ENCRUSTATION AND SCALING IN CONTINUOUS SUGAR VACUUM PANS

By P. W. REIN

Tongaat-Hulett Sugar Ltd, Glenashley

Abstract

Experience gained with encrustation and scaling occurring in continuous vacuum pans is reviewed. This covers both encrustation on internal pan surfaces and scaling of heating surfaces. Practical results are compared with information published in the literature, enabling conclusions to be drawn on the major mechanisms involved. Ways of minimising or dealing with encrustation are given.

Introduction

In batch vacuum pans, the vessels are steamed out or cleaned on a routine basis, as the pans are emptied every few hours. In continuous pans however, the vessels operate for long periods without emptying. Encrustation of sugar in the vessel becomes a concern under certain circumstances. Indeed, fear of encrustation was one of the factors initially impeding acceptance and installation of continuous pans, particularly for high grade products.

Although low grade continuous vacuum pans may operate on a continuous basis for long periods, it has been found necessary to liquidate and clean high grade pans on a more frequent basis. This is due to two factors:

- Unless preventive steps are taken, sugar builds up on surfaces in the pan. This encrustation breaks off in pieces which, on liquidating can block tubes or outlets.
- Progressive scaling of the heat transfer surfaces occurs. This reduces the rate of heat transfer, requiring that calandria pressures be increased. When the limit of this adjustment is reached, cleaning of the heating surfaces is required if production rate is to be maintained.

Encrustation is clearly a function of purity of the massecuite being boiled. In C-massecuite continuous pans in raw sugar mills (± 52 purity) the pans can be operated for a full season of about 38 weeks without having to stop and clean out the pan. In A-massecuite pans (± 85 purity), encrustation becomes severe after a few weeks and it is necessary to empty the pan and clean out the encrustation.

Encrustation can occur above the boiling massecuite or on surfaces below the massecuite level. The mechanisms involved appear to be somewhat different.

Continuous pans have now been in operation in the South African sugar industry for 15 years. This paper relates experience gained in different types of continuous pans, on different grades of massecuite. It outlines some of the reasons for the behaviour observed, and practices adopted to overcome or cope with encrustation.

Encrustation above the boiling level

Experience with continuous pans

Experiments were undertaken at Maidstone Mill to investigate how long a Tongaat-Hulett A-massecuite pan could be operated before boiling out was required. It was found that four weeks was the limit of operation (Kruger[6]). If the pan was operated for longer, lumps of encrustation broke away causing choking of the crossover chutes between compartments, lodging of lumps in some of the tubes, and blocking of some of the discharge valves, evident on draining the pan. However, lumps were not noticed in the product sugar.

Subsequently the cross-over port arrangement has been changed from the Maidstone design. Instead of being in the downtake area where massecuite moves slowly, it is now directly above the calandria, where boiling massecuite keeps the opening clear. Work done at Delft confirmed that encrustation only occurs more than 100 mm above the boiling massecuite level (Heffels *et al* [3]).

It was found in Tongaat-Hulett pans that above-massecuite encrustation can be eliminated entirely by the use of fine sprays directing water onto exposed surfaces (Kruger[6]). Only small amounts of water are required. This is confirmed by the fact that encrustation has been observed to have been washed off baffles directly below water sprays which are used periodically to clean light glasses or inspection port-holes.

Experience with Tongaat-Hulett pans at Felixton has shown that any lumps found in A pans are usually friable, i.e. easily broken up with the fingers, and any large lumps escaping through the massecuite outlet are normally broken up by a positive displacement pump. Smaller lumps will however get through the system, and if they go through the sugar drier they will harden and end up as hard pieces. They can however be easily removed by scalping screens on the drier outlets. Lumps have not been found to be a problem with Felixton A pans over a 2–3 week operating period, but lumps are found consistently from Felixton B pans (Montocchio[8]). These are large enough to be screened out at the end of the barometric seal box and returned to the remelter. The lumps are usually flat pieces resembling encrusted massecuite broken off pan internal surfaces. No lumps are observed from the C pans.

It is apparent that conditions favouring crystallisation in general also help to minimise encrustation, i.e. consistent mother liquor supersaturation and optimum crystal content. It has been found in Tongaat-Hulett Sugar mills that when continuous pans are operated under good control, ancillary problems like encrustation are reduced.

A different type of above-massecuite level fouling was reported on a C pan in Australia (Pozetti and Sheedy[9]). Massecuite which splashes onto hot incondensible outlet pipes or steam pipes was reported to form hard caramelised lumps. When these break off they cause havoc with centrifugal screens. This was overcome by lagging the hot pipes inside the pan.

Mechanism of encrustation

Some work on the factors affecting encrustation has been done at Delft University of Technology. This work showed (Heffels *et al.*[3]) that encrustation was a function of the crystal surface area/unit volume and the supersaturation in the mother liquor, both factors which affect the crystallisation rate. It was also affected by the rate of evaporation, which influenced the rate at which splashes of massecuite attached to the wall, and the viscosity of the massecuite, i.e. the time spent by massecuite running down the encrusted surface.

The longer massecuite takes to travel down the surface, the greater the potential for crystallisation.

Heffels and de Jong[4] report that encrustation is enhanced by higher crystal content and small crystal size. Encrustation starts with crystals getting stuck to the surface. Both more and smaller crystals will promote this. This suggests that encrustation could be more severe in early compartments.

Some reports on pans operating with high grade massecuites indicate that encrustation is more severe in particular parts of the pan. In practice, it has never been possible to establish in Tongaat-Hulett pans that encrustation occurs to a greater extent in early or late compartments of the pan. In the first few compartments, crystallisation rates are higher (due to the lower impurity/water ratio in the mother liquor), while in the later compartments, the crystallisation rate is lower, but the viscosity is increased.

The Delft work has shown (Heffels *et al.*[3]) that the initial onset of encrustation is delayed if the surface is coated with a synthetic material which is hydrophobic. Laboratory tests showed that encrustation started on a steel plate after five minutes in a laboratory pan, but after 25 minutes on a teflon plate. However, once encrustation was initiated, it occurred at the same rate on either steel or teflon. They also showed that the roughness of steel has no effect on encrustation, i.e. there is no advantage in the use of polished plate.

Experiments by Tongaat-Hulett Sugar indicated that synthetic surfaces such as teflon or epoxy coatings can have a beneficial effect. However, the method of attachment of such a surface caused considerable problems, and this approach does not eliminate the problem. Further, concern was expressed at the potential for accelerated corrosion in the space above the boiling massecuite provided by a pinhole or some other discontinuity in an epoxy coating.

Encrustation below the massecuite surface

Below the surface of the massecuite, some encrustation does occur. It is far less severe, and has never caused serious problems. In certain cases it has caused difficulty in extracting massecuite samples through small valves in the bottom of the pan. The Delft researchers (Kuijvenhoven[7]) suggest that good insulation of the pan will prevent below-massecuite level encrustation on external surfaces, but that encrustation will be promoted at sharp corners or discontinuities, e.g. probe tips or the edges of submerged baffles. Alternatively, heating the walls to a temperature just above saturation temperature can be employed (Heffels and de Jong[4]).

The Seaford continuous pan installed at Aarberg in Switzerland on seed production contains a rotating paddle turning in the massecuite. Initially a sharp-edged paddle constructed from angle iron sections was used. Encrustation on the paddle was observed to occur after a few hours in beet high grade massecuites. Subsequently the paddles have been changed, eliminating sharp edges, and the encrustation is markedly reduced.

Another example of encrustation at sharp discontinuities is given by Witte.[12] In a beet white (BMA) continuous pan, serious encrustation occurred around the ends of tubes protruding from the calandria tube sheet. This problem disappeared when the tubes were recessed into the tube sheet and welded in to give a smooth inlet. The fact that this effect has not occurred in tubular calandria pans on raw A massecuites indicates that encrustation at discontinuities is more serious with high purity or refined sugar massecuites.

Scaling of conductivity electrodes or temperature elements used on boiling point elevation control is severe for the same reason, particularly in high grade massecuites. In C massecuites, conductivity electrodes need to be removed almost daily for cleaning, if good control is to be maintained. With A-massecuites, conductivity probes need to be removed every few hours, which is not practical. The Duotrac RF probe was developed to overcome this problem (Radford *et al.*[10]); because it measures electrical properties at high frequency, the effect of scaling of the electrodes has much less effect, but still the RF probes need to be removed and cleaned regularly on A massecuites.

Experience at Maidstone has shown that where the interconnecting ports between compartments are below the boiling massecuite level, encrustation around the opening occurs. This can be a restriction to massecuite flow, and Fives-Cail Babcock (FCB) pans in South Africa have been supplied with steam jiggers at the cross-over ports to overcome this.

Encrustation and build-up can occur in regions of a continuous pan where circulation is poor. This has been evident in C pans which have operated for long periods without cleaning. Hard deposits in the bottom of an FCB C pan have been seen at Maidstone after a full season's operation. The formation of hard caramelised lumps was also reported from an Australian C pan (Pozetti and Sheedy[9]), thought to be due to poor circulation in the last compartment following shut-down and start up of the pan.

The influence of the design of the pan on lump formation is evident at CG Smith's Sezela factory. Two different types of continuous C pan are installed, but only one is generally used at any one time. Lumps are regularly observed in the massecuite when one of the pans is in use, and are absent when the other is operating.

Scaling of Calandria Heating Surfaces

The factor determining raw sugar A-pan operating time can sometimes be the scaling up of the calandria heating surface, rather than occurrence of encrustation. Tests done at Maidstone on the effect of time on heat transfer rate in an A-massecuite pan are shown in Figure 1. There is a fair amount of scatter, but the general trend is to lower heat transfer coefficients after longer periods of operation. Typically at Maidstone, the calandria pressure immediately after pan clean-out is 80 kPa abs., and at the end of the period has risen to about 100 kPa. Since V1 pressure is about 130 kPa, they could continue to operate for slightly longer periods, but have generally adopted a routine of cleaning out the continuous A-pan every two weeks. This coincides with

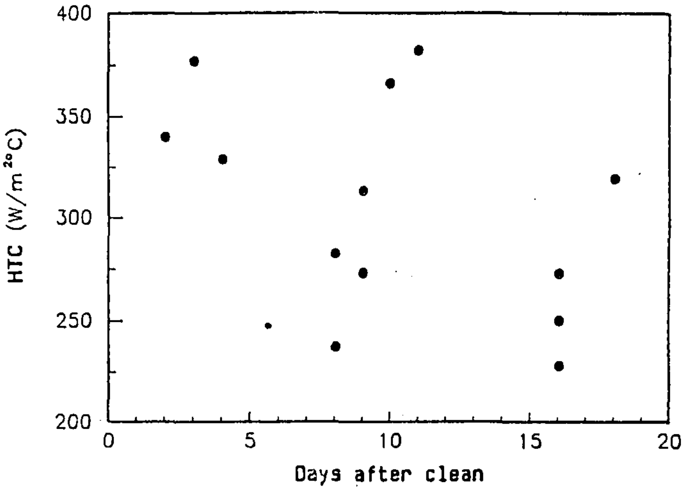

FIGURE 1 Overall heat transfer coefficients measured on Maidstone continuous A pan in relation to time since cleaning out the pan

the shut-down of their diffuser extraction line, so taking the pan off-line does not present a problem in terms of production.

At Felixton it has been established that the continuous A-pans can be operated for at least three weeks without encrustation becoming problematical. Generally however it is scaling of heat transfer surfaces which causes Felixton to boil out the pan on a two-week (or less) cycle.

The scaling of heating surfaces has never been a concern at Maidstone. At Felixton however, some strange and unpredictable scaling effects have been experienced. In some cases virtually no reduction in heat transfer rate has been experienced over a two-week period. But over a period of a few months in the 1986/87 season, heat transfer generally dropped sharply, sometimes stabilised, and in some cases even increased again.

During this time, very severe scaling of heat transfer surfaces was experienced, with the pan sometimes having to be emptied and boiled out after just a few days. This was found to occur after periods of heavy rain. Measurements of evaporation rate during this period are shown in Figure 2.

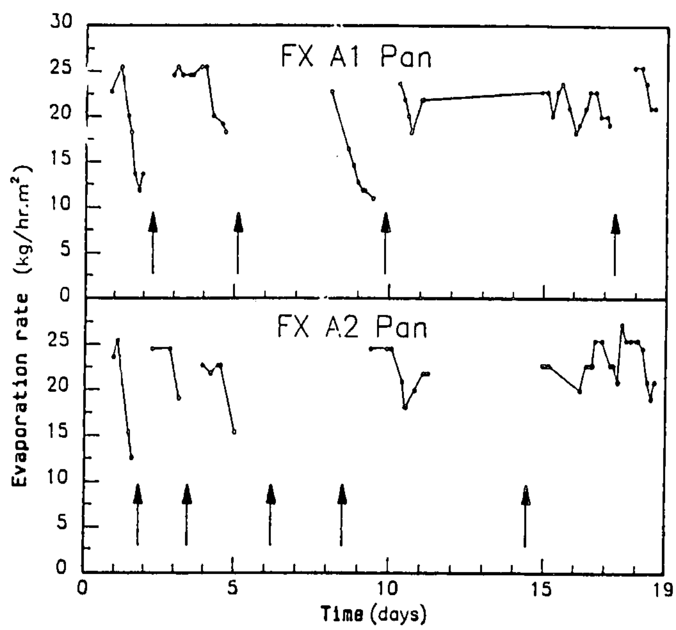

FIGURE 2 Evaporation rates measured on Felixton continuous A pans during time of severe tube scaling. Arrows indicate times when pans were emptied and cleaned.

Analysis of the scale inside the tubes when this first occurred showed the scale to contain 41% silica. This led to the conclusion that the excessive sand accompanying cane after rain was implicated in the scaling process. However, subsequent analyses of scale after other severe scaling conditions gave a very high loss of weight on ignition, i.e. the scale was mainly carbonaceous, originating from carbohydrate material. Subsequent scale analyses confirmed this finding (Bachan and du Boil[2]). The scale was always found to be easily removed by a water wash.

Attempts to establish the cause of this serious scaling have been in vain. Since there are two identical continuous A-pans at Felixton, it was possible to run different operating conditions on the two pans during the scaling periods. This established conclusively that the scaling is not caused by changes in operating conditions, but that it is solely dependent on certain constituents of the cane juice, which have not yet been identified.

Initial theories linked scaling to excessive sand in juice. Since Felixton contains the highest average ash % cane in the South African industry, this could also have explained why the problem was experienced at Felixton but never at Maidstone. However, further observations have shown that this severe scaling problem is not always related to the sand content of the cane. The fact that the occurrence of the problem is associated with downtime following rain suggests that the phenomenon is related to stale cane. In the past this phenomenon has been observed in A-batch pans at one or two factories only, but has been sufficient to slow down boiling even in batch A boilings. Its occurrence there has also been ascribed to excessive cane delays.

In the season following the problems at Felixton, the SMRI regularly analysed encrusted material from the A pan tubes. Extensive tube fouling did not occur during this period, and the analytical results were indicative of normal conditions. However, the results tend to indicate selective accumulation in the scale of calcium and silica (Bachan and du Boil[2]). This severe scaling problem has not recurred.

Implications for Continuous White Sugar Boiling

It is unlikely that the scaling of heating surfaces will occur in white cane sugar refinery boilings. The sugar has been through an intensive decolourisation and filtration process, and the scale-forming compounds are absent. This is proven by the operation of batch white pans at Hulett Refinery which are not steamed out at all over a four-week period, with no evidence of heating surface scaling.

Likewise, it is considered highly unlikely that heating surface scaling will be a significant factor in beet high grade white boilings, because of the more intensive purification and filtration processes employed in the beet factory.

In both cases therefore, the factor determining the length of operation of continuous pans between cleaning is likely to be encrustation. In the absence of any measures taken to avoid encrustation, it is likely that periods between cleaning will be similar to those experienced on raw sugar A-grade boilings, i.e. of the order of two to four weeks. Optimum operation of continuous white pans should result in high crystal contents, and with high crystallisation rates, relatively low supersaturation in the mother liquor and lower mother liquor viscosity. This may be countered from an encrustation point of view by the higher crystallisation rates, so that the net effect is likely to be a similar encrustation rate to that experienced by raw A-pans. This pre-supposes however, that conditions in each and every compartment of the pan are well controlled.

In practice, operating periods between cleaning on white pans have been variously reported as being between one and four weeks.

Methods of reducing or coping with encrustation

Use of water or feed syrup sprays

Encrustation above the massecuite level can be overcome almost entirely by the periodic use of water sprays directing water onto the exposed surfaces (Kruger[6]). If the sprays are activated by a timer the amount of water added can be a negligibly small proportion of the total evaporation load.

An alternative which has been adopted in some continuous pans is to direct the syrup feed onto the exposed surfaces above the massecuite level. This can also be effective but suffers from the drawback that the lower density feed does not get rapidly mixed in with the massecuite and can be the cause of false grain formation (Kuijvenhoven[7]). It is generally better to add the feed in an area where intense mixing takes place, e.g. immediately above a stirrer or directly below the bottom tube plate.

An alternative approach is not to lag the top of the continuous pan. Then some of the vapour condenses on the side walls and runs down the walls with the same effect as the water sprays. However this does not ensure that the dividing plates between compartments get washed.

Raising of massecuite boiling level

Experience with the Seaford pan at Aarberg has shown that encrustation above the boiling massecuite can be removed by raising the boiling level. This is an application of the findings at Delft that the action of the massecuite at the boiling level washes the surfaces clean.

Vibrating plates or membranes

A suggestion has been made by Austmeyer[1] that thin plates or membranes could be fitted to areas susceptible to encrustation. These membranes vibrate from the pressure fluctuations caused by the flow of the massecuite, thus cracking off encrustations. It is suggested that membranes can be fitted to walls and baffles as well as to stirrer blades. A similar result could perhaps be achieved by using flexible polyethylene baffles.

Positioning of crossover ports

If crossover ports are situated below the massecuite boiling level they are subject to encrustation. Because the area immediately above the boiling massecuite is not susceptible to encrustation, the positioning of crossover ports immediately above the calandria ensures that they are always kept clean.

Bypassing of compartments

The BMA continuous pan which consists of four compartments, one above the other, has in some cases been fitted with additional piping such that any single compartment can be bypassed on the run. During the time that one of the compartments is boiled out and cleaned, production capacity would generally be reduced to 3/4 of normal capacity. A further disadvantage however is that crystal size distribution suffers as the reduction in number of compartments from four to three is severe.

An alternative is to use two smaller pans on high grade duty, or to divide a pan into two separate sections, so that one half can be liquidated at a time, to reduce the effect on production rate.

Arrangements for easy draining and cleaning

Disruption to production can be minimised by giving special thought to all the individual activities involved in emptying, cleaning and re-filling.

Since the occurrence of the severe scaling problems at Felixton, attention has been given by the Mill staff to reducing the time required to empty and clean out a pan. Thus, even if severe scaling occurs during a high throughput period, disruption to production will be minimised.

A breakdown of the activities involved in emptying and cleaning out a 120 m^3 A-pan before and after this investigation (Montocchio[8]) are given in Table 1.

An improvement was achieved by changes to liquidating procedures, but the major improvement was due to a change from boiling water in the pan to merely blowing vapour into the pan. This is done with the drain valves open, so that all liquid drains as it forms into the molasses tank.

Table 1
Time taken to empty and clean a 120 m^3 A pan at Felixton

Before modification	Time	After modification	Time
Closing steam and breaking vacuum	5 min	Closing steam and breaking vacuum	5 min
Liquidating	45 min	Liquidating	30 min
Steaming out	10 min	Steaming out	—
Feeding water	60 min	Feeding water	—
Boiling water	180 min	Steaming pan	120 min
Draining to A-molasses	15 min	Draining to A-molasses	—
Cutting over	60 min	Cutting over	60 min
Total	± 6¼ hours	Total	± 3½ hours

Need for good control

Since encrustation is largely affected by the condition of the massecuite splashing up onto the surrounding surfaces, it can be significantly reduced by maintaining good crystallisation conditions in each compartment. If a high crystal content and a relatively low supersaturation can be maintained in the compartment, the encrustation which occurs above that compartment must be lower than in cases where either of these important variables strays away from optimum values. In this respect it must be an advantage to be controlling the massecuite condition in every compartment as is done in Tongaat-Hulett pans (Rein[11]), rather than regulating only the massecuite density at the exit of the pan and making manual adjustments to the feeds to individual compartments. The latter system does not automatically compensate for changes in heat transfer or crystallisation rates in individual compartments.

If control in any compartment is inadequate and false grain forms (nucleation), the small crystals resulting can also promote above-massecuite encrustation (Heffels and de Jong[4]).

Pan circulation patterns

In order to reduce below-massecuite encrustation to a low level, it is important to ensure that the design of the pan ensures good circulation and particularly that there are no dead zones where crystal can settle. Care needs to be taken also to ensure that on pan start-up circulation starts quickly, or else caramelization of massecuite in contact with hot calandria surfaces can occur.

Elimination of discontinuities

In order to reduce below-massecuite level encrustation, it is important to minimise any sharp edges in contact with the massecuite, particularly where high grade massecuites are being boiled. It is a well established fact that encrustation will occur at any sharp discontinuities.

Since most of the measurement probes employed will encrust for the same reason is it desirable to have them easily removable for periodic cleaning.

Heating of surfaces below massecuite level

Some pans have also been built with heating jackets around the areas containing the massecuite. In certain cases the heating jackets have been dispensed with and, instead, the surfaces in contact with massecuite have been well insulated to prevent cooling.

Conclusions

It has been shown that encrustation problems are largely dependent on massecuite purity, and really only become significant in high grade boilings.

Some understanding of the factors influencing encrustation has been obtained. This has influenced the design and operation of continuous pans in order to minimise the effects of encrustation. However it is still not possible to predict *a priori* the extent of encrustation for a given situation.

REFERENCES

1. Austmeyer, KE (1988). Some thoughts on further development of sucrose crystallisation. *Zuckerind* 113 (5): 389-397.
2. Bachan,, L and Morel du Boil, PG (1989). Felixton pan tube fouling. *SMRI Tech. Note* No. 6/89.
3. Heffels, SK, Kuijvenhoven LJ and de Jong, EJ (1984). Incrustation above the level in sucrose crystallisers. *Process Technol* Proc 2: 217-222.
4. Heffels, SK and de Jong, EJ (1988). Incrustation in sucrose-water solutions. *Zuckerind* 113 (10): 873-877.
5. Kruger, GPN (1983). Notes on observations on the continuous A-pan. *Tongaat- Hulett Sugar Internal Report*, 12/8/83.
6. Kruger, GPN (1983).Continuous A-pan boiling at Maidstone sugar factory. *Proc S Afr Sug Technol Ass* 57: 46.
7. Kuijvenhoven, LJ (1983). Aspects of continuous sucrose crystallisation. WTHD No. 156, Delft University of Technology.
8. Montocchio, G (1988). Continuous boiling at Felixton. *Comm 3e Congr Assoc Réun Dev Tech Agric Sucr* 198-207.
9. Pozetti, C and Sheedy, BB (1989). Improving the performance of 120 m^3 continuous low grade pan at Farleigh. *Proc Aust Soc Sug Cane Technol* 11: 168-174.
10. Radford DJ, Tayfield, DJ and Cox, MGS (1988). Further developments in automated white pan boiling using radio frequency control. *Proc Sug Ind Technol* 47: 90-107.
11. Rein, PW (1987).A review of experience with continuous vacuum pans in Tongaat-Hulett Sugar. *Int Sug J* 89 (1058): 28-34.
12. Witte, G (1988).Further experience with continuous crystallisation at Wabern sugar factory. *Zuckerind* 113 (5): 414-420.