REFEREED PAPER

MODULAR EVAPORATORS

VOIGT I AND DU PLESSIS NJ

Bosch Projects (Pty) Ltd
PO Box 2009, Durban
voigti@boschprojects.co.za duplessisn@boschprojects.co.za

Abstract

Reboiler evaporators are common in process industries, including cane ethanol plants. They are used to provide heat to distillation columns by boiling the liquid from the bottom of a distillation column to generate vapours, which are returned to the column to drive the distillation separation. Typically, a reboiler is situated externally to the distillation column. Recently the concept has been applied to cane juice evaporation and has a number of advantages worth considering. Firstly, the heating surface capacity of an existing evaporator vessel can be increased by the addition of a reboiler, thus offering a simple means of increasing the capacity of an evaporation train. Secondly, multi-reboilers can be used as a single effect in an evaporator train, all connected to a single separator. The advantage of this arrangement is that each reboiler can be removed from service individually for cleaning, without removing the entire effect from service. A second advantage is that mechanical cleaning can be performed without entering an enclosed vessel, as this is considered in some industries to be a health and safety risk. Thirdly, the capacity of a multi-reboiler effect can be increased by the addition of reboilers that use the existing separator vessel.

Effectively, the multi-reboiler concept is a modular evaporator.

Modular evaporators are now gaining favour in the Brazilian cane industry. Bosch Projects and Bosch Engenharia have developed unique arrangements of modular evaporator systems for use in any effect of an evaporator train, with evaporator tube lengths of 2-7 metres. This paper discusses the concept of modular evaporators and the unique arrangement of the system developed by Bosch Projects.

Keywords: evaporators, reboilers

Some types of reboilers

In distillation processes, steam is frequently provided to a column by a reboiler. The most common type of reboiler is some variant of a shell-and-tube exchanger, and normally steam is used as the heat source. Some commonly used heat exchanger type reboilers are discussed below, although this list is not exhaustive. The descriptions below are taken from the texts of McKee (1970), Palen (1983) and Whalley and Hewitt (1983).

Internal reboilers

One approach is to mount the reboiler in the distillation column itself, as is illustrated in Figure 1. Boiling takes place in the mass of liquid at the bottom of the column, the steam being inside the bundle of tubes. Often a U-tube bundle is used. A major benefit is elimination of external piping and the tube housing. This design frequently is chosen where the application is very clean and minimal bundle maintenance is likely to be necessary. The major problem with internal reboilers is the limitation imposed by the size of the distillation column, which limits the size of the reboiler.

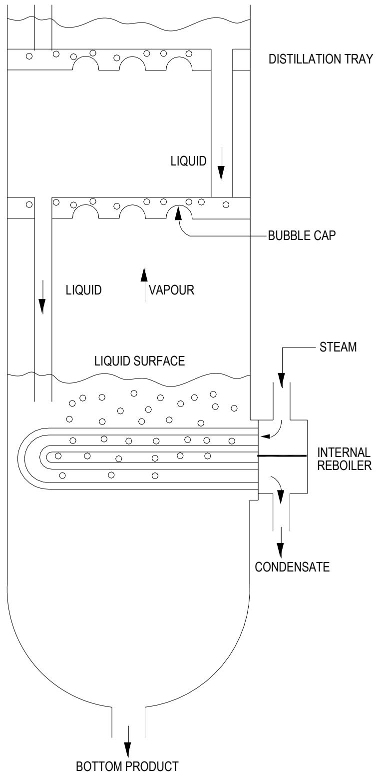

Figure 1. Internal reboiler.

Kettle reboilers

The layout of the kettle reboiler is illustrated in Figure 2. Some require pumping of the column bottoms into the kettle, or there may be sufficient hydrostatic head to deliver the liquid into the reboiler. The liquid from the bottom of the column flows through the shell side, whilst steam flows through the tube bundle and exits as condensate. An overflow weir maintains a constant liquid level over the tube bundle. Vapour is removed from the top of the shell and returns to the column.

Thermosyphon reboilers

Thermosyphon reboilers do not require pumping of the column bottoms liquid into the reboiler. Natural circulation is obtained by using the density difference between the column bottoms liquid and the heated two-phase mixture to provide the driving force for flow. Horizontal thermosyphon reboilers (Figure 3) usually have steam inside their tubes and the column bottoms flow in the shell side. In vertical thermosyphons (Figure 4) the liquid evaporation takes place inside the tubes and the steam is on the outside of the tubes, as in a typical sugar factory evaporator. However, additional height is required in order to mount the reboiler. Both types differ from a kettle reboiler, in that a two-phase flow returns to the column rather than saturated vapour only.

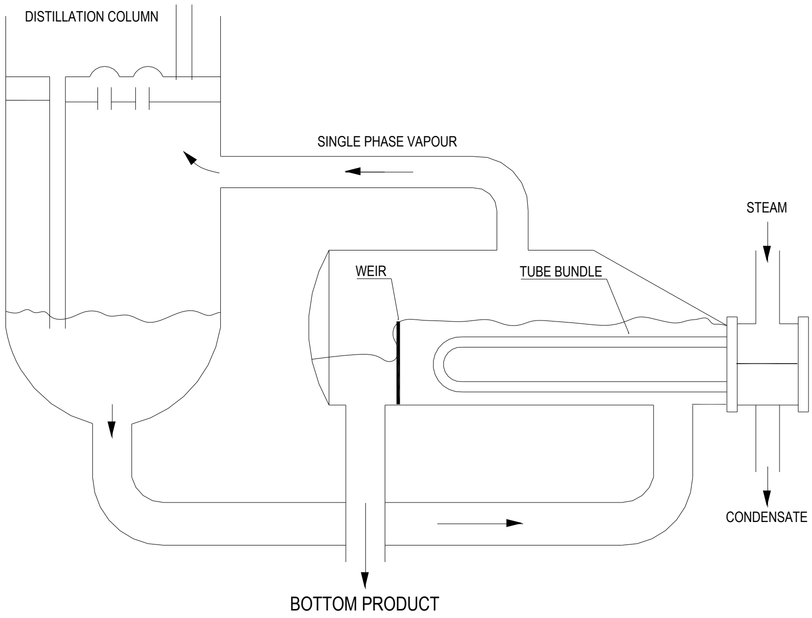

Figure 2. Kettle reboiler.

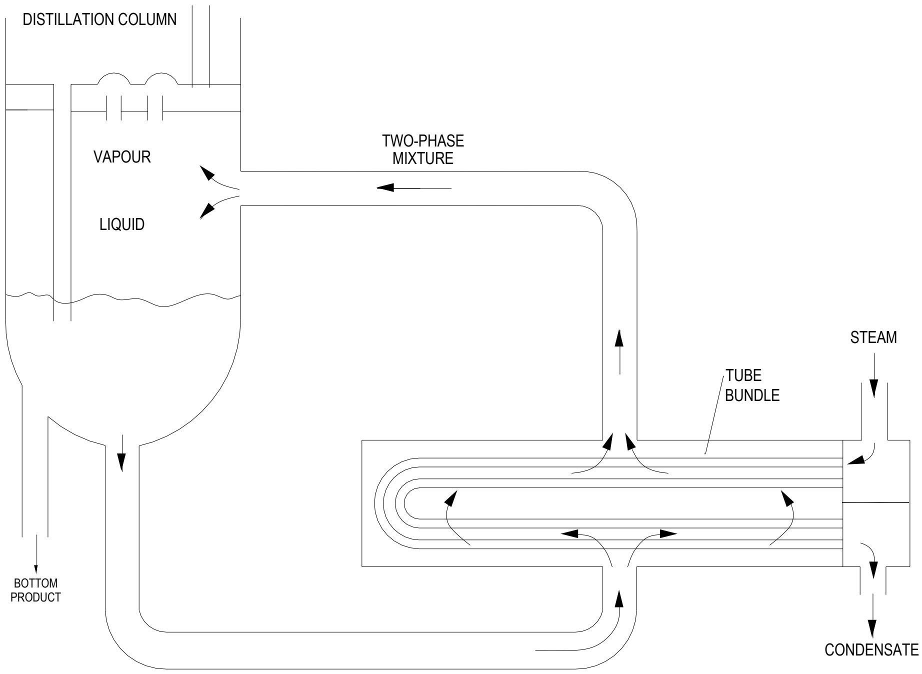

Figure 3. Horizontal thermosyphon reboiler.

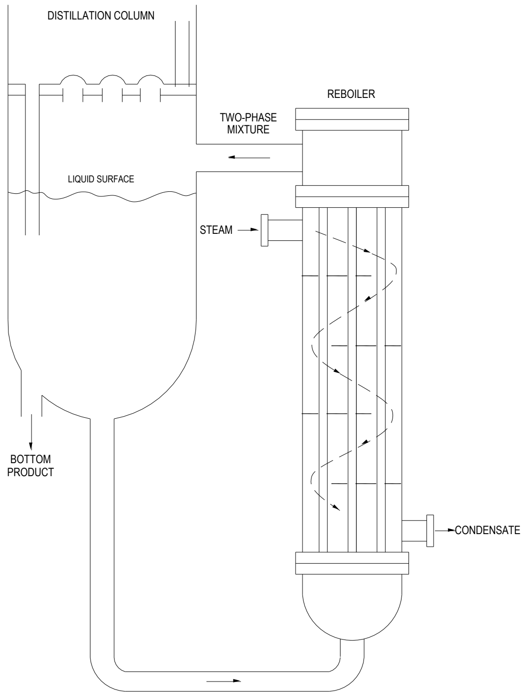

Figure 4. Vertical thermosyphon reboiler.

Application to the sugar industry

It is evident from the above description that the vertical thermosyphon reboiler offers similarities to sugar factory evaporators, especially Kestner types. Common characteristics are:

- Vertical tube orientation
- Tube-side evaporation and with steam on the shell side
- Two-phase fluid exiting to the stand-alone separator
- Natural circulation of liquid from the separator to the heat exchanger.

Kestner-type evaporators

Kestner evaporators are first mentioned in the South African Sugar Technologists' Association (SASTA) proceedings by Walsh (1957). The first semi-Kestner installation reported was at Dalton (Buck, 1965), and Kestners were reported at Darnall and Felixton in 1969 (Allan, 1969). Kestner (and semi-Kestner) evaporators are characterised by longer tubes than the traditional Roberts evaporators. As a result, the velocity of juice from the tubes is higher as is the probability of gross entrainment. Consequently the vapour separator is traditionally a stand-alone vessel with its own entrainment separation devices. It is possible to use one separator vessel for two Kestners, as was the case at Illovo (Taylor, 1987) and Amatikulu (Montocchio and Scott, 1985) mills.

Previous installations of side-stream/booster evaporators

During the period 1994-2003, a number of technologists researched the use of plate evaporators in the cane sugar industry. Nilsson (1994), Walthew and Whitelaw (1996), Walthew *et al.* (1996), de Beer and Moult (1998), Rein (2002) and Loubser *et al.* (2003) all reported on their experiences with plate evaporators. In four cases, these were either pilot plant evaporators or full-scale evaporators, installed parallel to existing Roberts evaporator vessels. Juice from an evaporator body was passed through the plate evaporator and the two-phase fluid returned to the vapour space of the evaporator, where the vapour and liquid were separated. This arrangement is obviously the same as for a thermosyphon reboiler described earlier, and suggests the feasibility of a booster evaporator that uses the separator of the main evaporator vessel. However, no evidence has been found in SASTA literature that indicates calandria-type booster evaporators being used.

The Bosch Projects modular evaporator concept

The idea of a reboiler being used to boost the capacity of an evaporator appears to be acceptable, and no obvious reasons can be found why a calandria-type reboiler should fail in an application where plate-type reboilers have been successful. It is presumed that the only limit to the size of reboiler that is added to an existing evaporator vessel will be the capacity for liquid/vapour separation in the vapour space. An extension to this concept is to arrange multiple calandrias around a central separator. As in the arrangement by which a Kestner evaporator receives clear juice and juice recycled from the separator, so multiple calandrias can be arranged to receive juice below the tube plate and to discharge to two-phase fluid into an adequately sized separator. A number of design considerations are discussed below.

The calandria for the evaporator may be of the conventional short tube type (comparable to a Roberts evaporator) or the longer tube Kestner or semi-Kestner type. In both cases, the calandria is designed so that it may be easily isolated from the rest of the system for cleaning. The top dish of the evaporator is bolted with swing bolts (similar to a juice heater) rather than the Kestner type bayonet, and is hinged to allow for easy removal without the use of lifting tackle. Actuation by hydraulic cylinder is also an option. A suitable O-ring type of seal rather than gaskets is used between the top dish and the calandria body.

As with conventional evaporators, options exist for mounting the calandrias and separator at the required elevation onto structural steel or onto extended skirts from ground level. When considering long tube evaporators, the only sensible arrangement is the latter. In both cases, the relative arrangement of the calandrias and the separator is important to maintain the correct juice level within the calandria (15-30% of tube height, depending on its length) and to allow for hydrostatic recirculation of the juice from the separator to the calandria.

The design of the separator takes into account the quantity of vapour to be received, both in the initial stage and after the future addition of calandria. The Bosch Projects design allows for both the tangential inlet of the two-phase fluid and for changes of direction within the separator to separate vapour and juice. The return of juice from the separator to the calandria is also through take-offs tangential to the separator body.

Entrainment of juice droplets in the vapour can result from five different circumstances (Rein, 2007): (i) splashing of the boiling liquid, (ii) localised spouting due to non-uniform conditions, (iii) foaming or frothing of juice, usually associated with unsteady operation, (iv) operational issues such as sudden pressure changes, high levels or poor condensate removal, and (v) the entrainment of droplets too small to drop out of the vapour flow in the disengagement area. The first four factors generally result in gross entrainment of large droplets of juice which are easily separated. The fifth factor is considered the most relevant to the modular evaporator separator and can be conveniently handled by a well-designed entrainment separator. An internally mounted chevron-type entrainment separator provides the final stage of droplet removal from the vapour.

Clear juice can most conveniently be supplied into the separator and thus evenly distributed to each calandria. However, the positive benefits of the flashing of preheated clear juice would be lost in the separator. The preferred arrangement is to supply clear juice to each calandria where the flash steam promotes boiling in the tubes. This division of clear juice forms a part of the system control philosophy.

The control system for the modular evaporator considers a number of parameters and is similar to that of a conventional evaporator station. Importantly, the rate of condensate flow from each calandria is measured and is used as an indication of the extent of scaling of the tubes in each calandria in order to schedule tube cleaning.

The applicability of the multi-reboiler concept in Brazil

One advantage of involvement in foreign sugar industries is the opportunity to observe alternative technologies. Each industry is faced with different challenges, and the specific technologies selected reflect these challenges. Amongst others, Brazil is faced with the challenges of an expanding industry, including the viability of new greenfields plants; the challenge of technical and managerial skills to keep pace with industry growth; fluctuating commodity prices; and stricter safety and environmental legislation.

Recent legislative focus on health and safety, as well as the affordability of new greenfields plants, may have contributed to acceptance of multi-reboiler technology. Health and safety regulations place high demands on factory management for the entry of personnel into enclosed spaces, such as evaporator vessels. Even the entry into cooled diffusers is deemed an health and safety risk, to be accompanied by appropriate paperwork.

The aspect of affordability of new plants receives focus in most industries. In Brazil, the industry was commissioning up to 30 new plants per year (as in 2008). To process the maximum cane crop for the lowest capital cost, the issue of plant availability was carefully considered, and technology was implemented to avoid downtime. (In fact, the Bosch Projects experience at greenfields factories in Brazil is that maintenance stops are seldom scheduled. It is common to carry out maintenance during rain stops, to the greatest extent possible.)

Another reality of a growth industry is that brownfields factory expansions are required. Often new factories are designed with future expansion in mind. Two options cater for future capacity expansions in any factory: the over-sizing of equipment in the initial installation; and the allowance for additional equipment to be added in future. The disadvantage of the former is that excess capital expenditure is incurred in advance of the production benefits.

In this environment, the multi-reboiler concept answers some of these questions.

- Firstly, each calandria may be isolated from the rest, opened and mechanically cleaned while the rest are still in use. This is similar to the practice in South Africa for juice heaters, where a spare heater is installed to allow for cleaning. The obvious advantage is that stops need not be scheduled for evaporator cleaning.

- Secondly, there is no need to install a second evaporator train to allow for the non-stop operation (as is practised in some industries), with obvious capital cost benefits.
- Thirdly, mechanical cleaning does not require personnel to enter an enclosed space.
- Finally, the capacity of an evaporator can be increased by adding calandrias, as long as the separator vessel has sufficient capacity.

At this stage, only reboilers with shorter tubes (2 m) have been erected in Brazil. The implementation of this technology at Raizen's Jatai and Barra factories and at Ipiranga Escalvado have been successful. These are shown in Figure 5.

Figure 5. Multi-reboiler installations at Brazilian sugar factories.

Operational results

The measurement of evaporator performance has been attempted at two installations in Brazil. Both were first effect evaporators and the tests were run over a six hour period. The results for Mill A are tabulated in Table 1.

The performance of the evaporator at Mill B was below expectations. Some modifications were carried out and operational procedures were revised. It is reported that performance has subsequently improved, but specific results of these are not available. The performance results at Mill A show acceptable heat transfer performance, in comparison with sugar factory norms.

Table 1. Performance test results at Mill A.

Exhaust steam 2.52 bar, 128°C							
Vapour-1 1.84 bar							
Inlet juice 108°C							
		08:00	**09:00**	**10:00**	**11:00**	**12:00**	**13:00**
Inlet juice flow	m³/h	1760	1800	1800	1800	1800	1780
Inlet juice flow	ton/h	1848	1890	1890	1890	1890	1869
Brix outlet juice	%	25.4	23.8	23	23.8	23.4	23.3
Brix inlet juice	%	14	13.8	13.7	13.8	13.7	13.8
Heat surface area	m²	25200	25200	25200	25200	25200	25200
Outlet Juice flow	ton/h	1019	1096	1126	1096	1107	1107
Evaporated water	ton/h	829	794	764	794	783	762
Specific evap rate	**kg/h/m²**	**32.91**	**31.51**	**30.33**	**31.51**	**31.09**	**30.24**
BPE (hydr head + DS)	°C	1.09	1.06	1.05	1.06	1.06	1.06
Outlet juice temp	°C	118.7	118.7	118.6	118.7	118.7	118.7
Heat transferred	kW	617301	591108	568897	591108	583192	567265
Exhaust steam	ton/h	995	953	917	953	940	915
HTC	**kW/m²/°C**	**2.72**	**2.60**	**2.50**	**2.60**	**2.56**	**2.49**
HTC predicted by Dessin equation	**kW/m²/°C**	**2.51**	**2.54**	**2.55**	**2.54**	**2.54**	**2.54**

Conclusions

Process equipment innovations are not common in the sugar industry. However, the changing environment in which the industry operates does occasionally promote new designs, and the modular evaporator is an example of such an innovation. This concept allows the heating surface area of existing evaporators to be increased relatively cheaply, and provides for continuous evaporator operation that avoids unproductive cleaning time. In an operating environment where factories need to achieve increases in their annual production capacity, or where greenfields plants need to be constructed with the best financial return, modular evaporators are considered an exciting new development. They help to achieve these objectives by reducing planned downtime and providing expandability of evaporator trains.

REFERENCES

Allan GN (1969). Process plant installations at South African sugar factories. *Proc S Afr Sug Technol Ass* 43: 177-189.

Buck WR (1965). Dalton - South Africa's first milling diffusion sugar factory. *Proc S Afr Sug Technol Ass* 39: 114-121.

de Beer TH and Moult JM (1998). Experience with plate evaporators at Ubombo Ranches in Swaziland. *Proc S Afr Sug Technol Ass* 72: 228-233.

Loubser RC, Sahadeo P and Singh I (2003). Tests on a plate evaporator pilot plant at Malelane. *Proc S Afr Sug Technol Ass* 77: 463-473

McKee HR (1970). Thermosyphon reboilers: A review. *Ind Eng Chem* 12: 62-76.

Montocchio RG and Scott RP (1985). Experiences in evaporator control at Amatikulu. *Proc S Afr Sug Technol Ass* 68: 99-101.

Nilsson I (1994). Industrial plate evaporators. *Proc S Afr Sug Technol Ass* 68: 125-127.

Palen JW (1983). Shell-and-tube reboilers. In: *Heat Exchanger Design Handbook*. Hemisphere Publishing Corporation, New York, USA.

Rein PW (2002). Aspects of the Louisiana sugar industry of interest to South African technologists. *Proc S Afr Sug Technol Ass* 76: 36-41.

Rein PW (2007). Evaporation In: *Cane Sugar Engineering.* 1st Edition, Bartens, Berlin, Germany.

Taylor K (1987). The washing of demister screens at Illovo. *Proc S Afr Sug Technol Ass* 61: 62-64.

Walsh WH (1957). Group discussion on the prevention of entrainment and the construction of save-alls. *Proc S Afr Sug Technol Ass* 31: 56-60.

Walthew DC and Whitelaw RW (1996). Factors affecting the performance of long tube climbing film evaporators. *Proc S Afr Sug Technol Ass* 70: 221-224.

Walthew DC, Wienese A, Squires R and Friedrich C (1996). Preliminary assessment of rising film plate evaporator. *Proc S Afr Sug Technol Ass* 70: 225-230.

Whalley PP and Hewitt GF (1983). Reboilers. In: *Multiphase Science and Technology*. Vol. 2, Hemisphere Publishing Corporation, New York, USA.