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Designing Continuous Pans for Low Energy Consumption

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Abstract

This presentation marries two topics of this Workshop – pan design and energy utilisation.

A recent energy balance for a typical three-boiling cane sugar factory showed that, of the factory's total energy requirement for producing sugar from the input cane, some 30% was needed for boiling and crystallising in the pans. This high percentage is because the pans boil in single effect, with large losses to their condensers.

Many factories now export power or steam for refining, by-products, irrigation, co-generation, etc. Bosch Projects therefore includes energy efficiency as one of the main criteria to be considered in the design of both their batch pans and their continuous pans (CVPs). This presentation covers aspects of CVP design that can reduce the energy usage of the pan floor.

It covers specifically reduction of energy requirements by:

- Maximising the proportion of crystallisation done in continuous (as opposed to batch) pans
- Designing pans capable of operating at low ΔT values in order to use the lowest possible grade of vapour
- Designing pans for strong natural circulation, aided where necessary by incondensable gas jiggers, so as to avoid energy-intensive mechanical stirrers
- Maximising A and B pan exhaustions to minimise the overall amount of pan boiling
- Producing uniform-sized crystals to minimise re-boiling of sucrose lost in centrifugation and in affination for refining
- Maximising intervals between CVP boil-outs
- Possibly using vapour recompression

It is shown by results quoted that good CVP design can contribute significant factory energy savings. Some of the energy-saving features described are unique to Bosch CVPs – the under-base heating, the distributed feed and jigger injection beneath the massecuite and the mid-compartment flow-directing baffles.

Keywords: Continuous pans, CVP design, Energy efficiency

Presentation

1. Introduction

Energy conservation is becoming ever more important. Analysis of a recent energy balance for a typical three-boiling cane sugar factory (Ubombo Sugar, Swaziland) showed that the total enthalpy in the steam used to produce raw sugar (i.e. excluding refining and power exports) was used as follows:

- 16% (from HP steam) to produce power for cane preparation, extraction and factory plant
- The remaining 84% (in exhaust steam) for process heating and evaporation, including the losses in condensers.

The percentages will obviously vary according to many factors: – diffusers require less power but more heating than mills; number of evaporator effects; use of steam bleeds; boiling program; etc. However, these will not change the conclusion that more than 80% of the energy is required for processing. For this typical factory, of the 84% used in process, 36% (i.e. ***more than 30% of all the energy***) was needed for boiling and crystallising in the pans. The reason for this high percentage is that the pans boil in single effect, with large losses to their condensers.

The energy efficiency of pan boiling should therefore be an extremely important focus for factories required to export power or steam for refining, by-products, irrigation, co-generation, etc. Bosch Projects therefore includes this as an objective in the design of its pans, both batch and continuous. This presentation covers specific aspects of energy efficiency that have been addressed in their CVP design.

- Maximising the proportion of crystallisation done in continuous (as opposed to batch) pans
- Designing pans capable of operating at low ΔT values in order to use the lowest possible grade of vapour
- Designing pans for strong natural circulation, aided where necessary by incondensable gas jiggers, so as to avoid energy-intensive mechanical stirrers
- Maximising A and B pan exhaustions to minimise the overall amount of pan boiling
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Each of these is addressed in turn below.

2. Design pans able to maximise the proportion of crystallisation done in continuous pans.

Continuous vacuum pans (CVPs) have a big energy advantage over batch pans in that CVP steam demand is steady, with few stops. There is no wasteful steaming out between boilings and no breaking / re-establishing of vacuum. Another major advantage is the lower vapour grade that they can use (see section 3 below).

Batch pans remain the preferred equipment for seed boilings (graining), as they are well suited to handle the changing conditions during shock seeding and / or washing out of fine crystals from a magma. Continuous pans should be used for taking this seed up to final strike massecuite.

On most pan floors with batch seed pans and continuous strike pans, the seed is transferred from the batch to the continuous pans with the crystals at 60% - 65% of their finally required size, i.e. leaving a crystal size ratio (final crystal size / seed crystal size) of about 1.6 for the continuous pans. However, for energy efficiency, the seed pans should be used *only* until a good, even-sized crystal population has been established. ***Provided the CVP concerned exhibits good plug flow characteristics*** (see section 6 below), much higher crystal size ratios (up to 2.0 or above) can be used, thereby transferring more of the boiling from batch to continuous pans.

3. Design pans able to operate at low ΔT values in order to use the lowest possible grade of vapour

Another reason for maximising the proportion of boiling done in CVPs is that they require lower grade vapour for their operation. Vapour 1 (V1) has already provided its own mass of the water evaporation required in the evaporators. V2 has provided approximately double its own mass of evaporation and V3 three times its mass. Using lower grade vapours therefore significantly reduces the overall process energy requirement.

As a batch pan boiling progresses, the massecuite head in the pan increases (by up to 2000 mm above the calandria in some designs). Depending on purity and head, the hydrostatic boiling point elevation at calandria level is often well over 20K, so that a considerably higher calandria steam pressure is required to achieve the necessary heat transfer. Further, the flow pattern above the calandria loses definition (see Figure 1).

In contrast, the head in continuous pans remains low throughout the boiling (Figure 2). There is thus minimal boiling point elevation and lower calandria pressures can be used; just how low depends on the pan's design.

The boiling pressure inside the pan is usually fixed at between 13 and 16 kPa abs. by considerations such as injection water temperature, condenser equipment and process staff wishes. The minimum pressure for the supply vapour therefore depends on the pan's ability to operate with good heat transfer rates at low ΔTs. It is obviously important to sustain the low ΔT capability over a protracted period between boil-outs (addressed in section 7 below).

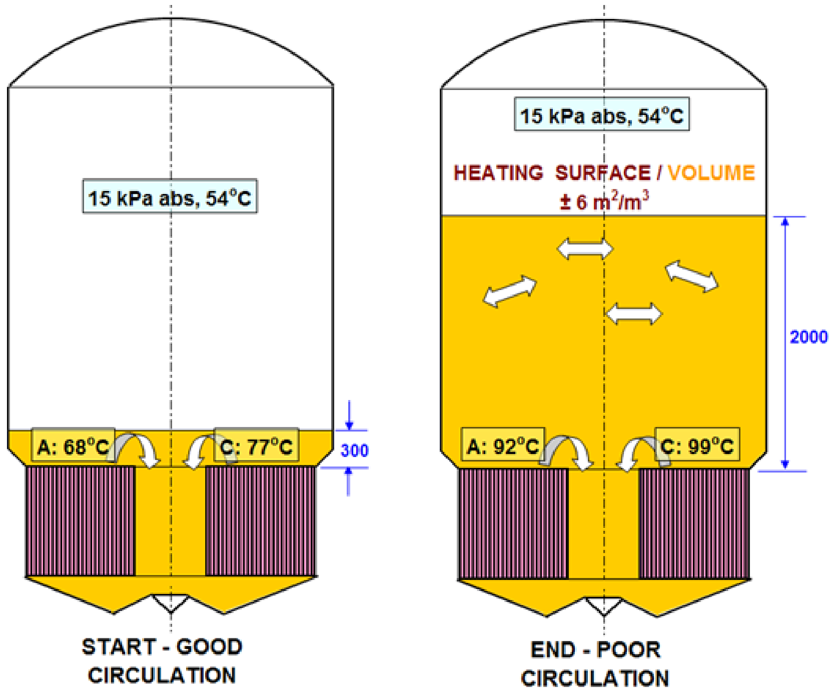


Figure 1: Batch boilings, start and end

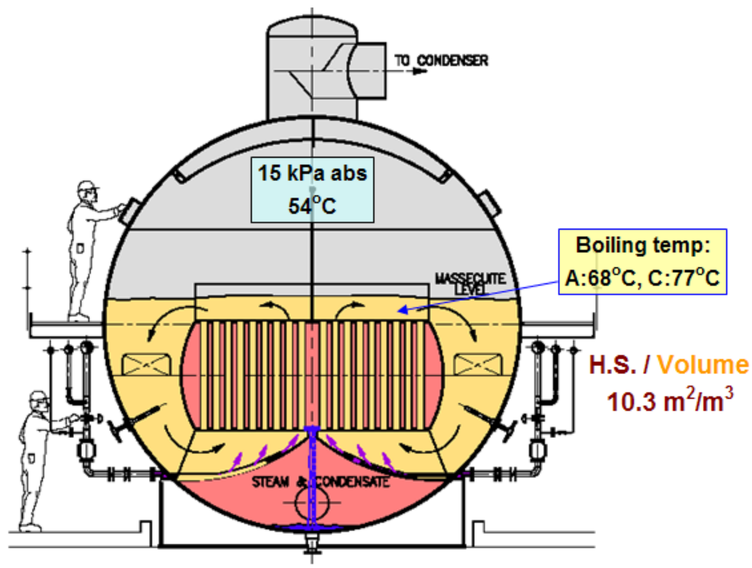


Figure 2: Continuous pan boiling (Bosch)

Good heat transfer coefficients (HTCs) and low ΔTs require high massecuite velocities over the heating surfaces. The Bosch CVPs achieve this by a combination of:

- Unique under-base heating from the steam/condensate chamber (see Figure 3a)
- Vertical flow boiling tubes in a good natural circulation profile
- Alternating injection into the massecuite of flashing (± 70°C) syrup or molasses feed and jigger steam, through multiple injection points beneath the calandria. There are usually 12 feed points per pan compartment, distributed along the floor

underneath the massecuite so as to promote up-flow into the tubes (see Figures 3a and 3b).

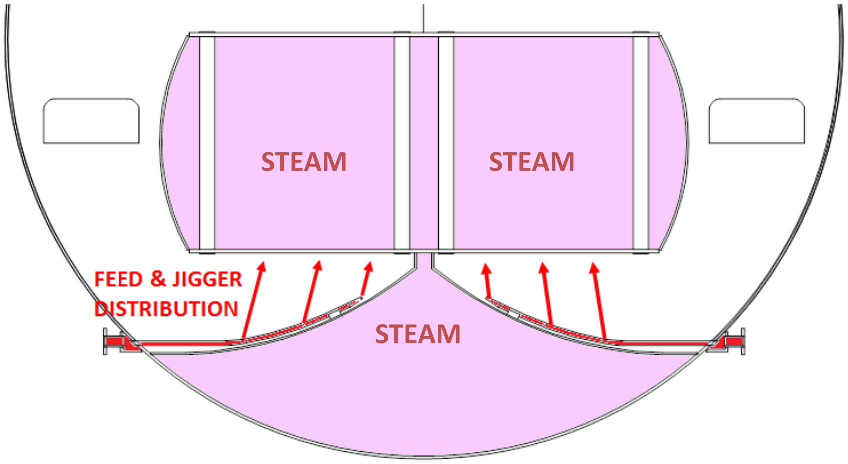


Figure 3a:Feeds and Jigger steam injected below massecuite

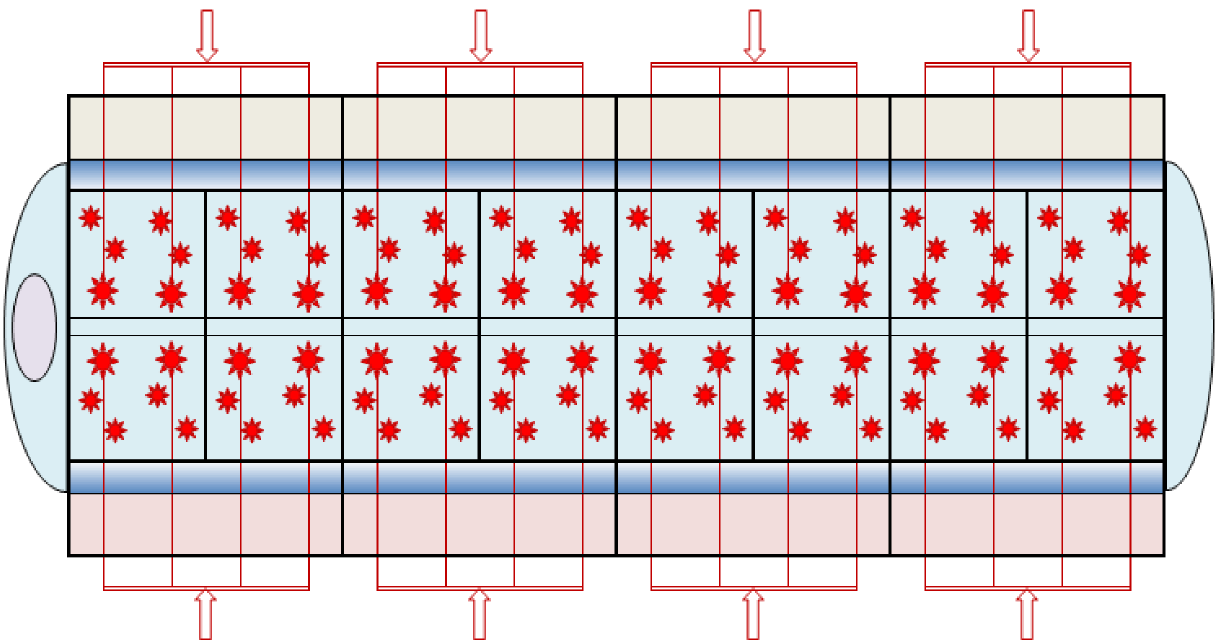


Figure 3b. Feed and jigger distribution beneath calandria

As a result, these pans have operated well for protracted periods, often with ΔT values of less than 20K on ‘A’, ‘B’ and ‘C’ boilings, with high final brix massecuites and high HTCs. Table 1 shows the ranges of measurements from eleven Bosch pans at F.U.E.L. (Mauritius), Ban Rai, Thai Roong Ruang, Khon Kaen, Mitr Kalasin, Mitr Phu Luang (all Thailand), Bois Rouge (Reunion) and Sao Martinho (Brazil). Some of these are taken from commissioning tests, others during normal factory operations.

Table 1: Brixes, HTCs & Exhaustions from Bosch CVPs

Pan Duty	**Final Brix (^{o}) (refractometer)**	**HTC ($W/m^2.K$)**	**Pan Exhaustion %**
A pans (7 off)	**92.0 – 94.6**	**400 - 540**	**66.8 – 70.8***
B pans (2 off)	**91.6 - 95.2**	**330 - 440**	**71.0 – 72.5**
C pans (2 off)	**96.2 – 97.2**	**220 - 230**	**63.6 - 65.4**

*This table excludes Mitr Phu Luang, optimised with KC Koster on 7 February to produce the astonishing results:

Massecuite Brix	**%**	**94.6**
Massecuite Purity	**%**	**89.87**
Nutsch Purity	**%**	**63.37**
Purity Drop	**%**	**26.50**
Pan Exhaustion	**%**	**80.50**
Crystal Content	**%**	**68.44**

(Reducing sugar / Ash > 2.6 in final molasses)

The vapour supply to a CVP with these characteristics can always be at least one grade and often two grades lower than that required by the batch pans. Without stirrers, batch pans usually require at least 120 – 150 kPa abs steam (usually V1) for successful operation, whereas Bosch ‘A’ CVPs are operating well on V3 at 80 kPa abs in factories in both Mauritius and Thailand. A split-type B pan in Brazil operates with the calandria pressure in the first 6 compartments at 60-65 kPa abs and at 75 -80 kPa abs in the final 6 compartments.

4. Design pans to avoid the use of mechanical stirrers; use incondensable gases for jiggers

Mechanical stirrers are used for crystal quality purposes during graining, to prevent agglomeration in refinery boilings and/or to enhance heat transfer by increasing the massecuite flow velocity over heating surfaces. These purposes are justifiable under appropriate circumstances in batch pans. However continuous pans are not generally used for graining and with their low boiling heads, alternatives requiring less energy are available.

As shown by the results in Table 1, good circulation and excellent HTCs can be achieved without mechanical stirrers by a combination of energy efficient means. One of these means is incondensable gas jiggers. Moor (2002) presented a paper at the ISSCT Energy Workshop in Berlin wherein he showed that the pressure of incondensable gases in CVPs is always sufficient to inject these as “free” jigger steam. The benefits of this are obvious, particularly as an alternative to mechanical stirrers.

Bosch recommends the use of SRI-type jiggers, as described by Rackemann and Broadfoot (2007), in their batch pans and some SRI jiggers have been used in the final two compartments of Bosch CVPs. However, the results in Table 1 from CVPs with the normal Bosch jigger distribution suggest that this is equally effective for the base-heated pans.

Power (and maintenance) intensive stirrers can and should therefore be avoided in CVPs.

5. Design pans to maximise pan exhaustions, to avoid re-boiling

The energy benefit of maximising exhaustions (i.e. the proportion of total sucrose in a massecuite that is deposited onto crystals) is often overlooked. Low exhaustions in A and B boilings mean more sucrose is left in molasses and hence more pan boiling is needed to recover that sucrose.

Key requirements for good exhaustions include:

- Good, vigorous circulation to promote sucrose deposition onto crystals
- Sufficient crystal surface and residence time for this deposition
- High final brixes to minimise sucrose solubility in the mother liquor, thereby forcing sucrose out of solution.

As can be seen from Table 1, the Bosch CVP design generally promotes good exhaustions. The ability to achieve high brixes and good exhaustions should be a top priority in the selection of pans. Losses from poor pan exhaustions cannot be recovered in the crystallisers.

6. Design pans to produce good even-sized crystals, to minimise re-boiling of centrifugal and affination washings

Section 5 above has listed criteria for good pan exhaustions. However, this exhaustion needs to be retained through the process till after centrifugation.

In centrifugation, fines may either be washed out (dissolved) or pass through the screen. In massecuites with non-uniform crystal sizes, small grain has the propensity to fill the gaps between the larger crystals, resulting in a layer of crystals in the centrifugal that does not purge easily. This results in longer wash periods and more sucrose losses. To minimise losses in centrifugation, a uniform crystal size (low CV) is therefore of paramount importance. This requires:

- A good quality seed to the CVP
- Good brix control through the CVP
- Most importantly, good plug flow through the CVP.

The topic of crystal residence time distribution has been extensively covered by Thelwall (2000), Rein *et al (*1985), Broadfoot (1989), Arcidiacono (1992), Attard (1993), Moor (2007) and others. A pan's potential for a good final crystal size distribution is best determined by using a tracer (usually lithium) to measure its crystal residence time distribution. The results are compared to what would statistically be expected from a number of perfectly mixed tanks in series (t-i-s). The larger the number of equivalent tanks in series, the closer to plug flow.

It has been found that well-designed CVPs can produce t-i-s values greater than their actual number of compartments, whereas in poor designs, back mixing and short circuiting result in t-i-s values less than the number of compartments. Results from the literature published by Moor (2007) show that the best CVs are produced by horizontally configured, vertical tube CVPs with smooth flow profiles and at least 8 compartments (see Appendix). To encourage a spiral plug flow pattern, the Bosch CVP design incorporates mid-compartment baffles in the turbulent zones immediately above and below the calandria (Figure 4). These contribute to t-i-s values considerably higher than the number of compartments.

By definition, pans comprising a series of well-stirred units will provide t-i-s values only approximating the number of such units.

A good (low) CV is also important in order to minimise affination losses, and hence further energy requirements, in sugar for refining.

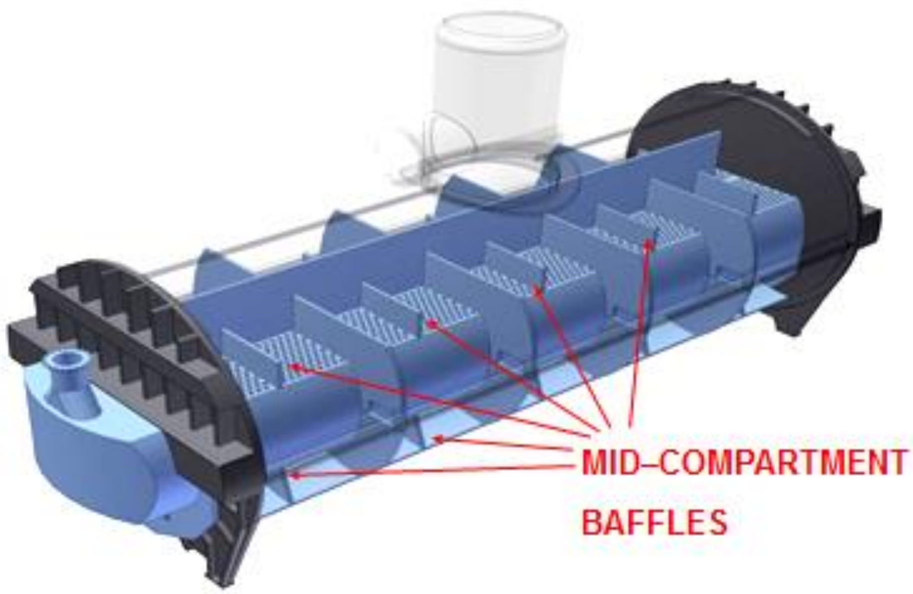


Figure 4: Mid-compartment flow baffles

7. Design pans for long intervals between CVP boil-outs

Boiling out to dissolve incrustation in CVPs obviously involves wasted energy – both in boiling low brix liquid to dissolve out the deposits and then in re-establishing normal operations thereafter.

To reduce the frequency of boil-outs, Bosch recommends the use of on-line steaming out for all grades of continuous boilings and their CVP operator’s manuals include details of how these are performed. It is a simple, easily automated process that involves suspending the boiling for less than five minutes. The recommended frequency is once a shift or twice a day for A boilings, once a day for Bs and once or twice a week for Cs.

A combination of a “clean” design (heated base to prevent sugar and massecuite build-up, avoiding incrustation and any stagnant massecuite zones) and on-line steaming out results in typical periods between boil-outs of 3 – 5 weeks for ‘A’ CVPs, 8 – 12 weeks for ‘B’s and one or no boil-outs per season for ‘C’s.

When boil-outs are required, water is often used to dissolve the deposits. This adds to the total evaporation requirement. A better diluent is clear juice, whose excess water would have to be evaporated in any event. Returning the pan washings to the clear juice provides multiple effect evaporation of its water.

8. Design pans for possible use of vapour recompression

The use of vapour recompression may be warranted where the energy balance for a factory shows that overall steam demand is exhaust-dependent rather than high pressure-dependent. Recompression on CVPs involves extracting the boiled off vapour and recompressing it back up to the pan supply pressure. The recompression can be done either mechanically (MVR) or thermally (thermo-compression). The steady conditions across a CVP render this feasible, but the high ratio of pan supply to exit pressures usually dictates that MVR rather than thermo-compression be used. This practice is rare in cane factories but more common in the beet industry and refineries.

No Bosch CVPs currently operate with vapour recompression, but their ability to operate at low ΔTs and ΔPs means that this would be a feasible option in a factory with an HP-dependent energy balance or with cheap electrical power.

9. Conclusion

In view of the high energy requirements for crystallisation, surprisingly little attention is devoted to this aspect of sugar production. The paper has highlighted key energy efficiency considerations for the design and selection of equipment for the pan floor. Of the energy saving features described, several are unique to Bosch CVPs – the under-base heating, the distributed feed and jigger injection beneath the massecuite and the mid-compartment flow-directing baffles. The effectiveness of these is reflected in results quoted.

10. References

Attard, R.G. (1993). Modifications to the Racecourse continuous pan. Proc. Aust. Soc. Sugar Cane Technol. 15: 180-185.

Arcidiacono, G., Pike, D., Scanlan, J. and Mclean, R.J.B. (1992). The continuous B massecuite pan at Tully Mill. Proc. Aust. Soc. Sugar Cane Technol.14: 276-286.

Broadfoot, R., Miller, K.F. and Davies, L.W. (1989). Commissioning trials on the SRI continuous high grade pan at Maryborough factory. Proc. Aust. Soc. Sugar Cane Technol. 11:152-161.

Moor, B.StC. (2002). Energy aspects of assisted pan circulation. Presentation at ISSCT Energy Management Worksop, Berlin, October 2002.

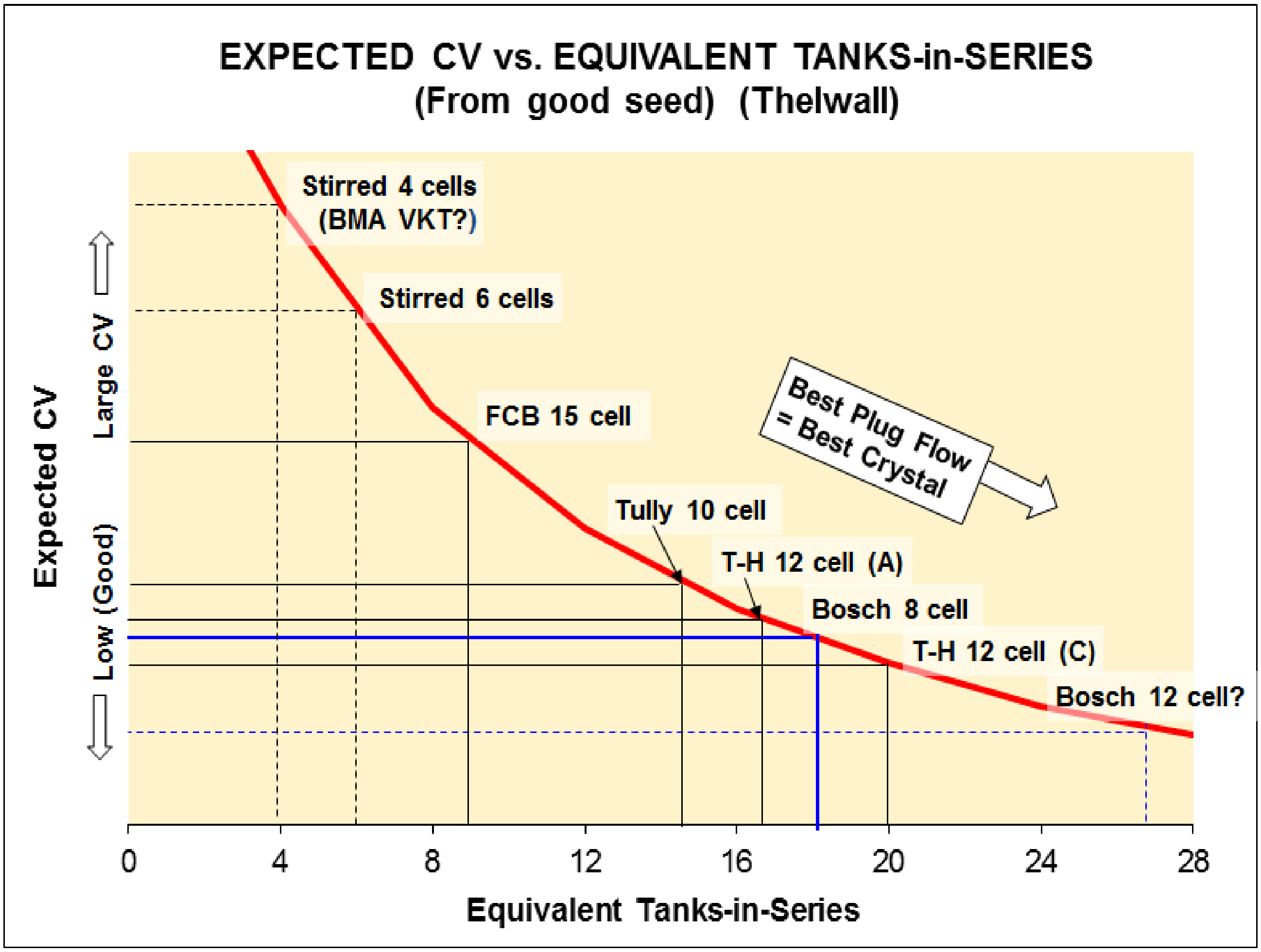
Moor, B. StC. (2007). Successful innovation: results from the Bosch continuous pan. Proc. Int. Soc. Sugar Cane Technol., 26: 1669-1675.

Rackemann, D.W. and Broadfoot, R. (2007). A new design of jigger system to improve vacuum pan performance. Proc. Int. Soc. Sugar Cane Technol., 26: 1564-1572.

Rein, P.W., Cox, M.G.S. and Love, D.J. (1985). Analysis of crystal residence time distribution and size distribution in continuous boiling vacuum pans. Proc. S.A. Sugar Technol. Ass. 59: 58-67.

Thelwall, J.C.deC. (2000). Features of continuous vacuum pan design. Int. Sugar Jnl. 102 No.1224: 630-637.

11. Appendix: Relationship of plug flow and CV



References:		
	FCB 15 cell;	Rein P.W. *et a* l (1985)
	Tully 10 cell	Arcidiacono, G. *et al* (1992)
	T-H 12 cell (A)	Rein P.W. *et a* l (1985)
	Bosch 8 cell	Moor, B.StC. (2007)
	T-H 12 cell (C)	Rein P.W. *et a* l (1985)