CRYSTAL RECOVERY EFFICIENCY: THREE YEARS ON

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Abstract

The South African sugar industry has been reporting *crystal recovery efficiency* (XRE) as an overall measure of sugar mill performance since the start of the 2003 season. Now that industry data has been collected over three seasons, it is appropriate to evaluate the practical performance of the XRE concept. Standard overall performance yardsticks, such as value recovery, are compared against XRE as a means of assessing factory performance independent of the effects of cane quality. Measured values of XRE are also correlated with changes in factory performance and with parameters such as target purity difference, in order to relate variations in XRE to actual changes in the factory. In this way, it is possible to demonstrate the usefulness of XRE as a true measure of overall mill performance, independent of the distorting effects of any underlying variations in cane quality.

Keywords: crystal recovery efficiency, factory performance, cane quality, factory process

Introduction

In 1999, the South African sugar industry moved from a cane payment system based on sucrose content to a more equitable system based on the related concepts of *recoverable value* (RV) and *value recovery* (VR). The definitions of RV and VR attempt to compensate for the effect of cane quality on sucrose recovery and factory performance, thereby providing a more accurate measure of the real value of the cane supply to the miller. However, it has long been recognised that some important cane quality factors are not effectively accounted for. Chief amongst these neglected factors is the quality of the non-sucrose fraction within the cane, as typically represented by the reducing-sugar-to-ash ratio (Smith, 1976).

An additional limitation of the RV system is the lumping together of cane evaluation and cane payment terms into one concept. This can lead to the measured value recovery of a mill varying from month to month as a result of changes in the relative prices of sugar and molasses, even though the actual performance of the mill has remained constant. Thus, while VR may properly represent the financial outcome of milling operations, it is not an effective tool for the evaluation of process performance.

A factory performance yardstick which is more truly independent of cane quality was presented by Peacock and Schorn (2002), based on suitable modification of the RV formula so as to account for the effect of the quality of the non-sucrose fraction in the cane supply on the sucrose loss in final molasses. This technique was originally proposed as a modification to the ERC formula (unpublished data[1]). The resulting equations for *modified ERC* (MERC)

[1] Smith IA (1985). An ERC formula which allows for quality of impurity. Tongaat-Hulett Sugar Internal Memorandum.

and *crystal recovery efficiency* (XRE) provide a more accurate measure of actual factory performance than either the existing ERC formula or the RV/VR formulae[2].

The South African sugar industry has been reporting MERC and XRE figures as a measure of factory performance since the start of the 2003 season. Now that industry-wide data has been collected over a period of three years, it is appropriate to evaluate the practical performance of the concept and to briefly review its usefulness in assessing mill efficiency independent of the effects of varying cane quality. The current study also aims to correlate changes in the measured values of XRE with operational changes relating to factory effectiveness (e.g. target purity difference).

Modified ERC and crystal recovery efficiency

The concept of *modified estimated recoverable crystal* (MERC) is defined by the following relationship (Peacock and Schorn, 2002):

$$\mathrm{MERC\%Cane} = \mathrm{S} - \mathrm{b}\cdot\mathrm{N} - \mathrm{c}\cdot\mathrm{F}$$

where *MERC%Cane* is the estimated quantity of *crystal* which can be recovered from the incoming cane supply (expressed in terms of *crystal* % cane)[3], *S* is the sucrose % cane, *N* is the non-sucrose % cane (calculated as brix % cane minus sucrose % cane), *F* is the fibre % cane, *b* is a molasses loss parameter and c is a bagasse loss parameter.

The value of the *b* molasses loss parameter in the above equation is defined by:

$$\mathrm{b} = \mathrm{R}_{\mathrm{NS}} \left\{ \frac{\mathrm{TPD} + \mathrm{k}_1 + \mathrm{k}_2\left[1 - \exp\left(\mathrm{R}_{\mathrm{FG}}\cdot\mathrm{k}_3\cdot\mathrm{I}_{\mathrm{FGA}}\right)\right]}{100 - \mathrm{TPD} - \mathrm{k}_1 - \mathrm{k}_2\left[1 - \exp\left(\mathrm{R}_{\mathrm{FG}}\cdot\mathrm{k}_3\cdot\mathrm{I}_{\mathrm{FGA}}\right)\right]} \right\}$$

where R_{NS} is the industry average recovery of non-sucrose in final molasses and product sugar as a fraction of the non-sucrose entering in the cane supply, *TPD* is the industry average target purity difference (based on molasses), and k_1, k_2 and k_3 are constants in the exponential target purity formula (Smith, 1995):

$$\mathrm{k}_1 = 43{,}1$$
$$\mathrm{k}_2 = -17{,}5$$
$$\mathrm{k}_3 = -0{,}74$$

R_{FG} is the industry average recovery of reducing sugars in final molasses and product sugar as a fraction of the reducing sugars in the mixed juice and I_{FGA} is the reducing sugar to ash ratio in the mixed juice.

The values of the 'constant' molasses and bagasse loss parameters are calculated for the industry by the Sugar Milling Research Institute (SMRI). While the value of the *c* bagasse loss parameter remains constant for all mills over the duration of each season, the value of the b molasses loss parameter varies from mill to mill on a monthly basis, based on the quality of

2 MERC and XRE are still imperfect performance measures, in that they do not account for all cane quality parameters (e.g. polysaccharides, individual ash components, etc). None of these additional components is, however, routinely measured in the SA sugar industry. As such, MERC and XRE thus probably represent the best level of cane-quality-independence that can currently be achieved.

3 The hypothetical concept of *crystal* was originally devised by van Hengel (1974).

the cane received by the mill during the previous month. Typical trends in the monthly values of the MERC *b* parameter for three 'representative' mills in the South African industry over the past three seasons are presented in Figure 1. Similar seasonal trends are evident in all the curves.

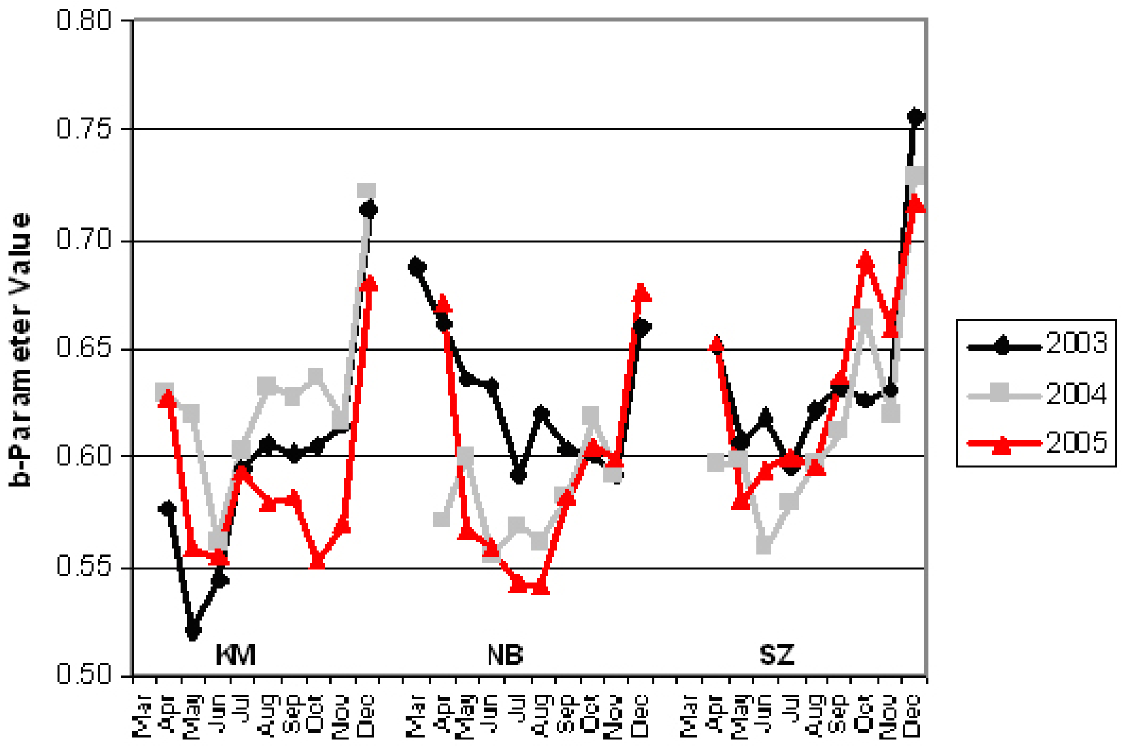

Figure 1. Typical monthly trends in the value of the MERC *b* parameter for three South African mills.

A measure of the factory performance actually achieved by a particular sugar mill may be calculated by dividing the quantity of crystal produced by the factory (in the form of crystalline sugar) by the quantity of crystal which could theoretically have been recovered from the cane supply by a factory operating at a standardised level of efficiency, expressed as a percentage. This measure of efficiency is referred to as the *crystal recovery efficiency* (XRE):

$$\mathrm{XRE} = 100\left[\frac{T_X}{T_C}\cdot\left(\frac{100}{\mathrm{MERC\%Cane} - (1-a)\cdot S}\right)\right]$$

where T_X is the tonnage of crystal actually produced (calculated using the methods of van Hengel, 1974), T_C is the tonnage of cane crushed and *a* is a constant parameter which represents the fraction of the sucrose entering in the cane supply which passes out of the mill in the form of product sugar, bagasse or final molasses. The value of the 'constant' *a* parameter is determined annually for the industry by the SMRI.

Overall mill performance

A summarised view of mill performance in the South African sugar industry over the past three seasons, as measured using the XRE concept, is given in Figure 2. Month-by-month XRE curves for each of the individual mills are also presented in the appendix.

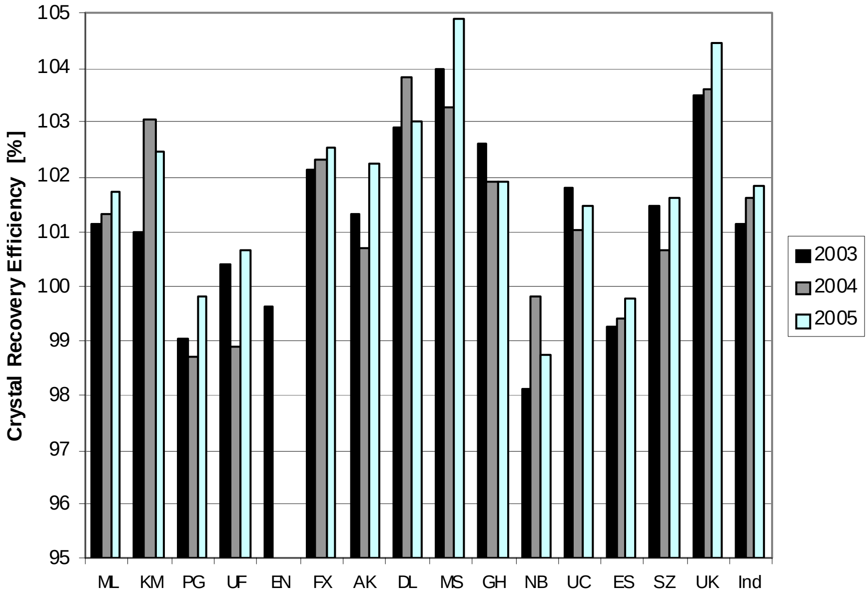

Figure 2. Summarised performance of South African mills over the past three seasons.

It is important to remember that the XRE calculation is based on a level of standardised factory efficiency determined using rolling weighted-average performance data over a three-year period. As a result, the industry average XRE calculated for each of the years shown in the figure is close to, but never exactly equal to 100%. In years in which the overall performance of the entire industry is increasing (e.g. when coming out of a period of drought), the performance of the industry average during any given year will be better than its performance over the three previous years. This results in the industry achieving an average XRE of greater than 100%. By contrast, in a period of relative decline, the effect would be reversed and the industry average XRE will tend to be less than 100%. This effect is evident in Figure 2 above, where the industry average XRE exceeded 100% in all three years examined.

XRE compared against other performance measures

Ideally, an overall factory performance yardstick (such as XRE) should (amongst others) meet two criteria of suitability for use in assessing sugar mill efficiency, namely:

- The overall performance measure to be used should be completely independent of all cane quality parameters.
- The value of the overall performance measure should not depend on any parameters which are irrelevant to the efficiency of the mill.

It is well accepted that traditional overall performance measures such as boiling house recovery (BHR) and the factory performance index (FPI) are dependent on variations in the quality of the cane entering the factory. Consequently, these yardsticks do not meet the first criterion discussed above and are not examined further here.

Besides XRE, the only overall performance measure which attempts to discount the effect of cane quality on performance is value recovery (VR). An attempt was therefore made to compare both VR and XRE against the two criteria discussed above in order to assess their suitability for use as a routine measure of factory efficiency.

Independence from cane quality

Both the VR and XRE performance measures are based on the ERC formula originally developed by van Hengel (1974). As such, they take into account the primary cane quality parameters of sucrose % cane, non-sucrose % cane and fibre % cane. They are thus, to some extent, independent of changes in cane quality. However, Smith (1976) showed that the original ERC formula failed to take into account the quality of the non-sucrose fraction (as typically represented by the reducing sugar-to-ash ratio) entering the factory in the cane supply. This means that the ERC formula is not entirely independent of the influence of cane quality. This limitation was noted by van Hengel (1974), but was not considered to be a serious disadvantage at the time.

The concepts of RV and VR, as currently employed in the South African sugar industry, are based on the original ERC equation. The molasses loss factor used in these equations has not been modified to take account of the effect of the quality of the non-sucrose fraction in the cane and thus suffers from the same disadvantage as the original ERC formula, in being partially dependent on cane quality.

By contrast, the concepts of MERC and XRE have been defined so as to account for the type of non-sucrose entering the factory in the cane supply. This makes XRE more truly independent of cane quality than any of the other overall factory performance measures currently available. This fact is demonstrated in Figure 3, where the numerical differences between the monthly values of XRE and VR for the 2005 season have been plotted for the four Tongaat-Hulett mills, as a function of the reducing sugar-to-ash ratio. It is clearly evident from the figure that the difference between the two performance measures is dependent on the non-sucrose quality ratio, which is accounted for in the definition of XRE but not by the definition of VR.

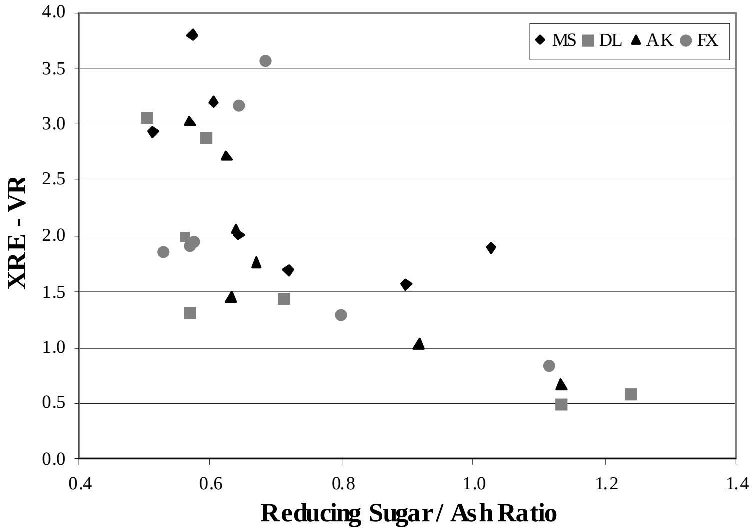

Figure 3. The difference between XRE and VR as a function of reducing sugar-to-ash ratio.

Value recovery thus fails the first criterion of suitability for use as an ideal overall performance measure, in that it is partially dependent on cane quality. The XRE yardstick does not suffer from this drawback.

Independence from irrelevant parameters

The concept of RV, as used for cane payment in the South African sugar industry, recognises that the final molasses produced by a sugar mill has an economic value. As such, while each unit of non-sucrose entering the factory in the cane supply is responsible for removing a fixed quantity of sucrose from the mill as final molasses, it is also responsible for generating a saleable product (namely the final molasses itself). In the RV formula, the constant b molasses loss parameter from the ERC equation is thus replaced by a constant d parameter which represents the quantity of sucrose lost to final molasses per unit of non-sucrose entering in the cane supply, but with a credit for the value of molasses recovered per unit of non-sucrose.

The equation for the determination of the d parameter in the RV formula is as follows:

$$d = b \cdot \left[1 - \left(\frac{m \cdot P_M}{R_{S/ES} \cdot b \cdot P_S}\right)\right]$$

where b is the molasses loss parameter in the original ERC equation, m is the industry average yield of molasses per unit of non-sucrose delivered in cane, P_M is the average molasses price, $R_{S/ES}$ is the industry average recovery of saleable sugar per ton of 'estimated sugar' (as defined in the South African Sugar Association official methods manual) and P_S is the average sugar price.

From the above relationship, it is apparent that the values of RV calculated using this definition (and hence the associated VR values) are dependent on the prevailing prices of sugar and final molasses at the time of calculation. Because both performance evaluation and economic parameters are lumped together in the concepts of RV and VR, it is possible for the measured value recovery at a sugar mill to vary from month to month as a result of changes in the prices of sugar and final molasses, even if the actual performance of the factory has remained constant. This effect is illustrated in Figure 4, where the numerical differences between the monthly values of XRE and VR for the 2005 season have been plotted for the four Tongaat-Hulett mills, against the prevailing average raw sugar price at the time of calculation. It is evident from the figure that the difference between the two performance measures is correlated with the sugar price, which is included in the definition of VR but not in the definition of XRE.

However, it is interesting to note that the theoretical effect of the sugar price on the calculated value recovery of a mill is an order of magnitude smaller than that shown in Figure 4. It would thus appear that other unknown factors also contributed to this graphical trend for the 2005 season.

While VR may properly represent the economic outcome of milling operations, it is not an effective tool for evaluating the technical performance of a sugar factory. It fails to meet the second criterion of suitability for use as an ideal overall performance measure, in that it is dependent on factors which are not relevant to the evaluation of process efficiency in a sugar factory. The XRE yardstick does not suffer from this drawback.

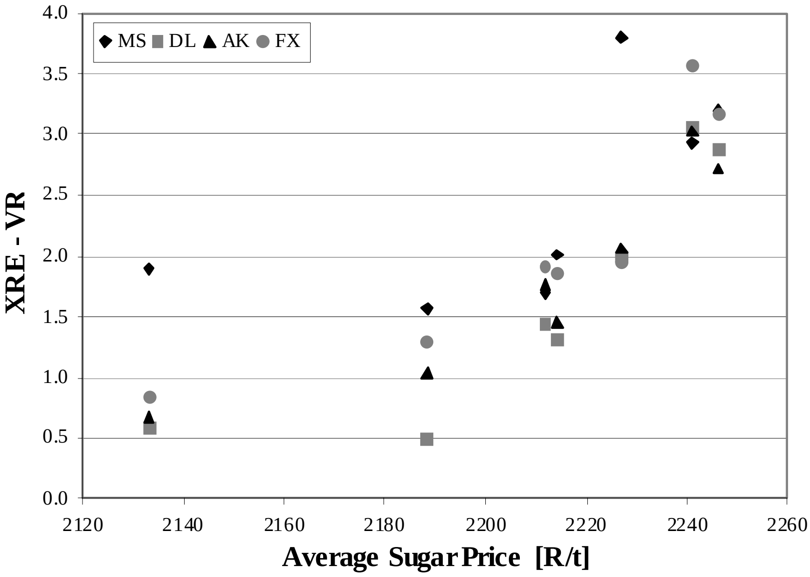

Figure 4. The difference between XRE and VR correlated against the average sugar price.

Measured XRE versus actual performance

To demonstrate the practical value of the XRE concept in assessing factory performance independently of the effects of cane quality, it is necessary to investigate two scenarios using the data collected over the past three seasons, namely:

- A scenario in which the cane quality entering the factory changes, but the actual efficiency of factory processing remains the same. Under these conditions, the reported value of XRE should remain constant.
- A scenario in which the cane quality entering the factory remains the same, but the actual efficiency of factory processing changes. Under these conditions, the reported value of XRE should change.

Changing cane quality

An example of a scenario of the first type is presented in Figure 5, where the performance of the Darnall (DL) mill during the 2005/06 crushing season is considered. Of particular interest are the figures for the two consecutive months of June and July (highlighted in the oval region of the graph).

In the figure, it can be seen that DL experienced a substantial increase in mixed juice purity from June to July. Consequently, it would be expected to see increased recoveries from the mill due to the drop in the level of impurities entering the mill in the cane supply. However, at the same time, DL also experienced a substantial drop in the reducing sugar-to-ash ratio. This change in underlying cane quality reduces the exhaustibility of the final molasses, and such a change would be expected to decrease the recovery achieved by the mill. The overall combined effect of both of these changes on the performance of the mill was a slightly improved value of overall recovery, as shown in the graph.

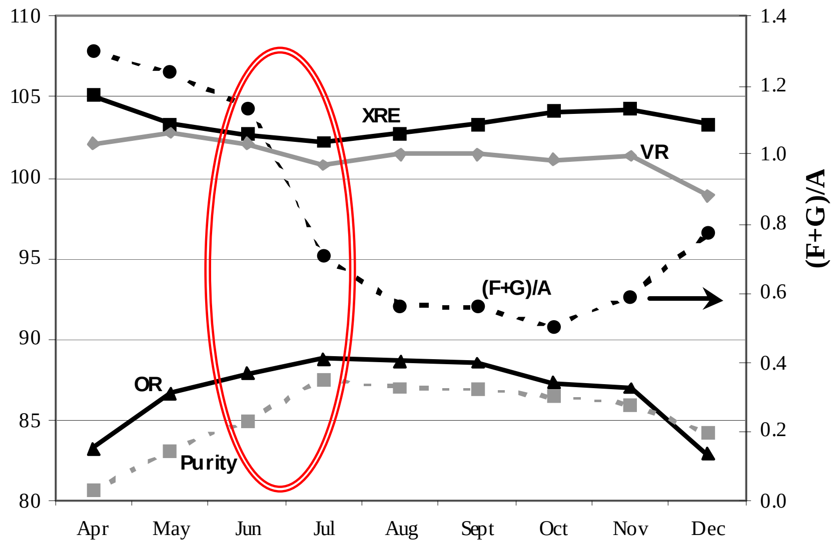

Figure 5. The performance of Darnall sugar mill during the 2005/06 season.

It is important to note that, under these circumstances, the calculated VR value for the mill only takes into account the increase in mixed juice purity. The change in the reducing sugar-to-ash ratio is neglected. This means that the mill staff are effectively 'penalised' by the VR formula because the final molasses has become more difficult to exhaust. This is reflected in the VR curve shown in Figure 5, where the measured VR for DL drops from June to July.

By contrast, the calculated value of XRE takes both cane quality changes into account. As a result, the measured XRE value for DL declined only slightly from June to July. This is a more fair reflection of the actual performance of the factory, which remained essentially constant even though the underlying cane quality changed.

A further example of a scenario of this type is shown in Figure 6, in which some performance data from the 2005/06 season for the Felixton (FX) mill are displayed. Of particular importance are the data points for the months of June and July, which are highlighted in the oval region of the figure.

As in the previous example, it is apparent that FX experienced a decrease in the value of the reducing sugar-to-ash ratio from June to July. Alongside this change, the incoming purity of the mixed juice increased slightly. As a result of the purity change, it would be expected that the factory could achieve a slightly better level of recovery. By contrast, however, the lower value of the reducing sugar-to-ash ratio would be expected to decrease the recovery achievable by the mill, due to the poorer exhaustibility of the final molasses under these conditions. The result of the interaction of these competing effects on the actual performance achieved by the factory was a slight increase in overall recovery, as is evident in the figure.

As mentioned previously, the calculated VR for the mill takes into account only the increase in purity level. The change in the quality/type of the non-sucrose fraction entering the factory in the cane supply is neglected, and the lowered exhaustibility of the final molasses is not allowed for. Consequently, the calculated value of VR for FX remained essentially the same from June to July.

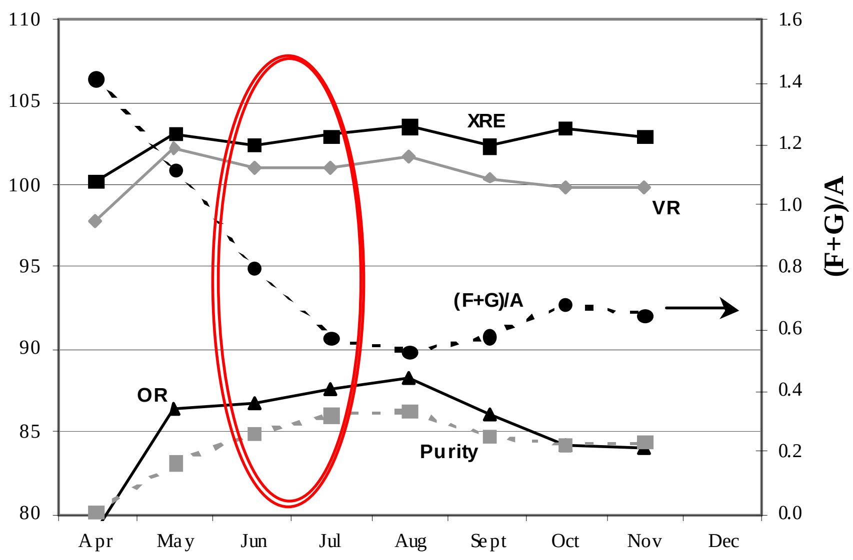

Figure 6. The performance of Felixton sugar mill during the 2005/06 season.

However, the calculation of XRE incorporates all effects of cane quality. As a result, the measured value of XRE increases slightly from June to July. This is a more fair reflection of the actual performance achieved by the mill staff, who did well to maintain (and even slightly improve) the efficiency of their plant in the face of reduced cane quality[4].

Changing factory efficiency

An example of a scenario of the second type is presented in Figure 7, where the performance of the Amatikulu (AK) mill during the 2005/06 crushing season is presented. Of particular importance are the later months of the year, from July onwards.

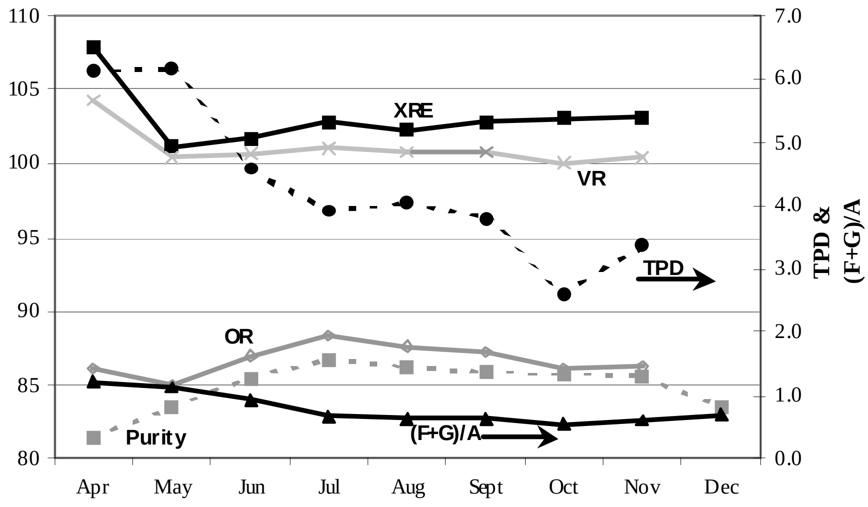

Figure 7. The performance of Amatikulu sugar mill during the 2005/06 season.

[4] Similar behaviour is evident for the months of May and June, during which the reducing sugar-to-ash ratio also sharply decreased. While the factory performance (as measured by XRE) decreased slightly during this period, the VR dropped by a bigger margin because it failed to take into account the full effects of the changing cane quality.

As a result of the hard work put in on the pan floor by the AK operational staff during 2005, they managed to continually improve their TPD results throughout the season. The declining TPD trend is evident on the graph. This result was achieved at an essentially constant level of cane quality (as reflected by the mixed juice purity and reducing sugar-to-ash ratio curves). The improved factory performance is clearly evident in the upward slope of the XRE graph in the figure.

Disadvantages of the XRE concept

It is readily apparent that the MERC and XRE concepts suffer from a number of disadvantages when compared to more traditional measures of factory efficiency, such as boiling house recovery and overall recovery. These include the following:

- The concepts themselves are not as intuitive as the more traditional recovery measures. While the standard sugar industry recovery measures can be readily understood by new operational staff when exposed to them for the first time, the more elaborate measures of process performance (such as RV, VR, ERC, FPI, MERC and XRE) are more difficult for even experienced sugar technologists to comprehend. This is unfortunately the price that always needs to be paid when moving to more accurate and comprehensive measures of efficiency.
- Values of the MERC and XRE measures are not easily determined by the mill staff during day-to-day operations and are available only on a weekly basis from the SMRI. This limits their utility as a routine measure for factory operation and control.
- The value of the *b* molasses loss parameter in the MERC equation is determined on a month-by-month basis by the SMRI, based on chromatographic analyses carried out on mixed juice and molasses. This is far more complex than making use of a fixed-value b parameter (as for the original ERC formula). However, no serious problems have so far been encountered in this regard during the past three seasons and the production of weekly and monthly MERC and XRE data by the SMRI has proceeded smoothly.

Notwithstanding these disadvantages, XRE is considered a useful overall measure of factory efficiency and it is recommended that its use within the South African sugar industry be continued.

Conclusions

The South African sugar industry has been reporting XRE as an overall measure of sugar mill performance for the past three seasons. It was thus considered appropriate to carry out a preliminary evaluation of the practical performance of XRE during this time.

Standard overall performance yardsticks, such as overall recovery and value recovery, were compared against XRE as a means of assessing factory performance independent of the effects of cane quality. XRE was found to be the only available performance measure which is substantially independent of cane quality and which does not include parameters within its definition which are irrelevant to the evaluation of process efficiency within the factory.

Measured values of XRE were also correlated with changes in cane quality and in factory performance, in order to relate variations in XRE to actual changes in the factory. In this way, the usefulness of XRE as a true measure of overall mill performance, independent of the distorting effects of any underlying variations in cane quality, was demonstrated.

Acknowledgments

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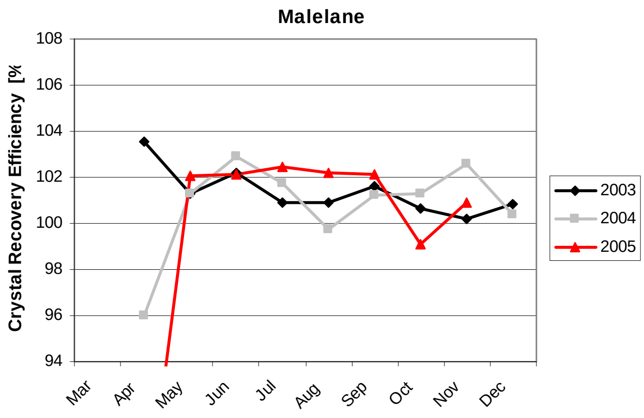
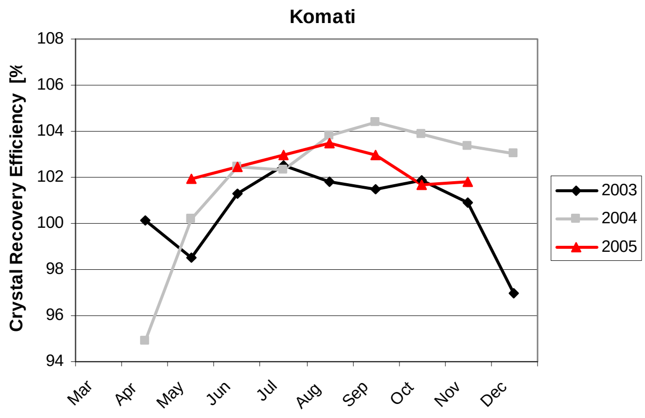
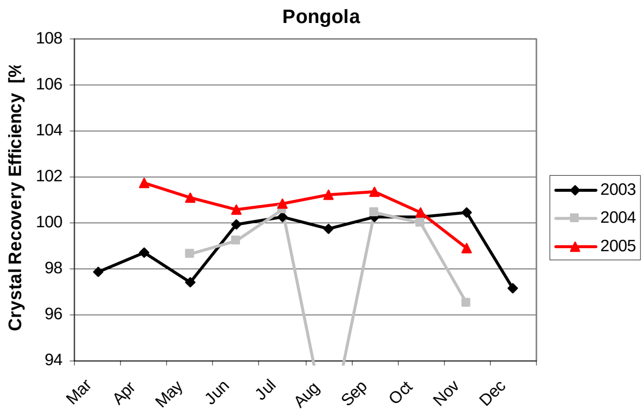
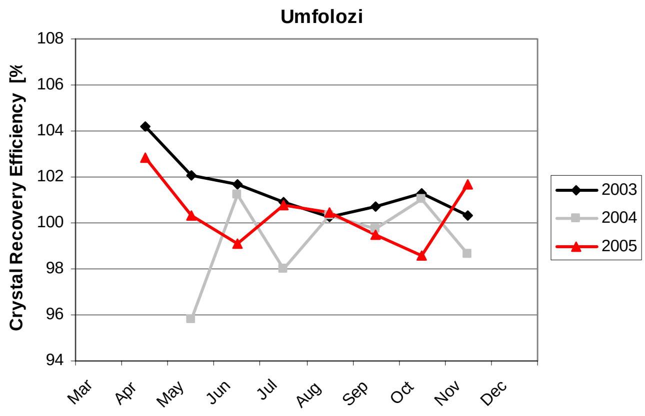
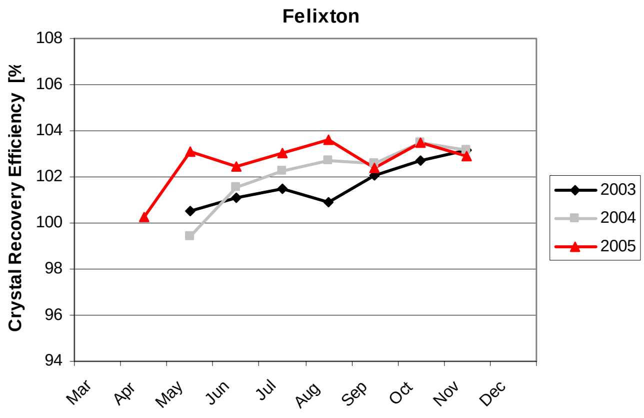
APPENDIX
SOUTH AFRICAN MILL PERFORMANCES OVER THE PAST THREE SEASONS

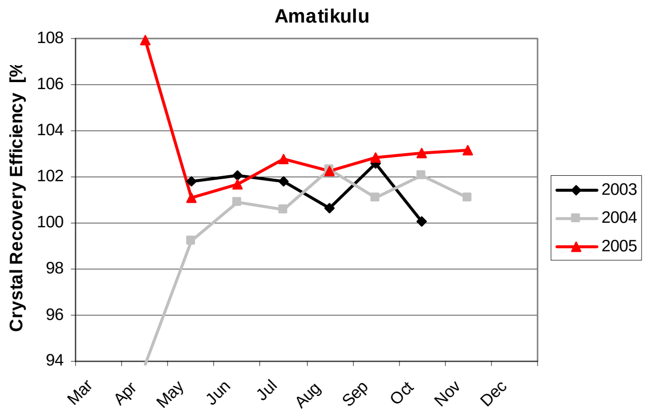


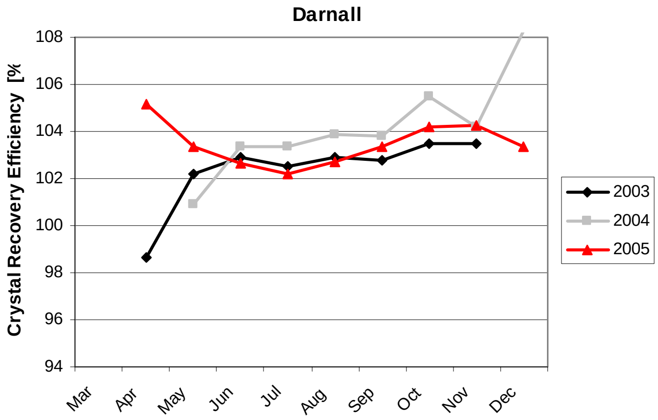











Darnall
Crystal Recovery Efficiency [%
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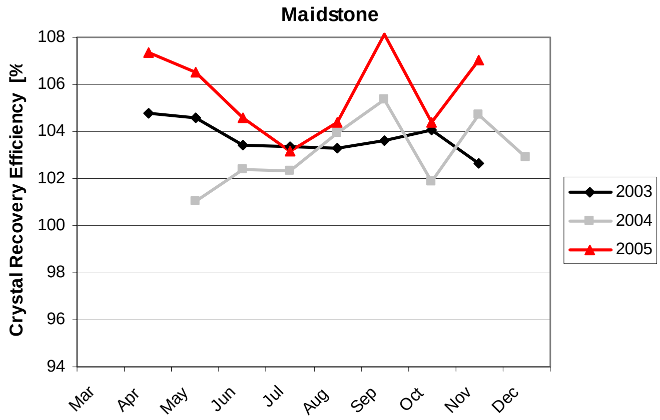
Maidstone
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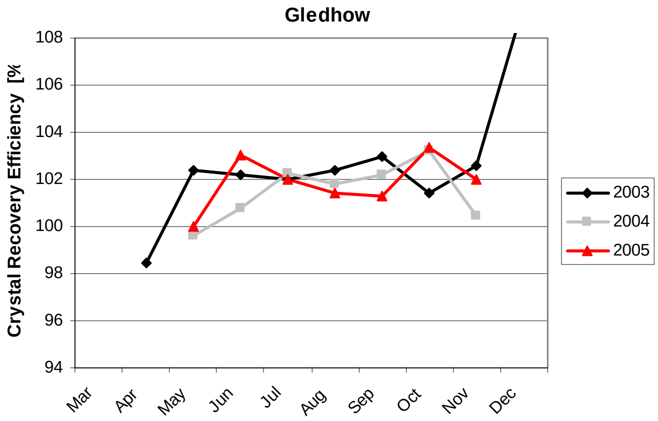
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Crystal Recovery Efficiency [%
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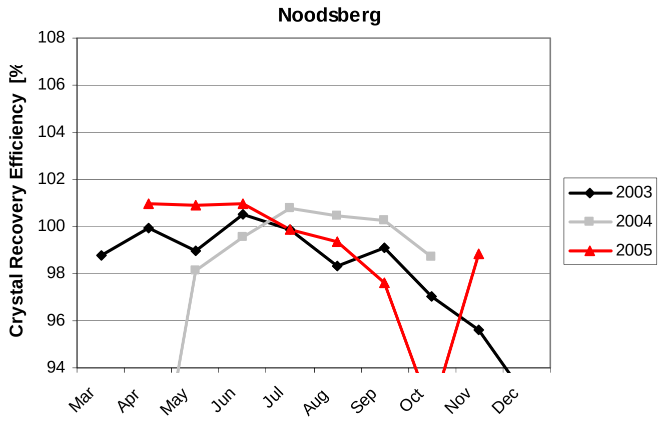
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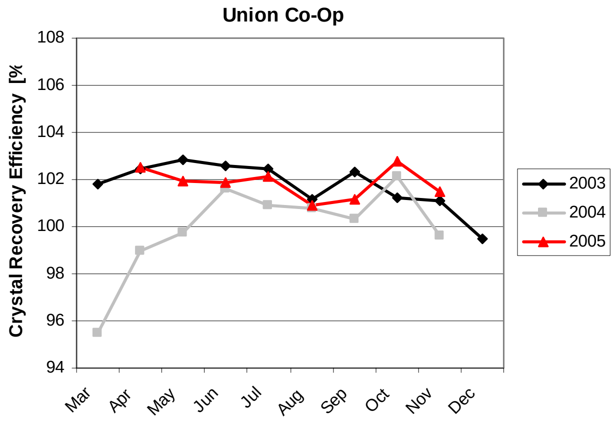
Union Co-Op
Crystal Recovery Efficiency [%
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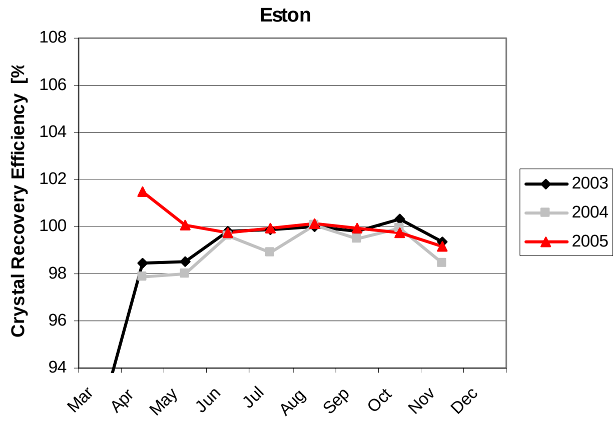
Eston
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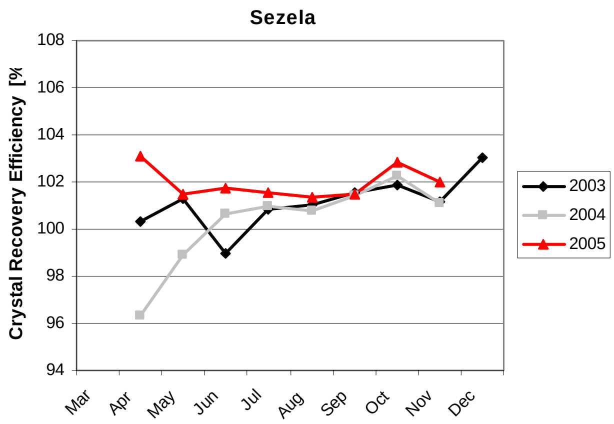
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Crystal Recovery Efficiency [%
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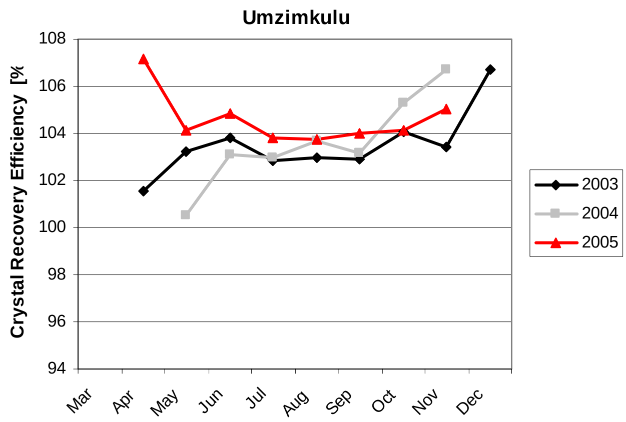
Umzimkulu
Crystal Recovery Efficiency [%
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