporators. However, due to the tube wall thickness (1.2 mm to 2.5 mm), the evaporator has a high thermal resistance, a long residence juice time and a large temperature difference. Each of these factors increase the color formation of the juice.

A *Robert* evaporator with a diameter of 4400 mm and a height of approx. 11 m provides heating surface of 2000 m^2. In comparison, a hybrid tubular plate heat exchanger with slightly smaller dimensions (diameter just 4000 mm and a height of 11 m) offers a heating surface of 5000 m^2 due to its modular design.

If a retrofit of the evaporation station is planned, the existing vessel could be reused to integrate the hybrid tubular plate heat exchanger. The system then operates with a larger heating surface and *k* values that are around 65% higher for thin juice and up to 300% higher for thick juice.

Depending on the evaporation effect and the dry substance content, a *Robert* evaporator is operated with an average temperature difference of 8 K, while a hybrid tubular plate heat evaporator can be operated with an average temperature difference of only 3 K.

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Table 1: Comparison of the different evaporators

	Natural circulation evaporator *Robert* evaporator	Tube falling film evaporator	Plate type falling film Hybrid tubular falling film evaporator
Fluid management	Juice in the tube	Juice in the tube	Juice in the tube side
	Steam in the shell	Steam in the shell	Steam corrugated side
Material thickness in mm	1.2 – 2.5	1.2 – 2.0	0.8
Heating surface in m²	2000 (ø 4.4 m, height 11 m)		5000 (ø 4 m, height 11 m)
Average temperature difference in Kelvin	8	6	3
Wetting rate in L/(cm · h)	flooded	8–16	2–5
Specific heating surface density in m²/m³	80–120	80–120	200–250

In addition, long residence times of the fluid to be thickened, combined with high temperature differences to the heating medium, lead to higher levels of fouling of the heating surfaces and thus increase the energy requirement during the campaign.

As a result of the replacement of the *Robert* evaporator with the tube falling film evaporator – in which the juice flowing within the tubes and the heating steam is condensed in the shell – the juice residence time was reduced. The thermal resistance due to the tube wall (thickness 1.2 mm to 2.0 mm) is on a similar level as the *Robert* evaporator, but the average driving temperature differences of 6 K are slightly lower.

A comparison of the *k* values between a tube falling film evaporator and a hybrid tubular plate falling film evaporator, shows that the later works approx. 35% more efficient for thin juice and up to 60% for thick juice.

Depending on the variable shaping depth of the evaporator plates, the hybrid plate evaporator has a specific heating surface density of 200 to 250 m² per m³. Depending on the tube diameter, a tube bundle heat exchanger offers between 80 and 120 m² per m³.

The tubular falling film evaporator works with a wetting rate of 8 to 16 L/(cm · h) while the hybrid plate evaporator works under safe operating conditions with a wetting rate of 2 to 5 L/(cm · h).

The heat transfer coefficient improves slightly with a smaller film thickness, but the values given in Table 1 have proven to be optimal for safe operation in practice. Both types of falling film evaporators have an additional circulation juice compartment for better control of operation. The residence time and as a result of the color formation is higher in case of a tube falling film evaporator than with the hybrid plate evaporator.

In consideration of the *k* values, the influence of the flash evaporation of the superheated juice entering the evaporator and the possibly necessary preheating of the juice up to the boiling temperature are often neglected. Due to flash evaporation caused by a pressure release, the *k* value appears to be higher and due to the preheating up to the boiling temperature, the *k* value is lower than it is for the evaporation as such.

4 How does a hybrid tubular plate falling film evaporator work

The plate geometry of a hybrid tubular plate falling-film evaporator from VAU Thermotech provides an ideal cross-flow of thin juice and heating steam. The shape of the plates is variable and corresponds to the geometry of half a pipe. When the plates are stacked and welded, a tubular cross-section results on one side and a wave-shaped cross-section around the pipes on the other side.

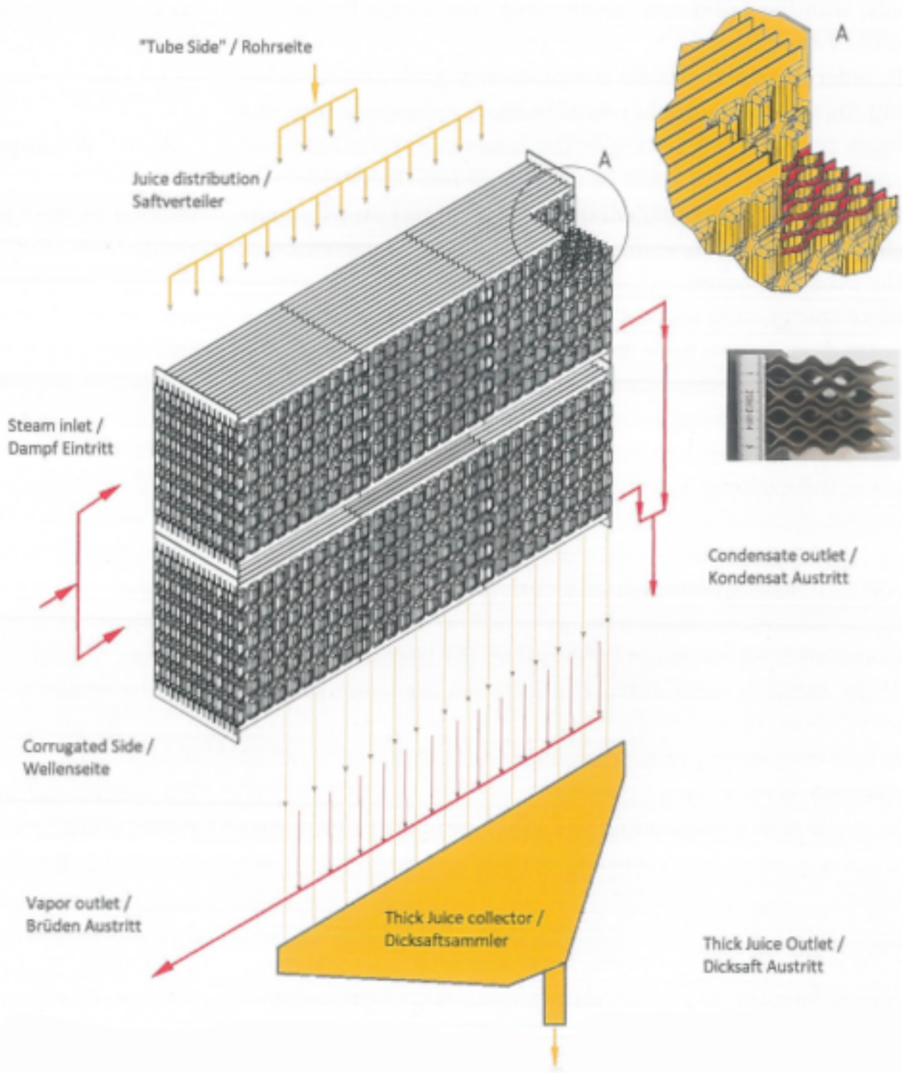

Fig. 1: Basic flow arrangement Tubular falling film evaporator

Fig. 2: Cross-section through a plate package

The tubular shaping (tube side) comes very close to the flow channel cross-section of a tubular falling-film evaporator. There are no flow corners or dead spaces in which deposits such as sugar coal or blockages can form.

This geometry of the plate shaping is unique among the plate heat exchangers. The juice flows in a straight line directly downwards, so to speak without any "stumbling blocks".

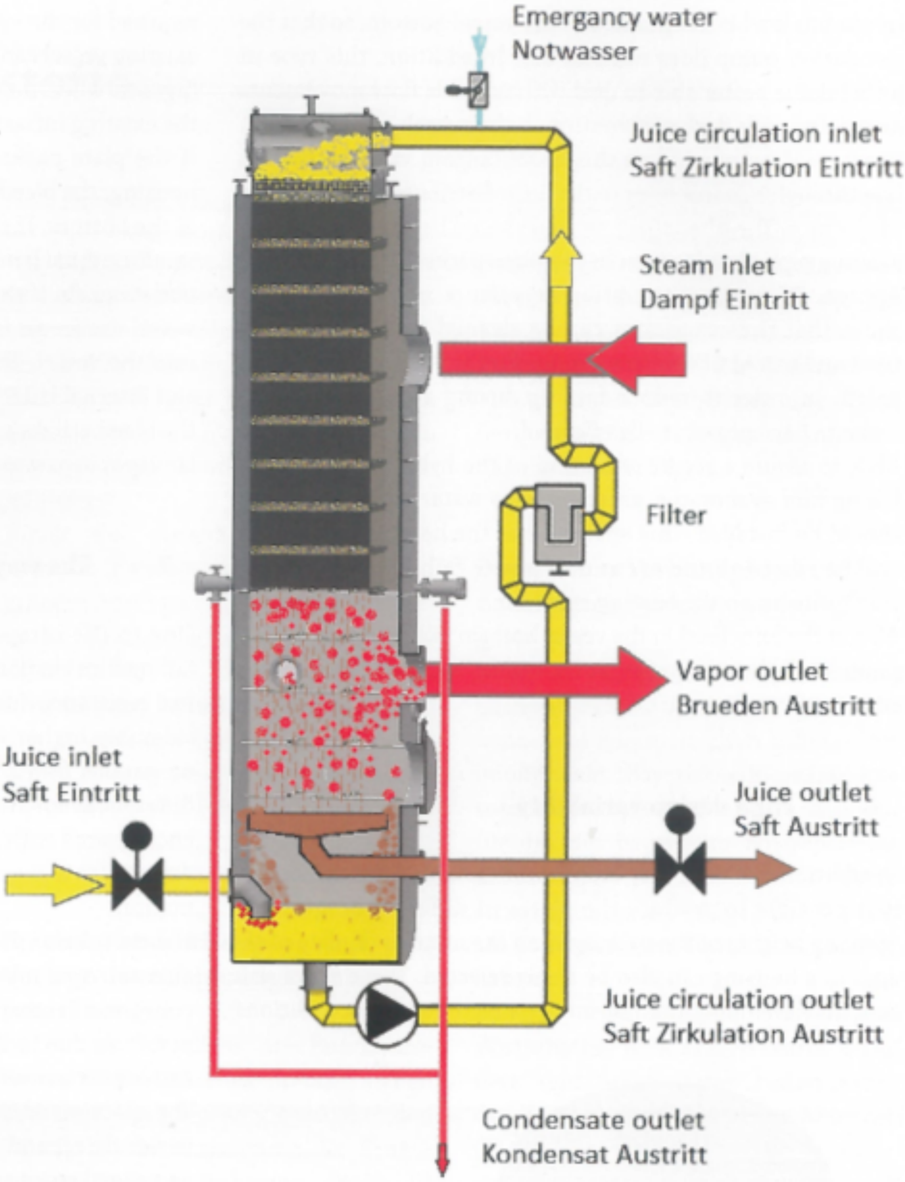

Fig. 3: Simplified flow diagram of a hybrid tubular plate falling film evaporator in a rectangular design

The plate packs are heated on the corrugated side using turbine steam in the first effect or bleed vapor in the later effects. In case of a hybrid tubular plate falling film evaporator with 5000 m^2 heating surface, the steam flow is parallel for approx. 3200 plate channels with a length of approx. 2.5 m, on the tube (juice) side these are approx. 32,000 tubes with a diameter of 9 mm. On the tube and corrugated sides, this results in relatively low pressure drops in the plate pack, which in turn have a positive effect on the driving temperature difference.

The juice is evenly distributed above the plate packs via a distribution system and flows as a film on the walls from the top to the bottom through the plate packs, which are arranged in series. The vapor formed by evaporation flows in the same direction as the juice.

In the design phase, the free flow cross-section on the tube or juice side is to be dimensioned in such a way that there is a sufficient juice wetting rate at the outlet of the last plate pack, the vapors generated have a sufficient free cross-section to flow off and the pressure loss in the packs is kept low. If these general conditions are not observed, the evaporator can tend to pulsate if the juice flow rate is too large and color formation can set in, if the the juice flow rate is too low; in the worst case scale formation can occur.

In the past, evaporators with a shaping depth of 3, 4 and 4.5 mm and tube diameters of 6, 8 and 9 mm were operated with juices of a dry substance content between 17 and 70%. By reducing the shaping depth from 4.5 to 3 mm, about 30% larger heating surface can be installed in the same stack height. There is no linearity in the increase of the heating surface, since a deeper shaping results in a larger heating surface due to the greater deformation.

The vapors are deflected to the side below the plate packs and led to the mist separator.

The concentrated juice falls into the vessel bottom and is directed to the next evaporator effect or to the standard liquor tank via the juice outlet, the condensate is fed to a condensate cigar.

5 Safe operation of a hybrid tubular plate falling film evaporator

To ensure a secure operation of a VAU Hybrid tubular plate falling film evaporator, the juice to be thickened is fed into the lower part of the vessel bottom of the evaporator. A certain

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minimum level is maintained in the vessel bottom, so that the circulation pump does not run dry. In addition, this type of juice inlet is better able to deal with possible flow movements associated with flash evaporation in the vessel.

The juice is pumped from the vessel bottom via a circulation line through a coarse filter to the juice distributor on top of the evaporator. The filter cross-section should be smaller than the existing pipe cross-section in the plate packs.

Approx. 35 years of operating experience in many factories show, that the evaporator can be cleaned very well using a tried and tested CIP cleaning procedure at the end of the campaign. In order to reduce fouling during a campaign, antiscalants have proven to be effective.

Also, to assure a secure operation of the hybrid tubular plate falling film evaporator, an emergency water addition system should be installed. This ensures that the heating surface can still be rinsed in the event of a power failure and the juice won't incrust on the heating surface.

Also, if the juice level in the vessel bottom falls below the minimum level, the emergency water system will give the operator additional time to react.

6 High design variability

In addition to the already mentioned variable shaping depths, it is possible to produce the plates of different length. The stacking heights of the packages and the number of plate packages in a housing can also be freely selected. These serve as a tool for developing the thermodynamic boundary conditions required for the evaporation process. Due to this flexibility, an existing vessel can possibly be used. This is particularly advantageous when upgrading existing systems (retrofit), because the existing infrastructure can be further used.

If the plate packs are installed in a round pressure-bearing housing, the bleed vapors can be drawn off either at the top or at the bottom. If the bleed vapor is drawn off at the bottom, a small external lamella separator is usually flanged to the vapor outlet nozzle. If the bleed vapor is to be directed into the upper vessel dome, an internally built-in separator is usually built into the vessel. The fixtures are accessible through manholes and internal ladders. In case of a compact, rectangular design, the bleed vapors are usually fed directly into an external lamellar vapor separator at the bottom.

7 The way to higher sugar quality

Due to the compact heating surface a hybrid tubular plate falling film evaporator has shorter flow paths. The lower thermal resistance due to the plate thickness of 0.8 mm, the considerably higher *k* values, the reduced pressure losses based on parallel flow channels enable smaller driving temperature differences for the evaporation. Smaller temperature differences paired with larger heating surfaces reduce the heat flow density for a given output and thus also reduce the color formation.

Hybrid tubular plate falling film evaporators are an intelligent alternative to tube bundle heat exchangers and ideal for cost-conscious factory operators. The significantly lower use of materials due to the compact design reduces the overall mass and lowers manufacturing costs.

The space saved can be used in the evaporation station to conveniently expand the heating surface without having to make additional space available on the site. Since all connections are welded to the vessel, there is significantly more flexibility in terms of individual adaptation to the existing pipes or vapor lines.

Specifically, the redesign of the evaporator system and the use of hybrid tubular plate falling film evaporators from VAU Thermotech in a medium-sized sugar factory in northern Germany led to a reduction of 10% in the total energy costs per year. As a result of these savings, the system change pays for itself within approx. three to four years, depending on energy prices. It also reduced CO_2 emissions by around 10%.

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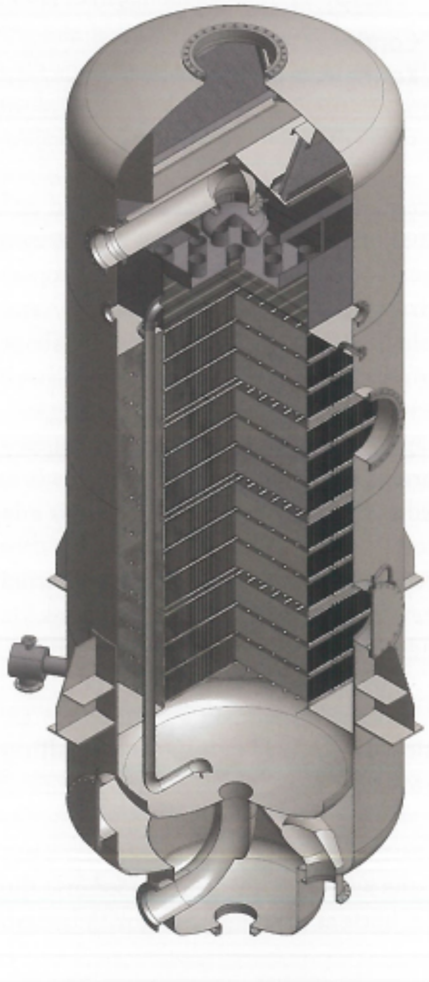

Fig. 4: Hybrid tubular plate falling film evaporator in a round pressure vessel with a lamella separator in the upper vapor dome