PERFORMANCE OF CONTINUOUS HIGH GRADE FUGALS

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ABSTRACT

Continuous high grade centrifuging has achieved rapid adoption in the Australian sugar industry as a cost-effective technology. This is despite some continuing difficulties, particularly with respect to the inability to produce sugar at high polarisation, the production of wetter sugar than from batch fugals and the increase in the fines component of the size distribution of the crystals.

The paper reports on the results of trials undertaken by SRI into the performance of various continuous high grade fugals machines.

Overall, continuous high grade fugals provide benefits in terms of productivity per unit of capital cost, steady power demand, and potential lower maintenance costs. The major processing disadvantage is the difficulty in producing high pol sugars from all high grade massecuites. The disadvantage arises from the inferior purging and washing performance of continuous fugals relative to batch machines.

It is concluded that the greatest improvement would be achieved by improving the purging characteristics of the feed massecuite, primarily by conditioning the material just prior to fugalling to reduce the mother molasses viscosity.

Keywords: Continuous fugals, high grade massecuite, purging, crystal breakage, washing efficiency.

INTRODUCTION

Continuous high grade fugals are now installed at fifteen Australian raw sugar factories for processing A and B massecuites. This uptake represents a rapid adoption of the technology since the first continuous fugal for processing high grade massecuites was introduced into the industry in 1989 (Kirby et al., 1990).

The primary objectives of the SRI trials were to:

- establish the upper limit of pol of the discharged sugar and to determine the variation of pol with massecuite processing rate, water addition rate etc.;
- assess the extent of crystal breakage;
- determine the moisture of the discharged sugar.

The trials were undertaken on NQEA Superfugals at two mills (Mills A and B) and STG fugals at three mills (Mills C, D and E). The results of other SRI studies (Broadfoot and Miller, 1996) have allowed the effect of differing massecuite properties (viz. mother molasses viscosity, mean aperture, coefficient of variation (CV)) to be taken into account in determining the performance of the different centrifugals.
EVALUATION PROCEDURE

The investigations were undertaken as two separate studies:

General assessment of performance. Trials were undertaken on two Superfugals (at Mills A and B) and one STG fugal (at Mill C) for a total of thirteen B massecuites (82 to 85 true purity) and five A massecuites (85 to 89 true purity). A total of 60 fugalling tests at different processing conditions was undertaken. The fugal trials at Mill A were undertaken at two speeds viz. 750 and 960 r.min⁻¹, at Mill B in the narrow speed range of 750 - 785 r.min⁻¹, and at Mill C at a fixed speed of 800 r.min⁻¹.

The operating parameters which were varied during the trials included:
- massecuite feeding rate;
- water addition rate and allocation of water among different positions on the basket;
- water spray at the top of the basket or onto the anti-breakage baffle;
- fugal rotational speed (where a variable speed drive was fitted).

Because of the limited number of tests which could be undertaken on a single batch of massecuite, it was not possible to undertake a detailed examination of the fugal performance in terms of all the above processing variables. The procedure adopted (in general) was to limit the change in process conditions in each test to a single variable.

Washing efficiency trials. Trials were undertaken on two STG fugals (at Mills D and E) in processing A massecuites (true purity range 85.0 to 87.5). The tests within a series employed a range of wash water addition rates through the basket sprays and were conducted on massecuite from the same batch strike at the same throughput rate. For the trials at Mill D, probe water was used at rates between 1.2 and 2.9% on massecuite. For the trials at Mill E, probe water was not added into the feed massecuite stream. Samples of the product sugar were taken for analysis to determine the effect of wash water addition rate on sugar purity.

RESULTS AND OBSERVATIONS FROM THE GENERAL ASSESSMENT

The experimental program was predominantly conducted on B massecuites, with a short series of tests undertaken in fugalling A massecuites. In general terms, compared with batch fugalling of B massecuites, continuous fugals demonstrated the following behaviour:

High massecuite throughput rates

For Brand 1 sugar production (~ 99.2 purity) it appears B massecuites can be processed at about 25 to 30 t.h⁻¹ and A massecuites at about 45 t.h⁻¹. The throughput capacity when producing sugar to the same pol specification is substantially higher for A massecuites than for B massecuites.

High water addition rates

The water rate applied to continuous fugals typically ranges from 6 to 12% on massecuite. This compares with the usual water usage in batch fugals of between 1 and 2% on massecuite. The high water usage in the continuous machines is necessary to achieve an acceptably high pol of sugar.
A major consequence of the high water usage is the production of molasses of low solids concentration. The dry substance of the separated molasses is typically around 70. The production of low brix molasses may create processing problems such as:

(a) reduced boil-on rates on pans,
(b) increased steam consumption, and
(c) increased loading on stock tank capacity.

**Difficulty producing high pol sugar**

The highest pol of sugar is achieved at low massecuite feed rates and high rates of water addition. Even at very high water addition rates (e.g. greater than 12% on massecuite) it is generally difficult to produce sugar at much higher than 99.2 purity specification.

**Wetter sugar production**

The moisture in the discharged sugar is typically in the range 1.6 to 2.2%. This compares with the moisture content of batch produced Brand 1 sugar of about 0.7 to 0.9%. The moisture of the discharged sugar appears to be not correlated to the wash water addition rate (i.e. to the basket or probe water) but is affected by the water application rate to or near the rim of the basket. The water rate to the top sprays should be controlled to 0.6 L.min⁻¹ or lower. This water application rate corresponds to about 0.2 to 0.3 percent on sugar production. Operation of the fugals at higher rotational speeds does reduce the moisture content of the discharged sugar.

**Reduction in crystal size and increase in fines**

Operation at higher rotational speeds produces sugar at higher pol and lower moisture but at the expense of greater crystal breakage. Fig. 1 shows the change in the grist (mass percentage with size less that 0.6 mm) of the crystal size distribution in comparing the crystal discharged from the fugal with that in the feed massecuite.

![Figure 1. Change in the grist of the crystal size distribution during the different tests.](image-url)
The maximum speed should be selected to contain crystal breakage to an acceptable level and this corresponds to a discharge velocity for the crystals of about 48 m.s⁻¹ (at the top rim of the basket). This observation agrees with the findings of Greig et al. (1995). For a basket of 1100 mm diameter this corresponds to a rotational speed of 820 r.min⁻¹ and a relative gravitational force at the top rim of the basket of approximately 410. Under these conditions, the increase in grist should typically be about 3 to 6 units for 99.2 purity sugar production.

The increase in grist is quite large and there is no scope to allow any worsening of performance in this regard. It is important that close attention is given to the positioning of the anti-breakage baffle in the monitor casing and that crystal is not allowed to accumulate on the baffle. Sufficient water/steam/air must be applied to the baffle (or to the top of the basket) to ensure the anti-breakage baffle remains clear.

The problems of increase in grist in continuous fugals will assume greater importance as a larger proportion of a factory's sugar production is processed through continuous fugals and a lower proportion through batch fugals.

On average the reduction in mean aperture during fugalling was about 0.05 mm for Brand 1 sugar production. The change in the crystal mean size during fugalling occurs as a result of three main effects, viz. dissolution due to washing, attrition of the corners and faces of the crystals as they slide across the filtering screen, and breakage of the crystals due to impact during deceleration in the monitor casing. Dissolution and crystal breakage are thought to have the major influence under normal processing conditions.

In addition to these three effects, dissolution of sugar in the moist layer on the surface of the crystals after discharge will reduce the mean aperture of the crystals (Broadfoot and Miller, 1998). During drying some of the sucrose in the film may crystallise onto the surface of the crystals while most may nucleate and either agglomerate onto the crystal surfaces or form sugar dust.

In general the production of sugar of higher purity caused a larger increase in the grist of the sugar and a larger reduction in the mean aperture. As a guide, an increase in the purity of the sugar by 0.25 units caused an increase in grist of about 2 units and a decrease in mean aperture of about 0.01 to 0.015 mm.

**Crystal dissolution and molasses purity rise**

The purity rise of molasses in the fugals was typically in the range 1 to 3 units. In batch fugals this can largely be related to the dissolution of sugar by the added water, as the syrup is removed from the deep bed of sugar almost at saturation. In continuous centrifugals the water contact time is much shorter and the purity rise is much smaller for the same water quantity. As it is less related to the water added a different relationship between the change in the mass of the discharged crystal and the rise in molasses purity was tested. The change in the total mass of crystals was calculated from the difference between the third moment of the size distribution of the discharged crystals and the crystals in the feed massecuite and with an assumption that one crystal in 20 breaks to form two fragments. Based on visual inspection this was expected to be at the upper level of breakage that would occur in practice. The relationship between this calculated change in crystal mass and the molasses purity rise is shown in fig. 2. This plot does not include the data for the trials at 960 r.min⁻¹ at Mill A which were distinctly different owing to the effects of increased breakage at the higher rotational speed.
Figure 2. Estimate of the relative change in crystal mass versus the rise in molasses purity.

Despite the scatter of data resulting from errors in sampling, size measurement and chemical analysis of the molasses there is a general relationship, as expected, of a larger decrease in crystal mass with a larger increase in the molasses purity. This result supports the assumptions as the measurements on the two axes are totally independent.

It was concluded from the relationship shown in fig. 2 that a significant amount of crystal dissolution does occur with the wash water application. Greig et al. (1995) consider the washing process in continuous sugars to be mainly one of displacement of the molasses film. However, the evidence here is that a significant amount of dissolution is also occurring. Visual assessments also support evidence of crystal dissolution with crystal faces often exhibiting marked erosion and pitting.

RESULTS OF THE WASHING EFFICIENCY TESTS

The results for each series of washing efficiency tests are illustrated in the fig. 3. Within each series the water addition rates for the tests were selected randomly. A trial at zero water addition (giving a base sugar purity) was included in each series. The sugar purity achieved for zero basket wash addition is dependent on the purging qualities of the massecuite and on the massecuite throughput rate. For the tests at zero basket wash water addition, a higher purity of sugar is produced at lower massecuite feed rates.
Figure 3. The effect of wash water addition rate on the product sugar purity from continuous high grade sugarcane.

In general, for all series, the addition of basket wash water up to 5% water on massecuite produces a substantial increase in the purity of the sugar (typically about 2 units for these trials on A massecuite). However, the application of higher wash water rates produces diminishing benefit in the increase in sugar purity.

In practical terms the results show that it is difficult to achieve sugar purities greater than 99.2% by relying on the addition of wash water only and that additions of wash water at rates greater than 7 to 8% of the massecuite have little effect on the sugar purity. A limit appears to exist to the extent that wash water application can raise the purity of the sugar. From other trials on B massecuites it appears that little increase in sugar purity is achieved for washing rates above about 10% on massecuite (Broadfoot and Miller, 1998).

Model of washing efficiency

SRI analysed the washing efficiency data and determined that the following model best describes the change in sugar composition with wash water addition rate.

\[
\frac{1\%SUG}{1\%SUG_{NO\ WASH}} = \frac{100 - A (1 - e^{-Bw})}{100}
\]

where

- 1%SUG = impurity % sugar solids
- 1%SUG_{NO\ WASH} = impurity % sugar solids without wash water addition
- w = wash water % massecuite feed rate. The variable w is the total water added (probe water + basket water).
- A = coefficient defining the limit of removal of impurities at very high wash water addition rates. The larger the value of A the greater the amount of impurities removed at the limit.
- B = coefficient defining the rate of removal of impurities with wash water addition. The larger the value of B the more readily impurities are removed with wash water addition.
Table 1 provides the values of the parameters A and B for the best fit (minimum root mean square error) to the model for the individual series of tests. Fig. 4 shows the fit of the model for the three series of washing trials conducted for Mill E. For the data of the six tests analysed collectively the best fit was provided for $A = 73.2$ and $B = 0.31$. The value of the root mean square error for $\%\text{SUG}_{\text{NO WASH}}$ was 0.05.

Table 1: Parameters for the washing efficiency model

<table>
<thead>
<tr>
<th>Mill</th>
<th>Series</th>
<th>Parameter A</th>
<th>Parameter B</th>
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<td>E3</td>
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<td>0.038</td>
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</tbody>
</table>

*RMSE is the root mean square error in $\%\text{SUG}/\%\text{SUG}_{\text{NO WASH}}$ between the experimental data and the model.

Figure 4. Impurity removal data and models for the washing trials at Mill E.
PURGING AND WASHING PERFORMANCE

Variability in the purging qualities between massecuite batches affects the performance of continuous fugalns and the amounts of wash water required to achieve target sugar purities. This is apparent from the data in figure 3. For the same fugalning conditions (speed and massecuite throughput rate) the base sugar purity for A massecuites is typically about two units higher than for B massecuites (Broadfoot and Miller, 1998). Consequently, to produce a sugar of nominated purity specification from an A massecuite requires substantially less water addition than does a B massecuite. This emphasises the importance of achieving good purging qualities in high grade massecuites to be processed in continuous fugalns.

The washing efficiency is substantially inferior to that in batch fugalns, as evidenced by the very high wash water application rates required to increase the sugar purity. It is considered that the very short residence time for crystals in the continuous fugalns (less than two seconds) prevents the wash water from approaching saturation. As a guide, it appears that for each additional unit of water%massecuite, the reduction in the mass of crystals which is recovered lies in the range 0.8 to 1.3%. This compares with a typical value in batch fugalns of about 4 to 6% crystal loss per unit of water added. On average, for each additional unit of water%massecuite to a continuous fugal the molasses purity increased by about 0.3 units. This compares with a typical value for batch fugalning of B massecuite of 1.5 units rise in purity for each unit of water%massecuite. It should be remembered, however, that batch fugalns require a much lower total water addition rate.

CONCLUSIONS

Overall, continuous fugalns provide substantial benefits over batch fugalns for high grade massecuite processing, particularly with respect to capital cost per unit throughput rate, steady power demand, and benefits to the sugar drying process through the supply of sugar at a steady rate. There are, however, some significant processing disadvantages which for some mill applications would discourage their installation. The major impediment, compared to batch fugalns, is the inability to consistently produce sugar of high polarisation from other than high purity, good quality A massecuites. This results from two main effects:

1. Inferior purging performance. This is attributable mainly to the very short residence times for crystals on the basket (less than two seconds) and the relatively low centrifugal force compared with batch fugalns. The centrifugal force at the top rim of the basket in a continuous centrifugal is about 400 Gs compared with the centrifugal force at the top speed in batch fugalns of between 600 and 1000 Gs.

2. Inferior washing efficiency. Typically for Brand 1 sugar production the wash water application rates for batch fugalns are in the range 1 to 2% on massecuite and 6 to 12% on massecuite for continuous fugalns.

It appears that the greatest increase in the polarisation of the sugar can be achieved by improving the purging of the massecuite. Two procedures which would assist in this regard are: (i) conditioning the massecuite just prior to fugalning to reduce the mother molasses viscosity, and (ii) operating the fugalns at higher rotational speeds. Both these procedures would also improve the washing efficiency to some extent. However, there is no scope to increase the rotational speed owing to the increase in crystal breakage that would occur. Already, for the current procedures and designs for collecting the discharged sugar, the extent of breakage is at the upper limit of acceptability. Further research is required to improve the purging and washing efficiency of continuous fugalns and to reduce the extent of fines generation.
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REFERENCES


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COMPORTAMIENTO DE CENTRIFUGAS CONTINUAS DE ALTO GRADO

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RESUMEN

Centrifugación continua de alto grado ha alcanzado adopción rápida en la industria azucarera australiana como una tecnología de costo efectivo. Esto es a pesar de dificultades continuas, particularmente con respecto a la capacidad para producir azúcar de alta polarización, la producción de azúcar más húmeda que la de centrifuga discontinua y el aumento de componentes finos en la distribución de tamaño de los cristales.

Este estudio reporta los resultados de pruebas llevadas a cabo por el SRI en el funcionamiento de varias máquinas de fugas continuas de alto grado.

En general, fugas continuas de alto grado proveen beneficios en términos de productividad por unidad de costo de inversión, demanda de energía fija, y costos de mantenimiento de bajo potencial. La desventaja mayor del procesamiento es la dificultad en la producción de azúcar de polarización alta a partir de templas de alto grado. Las desventajas vienen de la incapacidad de purga y lavado, los cuales son inferiores en centrifugas continuas en relación a la máquina discontinua.

Palabras Claves: Fuga continua, masa cocida de alto grado, purga, rotura de cristal, eficiencia de lavado.
LA PERFORMANCE DES CENTRIFUGE CONTINUES

Broadfoot et Miller

RÉSUMÉ

Les centrifuges continues, pour masses cuisées de hautes pureté, ont bien pénétré l'industrie australienne. Elles offrent une solution d'un coût intéressant et quinze sucreries s'en servent pour les masses A et B.

Les centrifuges continues offrent les avantages suivants, vis-à-vis des discontinues. Le coût d'investissement par unité de production est plus bas, l'utilisation d'électricité est constante et la production du sucre vers le sécheur est plus stable. Il existent toutefois des désavantages sérieux, qui rendent leur utilisation difficile dans certains cas. Le désavantage le plus important est l'impossibilité de produire des sucres de hautes polarisations si la masse cuite A n'est pas d'une qualité excellente. Les autres problèmes sont la production d'un sucre humide et la formation de poussières.

Ce papier présente les résultats du travail entrepris par le Sugar Research Institut.

On note aussi qu'il faudra poursuivre le travail pour optimiser la séparation et l'efficience du lavage. Il faudra aussi réduire la formation de poussière.

Se concluyó que la ventaja mayor se obtendría al mejorar las características de purga de la templa de alimentación, primordialmente al condicionar el material, justo antes de la fuga, para reducir la viscosidad de la melaza madre.

Palabras Claves: Fuga continua, masa cocida de grado alto, purga, rotura de cristal, eficiencia de lavado.