AN EVALUATION OF VERY FINE SHREDDING

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ABSTRACT

The historical development of fine cane preparation is outlined, with reference to some of the most valuable research work in this field. Advancing technology has removed former limitations on the degree of fineness to be sought, and "ninety-plus" preparation is now both practicable and desirable. Three commercially available machines capable of this degree of shredding are described and commented upon. The results from such a machine at Tongaat are analysed in some detail. These results are used to develop predictions of the benefits to be gained by better preparation on other milling trains. Some observations are made on the relative merits of investment in shredding and in milling.

HISTORICAL PERSPECTIVE

Sugar Technologists have long recognised that the extraction of sucrose from cane can be the more efficiently achieved the greater the degree of disintegration of the cane. Nevertheless, highly effective disintegration equipment has only been developed within the last decade. The former lack of progress in this field can be ascribed mainly to three factors.

Firstly, it was believed that very fine preparation would be detrimental to mill feeding (Behne3). However, the recent introduction of underfeed rolls, four roll mills, pressure feeders, Donnelly chutes and surface roughening of mill rollers by arcing and welding have so enhanced mill "feedability" that the optimum preparation now will certainly be greater than that found by Behne, and is probably beyond the fineness practically attainable for all but the softest, low fibre (say less than 12%) canes.

Secondly, fine preparation requires extra power, although this is partially compensated by reduced power requirements for the succeeding mills (Hugot11 and Behne3). However, to achieve the same improvements in extraction and capacity by extra milling would probably require a greater increase in power.

Thirdly, the maintenance of the new high performance shredders would have been costly before the development of modern low-cost hard-surfacing techniques.

The present emphasis on the value of fine shredding in cane milling appears to have originated from the 10th Congress of the ISSCT in 1959, at which both Douwes Dekker6 and Murry and Shann14 stressed the dependence of extraction levels on the degree of preparation. Subsequent researchers, notably Henderson10 and Foster and Shann,8 have substantiated these findings, and Murry13 has reported the achievement of a computer-predicted improvement from better shredding of 0,9% in extraction for a crushing train handling 34 tons fibre/hr.

For diffusion, preparation has been found to play an even more vital role. In fact, it is obvious from the work of leading researchers in this field such as
Payne, Brünische-Olsen and Bundgaard and Rein, that very fine preparation is a sine qua non for high diffuser extractions.

MEASUREMENT OF PREPARATION

The value of very fine shredding has thus been well established both for milling and diffusion purposes, and most extraction plants would undoubtedly benefit from improved preparation.

Various methods of measuring preparation have been devised, but in the range of fine preparation under consideration in this paper the most satisfactory type of measure would appear to be one of the numerous “percentage broken cells” determinations. Buchanan, Payne, Aldrich and Rayner and Foster are some of the authors who have defined methods of this type, also variously termed “% pol in open cells”, “displaceability index” and, in the most recently standardised method in South Africa, “preparation index”. For standards of preparation giving index figures of less than about 85, the measured results can differ quite widely depending on whether pol or brix is measured, on the equipment used, and on the parameters (such as dilution ratios and tumbling and disintegrating periods) of the particular method used. However, in the range of finer preparations there is a much closer agreement between results obtained by different methods and this is borne out in comparisons done by the SMRI, by Henderson and by Tongaat staff. To deliberately skirt around many of the finer academic distinctions, it is suggested here with some justification that the methods of Buchanan, Payne, Aldrich and Rayner, Foster and the SMRI give results within 2% of each other in the range of index values between 90 and 100. Payne has shown that even a difference of 2 can have a measurable effect on the extraction of a cane diffuser. However, in the results described in this paper, relative standards are more important than absolute measures, and for this purpose the five methods may be assumed to give sensibly equivalent figures for very fine preparation. It is therefore proposed to specify the method of determination for figures of less than 90, but not for the finer preparations which fall into the “ninety-plus” range.

MACHINES FOR “NINETY-PLUS PREPARATION”

Descriptions of three devices designed to achieve ninety-plus preparation have been described in recent papers.

Silver shredders

Payne, in 1968 described Silver preparation equipment comprising 2 swing hammer shredders (“buster” and “fiberizer”) in series. This combination is reported to regularly achieve a displaceability index in excess of 94 at Pioneer in Hawaii. This highly prepared cane still contains long fibres, allowing permeability for diffusion or feedability for milling. Power requirements are however high, with approximately 130 kW/ton fibre per hour installed at Pioneer.

Walkers “Extra Heavy Duty” shredder

Hartley and Clarke in 1972 described the Walkers “extra heavy duty” shredder installation at the South Johnstone Mill in Queensland. The shredder
follows 2 knifing stages, with a total installed power on knives and shredder of about 75 to 80 kW/ton fibre per hour — approximately 60% of that provided at Pioneer.

Early mechanical problems, in particular with the hammers, necessitated running the shredder at less than its designed speed for much of the first season, and the average preparation for the whole season fell a little short of the “ninety-plus” level. However the pol in open cells exceeded 90 for the periods of full speed operation.

Tongaat shredder (Mirrlees Watson)

The third of the “ninety-plus” machines is the Tongaat shredder, described in 1972 by Moor. A detailed description of this shredder (since marketed by Mirrlees Watson) was given, together with a preliminary assessment of its influence on the performance of the larger of the 2 milling tandems at Tongaat, Natal. More comprehensive testing has since been carried out, and these results form the basis of the present paper.

In the Tongaat installation the shredder is evenly fed with well knifed cane from 2 conventional knife sets, the second of which discharges directly into the shredder. The knife preparation has been measured by the SMRI Method to have an average preparation index of between 65 and 70.

The overall dimensions of the shredder (2 150 mm × 1 525 mm × 1 200 rpm, giving a hammer tip speed of 96 m/s) are identical to those of the Walkers extra heavy duty machine described by Hartley and Clarke. The construction, however, is very different. Instead of circular discs and spacers, the rotor comprises alternately staggered profiled plates. This arrangement provides overlapping coverage of alternate rows of hammers, and the thick plates enable small diameter hammer bars to be used. This in turn allows smaller holes in the hammers and consequently lower stresses in the vicinity of the hammer eye. Moor’s paper describes numerous other features of this shredder, one of which is the use of “tuned” hammer proportions, suggested by Shaw at the 1971 ISSCT Congress.

At existing steam conditions, installed power on the Tongaat shredder is only 750 kW, or 25 kW/ton fibre per hour. With 21 kW/ton fibre per hour installed on the 2 knife sets and a further 9 kW/ton fibre per hour on a lightly loaded “leveller”, the total installed feeding preparation power is only 55 kW/ton fibre per hour — just over 40% of the Pioneer figure.

Operating experience with the Tongaat arrangement has shown that the leveller and knives are overpowered, but the shredder drive would have benefited from an extra 5 to 10 kW/ton fibre per hour. To handle the required 30 tons fibre/hour with the existing drive it is necessary either to leave out 2 of the 6 grid bars or to allow the shredder to run at about 1 000 rpm instead of the designed 1 200 rpm. Despite the inadequate drive, this shredder has consistently achieved a PI of over 90 during its first 2 seasons, and during a test run of about 3 months with the turbine exhausting into the vapour range to provide an extra 120 kW (4 kW/ton fibre per hour), the PI averaged over 92.

Figures 1 and 2 illustrate the type of preparation achieved. The PI of this sample was measured at 92.2 and the cane had been burned. The long stripped fibres can be seen, together with the separate juicy pith particles. When unburned cane is shredded, larger particles of trash can normally be

FIGURE 2. Ninety-plus shredding, showing pith separated from fibre.
seen. These do not "slatter" in the shredder, but contain no sucrose-bearing cells.

Total maintenance costs have been less than with the previous much lighter Gruendler shredder, mainly because wear at the hammer pivots of the Tongaat machine is negligible and the main wearing components (hammers and grid bars) are simple and inexpensive. Fig. 3 shows a 15.8 kg hammer from a set which has shredded over 1 500 000 tons of 15.3 fibre cane. The wear in the unbushed eye of this hammer is approximately 2 mm on diameter along the hammer length. Less hard surfacing is now being applied to new hammers.

RESULTS OF NINETY-PLUS SHREDDING AT TONGAAT

Of all the references made above to the effects of good preparation, the only results since Behne's\textsuperscript{2} investigations in 1940 which have been based on actual factory operations (as opposed to laboratory or pilot plant experiments) are the brief observations of Henderson\textsuperscript{10} and Murry.\textsuperscript{13} Partly because of the paucity of published information of this type, Tongaat staff have started to gather more detailed information regarding the first Tongaat shredder installation and its effect on the associated milling train.

Over the past 4 seasons this tandem has been essentially unaltered except for the replacement during the 1972 off-crop of the previous 335 kW motor-driven Gruendler shredder with the 770 kW turbine-driven Tongaat shredder. At this stage one carrier was eliminated, since the new shredder was sufficiently robust to be fed directly from the discharge of the final knives. However, the original knife sets and drives were retained. Furthermore, throughout all four seasons the mills were set to crush 29 tons fibre/hr. The results for the 4 seasons therefore afford 2 directly comparable pairs of seasons, apart from variations in cane quality and imbibition rates.

However, from analysis of the daily results together with a series of comprehensive trials run over the past 4 seasons, reliable and accurate data on the effects on this particular milling train of imbibition rates, pol % cane and fibre % cane has been obtained. These effects are described in Appendix A. By a fortuitous coincidence, at the time of compiling the results for Table I (shortly before the end of the 1973-74 season), the to-date average fibre % cane for the second pair of seasons exactly equalled the average for the first pair. However, the extraction and pol % bagasse were adjusted as described.
in Appendix A to allow for differences in pol % cane and imbibition % fibre. The 2 125 mm wide milling tandem comprises:

1 Light cane leveller
2 Knife sets (335 kW and 300 kW)
1 Shredder
1 Mirrlees mill with Walkers pressure feeder (550 kW)
5 Mirrlees mills with Donnelly chutes (300 kW each)
1 Walkers pressure-fed mill (450 kW)

All mills have nominal roller diameters of 965 mm.

**TABLE 1.**

<table>
<thead>
<tr>
<th></th>
<th>Average 70-71 and 71-72 with 335 kW</th>
<th>Average 72-73 and 73-74 with 770 kW</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tons cane / hr</td>
<td>191</td>
<td>198</td>
<td>7</td>
</tr>
<tr>
<td>Fibre % cane</td>
<td>15,3</td>
<td>15,3</td>
<td>—</td>
</tr>
<tr>
<td>Tons fibre / hr</td>
<td>29,2</td>
<td>30,3</td>
<td>1,1</td>
</tr>
<tr>
<td>Pol % cane</td>
<td>12,6</td>
<td>13,1</td>
<td>0,5</td>
</tr>
<tr>
<td>PI Shredded cane</td>
<td>77*</td>
<td>91</td>
<td>14</td>
</tr>
<tr>
<td>1st Mill extraction</td>
<td>61,5</td>
<td>69,1</td>
<td>7,6</td>
</tr>
<tr>
<td>Pol % bagasse†</td>
<td>1,63</td>
<td>1,39</td>
<td>-0,24</td>
</tr>
<tr>
<td>Extraction†</td>
<td>95,61</td>
<td>96,24</td>
<td>0,63</td>
</tr>
</tbody>
</table>

* Measured by method of Buchanan.
† Corrected to 13,1 pol % cane and 280 imbibition % fibre.

The following comments can be made on these results:

1) The cane quality was typical of Natal — a fairly high (and “tough”) fibre content, and low sucrose. Extraneous matter (tops and trash) averages about 10% by weight. No significant differences in PI have been noted between shredded burned cane and shredded trash cane, though cane throughput is considerably higher with burned cane.

2) The finer shredding has increased mill throughput for the same settings by nearly 4%. This is ascribed to the greater bulk density of the cane feed, and agrees with results reported by Murry and Shann and Shaw. As can be seen from Fig. 1, long fibres are still present in the finely shredded cane so the “millability” is retained.

3) The effect of the increase in PI from 77 to 91 was to increase the extraction of this powerful milling train by 0,63%.

**PREDICTED EFFECT FOR OTHER MILLING TRAINS**

Hugot has given semi-empirical formulae for the effects of various types of shredding on milling trains of various lengths. In each case the formula is of the form:

\[
K = \frac{\text{Increase in extraction}}{\text{N} - 8}
\]

where N = Number of rollers in milling train,
and K = Empirically determined factor for the particular type of shredder.
If we accept the general form of this formula, the equation (1) can be quantified for the potential improvement to be gained from replacing moderate preparation (77 PI) with ninety-plus preparation, by substituting the results of the previous paragraph, viz.:

\[ \varepsilon = 0.63 \]

and \( N = 25 \) rollers for the tandem tested.

Hence we get \( K = 10.7 \), and the formula becomes

\[ \varepsilon = \frac{10.7}{N - 8} \quad (2) \]

Using equation (2), typical gains for shorter milling trains would therefore be:

For a train of \( N = 20 \) rollers, \( \varepsilon = 0.9\% \)
- 15 rollers, \( 1.5\% \)
- 12 rollers, \( 2.7\% \).

The law of diminishing returns obviously applies for longer milling trains.

It should be stressed that these extraction gains were derived from a preparation index increase from 77 to 91. If preparation is already at a higher level than 77, the potential gains will be less; if preparation is below 77, the potential gains will be greater. In general, preparation from knifing alone will be rather less than 77 (good knifing at Tongaat achieves 65 to 70) although some mills in South Africa have achieved 80 with powerful knife sets operating over a shredder-type adjustable washboard.

When the low capital cost (of the order of 35% of that for a 3-roll mill) and low maintenance costs (about 50% of those for a mill) are considered, investment in better preparation is clearly an attractive proposition for most factories. The Tongaat shredder paid for itself in just over one season of 9 months, and that on a long milling train which previously included a lighter shredder.

**MILLING WITH NINETY-PLUS PREPARATION**

Having observed how much influence the new shredder had on the performance of the milling train, it was decided to investigate the effects of preparation in more detail. The more interesting results of studies so far undertaken are given below.

1) **Mill extraction curves**

The average cumulative extraction to each mill for the 2 seasons preceding the installation of the Tongaat shredder (70 - 71 and 71 - 72) and for the 2 seasons following its installation (72 - 73 and 73 - 74) are shown in Fig. 4. As with the results listed in Table I, adjustments have been made for differing imbibition rates (see Appendix A). Unfortunately reliable information regarding the influence of imbibition rates is only available for final bagasse. To adjust the results for the second to sixth mill bagasse it was assumed that the same relationship between milling loss and imbibition level was applicable. First mill bagasse is obviously unaffected by imbibition.

The ratio of "pol lost in bagasse with 77 PI" to "pol lost in bagasse with 90 + PI" for each mill is plotted on the same diagram. It can be seen that the ratio remains virtually constant at between 1,2 and 1,3 for each milling stage.
FIGURE 4. Extraction improvement from finer shredding, by milling stages.

2) Comparative effects with plant by-passed

With only a 10 hour maintenance stop scheduled each week, it is occasionally decided to by-pass plant in the event of a protracted breakdown such as a gearing failure. Advantage has been taken of such mishaps to gather further information on plant performance. Results under these circumstances are based on only a few readings and are therefore much less reliable than those depicted in Table 1, and can also be criticised on the grounds that the remaining plant has not been re-set to take account of the temporary changes. Nevertheless, some interesting information is provided by the comparisons in Table 2. The results are all taken from the same milling tandem but with various plant combinations.

TABLE 2.

<table>
<thead>
<tr>
<th>Plant</th>
<th>Tons fibre per hour</th>
<th>Extraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tongaat shredder + 7 mills (1972-74)</td>
<td>30.3</td>
<td>96.2</td>
</tr>
<tr>
<td>Gruendler shredder + 7 mills (1969-71)</td>
<td>29.2</td>
<td>95.6</td>
</tr>
<tr>
<td>Tongaat shredder + 6 mills (October 1973)</td>
<td>28.0</td>
<td>94.4</td>
</tr>
<tr>
<td>Gruendler shredder + 6 mills (July 1971)</td>
<td>28.2</td>
<td>93.3</td>
</tr>
<tr>
<td>No shredder + 7 mills (May 1972)</td>
<td>22.5</td>
<td>94.7</td>
</tr>
<tr>
<td>No shredder + 6 mills (October 1973)</td>
<td>21.2</td>
<td>91.6</td>
</tr>
</tbody>
</table>

Extraction figures have all been corrected, as described in Appendix A, to the equivalent for 15.3 fibre % cane, 280 imbibition % fibre and 13.1 pol % cane. In all cases of 6 mills it was the final mill that was by-passed, and mill settings for the remaining mills were therefore near optimum. The unhappy circumstance of the shredder and final mill being simultaneously by-passed pertained only for 24 hours.

By-passing the final mill reduces the milling train to a 20 roller tandem. In terms of the formula derived above, for a train of \( N = 20 \) rollers, the difference in extraction between the Gruendler shredder + 6 mills and the Tongaat shredder + 6 mills should therefore have been about 0.9%. In fact the difference found during the rather short run was 1.1%, which is close to the predicted figure.

Throughput is seen to have been drastically curtailed when the shredder was by-passed. This was due mainly to the inability of the first mill to feed a
coarsely prepared cane at its normal settings. As would be expected, by-passing the final mill did not have a significant effect on throughput.

Extraction with the Tongaat shredder but without the final 5-roller mill was only 0.3% lower than without the shredder but with the mill. When the difference in throughput is taken into account, it is apparent that in this tandem the shredder is now much more valuable than one mill.

3) Mill bagasse analyses, by pol and size fraction

A series of 42 bagasse samples from the various mills and similar samples of shredded cane were analysed for particle size distribution by mass and the pol and brix of each size fraction.

The tests were conducted between September 29 and October 27, 1973. During this period mill settings and imbition levels were not altered and the changes in cane quality were not sufficient to significantly affect results. Average pol % cane for the period was 12.9 and fibre % cane averaged 15.4.

The size gradings were obtained by successive hand sievings through various mesh screens for approximately 15 to 20 seconds each, except in the case of the shredded cane samples. Here the stickiness of the product required longer sieving periods of about thirty seconds for reasonably complete separation. The sieves were shaken only horizontally, so that long particles which could pass through the screen longitudinally but not laterally were retained on the screen. In most of the samples all particles would have been able to pass lengthwise through the 25 mm mesh screen. The sieving technique adopted appeared to provide a reasonable size grading method. The different fractions obtained are denoted in Figs. 5, 6 and 7 in the sequence of sieving as follows:

- Size A: Large particles, retained on a 25 mm screen.
- Size B: Through 25 mm screen, retained on 12 mm screen.
- Size C: Through 12 mm screen, retained on 6 mm screen.
- Size D: Through 6 mm screen, retained on 3 mm screen.
- Size E: Fine particles, through 3 mm screen.

The average size composition by mass for each milling stage is shown in Fig. 5.

In Fig. 6 the pol % of each size fraction for each milling stage is plotted. No allowance was made for evaporation during sieving, but this would not significantly affect the relative results. The brix analyses followed a similar

![Figure 5. Bagasse size grading along milling train.](image-url)
pattern to the pol figures and have therefore not been shown.

These 2 diagrams reveal several points of interest. Fig. 6 shows clearly that pol was extracted much more rapidly and also much more completely from the fine particles than from the coarser fractions. This result was expected, though perhaps the extent of the difference between fine and coarse will surprise those who believe mill roll pressures to be the governing factor in extraction. In fact, in a final bagasse averaging 1.3 pol %, the average pol % of the fine fraction was 0.8 compared with 3.0 for the coarsest particles. The advantage to be gained from reducing particle size is obvious.

What was perhaps unexpected in Fig. 6 was the complete reversal of pol contents after the first mill. The explanation is probably that in the shredded cane the pol is concentrated mainly in the fine "pithy" particles, whereas the coarse particles comprise mainly low pol rind, nodes and trash. By the time the cane is discharged from the first mill the pol differences have been reduced because pol is more easily expressed from the fine particles. Thereafter lower brix maceration is applied to all fractions but more completely absorbed into and removed from the finer particles.

The limitations of a mill as a "preparation machine" can be seen from Fig. 5. In the shredded cane nearly 30% by mass is sufficiently finely divided to pass through a 3 mm mesh screen, and more than 60% will pass through a 12 mm mesh. The seven mills effect comparatively little further reductions in size. During the period of the test top roll loads averaged about 150 t/m width and mill roll teeth were in good, sharp condition. The shredder preparation averaged 91.5 PI for the week during which the shredded cane samples were taken.

**EFFECTS OF SHREDDING AND MILLING ON EXTRACTION**

The test results plotted in Figs. 5 and 6 draw attention to differences in
the mechanisms whereby finer shredding or additional milling improve extraction. These differences can be most clearly illustrated by considering an analysis of the pol lost in final bagasse (milling loss).

From results of size grading and pol a block diagram can be constructed. Fig. 7 shows such a diagram for the final bagasse of the milling train used for the above tests. The horizontal axis is divided into 100 parts and along this are successively plotted the % by mass of each size fraction. The pol % in each fraction is then plotted vertically and a series of rectangular blocks constructed. The area of each such block is then proportional to the total pol lost in bagasse of this size, and the sum of the areas of all the blocks consequently represents the total pol lost in the bagasse. The total area divided by 100 gives the average pol % for the bagasse — in this case 1.3%.

Such a diagram can be of use to a mill engineer in resolving the frequently asked question of whether to invest in an extra mill or in a new or more powerful shredder. The way in which extraction improvements can be expected are depicted for a hypothetical milling train in Figs. 8 (a) and 8 (b). In each case the outer boundary of the blocks represents the present bagasse analysis, and the inner (shaded) blocks the potential analysis with the extra plant.

In Fig. 8 (a) a high performance shredder has been added. The proportion of large high-pol particles has been reduced, but the average pol in each size fraction has not been significantly changed except in the largest size grading. Here the elimination of very large, high pol particles has reduced the pol % of the fraction.

In Fig. 8 (b) an extra mill (and consequently an extra imbibition stage) has been added. Very little further is achieved by way of size reduction, but the pol % of each size is reduced by the extra milling stage.
FIGURE 8. Effects on pol loss from (a) improved shredding and (b) an extra milling stage.

The hypothetical mill depicted clearly benefits considerably from either alternative. Unfortunately, insufficient information is available to quantify accurately the detailed potential effects of such new investment. Nevertheless, a close examination of final bagasse on this basis could prove a useful adjunct to the capital and maintenance cost considerations in the investment decision.

ACKNOWLEDGMENTS

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REFERENCES

APPENDIX A

INFLUENCE OF FIBRE, POL AND IMBIBITION ON EXTRACTION

From analysis of a large number of daily and weekly results, as well as of a few special test runs, a multiple regression was calculated for the effects of pol % cane (P) and imbibition % fibre (I) on the reduced extraction of the Tongaat milling train described in the paper. This regression is now used by mill management to predict extractions and to set a target against which to measure mill performance.

Within the normal range at Tongaat of each of the variables concerned, the regression can be split into the following dependencies, by which all adjustments in this paper have been made:

1) Pol in cane effect
The change in extraction ($\Delta E_P$) to be expected from an increase in pol % cane of $\Delta P$ is given by:
$$\Delta E_P = + 0.2122 \Delta P$$

2) Imbibition level effect
The change in extraction ($\Delta E_I$) from an increase in imbibition % fibre of $\Delta I$ is:
$$\Delta E_I = + 0.00985 \Delta I$$

3) Fibre in cane effect
The actual extraction (E) is corrected for pol and imbibition effects before superimposing the fibre effect. Hence, for an increase in fibre of $\Delta F$ from an actual fibre of $F$:
$$\Delta E_F = \left( \frac{100 - E - \Delta E_P - \Delta E_I}{F} \right) \Delta F$$

4) Overall effect
The overall effect on extraction ($\Delta E$) is given by:
$$\Delta E = \Delta E_P + \Delta E_I + \Delta E_F$$

UNA EVALUACION DEL DESMENZAMIENTO MUY FINO

B. St Č. Moor

RESUMEN
Se hace un esbozo del desarrollo histórico de preparación fina de la caña, haciendo referencia a algunos de los más valiosos trabajos de investigación en este campo.

Las nuevas tecnologías han suprimido las anteriores limitaciones sobre el grado de desfibramiento a lograr y ahora se desea y se trata de obtener la mejor preparación posible. Se describe y se comenta sobre las tres máquinas comerciales capaces de lograr este grado de desfibramiento. Se analiza con algún detalle los resultados conseguidos con una de estas máquinas de Tongaat.
Estos resultados se utilizan para desarrollar pronósticos de los beneficios que se podrían conseguir con una mejor preparación en otros trenes de molienda. Se hacen algunas observaciones sobre los beneficios relativos de las inversiones en la desfibración y en la molienda.