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EVAPORATORS FOR LARGE FIRST AND SECOND EFFECTS

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Abstract

Increasing factory sizes, back-end refineries, higher imbibition rates, the need for energy efficiency and the development of continuous pans that can operate on low pressure vapour have all created a demand for large first and second evaporator effects – often with heating surfaces of 6 000 m^2 to 20 000 m^2 per effect. Potential solutions for providing large capacity such as falling film, Kestner and the Bosch Long Tube Evaporator are compared.

The traditional solution was to use multiple and large Robert type vessels, but it has been shown that the long juice retention times in these at high temperatures results in large ‘undetermined’ sucrose losses by inversion. South African and Australian technologists have emphasised the potential theoretical losses. However, the practical extent was recently dramatically demonstrated by measurements at Gledhow when throughput was slowed by drought and in cogeneration studies in Australia.

The paper concludes that the use by many South African Sugar factories of long tube climbing film evaporators of the Kestner type is an appropriate solution. Bosch Projects have built on the proven advantages of this design to develop an improved long tube evaporator (LTE). Instead of the separate entrainment separator common in Kestners, this design has a high disengagement zone situated above the calandria with an efficient chevron louver separator. Operation and heat transfer coefficients are similar to conventional Kestners, but with a lower juice retention time (less than 2.5 minutes) due to no hold-up in a separator vessel.

Keywords: long tube evaporators, sucrose inversion losses, Kestner, large evaporator capacity, evaporator selection

Introduction

The evaporator station in a sugar factory is important, as it is the ‘engine room’ that drives all parts of the process and determines the energy efficiency of the factory. In recent times, traditional evaporator stations have had to be reviewed to accommodate changes such as:

- Increasing factory sizes
- Higher imbibition rates
- Rising costs of supplementary fuel
- Demand for energy efficiency for cogeneration
- Addition of distilleries, refineries or by-product plants
- Conversion from quadruple to quintuple evaporation

- The introduction of continuous pans and direct contact heaters that can operate on low pressure vapour.

These developments have all created a demand for large first and second evaporator effects – often with heating surfaces of 6 000 to 20 000 m^2 per effect. How can these best be provided? Four options for large first and second evaporator effects are:

1. Large and/or multiple Robert vessels
2. Plate evaporators of rising or falling film types
3. Falling film evaporators
4. Long tube climbing film evaporators.

The attributes of each of these evaporator types will be considered in relation to important aspects of the sugar process – especially the serious but often overlooked issue of sucrose inversion. It is overlooked because normal measuring techniques available to factories do not have sufficient precision to measure the small differences between total sucrose into and out of the evaporators. The extent of inversion can therefore only be established by the use of markers and sophisticated measurement of the products of the inversion.

Sucrose inversion

Sucrose inversion is most severe at low brix, high temperatures, low pH and high retention times – conditions that generally pertain in the early effects of evaporator stations. Large first and second effect vessels inevitably contribute to undetermined losses from sucrose degradation. Purchase *et al.* (1987) reported that there is a correlation between the relative size of the first two effects and undetermined sucrose loss. Using data from South African factories it was noted that factories with larger heating areas in the first two effects experienced relatively higher sucrose inversion losses (Purchase *et al.*, 1987). More recently, losses as high as 2% have been measured in the evaporator station of the Gledhow sugar factory in South Africa when cane throughput was severely reduced due to drought (Dairam *et al*., 2016). Clear juice was diluted in an attempt to ensure sufficient tube wetting rate and also to meet V1 vapour requirements for the back end refinery. However, it was noted that the sucrose losses were high when the clear juice was diluted to low brix (Dairam *et al*., 2016).

The extent of inversion losses was presented in graphical form by Honig (1953), based on information from research by Stadler. However, as pointed out by Rein (2016), there are problems with the Stadler results and the most accurate information is considered to be that by Schäffler (2001). Figure 1 shows the Schäffler relationships for juice in the typical ranges of juice sucrose temperatures and pH found in a first effect evaporator.

In fact, the impact of the sucrose inversion loss in the initial effects will be cascaded to the late effects if the invert sugars are degraded further to form acidic compounds that will lead to low juice pH, thereby promoting additional sucrose inversion loss. The products from the sucrose inversion will also contribute to more sucrose lost in final molasses due to the additional molasses made. Rackemann and Broadfoot (2016) estimate that 1.0% of sucrose inversion across the evaporators would cause a 1.6% reduction in sugar production compared with a factory operating with a 0.1% sucrose loss at the evaporators.

The juice in the initial effects of an evaporator is mainly at low brixes and exposed to high temperatures, and it is therefore of paramount importance to select vessels for these duties that provide a low retention time to minimise inversion losses. This factor is highlighted in the comparisons which follow.

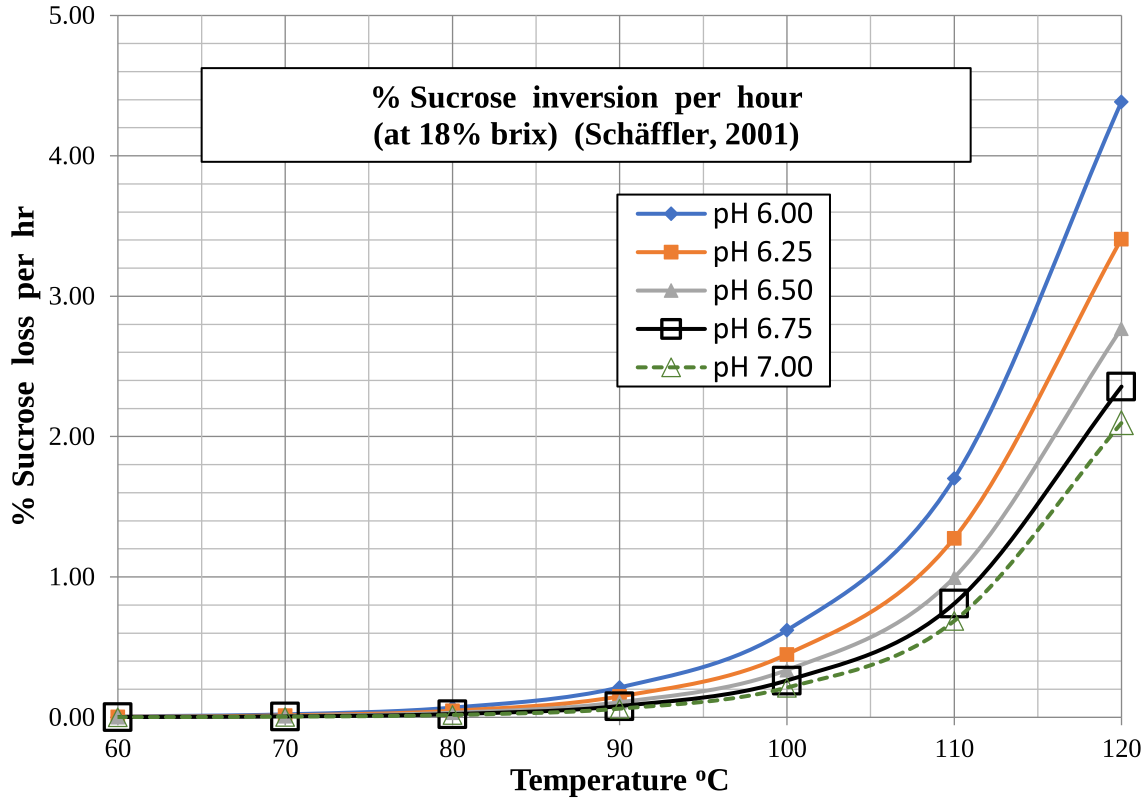

Figure 1. Sucrose loss per hour at different process conditions using the Vukov formula as per Schäffler (2001).

Robert (short tube climbing film) vessels

Some factories have adopted multiple and large Robert type vessels. Their physical size is often a constraint in existing congested factories, but by far the greatest concern with these is the unseen sucrose loss (manifesting as 'undetermined' loss) by inversion while the juice is retained at high temperature in the vessels. This loss can be large but is often unrecognised because the direct losses are not easily measured.

Several workers such as Dairam *et al*. (2016), Schäffler (2001) and Purchase *et al.* (1987) have found that the Vukov formula as widely used underestimates the actual inversion losses due to erroneous assumptions about the evaporator process conditions and flow rates used to estimate the retention time. Rein and Love (1995) measured an average retention time by tracer tests in four small Robert 1st effect vessels (total heating surface of 1 074 m^2) of 27.6 minutes. At an average brix in the vessel of 18%, juice temperature of 116°C (V1 pressure 170 kPa abs) and true pH of 6.7, the calculated sucrose loss would be 0.72%. The author's experience (unpublished) is that retention times in other Tongaat Hulett Robert vessels were measured at 20-28 minutes. Eggleston and Monge (2005) found average inversion losses of 0.55% sucrose in the Robert vessels at a USA factory.

Most recently, Rackemann and Broadfoot (2016) predicted sucrose destruction of 1.1 to 1.2%, resulting in up to 2.0% loss of sugar production, at an Australian cogeneration factory with large

Robert vessels at the front end of the evaporators. These authors stated that such conditions were common to a number of Australian mills.

Larger vessels have larger volume/HS ratios, so have longer retention times. The Australian Sugar Research Institute and ProSuTech developed a Robert design with multiple downtakes for large vessels (Wright *et al.* 2003), but retention times (not quoted) are still probably at least 15 minutes. This is because of the large volume of bottom dish and juice in tubes relative to the heating surface. These times are much longer than the 2.4 minutes residence time in rising film Kestners (including their separators) as measured by Rein and Love (1995) or in falling film evaporators.

There are a few so-called ‘semi Kestner’ designs, generally with tubes of 3.0 m up to just over 4.0 m, with Malalane mill’s longer at 4.6 m. These vessels are probably better described as ‘long tube Robert’ vessels, most with unrestricted juice downtakes. They are a sort of half-way house towards true Kestners, which typically have tubes ≥7.0 m and, since the work at Felixton in the mid-1980s, have carefully sized juice recycle arrangements.

Plate evaporators (climbing or falling film)

Plate evaporators provide a potential solution to the problem of sucrose destruction from long retention times and have been used successfully in the beet industry. However, cane clear juice that is untreated except by lime addition has a much greater potential for fouling on heating surfaces than beet juice, and most designs of plate evaporators are either extremely difficult or impossible to clean when severely fouled. Extreme fouling experiences have been reported from climbing film plate evaporators at Ubombo in Swaziland (de Beer and Moult, 1998) and Hippo Valley in Zimbabwe, and catastrophic fouling in falling film plate evaporators at Riche En Eau in Mauritius and La Gloria in Mexico. The latter two of these resulted in costly new plant having to be scrapped. Full scale plate evaporators are therefore not recommended for cane factories, although wide-gap plate heaters installed between Robert vessels or tube falling film may be used for marginal increases in capacity. The use of a plate heater with much less obstructed path and a separator as an evaporation stage is widely being adopted in various countries such as the USA, India and Vietnam (Schorn, 2018; Bothma, 2018). However, catastrophic fouling will be experienced if the plates dry out with steam on.

Falling film tubular evaporators

Falling film tubular evaporators have a small footprint, can achieve a low temperature difference (ΔT) and have short retention times, but they have practical issues:

- Any dry tubes foul/block rapidly, so it is essential that every tube receives an adequate flow of juice to ensure it is well wetted. This is effected by juice distribution systems that are often elaborate (two or more layers), may need frequent cleaning and obstruct access to the tubes beneath them. Solid cone sprays are a simpler solution, but require higher flows to ensure adequate coverage of every tube.
- To ensure adequate wetting at all times, a minimum juice flow of 30 litres/h/cm of tube peripheral length is required. For this, constant high volume recirculation pumping is necessary, which uses some 12.5 kW power per 1000 m^2 of heating surface (Rein, 2016).
- The recirculation pumps require an adequate sump capacity for consistent duty, and this buffer adds retention time at high temperature.

- In addition, provision must be made for immediate water addition in the event of pump or power failure.
- Protection instrumentation and controls of juice levels and flows are required to ensure sound and safe operation.

High heat transfer coefficients (HTCs) are claimed as an advantage of (clean) falling film tubular evaporators; however, Rousseau *et al.* (1995) found that this is offset by fairly high fouling rates. They recorded HTCs on a first effect vessel decreasing from 2.4 to 1.0 kW/m^{2}K over the course of a three week cleaning cycle.

Long tube climbing film tubular evaporators (e.g. Kestners)

Because of the disadvantages of the abovementioned options, Kestner long tube climbing film evaporators have been widely adopted as the preferred solution in South Africa, Colombia and several other countries due to their short retention time. The short retention in these vessels is because they have long tubes (typically 7.3 m) that allow for high evaporation loads per single pass resulting in high velocities which leads to high HTCs (James *et al.*, 1978). This allows a small and shallow diameter base for the Kestner, and the apparent juice level in operation is usually 10-15% of tube height (which compares with 30-40% in Robert vessels). Compared to large Robert evaporators, inversion losses (per the Vukov formula) in these long tube vessels are 80-90% less. They are significantly cheaper than Robert vessels and have a much smaller footprint (similar to falling film tubular vessels). They are simple to operate (as simple as Robert), are self-regulating and require no protection instrumentation and no recirculation pumps.

James *et al* (1978) showed that a pilot plant Kestner evaporator with 7000mm tubes exhibited better HTCs than conventional short tube Robert vessels on every effect of the Illovo mill evaporator station. General practical experience in the industry has confirmed that Kestners achieve slightly higher HTCs than Robert vessels on similar duties, first effects typically averaging 2.5 to 2.9 kW/m^{2}K over a two week cleaning cycle. For these reasons, Kestner evaporators now constitute 90% of the total 1st effect heating surface in the South African industry. One factory has three falling film tubular evaporators, and four factories still have old 1st effect Robert evaporators operating in parallel with newer Kestners.

The three falling film evaporators have not been followed by others because of their juice distribution requirements and the need for high volume recirculation pumps, neither of which are required by Kestner evaporators. With correctly sized recycle line(s), the juice level in Kestners is self-regulating, so that, unlike falling film evaporators, no instrumentation or operator intervention is required.

Bosch Projects have built on the proven advantages of the Kestner design to develop an improved long tube evaporator (LTE) (see Figure 2). Instead of the separate entrainment separator common in sugar industry Kestners, their design has a high disengagement zone situated above the calandria, followed by an efficient chevron louver separator. Vapour typically exits in two or more directions (one to the next evaporator and one or more to vapour bleeds). The design includes gravity-driven recirculation to ensure an adequate tube wetting rate. Operation and HTCs are similar to conventional Kestners, but with a lower juice retention time (less than 2.5 minutes) due to no hold-up in a separator vessel.

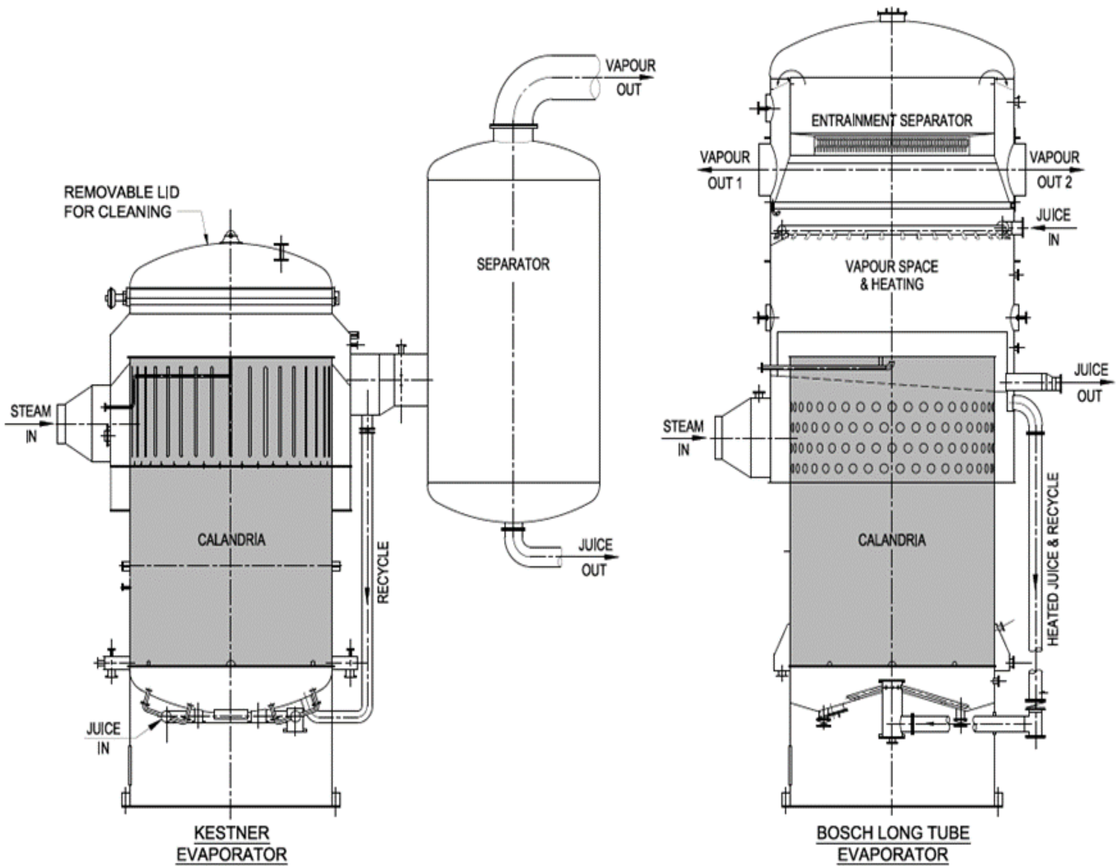

Figure 2. Kestner and Bosch Long Tube Evaporator with internal clear juice DC heater (both 6 000 m^2 HS).

The disengagement zone provides generous access for mechanical cleaning if desired; alternatively, a chemical cleaning facility can be incorporated in the headspace. Bosch has installed the LTE at NAT&L in Vietnam and in several factories in Thailand. Some of these have been supplied with a unique and effective arrangement for direct contact clear juice heating within the disengagement zone. As illustrated in Figure 3, this is achieved by spraying the incoming clear juice onto the vessel walls. This heats the incoming juice to 1-2°C below the vapour temperature, which is sufficient for effective boiling in the vessel. The low brix juice from the walls is preferentially selected for the recycling system, while higher brix juice out of the tubes is transferred to the next stage.

The vessels stand on an extended skirt on the ground floor, so foundations are simple, no supporting steelwork is required and the footprint is small. A 10 000 m^2 heating surface vessel would be approximately 7.2 m in diameter.

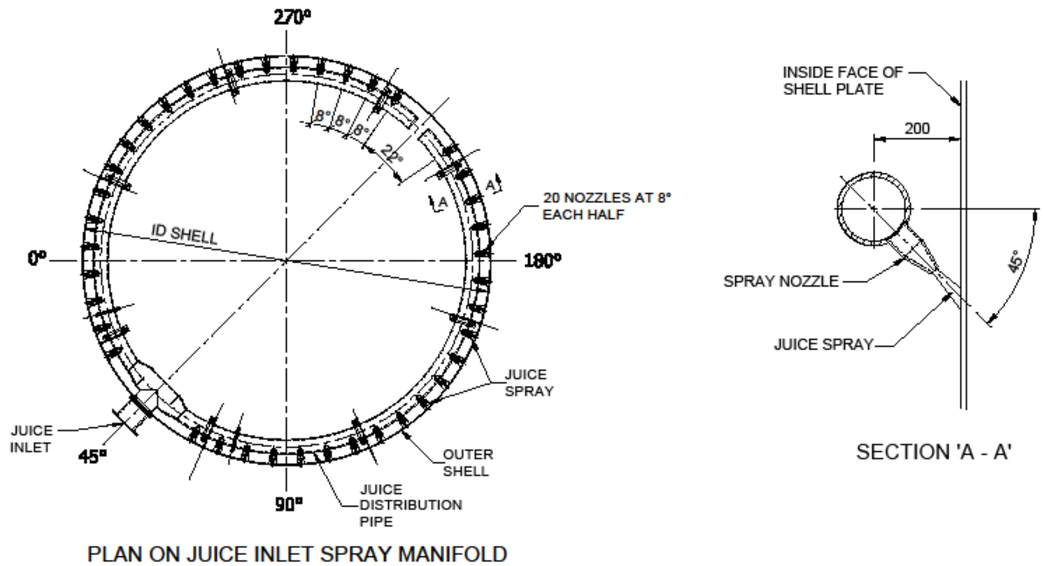

Figure 3. Arrangement of incoming juice sprayed onto vessel wall.

Conclusion

For many reasons, factories now require large first and second effects in their evaporator stations. Because of the high temperatures at this stage, sucrose is rapidly inverted and it is therefore essential to select vessels that minimise retention times. From the analysis of the options available, it is concluded that a novel design of climbing film evaporator provides the best solution in all important respects, particularly minimised sucrose inversion, low cost and operability.

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