MILL SETTINGS AND EXTRACTION

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Abstract

Various ways of calculating mill settings are discussed. In particular the Natal and Australian methods are dealt with in more detail. Based on the mill settings an extraction model for a milling tandem is presented. This model takes into account a separation efficiency, reabsorption coefficient and imbibition efficiency, each of which is described. The model is tested against real factory data.

Introduction

Extraction is a constant area of concern to every mill engineer. The influence of mill settings, cane quality, imbibition etc. on extraction is extremely difficult to quantify. An extraction model could help to alleviate this problem, could result in a better understanding of the extraction process and could eventually lead to an improved extraction. The extraction depends on the operation of the mills on the one hand and the characteristics of the bagasse on the other. Typical operational parameters are the number of mills in a tandem, cane throughput, applied hydraulic loading, mill speed, amount of imbibition, roller roughness and mill lift. Typical bagasse characteristics affecting the extraction are fibre percent cane, pol percent cane, ash percent cane and cane preparation. Several attempts have been made to quantify the effect of these individual parameters with little or no success. This is especially the case with extraction figures as high as 98% where one looks at marginal variations. What is needed is an empirical figure which combines the influence of some of these more difficult parameters. Fortunately this figure is already available in the form of "fibre % discharged bagasse", which forms either directly or indirectly the basis for the calculations of mill settings. Extraction should then be looked at in close relation to mill settings and that will be done in this paper. After a look at mill settings, an extraction model will be discussed and tested, which is based on the work carried out by Murry and Holt[5].

Mill settings

A recent review of the various methods of calculating mill settings is given by Upadhiaya[7]. All methods amount to calculating the work opening from a figure which expresses the degree of compression found in a milling unit. The set openings are subsequently calculated by subtracting the mill lift from the work opening while taking into account the mill housing inclination. With a standard inclination of 20 degrees this works out as:

set opening = work opening - 0.8 * mill lift

In South Africa the most common mill setting calculations used are the Natal method and the Australian method. These are very similar and are variations of a method developed in Java as far back as 1923.

The Natal method

The Natal method was developed by the Sugar Milling Research Institute and presented for the first time by van Hengel and Douwes Dekker[8] in 1958. It uses the fibre % bagasse in the nip between top and discharge roll to calculate the delivery work opening. A feed to delivery ratio is used to obtain the feed work opening:-

$$Kd = \frac{286 * 10^4 * C * F}{D * L * N * B} \qquad Kf = Kd * R$$

Fibre % discharged bagasse figures derived from information given by the various sugar factories are shown in Table 1.

Table 1
Fibre % discharged bagasse

Mill	UK	NB	MS	ME	DL	GH
1	32,00	32,35	29,71	26,85	30,00	38,82
2	34,00	30,08	33,68	30,14	33,20	42,05
3	36,00	30,46	37,82	33,43	36,10	45,29
4	38,00	35,58	39,12	36,55	39,60	48,52
5	44,00	35,04	43,18	41,19	42,80	51,22
6	48,00	37,74	45,88	42,70	46,00	62,00
7	49,00	-	49,91	49,60	48,00	-

The Australian method

The Australian method is, in South Africa, typically used on the Australian originated Walker mills. This method is based on what is called the "Fibre Fill" which is defined as the weight of fibre per unit area of roller surface. Both the delivery and the feed work opening are calculated using fibre fills:

$$Kd = \frac{5305 * 10^4 * C * F}{D * L * N * Fd} \qquad Kf = \frac{5305 * 10^4 * C * F}{D * L * N * Fd}$$

The discharge fibre fills for the various mills, corresponding with the fibre % discharged bagasse as given in Table 1, are given in Table 2.

Table 2
Discharge fibre fills

Mill	UK	NB	MS	ME	DL	GH
1	593,57	600,00	551,03	498,00	556,47	720,00
2	630,66	558,00	624,72	559,00	615,83	780,00
3	667,76	565,00	701,61	620,00	669,62	840,00
4	704,86	660,00	725,63	678,00	734,54	900,00
5	816,15	650,00	800,92	764,00	793,90	950,00
6	890,35	700,00	851,06	792,00	853,25	1150,00
7	908,90	-	925,86	920,00	890,35	-

In the above equations the following legends apply:-

Kd = delivery work opening in mm
Kf = feed work opening in mm
C = cane throughput in tons/hour
F = fibre % cane
D = average roll diameter in mm
L = roll length in mm
N = roll speed in rpm
B = fibre % discharged bagasse
R = feed to delivery work opening ratio
Fd = fibre fill at discharge opening in kg/m^3
Ff = fibre fill at feed opening in kg/m^3

Typical mill settings are shown in Table 3, which are those for Gledhow in the 1989 crushing season. These settings are based on a cane throughput of 200 t/h with a fibre % cane of 15,09%.

Table 3
Gledhow mill settings

Description	Mill 1	Mill 2	Mill 3	Mill 4	Mill 5	Mill 6
Diameter	1079,00	1070,00	1072,00	1068,00	1056,00	1079,00
Length	2134,00	2134,00	2134,00	2134,00	2134,00	2134,00
Speed	3,00	3,00	3,00	3,00	3,00	3,00
Mill lift	10,00	10,00	10,00	10,00	10,00	10,00
Fib % bag	38,82	42,05	45,29	48,52	51,22	62,00
f/d ratio	2,48	2,44	2,51	2,50	2,50	2,72
ff delivery	290,00	320,00	335,00	360,00	380,00	423,00
ff feed	720,00	780,00	840,00	900,00	950,00	1150,00
Set opening						
feed	87,91	84,93	80,61	74,76	71,30	85,71
delivery	30,63	30,13	27,34	25,10	23,72	26,47
Work opening						
feed	95,91	92,93	88,61	82,76	79,30	93,71
delivery	38,63	38,13	35,34	33,10	31,72	34,47

Both fibre % discharged bagasse and fibre fills are figures related to the degree of compression in a mill. To establish these figures is not an easy task and is generally an estimate, based on a sound understanding of the milling process and experience with the specific milling tandem. The divergence of these estimates is clearly illustrated by the figures in Table 1 and 2. In particular the fibre % discharged bagasse figures of the last mills lead to some interesting observations. With only a small percentage brix in final bagasse and an average moisture of 50%, these figures indicate for UK, MS, ME and DL mills a moisture in bagasse of approximately 50%, which is about right but leaves little or no room for reabsorption. For GH the moisture in bagasse is about 38%, which allows for a substantial reabsorption, while for NB this figure is 62%, which leads to a negative reabsorption. A negative reabsorption coefficient however is most unlikely and the fibre % discharged bagasse of NB is probably wrong. This mill is obviously not doing what one expects it to do which does not necessarily mean it is doing badly. After all, the calculation of mill settings is not so much a calculation of how the mill is going to operate as how one expects it to operate. A knowledge of the actual operation of a mill is however essential in order to optimize milling performance.

Extraction Model

In the South African sugar industry a milling tandem consists of 6 or 7 milling units. Cane is fed into the first mill and subsequently into the following units with bagasse leaving the tandem. The expressed juice from the first and second mills, together forming the mixed juice, is pumped away for further processing while the juice from the other mills is pumped in front of the preceding mills as imbibition juice. Imbibition water is applied just before the last mill (Figure 1).

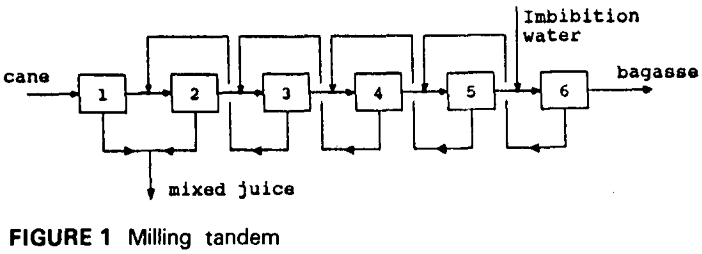

FIGURE 1 Milling tandem

A simple model can be developed by applying a straightforward mass balance on fibre, brix and water based on the following assumptions:

- The fibre through the mills is constant with all the fibre ending up in the bagasse and therefore leaving no suspended solids in mixed juice. This results directly in the amount of imbibition for a given imbibition % fibre in final bagasse
- The fibre % discharged bagasse for each mill is equal to the fibre % bagasse used to calculate the mill settings. In this way the residual juice and in turn the expressed juice can be easily obtained
- The brix % expressed juice for each mill is equal to the brix % residual juice. By doing so, the brix in mixed juice and therefore the brix extraction are easily calculated.

When the model is used in this form, the results are not reflecting the true situation. The imbibition and mixed juice are much too high while the final bagasse is too low. This leads to an inflated extraction, a situation which is aggravated by the fact that the brix % mixed juice is also higher then expected. Refinements to the model have to be made in the form of a separation efficiency, a reabsorption coefficient and an imbibition efficiency.

Separation efficiency

By assuming that all the fibre ends up in the bagasse, the amount of imbibition, which is based on that fibre, will be too high. This will lead, amongst other things, to a quantity of mixed juice which is in excess. The obvious solution to this problem is to allow for some of the fibre to end up in the expressed juice in the form of suspended solids. The introduction of the separation efficiency, which is defined as one hundred minus suspended solids % expressed juice, makes provision for this. This coefficient is mainly a function of cane quality and to a lesser extent of cane preparation. For the purpose of simplicity it is assumed that this factor is the same for all mills in the tandem.

Reabsorption coefficient

The volume of bagasse passing through the mill is normally greater than the escribed volume. This means that the fibre % discharged bagasse is lower than the fibre % bagasse figures used to calculate the mill settings. This phenomenon, which is well covered in the literature by Munro[4], Jenkins[2] and Hugot[1] is believed to be caused by a combination of extrusion, forward slip and reabsorption. The term reabsorption factor has been generally adopted and is defined as the ratio of the no-void bagasse volume to the escribed volume or, which is the same, the ratio of the fibre % bagasse in the mill to the fibre % bagasse after the mill, i.e.:

$$\text{Reabsorption} = \frac{\text{fibre \% bagasse in the mill}}{\text{fibre \% bagasse after the mill}}$$

In general this factor will be different for each mill in the milling tandem and is mainly a function of the speed, preparation, compression and to a lesser extent imbibition level. In the model however, again for simplicity, it is assumed that the reabsorption is the same for all the mills. Ignoring the reabsorption coefficient will lead to a low juice content of the final bagasse and therefore to an extraction which is too high.

Imbibition efficiency

The juice feed to a mill will normally not be homogeneous, i.e. the juice has a non-uniform brix distribution. Therefore the brix % expressed juice will in general not be equal to the brix % residual juice. The main reason for this is the incomplete mixing of the imbibition juice with the juice in the bagasse. The more diluted imbibition juice is more easily extracted than the latter which causes less brix to be extracted. Another reason is the presence of "brix free water" which has the opposite effect and leads to a slightly higher brix extraction. To account for this non homogeneous juice feed, the imbibition efficiency is introduced which is defined as the actual extraction divided by the theoretical extraction. The theoretical extraction is the extraction obtained when a uniform brix distribution exists in the juice feed. For the first mill, with no imbibition juice added, the imbibition efficiency can even be greater than 100%. For the other mills this factor will normally be below 100% and will be different for each mill in the tandem. According to Murry and Holt[5] the imbibition coefficient is influenced to some extent by the imbibition level and markedly by the brix of the imbibition liquid. Sullivan[6] mentioned cane preparation, imbibition application and juice extraction as the main factors. For the purpose of the model however it is assumed that the imbibition efficiency for the first mill is 100 while from the second mill onwards it is the same for every mill.

Model Application

One way of using the model is to establish the separation efficiency, the reabsorption coefficient and the imbibition efficiency from known factory data such as brix extraction, suspended solids in mixed juice, moisture in bagasse etc. These data are shown for Gledhow in the top part of Table 4 for six successive seasons. From these data together with the fibre % discharged bagasse figures from Table 1, the separation efficiency, the reabsorption coefficient and the imbibition efficiency are calculated and shown in the bottom part of Table 4.

Table 4

Factory data for GH for various seasons

Years	1984	1985	1986	1987	1988	1989
Fibre % cane	15,67	15,67	15,66	15,74	16,24	15,07
Brix % cane	14,25	15,68	14,36	13,40	14,25	15,37
Susp.s % MJ	0,67	0,65	0,57	0,58	0,56	0,57
Brix % MJ	11,03	12,12	11,16	10,74	11,32	12,88
Moist % bag	50,01	49,36	49,15	48,02	47,25	48,03
Brix % bag	1,74	1,72	1,54	1,48	1,50	1,48
Imb % fibre	371,36	373,04	366,55	335,34	335,68	309,66
Brix extr.	96,25	96,66	96,74	96,70	96,81	97,25
Separ. eff.	99,33	99,35	99,43	99,42	99,44	99,43
Reabs. cff.	1,28	1,27	1,26	1,23	1,21	1,23
Imbib. eff.	76,52	77,05	77,20	77,53	77,60	80,24

The separation, the reabsorption and the imbibition coefficient remained reasonably constant. Over the years the reabsorption coefficient has slightly decreased with a minor upswing in 1989. This decrease went together with a decrease in the moisture of the final bagasse to which it is directly related. The higher the reabsorption the higher the moisture in bagasse. The extraction has increased over the years despite a decrease in imbibition. This is mainly due to an increase in the imbibition efficiency. In 1989 the imbibition efficiency took a remarkable jump as did the extraction. Cane quality and in particular an increase in the pol to fibre ratio was mentioned as the main reason for this jump.

A totally different picture occurs when one looks at the different mills. Table 5 shows the process data and the separation, the reabsorption and the imbibition factor, for the 1989 season of all the milling tandems in the South African sugar industry.

Table 5

Factory data for various mills in 1989

Mills	UK	NB	MS	ME	DL	GH
Fibre % cane	15,94	14,75	15,16	14,31	14,62	15,07
Brix % cane	14,89	16,04	15,00	15,22	15,63	15,37
Susp.s % MJ	0,75	0,89	0,59	0,76	0,73	0,57
Brix % MJ	11,68	13,89	11,77	12,80	12,86	12,88
Moist % bag	50,28	51,28	54,97	51,28	53,55	48,03
Brix % bag	2,33	2,64	1,90	2,17	2,16	1,48
Imb % fibre	351,72	288,00	384,50	318,81	344,39	309,66
Brix extr.	95,04	95,09	95,75	95,88	95,70	97,25
Separ. eff.	99,25	99,11	99,41	99,24	99,27	99,43
Reabs. cff.	1,03	0,82	1,16	1,07	1,08	1,23
Imbib. eff.	71,64	71,50	76,28	78,35	75,54	80,24

The separation efficiency does not vary much from mill to mill. This cannot be said of the other two factors. The imbibition efficiency ranges from 71,50% to 80,24% and is directly related to the extraction. The higher the imbibition efficiency the better the extraction. Reabsorption diminishes the effective squeezing action of the mill through the increase in juice in bagasse in the mill to bagasse after the mill. One should therefore look at the reabsorption coefficient in conjunction with the fibre % discharged bagasse as shown in Table 1. The reabsorption coefficient acts as a correction factor for the fibre % discharged bagasse to calculate the true fibre % discharged bagasse after the mill. When comparing different factories, one should therefore rather look at the fibre % discharged bagasse divided by the reabsorption coefficient. When this is done for the last mill in the tandem the result is the fibre % bagasse in final bagasse. Table 6 shows these fibre % bagasse in final bagasse for the various factories during the 1989 season.

Table 6

Fibre % bagasse in final bagasse

Mills	UK	NB	MS	ME	DL	GH
Fibre % bag	47,39	46,08	43,13	46,55	44,28	50,49

Since final bagasse comprises mainly fibre and moisture and only a relatively small proportion of brix, the fibre % bagasse in final bagasse is directly related to moisture in final bagasse. A high fibre in final bagasse follows from a low bagasse moisture and vice versa. The high moisture figure for MS and the low figure for GH thus explains the opposite fibre figures for these tandems.

Alternatively the model can be used to predict the outcome of the milling process from known separation, reabsorption and imbibition coefficients. This prediction however is as good as these coefficients are constant. Fortunately it was found that for a particular factory they vary only slightly especially within a season. For GH the average values for the separation, reabsorption and imbibition coefficients during the 1989 season were 99,43; 1,23 and 80,24 respectively. These figures were successfully used to calculate the brix extraction for that year on a monthly basis. Figure 2 shows this calculated brix extraction in comparison with the actual brix extraction.

At this stage only the brix extraction is calculated but it is of course the extraction of sucrose that is of interest. Lionnet[3] has presented an empirical relationship between cane purity, mixed juice purity and sucrose extraction. For a milling tandem this relationship has the form:

$$Cp/Jp = 0,467 + 0,00533 * Sx$$

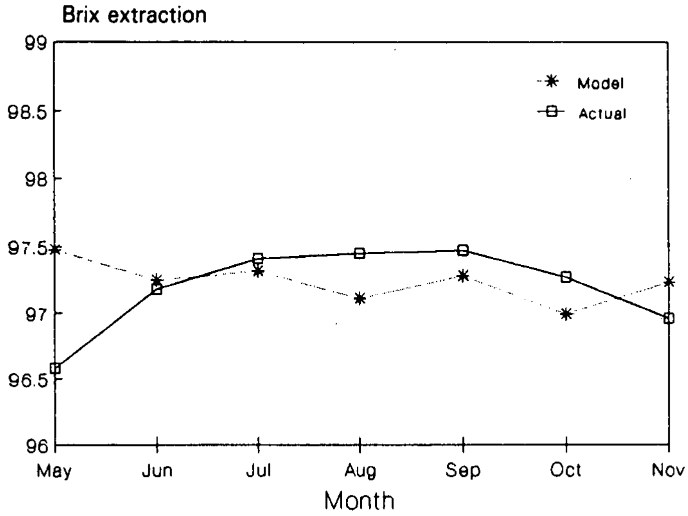

FIGURE 2 Brix extraction

From this equation the sucrose extraction can be expressed as a function of the brix extraction:

$$Sx = \sqrt{1919 + 187{,}6 * Bx} - \sqrt{1919}$$

in the above equations the following legends apply:

Cp = cane purity
Jp = mixed juice purity
Sx = sucrose extraction
Bx = brix extraction

From the brix extraction the sucrose extraction can now be calculated. Figure 3 shows this calculated sucrose extraction in comparison with the actual extraction of sucrose.

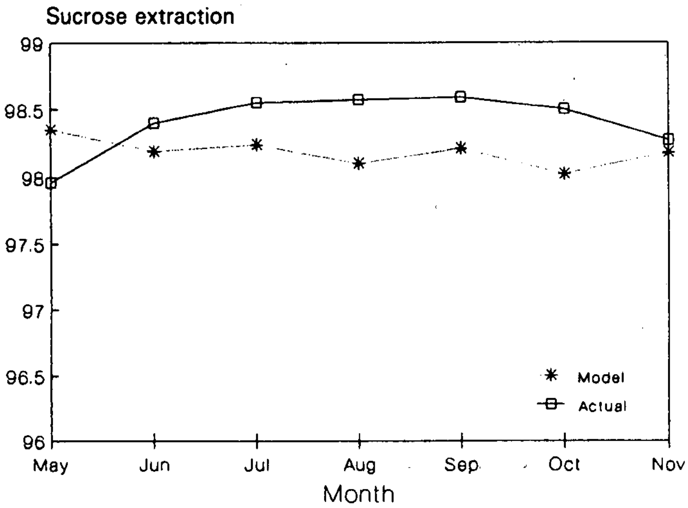

FIGURE 3 Sucrose extraction

It is common knowledge that an increase in imbibition water results in an improved extraction. The problem however is to quantify this relationship between imbibition and extraction. Unfortunately the available data show little variation in the imbibition figures and do not warrant any conclusions in this respect. Based on the model it is possible to draw a curve of extraction as a function of the imbibition. Figure 4 shows this curve for both brix and sucrose extraction based on the GH data for the 1989 season. Hugot[1] quotes a sucrose extraction of about 86-90% for dry crushing which is only slightly higher than indicated in the graph. At

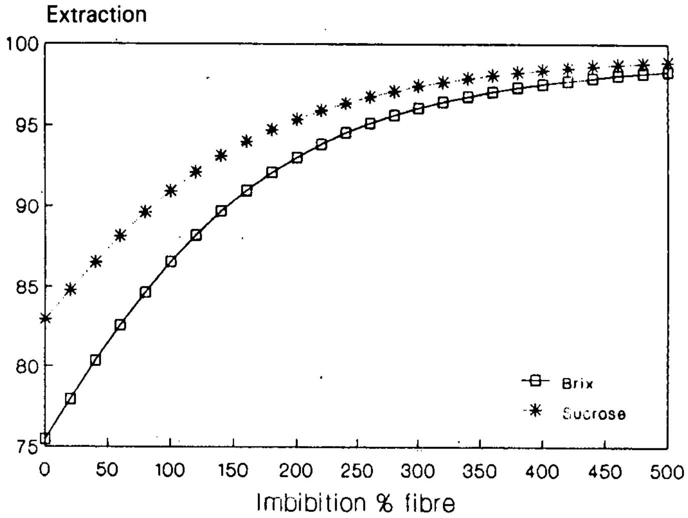

FIGURE 4 Extraction versus imbibition

the normal imbibition rates the graph should fit reasonably well since it is based on historical data of separation, reabsorption and imbibition efficiency.

The model does not only determine extraction, it calculates the mixed juice and final bagasse and their compositions. Since a mass balance, on brix, fibre and water, is carried out for each mill, the interstage juice and bagasse also form part of the output.

Conclusions

The model can be used in two ways. Firstly it can be used as a diagnostic tool by establishing the actual separation, reabsorption and imbibition coefficients from a known output. These coefficients provide information on the milling process on the basis of which steps can be taken to improve this process. Alternatively the model can be used to predict the outcome of the milling process from known separation, reabsorption and imbibition coefficients. Parameters such as extraction, suspended solids in mixed juice and moisture in bagasse, etc. then all form part of the output of the model. The model has proven to be quite successful in both applications.

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