HEAT EXCHANGER WORLD

Volume 3, Issue 6, November 2021

UNITING THE HEAT EXCHANGER SUPPLY CHAIN

Cover story:

Heavy Metal & Tubes (India) Pvt. Ltd.: A true believer of *"Make in India"* for global consumption

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

This article considers how to reduce energy costs and increase product quality while evaporating thin juice - using the example of the sugar industry.

By Manfred Hermanns, CTO VAU Thermotech GmbH & Co. KG

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 brown and hard coal. All energy sources cause around 2.1 million tons 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 coal, the sugar industry is investing in the conversion to natural gas boilers, which should be completed by 2030. Additional costs arise by further increasing energy costs and taxes for CO_2 emissions. Furthermore, profits are falling due to the abolition of the quota system and the minimum beet price stipulated by the regulations. 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-hungry evaporation stations in particular, the use of several evaporators connected in series, but above all the use of Hybrid tubular plate heat exchangers, reduces costs.

Save energy and reduce costs during operation

Evaporators have a major influence on the heat management of the overall system and on increasing energy efficiency in upstream and downstream process stages. Savings in the amount of steam to be generated reduces the primary energy consumption and lead to an effective reduction in energy costs.
Therefore, evaporation stations are built multi effect: 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 energy savings potential results from the use of falling film evaporators with hybrid tubular plate heat exchangers as heating elements instead of e.g. natural circulation evaporators or falling film evaporators with tube bundle heat exchangers.

From beet and cane to sweet sugar

Sugar beets have a sugar content of 17 to 18% and about 75% consist of water. In order to extract sugar crystals from beet juice or sugar cane, the water must be thermally separated. For this purpose, heat exchangers are used in multi-effect evaporation stations, the first effect being heated by means of bleed steam from the turbine and the subsequent effects from the vapor generated by the thickening of the upstream effects.
In the sugar factories, the incoming juice is brought almost 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% dry substance (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.

A comparison: why classic is not always better

In order to maintain a high product quality, the juice must be gently evaporated. That means: The thin juice

	Natural circulation evaporator	Tube falling film evaporator	Plate type falling film
	Robert evaporator		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	1,2 - 2,5 mm	1,2 - 2,0 mm	0,8 mm
Heating surface	2.000 m² (ø 4.4 m, height 11 m)		5.000 m² (ø 4 m, height 11 m)
Average temperature difference	8 Kelvin	6 Kelvin	3 Kelvin
Wetting rate	flooded	8 - 16 l / (cm*h)	2 - 5 l / (cm*h)
Specific heating surface density	80 - 120 m² / m³	80 - 120 m² / m³	200 - 250 m² / m³

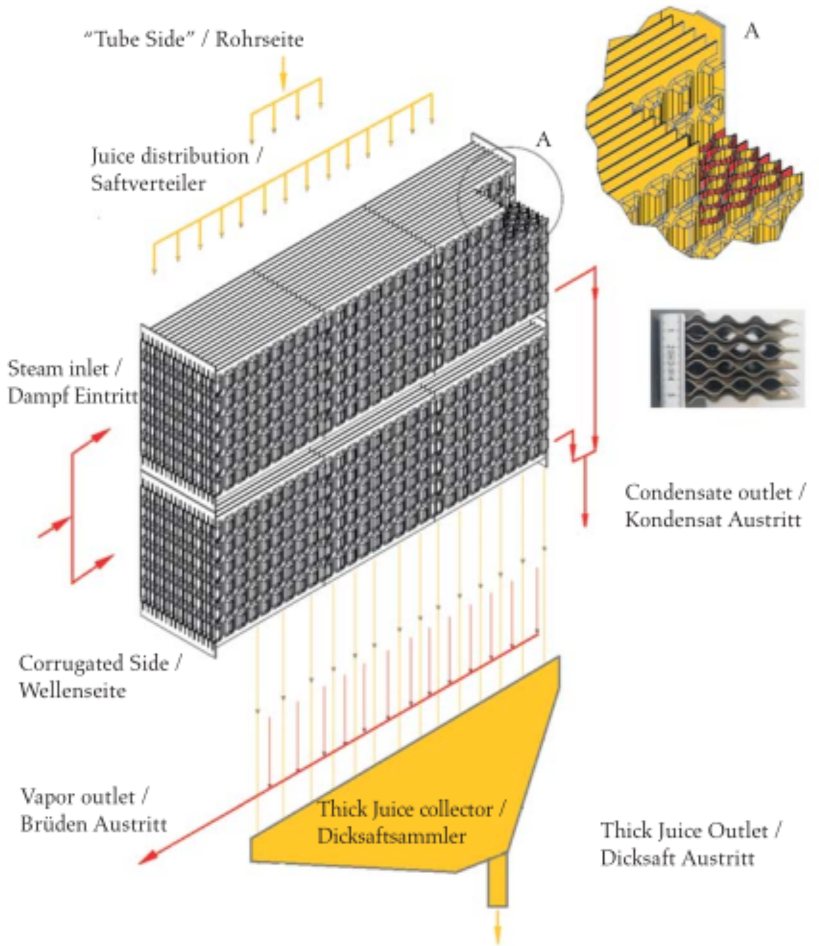

Fig. 1: Basic flow arrangement Tubular falling film evaporator.

is to be guided through the process with an appropriate covering (wetting rate), within a certain residence time and within a precisely defined temperature interval.
Classic "Roberts" are still used as natural circulation evaporators since the early 1980s. The juice is circulated several times until it is completely evaporated. However, due to the pipe wall thickness (1.2 - 2.5 mm), the evaporators has an increased thermal resistance, an increased residence time due to the higher number of circulations and a higher driving temperature difference, which comes from this specific type of construction. Each of these factors increase the color formation of the juice to be thickened.
A Robert evaporator with a diameter of 4,400 mm and a height of approx. 11 m provides heating surface of 2,000 m². In comparison, a Hybrid Tubular Plate Heat Exchanger with slightly smaller dimensions (diameter just 4,000 mm and a height of 11 m) offers a heating surface of 5,000 m² due to its modular built design.
If a retrofit of the evaporation station is planned, the existing vessel could be reused to integrate the Hybrid. The system then operates with a larger heating surface and U-values that are around 65% higher in thin juice and up to 300% higher in thick juice.
Depending on the effect and the dry substance content, the Robert evaporator is operated with an average temperature difference of 8 Kelvin, while the Hybrid is operated with an average temperature difference of 3 Kelvin to work economically.
With the change from the Robert to the classic tube falling film evaporator – in which the juice is guided in the tubes and the heating steam in the shell – the juice residence time was reduced. The thermal resistance due to the pipe wall thickness (1.2 - 2.0 mm) is on a similar level as the Robert evaporator, but the average driving temperature differences of 6 Kelvin are slightly lower.
A comparison between a tube falling film evaporator and a Hybrid tubular plate falling film evaporator in terms of U-values (K-values), shows that a Hybrid works approx. 35% more efficient in the thin juice and up to 60% in the thick juice.
Depending on the variable shaping depth of the evaporator plates, the Hybrid has a specific heating surface density between 200 and 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) and the hybrid works in safe operation with a wetting rate of 2 to 5 l / (cm*h).
Of course, the heat transfer coefficient improves slightly with a smaller film thickness, but these values have proven to be too low for safe operation in practice. Both types of falling film evaporators have an additional circulation volume for better control. The residence time and the driving temperature differences are higher with the tubular falling film evaporator than with the plate and thus have a stronger effect on the coloration formation of the juice.
Considering the U-values, the performance of the flash evaporation of the superheated juice entering the evaporator and the possible preheating up to the boiling temperature of the vessel pressure are often neglected. Due to flash evaporation caused by a pressure release in a vessel, the U-value appears to be higher and due to the preheating up to the boiling line, the U-value seems to be lower than it actually is for pure evaporation.
Ultimately, long residence times of the fluid to be thickened, combined with high temperature differences to the heating medium, lead to higher levels of fouling in the evaporators and thus increase the energy requirement during the campaign.

How a Hybrid tubular plate falling film evaporator works

The plate geometry of a Hybrid tubular plate falling-film evaporator from VAU Thermotech already provides an ideal flow guidance of thin juice and heating steam in a cross-flow, which means that the Hybrid has often proven itself in operation as a falling film plate evaporator.
Its plate shaping is variable and corresponds to the geometry of half a pipe. When the plates are stacked and welded, a tubular cross-section results on the one side and a wave-shaped cross-section around the pipes on the other side.
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 and directed downwards, so to speak without any "stumbling blocks".
The plate packs are heated on the corrugated side by means of turbine steam in the first effect. All further effects are heated by vapors from the upstream evaporator. In case of a Hybrid tubular plate falling film evaporator with 5,000 m² heating surface, the steam flow is parallel to approx. 3,200 plate channels with a length of approx. 2.5 m, on the tube (juice) side these are approx. 32,000 tubes with

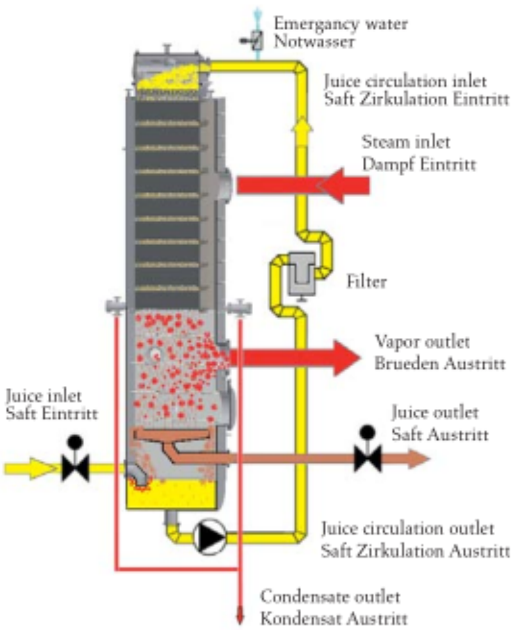

Fig. 2: Simplified flow diagram of a hybrid tubular plate falling film evaporator in a rectangular design.

a diameter of 9 mm. On the tube and corrugated side, 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 wall from top to bottom through the plate packs arranged in series. The vapor created by the evaporation flows in the same direction as the juice.

In the design, the free flow cross-section on the tube or juice side is to be dimensioned in such a way that there is 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 quantities are too large and the juice can be discolored if the quantities are too small, which in the worst case leads to the formation of deposits.

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 with a dry substance between 17 and 70%. By reducing the shaping depth from 4.5 to 3 mm, around 30% more heating surface can be installed in the same stack height. The linearity in the increase in the heating surface is not given here, since the deeper shaping has a larger heating surface due to the greater deformation.

The vapor flow generated is deflected to the side below the plate packs and led to the separator. After separation, the vapor generated is required for the next effect or for heating another process.

The concentrated juice falls into a thick juice collector and is directed to the next evaporator effect or for crystallization via the juice outlet, the collected condensate is fed to a condensate cigar.

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 sump of the evaporator. A certain level is maintained there as a juice supply, so that the circulation pump can process fluctuations in the supply better and does not run dry. In addition, the juice inlet immersed in the sump is able to deal better with possible flow movements associated with flash evaporation in the vessel and more specifically than in the upper juice distribution.

The juice is pumped from the sump via a circulation line through a coarse filter to the distributor 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 various 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, anti-scaling chemicals from various manufacturers have proven to be positive.

Also, to improve a secure operation of the Hybrid tubular plate falling film evaporator, an emergency watering system should be added in the upper feed as extra safety equipment. 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.

Even if the juice level falls below the level in the sump of the evaporator, the emergency watering will give the operator additional time to react.

High design variability of the Hybrid

In addition to the already mentioned variable shaping depths, it is possible to produce the plates in different lengths. 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 the flexibility of the heating surface, an existing vessel can possibly be used for the conversion. 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 vapors generated can be drawn off either at the top or at the bottom. If the vapor is drawn off at the bottom, a small external lamella separator is usually flanged to the

Fig 3: Hybrid tubular plate falling film evaporator in a round pressure vessel with a lamella separator in the upper vapor dome.

Fig. 4: Cross-section through a plate package.

vapor outlet nozzle. If the 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 the case of a compact, rectangular design, the vapors are usually fed directly into an external lamellar vapor separator at the bottom.

The way to higher sugar quality

Due to the more 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 U-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 reduces the color formation of the product to be thickened. Lower numbers of cycles in the juice circulation and more compact heating surfaces reduce production cycles in terms of time and save money and "color". If possible, high temperature differences should be avoided. During the campaign, the fouling on the heating surface increases, which increases the counter pressure on the turbine and thus the temperature difference.

Benefits already from the initial purchase

Hybrid tubular plate falling film evaporators are the 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 weight 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 pipelines or connections.

Specifically, the restructuring 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 reduced 10% of 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. Derived from a linearity, this reduces CO_2 by around 10%.

With regard to falling profits, increasing competitive pressure from competitors on the European and global level, the increasingly important environmental aspects and rising costs for energy and raw materials, a Hybrid offers the decisive advantage to be able to survive in the competition.

About VAU Thermotech

The owner-managed VAU Thermotech GmbH & Co. KG was founded in 1977. Owner and CEO is Osama Nasser. Headquarters and production are located in Heldrungen, Germany. The company manufactures brazed plate heat exchangers, fully welded hybrid tubular heat exchangers and gasketed plate heat exchangers. Design and production are all Made in Germany.