Observations on centrifugal operation. Part 2.

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Abstract

Aspects of centrifugals operation, performance and installation are considered in terms of improving process performance and reducing operating costs within the sugar factory. Topics considered include screens, massecuite crystal size, energy requirements and the structural support for a centrifugal. Some common misconceptions relating to centrifuges are discussed. It is intended that the information provided will be of help to users wishing to improve operation of their existing centrifugals and assist when selecting new centrifugals. The first part of this article was published in the December 2002 issue of Int Sugar Journal (104 (1248): 554-558).

Observaciones acerca de la operación de centrífugas. Parte 2.

Se discuten varios aspectos de la operación de centrífugas, su funcionamiento e instalación en términos del mejoramiento del funcionamiento de los procesos y la reducción de los costos de operación en una fábrica de azúcar. Entre los temas que se consideran se incluyen los tamices, el tamaño del cristal de la masa cocida, los requerimientos de energía, y el soporte estructural de una centrífuga. Se abordan también algunos conceptos equivocados comunes relacionados con las centrífugas. Se espera que la información provista pueda ser de ayuda para aquellos usuarios que deseen mejorar la operación de centrífugas existentes y/o asistirlos en la elección de centrífugas nuevas. La primera parte de este artículo fue publicada en el volumen de diciembre, 2002 del Int Sugar Journal, (104 (1248): 554-558)

Centrifugal screens

All centrifugals in a sugar factory used to produce crystalline sugar operate on the principle of filtration. For both batch and continuous centrifugals the point where the sugar crystal is physically separated from the mother liquor or molasses is the filter screen supported on the inner wall of the centrifugal basket. This basic description applies to both batch and continuous centrifugals, however, the filter screens used in each type differ widely in their design, operational life and criteria for selection. Two important parameters used to characterise screens are the open area and the slot or hole size. Hole (or slot) size is important in retaining the sugar crystals within the centrifugal basket whereas open area plays an equally important role in allowing the molasses to pass freely through the screen. These two aspects of screens are considered in more detail below together with the differences between batch and continuous screens.

Screen slot size

The purpose of a centrifugal screen is to retain the sugar crystals within the basket and allow the molasses to be removed rapidly under the influence of centrifugal force. In batch centrifugals the normal screen slot or hole size is similar to the crystal size. In continuous centrifugal screens the slot size is generally much smaller than the crystal size. Figures 1 & 2 clearly shows the differences between a batch and continuous centrifugal screens.

Figure 1. Batch screen : 0.5mm holes in stainless steel sheet, 20% open area.
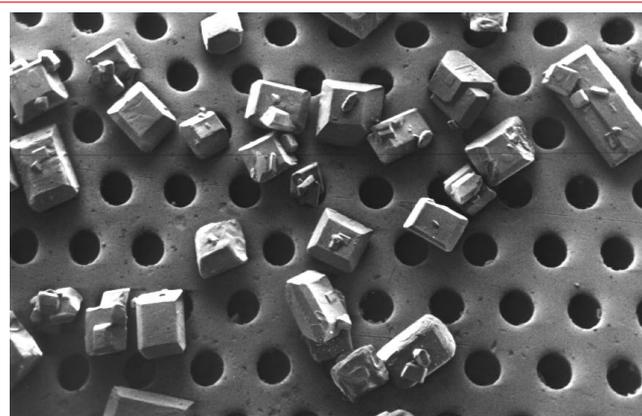
Given that any crystal less than the screen slot or hole size is likely to be lost though the screen it might be thought that the losses through the batch screen are large because the hole size is normally close to that of the crystals themselves. In fact this is not the case - crystal losses through the continuous screen are far larger. It is important to note that here we are considering solid crystals 'falling' through the screen hole/slots and not sugar being dissolved by washing passing through the screen in solution. One of the major differences between batch and continuous centrifugals is the simple fact that during processing the sugar doesn't move relative to the batch screen whereas it moves continually

Figure 2. Continuous screen : 90 microns slot width, 10% open area.
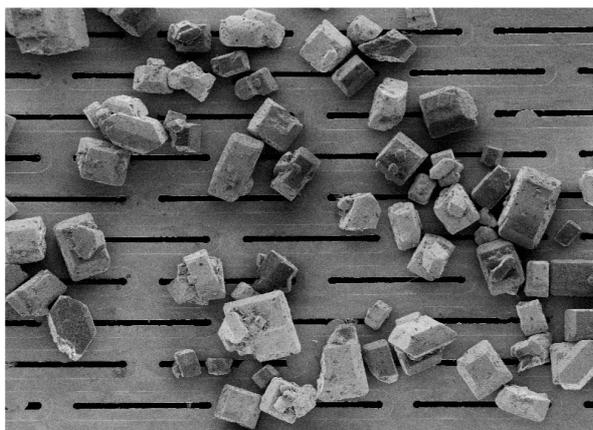
across a continuous centrifugal screen. If a crystal of less then the hole size is adjacent to a hole or slot in a batch screen it will probably get through and be lost. The remaining crystals will form an arch over the hole and prevent any further loss. It's easy to make a worst case estimate of the number of crystal loss through a batch centrifugal screen by assuming the crystal MA is the same as the screen hole size at 0.5 mms and that one crystal is lost through every perforation in the screen. For a basket containing a cake thickness of 150 mms and a screen with 20% open area this gives a figure of about one crystal lost in every 1,500 or 0.07% which is insignificant. To reinforce the point, in some application (e.g. dextrose) the average crystal size is less than the screen hole size and the losses remain low.

As might be expected the situation is more complex for continuous centrifugals. During the passage of a typical crystal along the screen in a continuous centrifugal basket it will pass over something like 250 - 500 slots with the exact number depending of the screen type and basket size. If the crystal size is less than the slot width then it will almost certainly fall through the screen and add to the purity of the molasses. In practice the crystal layer is a few millimetres thick so not all crystals are touching the screen at any one time. However as the crystal layer moves along the basket to the larger diameter discharge end of the basket cone this layer reduces in thickness and the crystals move around and change places within the layer giving most crystals a good chance to escape through a slot if they are small enough to do so. This means that the loss depends on number of crystals with a size below the screen slot width and this can be calculated from the particle size distribution defined[2] by the massecuite MA/CV and the screen slot size. Table 1 shows the results for slots widths of 40, 60 and 90 microns. The percentage of crystals lost through the screen is calculated for crystal MA ranging from 200 to 600 microns with CV's from 26 to 40. This calculation assumes :

- All crystals are treated as spheres and any less than the slot width pass through the screen.
- The crystal size distribution is gaussian defined[2] by the MA and CV.

The calculated losses range from 0.02% of the crystals (40 microns screens MA/CV 600/26) to 8.46% (90 microns screens MA/CV 200/40).

These figures are useful to assess the likely effect on losses of using a different screen slot width. Note that there is an additional crystal loss not included in Table 1 caused by the dissolution of sugar by any wash water or steam. The purity rise across the centrifugal is due to the total crystal loss and depends on the massecuite purity, crystal content etc. As a rough guide the purity rise for a recovery massecuite is about half the crystal loss. In other words a crystal loss of 1% corresponds very roughly to a purity rise of 0.5 points - although this depends strongly on the massecuite parameters.

One interesting aspect of this data is the much stronger dependence of sugar loss on CV rather than MA. This is best illustrated by Figure 3 which shows the MA and CV combinations that result in a 1% crystal loss for a 60 micron screen. For example the losses are the same for an MA/CV of 250/32.7 and 500/37.8.

Any losses at the final 'C' station are a direct sucrose loss to the factory. Consider the financial implications of a factory with limited 'C' station centrifugal capacity such that a larger screen slot width of 60 rather than 40 microns is being used to avoid centrifugal capacity problems. Taking a typical C massecute MA/CV of 300/38 reference to Table 1 show the additional loss is likely to be 1.76 - 1.13 = 0.63%. For a station with a capacity of 25 tonnes/hr, a massecuite crystal content of 38%, running for 23 hours/day and 140 days per year this equates to a sugar loss of-:

$$25 \text{ (t/hr) x } 23 \text{ (hrs/d) x } 38 \text{ (% xtal) x } 0.63 \text{ (% loss)}$$
$$\text{x } 140 \text{ (d/yr) = 193 tonnes/yr}$$

At $75 per tonne this represents a loss of revenue of $14,475 per year.

Screen open area

A typical open areas for a batch centrifugals screens is 20%. For a continuous screen the open area ranges from 4% to 20% depending on the design of screen and the process duty.

The molasses flows through the sugar cake within the basket then through the open area of the screen to the liquid discharge. It is interesting to compare the relative flow resistance of the cake and the screen for both batch and continuous centrifugals. One simple and approximate way to do this is to estimate the 'open area' of a typical sugar cake within the basket. The theoretical density[3] of a sugar crystal is 1,588 kg/m^3 and measurements of cake density of sugar packed in a batch centrifugal basket after spinning
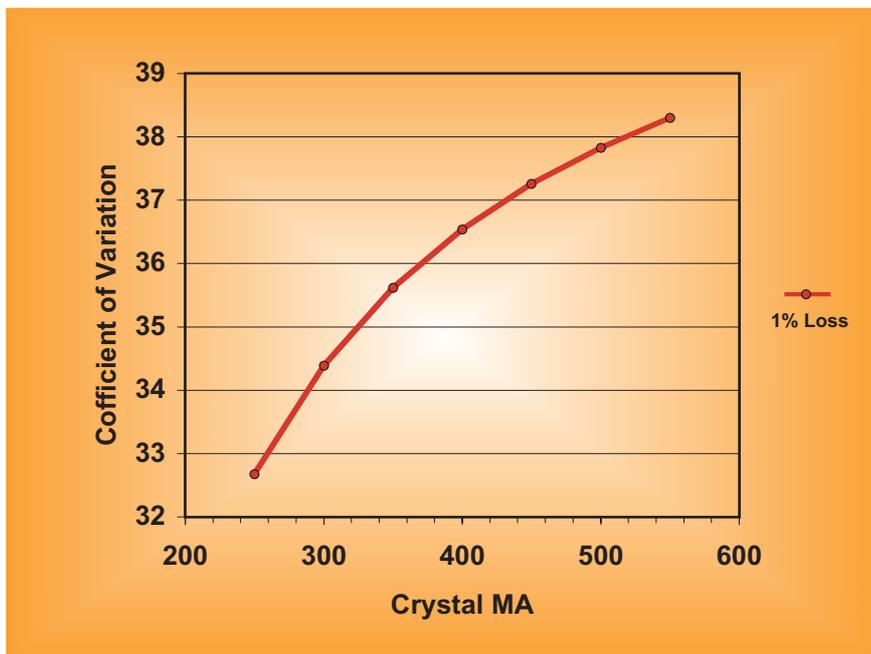
Table 1. Calculated crystal losses for 40, 60 & 90 microns screens.

Crystal Size Microns

Sugar losses - 40 microns screen slot.

Coefficient of variation. %

	26	28	30	32	34	36	38	40
200	0.10%	0.21%	0.38%	0.62%	0.93%	1.31%	1.76%	2.28%
250	0.06%	0.13%	0.26%	0.43%	0.67%	0.98%	1.35%	1.79%
300	0.04%	0.10%	0.19%	0.34%	0.54%	0.80%	1.13%	1.51%
350	0.03%	0.08%	0.16%	0.28%	0.46%	0.69%	0.99%	1.34%
400	0.03%	0.07%	0.13%	0.25%	0.41%	0.62%	0.89%	1.22%
450	0.02%	0.06%	0.12%	0.22%	0.37%	0.57%	0.83%	1.14%
500	0.02%	0.05%	0.11%	0.20%	0.34%	0.53%	0.77%	1.07%
550	0.02%	0.05%	0.10%	0.19%	0.32%	0.50%	0.73%	1.02%
600	0.02%	0.04%	0.09%	0.18%	0.30%	0.48%	0.70%	0.98%

Crystal Size Microns

Sugar losses - 60 microns screen slot.

Coefficient of variation. %

	26	28	30	32	34	36	38	40
200	0.35%	0.62%	0.98%	1.44%	1.98%	2.59%	3.27%	4.01%
250	0.17%	0.33%	0.56%	0.88%	1.27%	1.74%	2.28%	2.87%
300	0.10%	0.21%	0.38%	0.62%	0.93%	1.31%	1.76%	2.28%
350	0.07%	0.15%	0.29%	0.48%	0.74%	1.07%	1.46%	1.92%
400	0.05%	0.12%	0.23%	0.40%	0.62%	0.91%	1.26%	1.68%
450	0.04%	0.10%	0.19%	0.34%	0.54%	0.80%	1.13%	1.51%
500	0.04%	0.08%	0.17%	0.30%	0.48%	0.73%	1.03%	1.39%
550	0.03%	0.07%	0.15%	0.27%	0.44%	0.67%	0.95%	1.30%
600	0.03%	0.07%	0.13%	0.25%	0.41%	0.62%	0.89%	1.22%

Crystal Size Microns

Sugar losses - 90 microns screen slot.

Coefficient of variation. %

	26	28	30	32	34	36	38	40
200	1.72%	2.47%	3.34%	4.28%	5.29%	6.33%	7.39%	8.46%
250	0.69%	1.11%	1.64%	2.28%	2.99%	3.77%	4.61%	5.48%
300	0.35%	0.62%	0.98%	1.44%	1.98%	2.59%	3.27%	4.01%
350	0.21%	0.40%	0.66%	1.01%	1.44%	1.95%	2.53%	3.16%
400	0.14%	0.28%	0.49%	0.77%	1.13%	1.57%	2.07%	2.63%
450	0.10%	0.21%	0.38%	0.62%	0.93%	1.31%	1.76%	2.28%
500	0.08%	0.17%	0.31%	0.52%	0.79%	1.14%	1.55%	2.02%
550	0.06%	0.14%	0.27%	0.45%	0.69%	1.01%	1.39%	1.83%
600	0.05%	0.12%	0.23%	0.40%	0.62%	0.91%	1.26%	1.68%

Figure 3. MA/CV combinations which result in a 1% crystal loss on a 60 micron screen.

open area of the screen.

This simplistic analysis shows firstly that the benefits of larger open area batch screens are slight and secondly that the low open area of continuous screens can limit the molasses purging rate and therefore a larger screen open area will significantly improve throughput. Users with limited continuous centrifugal capacity should ensure that the largest open area is used wherever possible. The downside of this approach is that large open area continuous screens are delicate and expensive resulting in both higher capital cost for the screen and greater screen usage[4]. New screen technology giving long screen life coupled with a large open area would give significant process advantages to continuous centrifugal users. One candidate for an improved screen currently undergoing trials is the wedge-wire screen shown in Figure 5. These have the potential for a long screen life and coupled with good open areas and promise enhanced performance for selected applications.
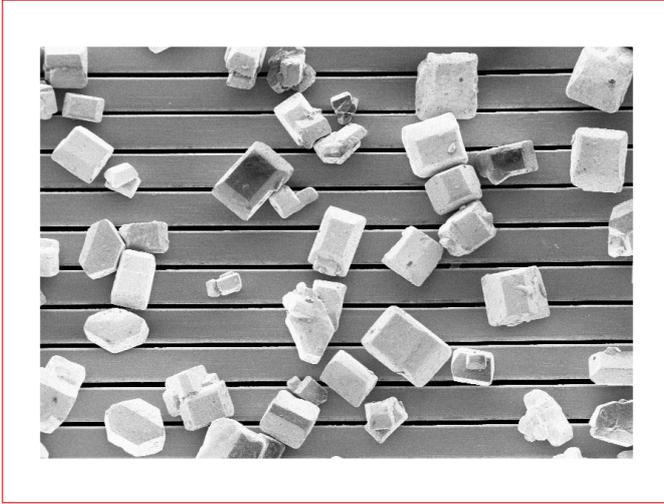
Continuous centrifugal power consumption and throughput

The energy requirements of low grade continuous centrifugals was discussed briefly in part 1 of this article[1]. The throughput of many continuous centrifugal stations are controlled by linking the massecuite feed rate to the drive motor current. This is a simple and reliable method of maintaining a reasonably constant feed to the centrifugals

Figure 4. Broadbent SPV continuous centrifugal installation

gives figures in the range 900 - 950 kg/m^3. This means that a typical sugar layer in a batch basket has gaps between the crystals amounting to (1 - 925 / 1588) or 42% of the total cake volume. If the sugar cake thickness is t then the flow path from the sugar cake surface to the screen will be larger than t due to the tortuous route the molasses must take flowing round the edges of the crystals. A simple but plausible assumption is to say this lengthens the flow path length to 1.25t. If the cake open volume is 42% and the average flow length is 1.25t then the cake open area is approximately 42 / 1.25 = 33.6%. This is larger than the screen open area (20%) suggesting that increasing the open area of the screen would improve molasses purging in batch centrifugals by removing the restriction caused by the reduced open area of the screen. However when the ratio of screen thickness (0.5 mms) and the sugar cake thickness (typically 150 mms) are taken into account (300:1) it is clear that the resistance to flow is dominated by the sugar cake rather than the screen and a larger open area screen is little real benefit.

The situation is markedly different for a continuous screen. Firstly the screen generally has a much reduced open area particularly for low grade massecuites where an open area of 10% is high and 5% is more typical for a screen with 0.04mm slots. Secondly, the conditions in the basket of a continuous centrifugal (see Figure 4) are very different with a layer of crystals 10 mms thick maximum which reduces significantly as the crystals slide along the wall of the conical basket. This movement along the basket also results in the layer of crystals being less closely packed easing the flow of molasses through the crystals. Taking these effects into account gives a cake open area of approximately 45% which is many times larger then the

Figure 7. Schematic of batch centrifuge support structure.

under normal changes in massecuite conditions. Figure 6 shows the variation of motor current against C massecuite feed rate over the range 8 to 18 tonnes/hr in a raw sugar factory.

The relationship shown in Figure 6 is dependent on the design and settings of the centrifugal, particularly the basket speed. For accurate results it is necessary to perform site tests to find the relationship between motor current and throughput for a particular installation.

Figure 6 shows that at zero throughput the motor current is approximately 50 amps. This rises approximately linearly to 120 amps at a feed rate of 18 tonnes/hr as the motor provides the energy to accelerate the sugar and molasses as it passes through the centrifugal. Figure 6 does not imply, as

might be first thought, that the energy required by a continuous centrifugal increases linearly with feed rate. Figure 6 shows motor current, not motor power consumption and the relationship between the two is strongly non-linear. For a 100kW 460 Volt motor full load current will be approximately 140 amps. The current at 50 kW will be something like 96 amps and at 25 kW 80 amps. The energy requirement of a continuous centrifuge falls into one of three areas.

Firstly there is the energy required to overcome windage and friction in the basket and bearings etc. This energy must be supplied to spin the basket at the design speed. For example a 1200 mm diameter centrifugal running at 1800 rpm this is around 16 kW. Secondly there is the energy necessary to accelerate the sugar up to the speed of the basket lip where it is discharged. This is relatively simple to calculate and for a feed rate of 15 tonnes/hr of massecuite at 40% crystal content our example gives an energy consumption of around 22 kW. Finally there is the energy required to accelerate the liquors (molasses and wash water) up to the basket speed at the point of discharge. If it is assumed that on average the liquor is discharged 30% of the way up the basket cone then the energy require-

Figure 6. Motor current as a function of massecuite feed rate.

ment is 14 kW giving a total of 52 kW.

Some designs of continuous basket are perforated with many holes to allow for immediate discharge of the liquor as soon as it has passed through the filter screen. Other have perhaps two discharge points, one half way up the basket the other near to the crystal discharge lip. For these designs the power required to discharge the liquor will be greater as the liquid remains within the basket to a larger radius which means more energy is required to accelerate the liquor prior to discharge. In the example above if it is all discharged at half way rather than 30% of the way up the cone then the power required to accelerate the liquors increases from 14 kW to 19 kW. Over a 20 year lifetime of a centrifugal this would increase the total electrical energy consumed by around 275 MWHrs.

Table 2. Typical minimum resonant frequencies of support structures.

Maximum rotational speed of centrifugal rpm			
900	1,000	1,100	1,200
Minimum resonant frequency of structure Hz			
22.5	25	27.5	30
Maximum average static deflection mm			
0.49	0.4	0.33	0.28

Centrifugal support structures

All batch and continuous centrifugals are inherently a source of vibration so the complete support structure of the centrifugal must be designed with adequate strength and the stiffness to resist and control the tendency to vibrate. Structures which are too flexible will give an uncomfortable working environment for operators and will degrade centrifugal performance by allowing vibration in one centrifugal to be transmitted to other centrifugals in the battery giving rise to nuisance trips. In extreme cases, vibration can lead to premature mechanical failure by fatigue of the centrifugals or support structure. It may also tempt users to take the foolish step of trying to disable the vibration detectors fitted by manufacturers leading to a significantly greater risk of dangerous vibration events caused by poor process conditions.

Correctly designed support structures will almost certainly be considerably more substantial than that required to simply support the static weight of the centrifugals and ancillary equipment. This section aims to provide the user with a few guidelines to avoid the main pitfalls.

Strength requirements

Manufacturers provide details of centrifugal mounting requirement including static dead weights W at each fixing point. These weights generally include the centrifugal plus a complete charge of massecuite in the basket. Where the mixer is included the dead weights of the tank, agitator, drive and a full charge of massecuite must be taken into account.

A simple way to account for the dynamic effects is to multiply the static weights by a vibration factor 2 to give the vertical forces V=2W at each attachment point as illustrated in Figure 7. In addition, allowance must be made for a rotating out of balance force H at the spindle suspension point on each centrifugal as specified by the manufacturer. This produces a horizontal overturning force which can be assumed to apply at any of the 4 principal directions shown in Figure 7. The structural design needs to be able to safely carry all the loads V and H simultaneously in the worst possible combinations.

Stiffness requirements

The dynamic loads are all excited by out of balance forces that will inevitably occur in all centrifugal operation from time to time. These forces are rotating at the machine speed and to avoid resonances the support structure and its individual members must be sufficiently stiff to ensure that their resonant frequencies are at least 33% and ideally 50% higher than the maximum running speed of the centrifugals. The resonant frequency of the structure is directly related to its static deflection under the dead weight W excluding any additional factor for vibration. For a typical batch centrifugal the structure will be sufficiently stiff if the average of the static deflections at all the load points is less than the value given in Table 2.

It should be noted that these figures are general guidelines only and it is important to follow the recommendations of the centrifugal supplier to get the correct loads, weights and support requirements for any specific machine.

The strength and stiffness requirements to achieve these deflections can usually be met by using heavy section I beams and main support beams and by minimising the horizontal spans. If the positioning of the building's main vertical supports necessitates long horizontal support beams, the span can be effectively reduced by adding diagonal braces to the verticals. Diagonal bracing in the plane of the floor is also recommended as a means of resisting swaying of the whole staging structure under the action of the horizontal forces.

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