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THE EFFECT OF IMBIBITION AND CANE QUALITY ON THE FRONT END MASS BALANCE

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Abstract

It is generally accepted that the fibre % cane, brix % cane and imbibition % fibre affect the performance of the front end of a factory. In an attempt to quantify these effects a model was developed giving front end mass balances on fibre, brix and water as a function of these parameters. The model is based on the assumption of constant ratios of [fibre % juice]/[fibre % bagasse], [brix % juice]/[brix % bagasse] and [water % juice]/[water % bagasse]. The model was tested against real factory data with surprisingly good results. As far as extraction is concerned the results were very similar to the corrected reduced extraction (CRE) equation as used in the South African sugar industry.

Introduction

The composition of the cane and the level of imbibition influence the performance of the front end of the factory. Some knowledge of the effect of these parameters is of interest for two reasons, firstly to compare performances with similar parameters and secondly to predict the effect on the performance due to a change in these parameters. A literature survey shows a multitude of papers on this topic. Deerr (1933), Hugot (1986), Mittal (1969), Rein (1975) and many others have studied the effect of fibre and pol % cane on extraction to derive what is now known as a corrected reduced extraction (CRE). Sullivan (1985), Wienese (1994) and others have looked at the effect of imbibition on extraction. There are however two distinct disadvantages of the approaches followed by these authors. The first is that performance is measured only in terms of extraction. Both the amounts of bagasse and juice and their compositions are however also affected and are important for different reasons, the bagasse from a fuel point of view and the juice from an evaporator point of view. The second disadvantage is that they deal either with the composition of the cane or with the level of imbibition but never with the combination of the two. One would prefer an approach in which the output in all its aspects is given as a function of all the relevant inputs. Such an approach leads to front end mass balances on fibre, brix and water.

Theoretical model

The input for the front end of a sugar factory consists of cane and imbibition. This combined input has a quantitative and a qualitative aspect. The quantity of the input is generally considered to be the throughput in tons of fibre. The quality can be expressed in terms of fibre, brix and water percentages. Similarly the output of the front end consists of bagasse and juice with their respective compositions of fibre, brix and water. Monthly factory figures covering the period between 1979 and 1993 were used to develop a standard mass balance using the averages of these figures and is shown in Table 1.

For a given input three independent output variables are required in order to complete mass balances on fibre, brix and water around the extraction plant. These could be, for example, brix % bagasse, moisture % bagasse and fibre % juice. It is now assumed that any change in concentration of fibre, brix or water in the input affects the concentration of these components in the output, in the same direction. This means that at a constant fibre throughput an increase in brix % input results in an increase in both brix % bagasse and brix % juice. Equally, a decrease in brix % input leads to a decrease in brix % bagasse and in brix % juice. If this is true then a constant brix % input must give a constant brix % bagasse and a constant brix % juice. This applies equally to fibre and water. Hence the imbibition water is treated the same as the water in cane. This is obviously not entirely correct but makes provision for changes in imbibition.

Table 1

Standard mass balance

	Input	Output	
	Cane + Imbibition	Bagasse	Juice
Fibre (%)	10,22	*46,20*	0,46
Brix (%)	9,67	1,98	*11,76*
Water (%)	80,11	51,82	*87,78*

Figures given in italics are calculated.

Any qualitative change in the composition of the input (Table 1 to Table 3) can be seen as the sum of two changes. The first is a change in brix % input at a constant fibre % input and the second a change in fibre % input at a constant brix % input. Since the first change does not affect the fibre % input, the fibre % bagasse and the fibre % juice stay constant. This gives two output variables and only one more variable is required in order to calculate a full mass balance for this particular change. If that variable is the brix % juice (12,58) then Table 1 changes to Table 2.

Table 2

Effect of brix on mass balance

	Input	Output	
	Cane + Imbition	Bagasse	Juice
Fibre (%)	10,22	46,20	0,46
Brix (%)	10,32	*2,00*	12,58
Water (%)	79,46	*51,80*	*86,96*

Figures given in italics are calculated.

Similarly the second change does not affect the brix % input, and the brix % bagasse and the brix % juice stay constant. Again two output variables are known and one more is required to establish a full mass balance. If that variable is the fibre % juice (0,44) then Table 2 changes to Table 3.

Table 3

Effect of fibre on mass balance

	Input	Output	
	Cane + Imbibition	Bagasse	Juice
Fibre (%)	9,78	*44,24*	0,44
Brix (%)	10,32	2,00	12,58
Water (%)	79,90	*53,76*	*86,98*

Figures given in italics are calculated.

The net result of the sum of these two changes should however still satisfy the condition that a change in a concentration in the input is followed by a change in concentration in the two outputs in the same direction. So far no solution has been found to meet this requirement and lead to realistic answers at the same time. The foregoing discussion paves the way however for a slightly different approach. When a change in concentration in the input results in a change in concentration in the output in the same direction then obviously the change in concentration in the bagasse and the juice are in the same direction. One way to achieve this is to assume a constant ratio between the concentration in bagasse and the concentration in juice. Since bagasse and juice consist of three components, fibre, brix and water, this results in three ratios [fibre % juice]/[fibre % bagasse], [brix % juice]/[brix % bagasse[and [water % juice]/[water % bagasse]. This is exactly the number of output variables that are required to calculate mass balances given a certain input. The ratios based on Table 1 are 0,010; 5,954 and 1,694 for fibre, brix and water respectively. Using these ratios the effect of the previous change in input (Table 1 to Table 3) is now shown in Table 4.

Table 4

Model applied to standard mass balance

	Input	Output	
	Cane + Imbibition	Bagasse	Juice
Fibre (%)	9,78	*46,48*	*0,46*
Brix (%)	10,32	*2,09*	*12,43*
Water (%)	79,90	*51,43*	*87,11*

Figures given in italics are calculated.

This "constant ratio" model applies to milling tandems and to diffusers alike. It provides a mass balance of the front end as a function of fibre % cane, brix % cane and imbibition at a constant fibre throughput.

Model verification

Testing of the model can obviously only be done against real factory data. The problem with such data is however that not only the quality of the input changes but also the quantity. Nevertheless the model was used to calculate monthly front end mass balances for the period between 1977 and 1993 using concentration ratios based on the average mass balance for that period (Table 1). These ratios for [fibre % juice]/[fibre % bagasse], [brix % juice]/[brix % bagasse] and [water % juice]/[water % bagasse] are 0,010; 5,954 and 1,694 respectively. Considering the relatively simple assumption of constant output concentration ratios, the results were surprisingly good. As far as tons imbibition, tons bagasse and tons juice are concerned there are virtually no differences between calculated and actual data. Figure 1 shows tons of bagasse.

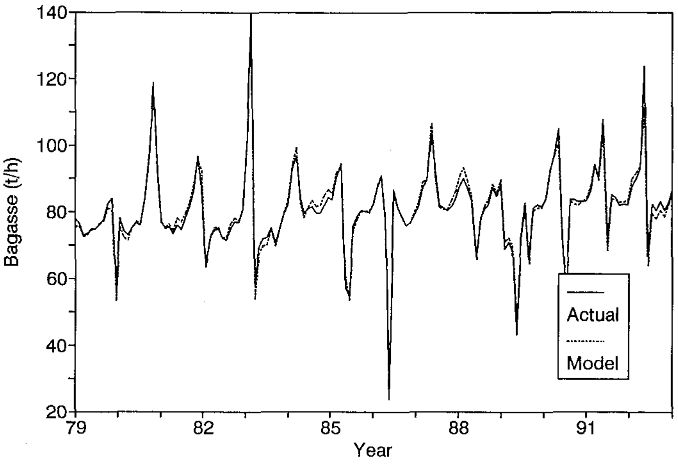

FIGURE 1 Tons bagasse.

The same can be said about tons brix in juice, tons fibre in bagasse, tons water in juice and tons water in bagasse. This is not really unexpected since these quantities are relatively large. When considering small quantities such as tons brix in bagasse and tons fibre in juice there are indeed greater differences between calculated and actual data but they still follow the same trend. Figure 2 shows tons brix in bagasse.

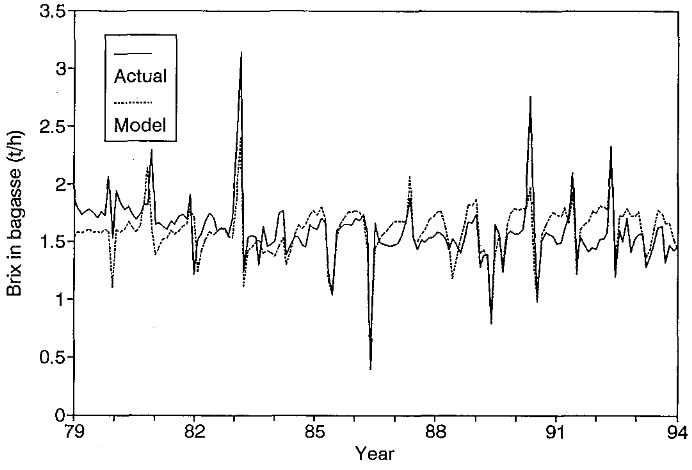

FIGURE 2 Tons brix in bagasse.

When looking at percentages rather than tonnages there are two extremes. The brix % juice and moisture % juice show perfect fits between calculated and actual data. As far as the former is concerned this is not unusual when considering the high levels of extraction that are achieved. Figure 3 shows the brix % juice.

By far the greatest discrepancy is found in the fibre % juice. The actual fibre % juice fluctuates much more than the calculated one. Since one would expect this figure to be

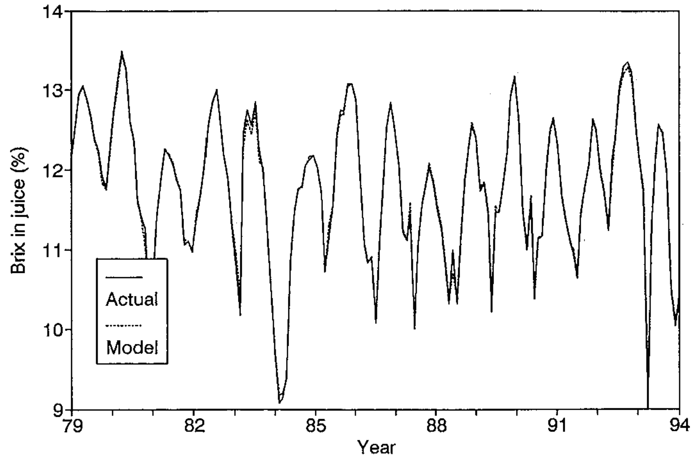

FIGURE 3 Brix % juice.

reasonably steady it is possible that these fluctuations are due to other factors than the quality of the input in terms of its fibre and brix. Sand which is considered part of the fibre could well play a role here. Fortunately the fibre % juice has only a small effect on the other variables of the mass balance. Figure 4 shows the fibre % juice.

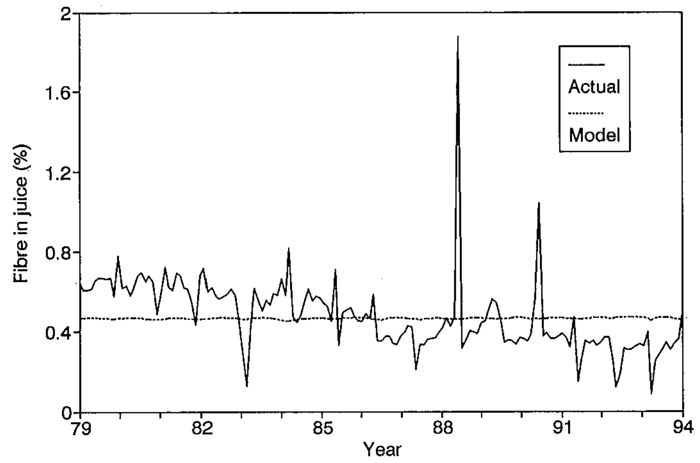

FIGURE 4 Fibre % juice.

Other percentages such as brix % bagasse, fibre % bagasse and moisture % bagasse do show some differences. These differences are however small and the calculated values certainly follow the actual values quite well. This is even true for a small and therefore difficult to determine variable like brix % bagasse which is shown in Figure 5.

One of the most important variables is obviously the brix extraction. With a consistently high extraction of about 97% with small variations this figure is very difficult to calculate accurately. Taking this into consideration the agreement between actual and calculated values is still very good. The actual extraction responds however more strongly to changes in the input than the calculated one. Figure 6 shows the brix extraction.

Corrected reduced extraction

There are various models for corrected reduced extraction (CRE) which is a comparative extraction that should be independent of cane quality. At the same time these models can be used to demonstrate the effect of cane quality on extraction, particularly the effects of fibre and pol in cane on pol extraction. The CRE model used in South Africa is a statistical approach developed by Rein (1975). When based on brix rather than on pol this CRE model has the following form:

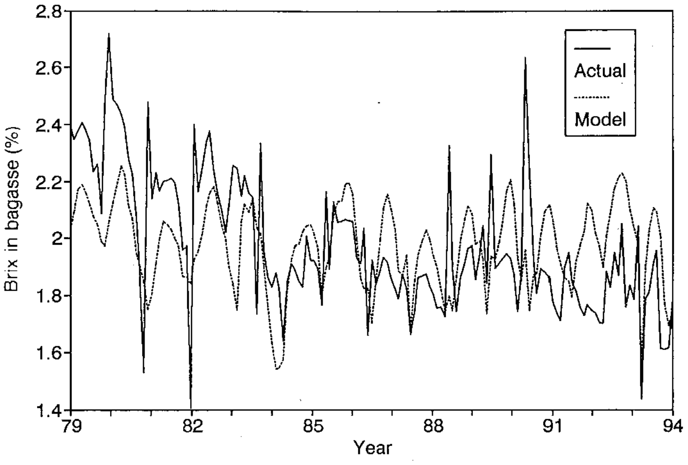

FIGURE 5 Brix % bagasse.

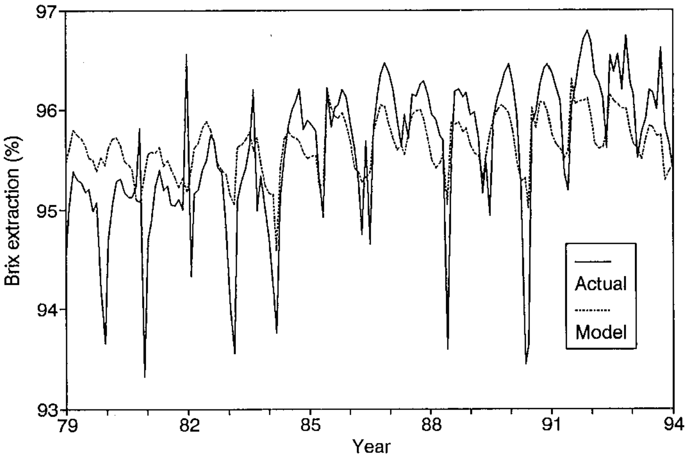

FIGURE 6 Brix extraction.

$$E_2 = 100 - (100 - E_1) * \frac{F_2 * (100 - F_1)}{F_1 * (100 - F_2)} * \left(\frac{B_1}{B_2}\right)^{0,6}$$

where the subscripts 1 and 2 refer to two different conditions.

E = brix extraction
F = fibre % cane
B = brix % cane

Using the data from Table 1 as the standard mass balance the effect of fibre % cane on brix extraction was calculated using the "constant ratio" and the CRE models. Around the standard fibre % cane the two models produce very similar results. Only at very high fibres, above 20%, the extraction calculated by the CRE model decreases at a faster rate. This is however outside the normal fibre range experienced in South Africa. Figure 7 shows the brix extraction as calculated by the two models.

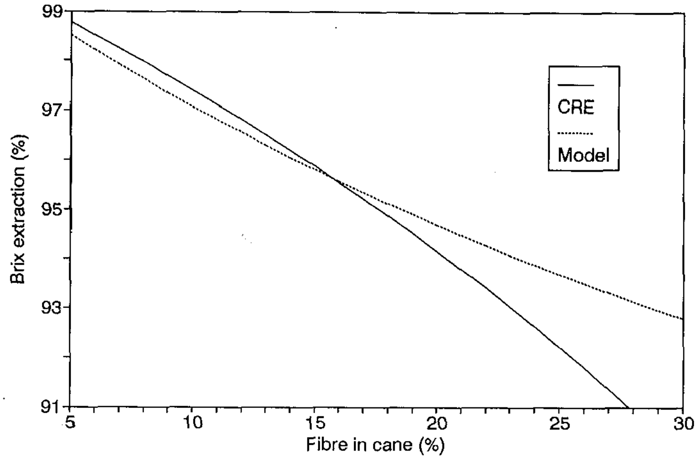

FIGURE 7 CRE and the effect of fibre on brix extraction.

Based again on the data from Table 1 as the standard the effect of brix % cane on brix extraction was calculated using both models. Although moving in the same direction this effect is much more prominent for the CRE model than it is for the "constant ratio" model. Within the normal brix range the differences are however within acceptable levels. Figure 8 shows the brix extraction as calculated by the two models.

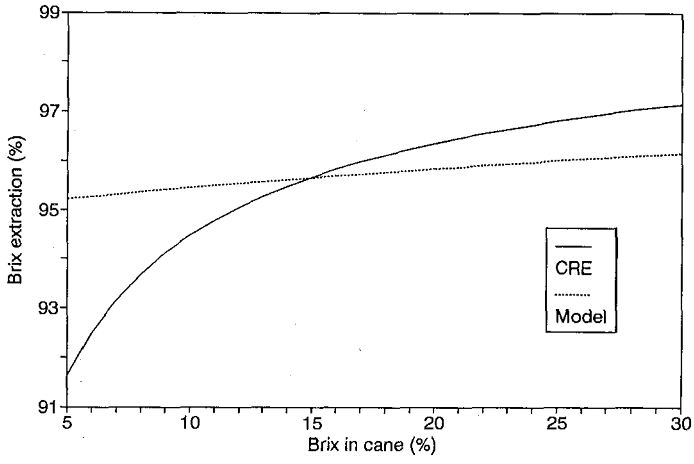

FIGURE 8 CRE and the effect of brix on brix extraction.

The combined effect of fibre and brix on brix extraction was calculated using the CRE model on the monthly data of 15 years. At the same time the "constant ratio" model was used on the same data. Although the latter model takes the imbibition into consideration as well as fibre and brix, the results were very much the same. This merely indicates that the imbibition levels have not changed much over the last 15 years. Figure 9 shows the brix extraction as calculated by the two models.

Applications of the model

The model would be much more useful if the brix extraction could be related to the sucrose extraction. Lionnet (1981) developed an empirical relationship between cane purity, mixed juice purity and sucrose extraction. Based on this relationship an equation of the following general form was derived:

Sucrose extraction $= a * \textit{Brix extraction}^2 + b * \textit{Brix extraction} + c$

where "a", "b" and "c" are constants. In order to calculate these constants three brix extractions and their corresponding sucrose extractions must be known. The first is the 0% brix extraction corresponding to a 0% sucrose extraction. The second is the 100% brix extraction which coincides with a 100% sucrose extraction. The third is the standard brix and sucrose extraction. With a standard brix extraction of 95,65% and a corresponding standard sucrose extraction of 97,33% the constants "a", "b" and "c" are −0,00404; 1,40428 and 0,0 respectively. With these three constants known, matching sucrose extractions can now be calculated from non-standard brix extractions. The foregoing applies to milling tandems as well as to diffusers.

With this addition the model provides a means to calculate mass balances on fibre, brix, water and sucrose whereby the output is a function of the input. Changes in the input can come from two sources, the amount of imbibition and the composition of the cane. While changes in the former are just straightforward increases or decreases in the level of imbibition, most of the changes in the latter are the result of seasonal effects and/or variations in harvesting practices, *i.e.* burning or trashing. The effect of these changes on the output touches on the performance of subsequent processes. The amount of juice together with the brix impact on evaporator capacity. On its own the brix is a measure of extraction and is directly related to sugar output. The suspended solids in juice control the load on the clarifier and mud filters. Bagasse normally serves as fuel for the boilers and both its quantity and quality influence boiler operation. The quality is mainly determined by its calorific value on which moisture and brix have an adverse effect. Too little or bad bagasse could mean the need to burn additional fuel in the form of coal.

The model could prove its usefulness in the study of all these effects. Some examples are the effect of imbibition on extraction and the moisture % bagasse, the effect of cane burning on the quantity of bagasse and the influence of seasonal changes in fibre and brix in cane on extraction. Figure 10 shows an example of the possible effect of the imbibition % fibre on sucrose extraction and moisture % bagasse based on the figures given above.

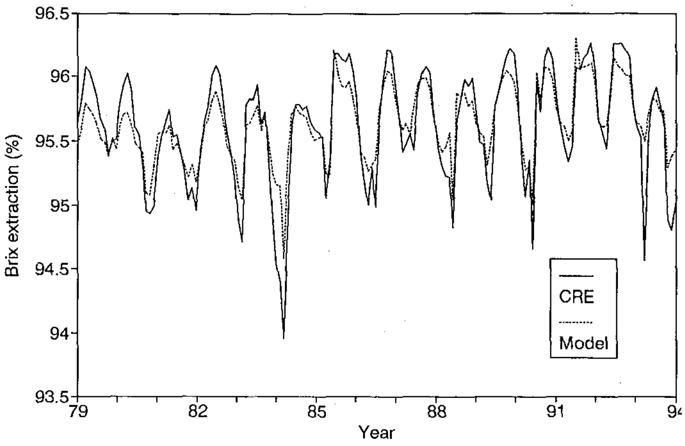

FIGURE 9 CRE and brix extraction.

Table 5

Standard mass balance at imbibition of 186% on fibre

	% Fibre	% Water	% Brix	% Purity	Mass Fl
Cane	14,15	72,27	13,58	82,70	100,00
Juice	0,90	85,97	13,13	83,06	95,22
Bagasse	45,05	51,30	3,65	78,43	29,51
Imbibition	0,00	100,00	0,00	0,00	24,73

Table 6

Calculated mass balance at imbition of 250% on fibre

	% Fibre	% Water	% Brix	% Purity	Mass Fl
Cane	14,15	72,27	13,58	82,70	100,00
Juice	0,89	86,95	12,15	83,06	103,50
Bagasse	44,73	51,89	3,38	78,43	29,57
Imbibition	0,00	100,00	0,00	0,00	33,06

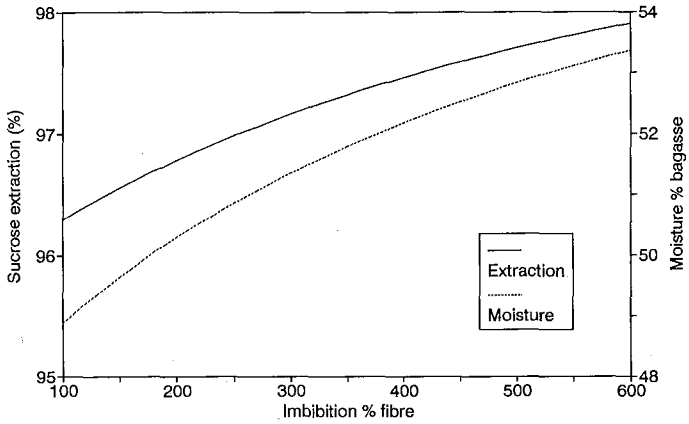

FIGURE 10 The effect of imbibition on sucrose extraction and moisture % bagasse.

The model was recently used to investigate the effect of an increase in imbibition on the mass balance from a particular factory. The standard mass balance of that factory at 186% imbibition on fibre is given in Table 5 showing a sucrose extraction of 92,47%.

This standard mass balance has ratios for [fibre % juice]/[fibre % bagasse], [brix % juice]/[brix % bagasse] and [water % juice]/[water % bagasse] of 0,020; 3,593 and 1,676 respectively. The constants relating brix extraction to sucrose extraction are a = −0,00056; b = 1,05608 and c = 0,0. Based on these figures the new mass balance at 250% inbibition was calculated and is given in Table 6. The sucrose extraction at that imbibition level is 93,02%.

All this is however only meaningful under constant operation conditions. Changes such as a change in fibre throughput, the addition of a mill, better cane preparation, different mill settings, *etc.* will most likely change the concentration ratios and therefore diminish the validity of the model. The model should also be applied within realistic limits. An imbibition level which causes flooding in the diffuser is typically outside these limits. Apart from being used for individual factories the model can also be employed for the industry as a whole to compare factories, in which case one needs to agree on common standards.

Conclusions

Using the "constant ratio" model on historical data of 15 years to calculate front end mass balances was surprisingly successful, surprising because of the relatively simple assumption of constant ratios of [fibre % juice]/[fibre % bagasse], [brix % juice]/[brix % bagasse] and [water % juice]/[water % bagasse]. All variables showed good agreement between calculated and actual values with the exception of the fibre % juice. When comparing the model with the CRE one, the effect of fibre was very similar in the usual fibre range while the effect of brix was somewhat less. The brix extraction calculated with both models did however give very much the same results. As the model describes the effect of cane quality and imbibition on the amount and composition of bagasse and juice, it can be used to predict the effect of changes in the input and to evaluate front end performance.

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