A MILLING REVIEW

A WIENESE

Sugar Milling Research Institute, Durban

Abstract

This review deals with equipment, operation and performance of mills in a tandem or as dewatering units as presently found in the South African sugar industry. With milling tandems gradually being replaced by diffusers the emphasis will be particularly on the last mill. On the equipment side items that are considered are the number of mills, mill rolls, roll grooving, feeding devices, trash plates and mill drives. On the operation side they are the mill settings, hydraulic loading, mill speed, arcing and control that are investigated. The most common performance indicators for the extraction plant as a whole are extraction and bagasse moisture with little or no indicators for individual mills. Some performance parameters for these mills are suggested.

Introduction

In the South African sugar industry milling tandems have slowly been replaced by diffusers over the years. Diffusers were first introduced in South Africa in the 1966/67 crushing season at UC and EN simultaneously. In 1984 the number of diffusers had increased to 14 out of 21 extraction plants. With more recently UF (1989), UK (1991) and MS (1995) changing from mills to diffusers, the opening of KM (1994) and the closing of ME (1994) the number of diffuser plants stands at 18 with only three milling tandems left; GH, DL and NB. NB, then called Jaagbaan (JB), was built in 1967 and is the latest factory with a milling tandem. All subsequent factories were fitted with diffusers. If this trend continues, and there is no reason why it should not, it is just a matter of time before milling tandems will be phased out of the South African sugar industry. In view of the above it is only logical that a paper on milling should concentrate on dewatering mills. Fortunately most matters that apply to dewatering mills apply equally to mills in a milling tandem.

Milling performance is usually measured in terms of extraction for milling tandems and bagasse moisture for dewatering mills. These parameters are however, affected very much by the quantity and quality of the input to the tandem or mill over which the "miller" has very little control. More controllable factors are in the choice of equipment and the method of operation. Some of these more important factors, in the view of the author, will be discussed in this milling review. Most of the information comes from the "Handbook of Cane Sugar Engineering" (Hugot, 1986), the "South African Sugar Factory Plant Installations" (Reid, 1992), SASTA papers and personal communications with factory staff. The factory data used are from the 1991/92 season since the subsequent seasons were abnormal due to drought conditions.

Milling equipment

Number of mills

The financial structure of the South African sugar industry and the long crushing season made it economically sensible for millers to invest in capital equipment which facilitated high extraction. Milling tandems are therefore usually long in comparison with other countries. The DL tandem consists of seven mills while the GH and NB tandems are each six mills long. While diffusers started as bagasse diffusers, at present there are only two that are preceded by mills: EN and GD. With the improvements in preparation equipment this arrangement will most likely disappear in favour of cane diffusers. After the diffuser the number of mills ranges from one to three. Where more mills are present they are arranged in series, in parallel or in a combination of the two. When mills are operating in series some imbibition is usually applied between the two mills. Mills in series have the advantage of multiple squeezes while mills in parallel have the advantage of a lower throughput per mill. Although the debate on the merits of each system continues, some experiments at SZ in 1989 did not show any preference for either configuration. There is however no doubt that there is a trade-off between throughput and performance. Column 6 in Table 1 shows the throughput of the last mill in tons fibre per hour.

Table 1

Equipment parameters for the last mill

Factory		Roll numbers	Groove pitch (mm)	Groove angle (°)	Mill power (kW/tfh)	Fibre load (tfh)
ML	*	5	25	45	18,1	31,0
PG	*	4	50	45	15,0	30,0
UF	*	5	50	35	33,3	22,5
EN	**	3	40	45	25,7	14,0
FX-A	*	6	50	40	25,4	26,0
FX-B	*	6	50	40	25,4	26,0
AK	*	5	50	40	26,7	11,0
DL		4	50	35	13,3	48,0
MS-A	*	5	50	45	17,0	33,0
MS-B		5	50	45	15,0	30,0
ME		5	38	55	13,6	33,0
GD	**	4	25	55	29,2	13,0
GH-A	*	4	50	45	25,3	19,0
GH-B		4	50	45	15,5	23,0
NB		4	50	50	14,1	46,0
UC	*	4	38	45	32,6	24,8
IL	*	4	50	45	24,2	31,0
SZ-A	*	6	38	40	38,2	15,0
SZ-B	*	6	50	40	38,2	15,0
UK	*	4	50	45	13,2	34,0

* Cane diffuser
** Bagasse diffuser

Mill rolls

Mill rolls consist of a cast iron shell heat shrunk onto a steel shaft. Tests to bond the shell to the shaft using an epoxy resin adhesive were carried out at ME and NB with limited success (Lawrence, 1985). The shell width is fairly standard at seven feet or 2134 mm. There are some shorter shells but they are the exception rather than the rule: EN (1676 mm), GD (1676 mm) and UC (1980 mm). Much more variation is found in the shell diameter ranging from 863 to 1168 mm for the last mill. The effect of the roll width must be linear in terms of throughput. The effect of the roll diameter is still very much under discussion. In Australia where the throughputs are usually much higher, the roll dimensions are generally also higher. Mayo and Wright (1983) mention rolls of

2750 mm wide with a diameter of 1375 mm weighing 42 tonnes. In spite of the robust construction of mill rolls, breakage of these rolls occurs at an average of one roll per factory per season (Reid, 1988). A mill consists of three rolls with up to three additional rolls depending on the feeding arrangement, one roll for an underfeed roll and two rolls for a pressure feeder. Table 1 column 2 gives the total number of rolls in the last mill.

Roll grooving

There are three types of roller grooving: circumferential, chevron and messhaert or juice grooving. The circumferential grooves are vee grooves circumferentially on the surface of the roll characterised by angle and pitch. The angle is usually between 35 and 55°. Below this value there is a danger of breakage, especially where deep grooves are adopted. The pitch of the grooves varies between 25 mm and 75 mm with 50 mm being the most popular. The smaller pitch is normally used in the last mills to facilitate juice drainage. Chevrons are vee grooves cut along the length of the roller to assist in feeding. The depths of these grooves are made slightly less than those of the circumferential grooves, to prevent the scraper tips from being caught. Chevron grooves are spaced about 200 mm apart and are inclined from the horizontal by between 16 to 25°. Messhaert grooves serve to improve extraction by promoting juice drainage. These grooves are typically found on the bottom rolls, particularly the front roll, and not the top roll. Juice grooves are either in between two circumferential grooves or in place of a circumferential groove. The width is normally not more than 20 mm and the depth varies between 20 and 50 mm depending on the quantity of juice to be handled. The pitch varies with that of the circumferential grooves and the amount of juice to be drained. Columns 3 and 4 of Table 1 show the pitch and angle of the circumferential grooves, respectively.

Feeding devices

With increasing throughputs a problem arose with the bagasse feed into the mills. Various feeding devices have been developed over the years to overcome this problem. Of these only a few are presently used in the South African sugar industry: the Donnelly chute, the underfeed roll and the pressure feeder. Each of these can be used on its own or in combination with any of the others. Most mills are presently fitted with Donnelly chutes. These are tall (3 to 6 meter) chutes in which the bagasse is forced by its own weight into the mill. The chute is divergent towards the mill by about 2° to prevent choking. Underfeed rolls are usually of smaller diameter than the main rolls and are arranged above the feed roll. They usually have grooves the same as the circumferential grooves of the mill rolls. They are driven either by chain and sprockets from the feed roll or by gears from the top roll, at a surface speed equal to that of the mill rolls. The two roll pressure feeder, developed in Australia and almost a standard in that country, is widely used in South Africa especially on the last mill. The rolls, which are the same size as those of the mill, force the bagasse into the mill. While most pressure feeders are driven off the same prime mover as the mill, FX has a separate turbine for this. The spikey tooth pressure feeder, also an Australian invention, provides an even more positive feed but has only been tried at AK and has never become popular in this country (van Breda, 1984). The number of rolls in column 2 of Table 1 is an indication of the feeding arrangement.

Trash plate

The purpose of the trash plate is merely to turn the bagasse into the discharge nip and not to extract juice from the bagasse. Trash plates are made of cast steel, cast iron or malleable iron. In a recent survey (Fairclough, 1988), cast steel was found to be the most common. The top of the teeth at least are hard faced but more often this is extended to the full surface. The roots of the teeth should not be hard faced as this could wear away the tips of the teeth on the roll and thus affect milling performance. Wear on the trash plate takes place at the front where the trash plate meets the feed roll and on the surface. When the wear causes a big gap between the trash plate and back roll resulting in bagasse droppings, packing plates are sometimes bolted to the back of the trash plate.

Mill drives

Although much work has been done in the past to ensure that mills are provided with the most efficient and economical prime movers, there has been a tendency to follow the turbine route, with scant attention being paid to the advantages of electrical and hydraulic drives. Turbines seem to have all the advantages for operation on sugar mills such as variable speed, quick response and constant torque. However installation cost and maintenance tend to be high. There is a variety of electrical drives in the industry. They are much more efficient and lower in maintenance but quite costly and less flexible. In South Africa there are virtually no hydraulic drives. They have a bad name due to a few unfavourable experiences. A limiting factor for a mill can be the installed power. Column 5 of Table 1 shows this installed power per ton of fibre for the last mill. The prime mover normally drives the top roll of the mill via a reduction gearbox. The top roll, in turn, drives the feed and discharge rolls using heavy pinions. Some experiments were done to operate the mill without a discharge pinion and let the bagasse do the driving. This was however never pursued.

Milling operation

Mill settings

The mill settings consist more generally of the settings of the three main rolls, the Donnelly chute, the underfeed roll, the pressure feeder and the trash plate. In South Africa the most common methods of calculating the relative positions of the mill rolls are the Natal and the Australian methods (Wienese 1990). These are very similar and are variations of a method developed in Java as far back as 1923. The Natal method was introduced by the Sugar Milling Research Institute and was presented for the first time by Van Hengel and Douwes Dekker (1958). It uses the fibre % bagasse in the nip between the top and discharge rolls to calculate the delivery work opening. A feed to delivery ratio is used to obtain the feed work opening. 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 fibre throughput on a mass basis divided by the escribed volume or volumetric flow. Both discharge and feed work openings are calculated using "fibre fills". Whichever method one chooses the most important point is that the mill lifts, after which the only parameter that can be manipulated and therefore has an effect on milling performance is the ratio between the discharge and feed work openings. This ratio which is normally around two is given in Table 2 column 2 for the various factories. At present smaller ratios are found where engineers are experimenting with Sullivan's theory that extraction should be done more on the front rolls leaving the back rolls to counteract the reabsorption. The opening of a Donnelly chute at the exit is normally between 8 and 10 times the discharge roll work opening for the last mill. The settings for underfeed

Table 2

Operation parameters for the last mill

Factory		Mill ratio	Roll force (MN)	Roll speed (m/min)	Arcing rods (kg/1000 t)	Bagasse moisture (%)
ML	*	1,9	5,6	9,4	–	52,7
PG	*	2,7	6,2	8,1	23,5	44,9
UF	*	1,6	4,5	3,4	9,6	53,1
EN	**	2,2	2,1	7,9	–	50,7
FX-A	*	3,0	6,3	8,6	7,1	51,8
FX-B	*	3,0	6,3	8,6	7,1	52,0
AK	*	3,6	4,5	4,7	2,8	50,0
DL		2,2	4,3	10,0	13,5	52,2
MS-A	*	1,4	3,8	9,1	7,5	54,0
MS-B		1,8	3,8	8,7	6,9	52,4
ME		2,0	4,5	9,7	13,4	49,9
GD	**	2,0	3,4	6,6	–	52,2
GH-A	*	2,5	5,7	5,9	14,7	50,2
GH-B		2,7	5,5	6,5	13,0	48,3
NB		1,9	4,4	9,0	21,8	52,8
UC	*	–	–	–	57,6	52,5
IL	*	2,2	5,5	7,9	10,2	49,4
SZ-A	*	1,5	4,3	3,4	11,7	49,2
SZ-B	*	1,5	4,3	3,4	11,7	48,3
UK	*	1,7	4,8	7,0	15,6	53,4

* Cane diffuser
** Bagasse diffuser

rolls and pressure feeders are usually 6 and 3 times the discharge work opening respectively. Although there appears to be as many ways of setting trash plates as there are mills, the differences are not great. The most important features are the height of the trash plate and the percentage drop over the length of the trash plate called the sweep. Recognising the fact that the actual pressing should be left to the rolls rather than to the trash plate, the present tendency is to opt for lower settings. The sweep is of the order of 4 to 5%.

Hydraulic loading

Originally the three rollers of a mill were fixed relative to each other. The pressure was then determined by the layer of bagasse passing through the mill. It increased with increasing throughput and decreased when the throughput dropped. The milling results varied accordingly. The greatest disadvantage of this system was associated with the passage of foreign bodies such as tramp iron or rocks. This led to the introduction of a floating top roll held under pressure by oil acting on hydraulic rams. This enables the top roll to lift with increasing feed while maintaining a constant pressure independent of lift and/or feed. Some mills also have, apart from this floating top roll, a floating discharge roll. The oil pressure is maintained by means of an accumulator of which the most common one to date is the Edwards accumulator. The average hydraulic system for a mill is designed for oil pressures between 25 and 35 MPa. The normal operating pressure is somewhat lower and is governed by:

- available power to drive the mill
- strength of the mill and mill rollers
- feeding of the mill
- maximum permissable bearing pressure (12 MPa)

The oil pressure results in a force on the mill roll. This force is often kept greater on the gear side than on the pintle side to compensate for pinion reaction. Values of the total hydraulic force on the roll are given in Table 2 column 3. Excluded from these forces are the forces due to the weight of the top roll and any accessaries which is in the order of 0,25 MN.

Mill speed

The mill speed depends mainly on the fibre throughput. An increase in this throughput requires an increase in speed and *vise versa*. In the South African sugar industry the circumferential speed for the last mill varies between 5 and 10 meters per minute. An increase in this speed usually goes together with a decrease in lift or with a thinner bagasse blanket. This phenomenon is due to a combination of factors and is known as reabsorption. The reabsorption factor which is defined as the volume of bagasse divided by the escribed volume varies between 1,1 and 1,3. Although a thin bagasse blanket in itself is an advantage, South African engineers favour low mill speeds when possible, because of the negative effect of reabsorption. Average mill speeds for the last mills are shown in Table 2 column 4.

Arcing

A high maintenance area in the mills is the treatment of the mill roll surfaces. In order to maintain a rough roller surface the rolls are continually arced. In the mid-seventies the industry changed from the old carbon arcing to arc welding which is now generally adopted. The arcing is applied to the tips and flanks of the roller grooving. The rods that are used are chromium based electrodes. The chrome forms an austenitic matrix of chromium carbides with a high resistance to wear together with good impact resistance and a hardness of about 58 HRc. The arcing procedure and the frequency of arcing vary enormously and appear to be open to improvement (Wienese, 1993). Table 2 column 5 shows the mass of arcing rod used per ton of fibre.

Control

The control strategy amongst the various factories is very similar. In the case of a milling tandem the first mill runs at a constant speed. The bagasse level in the chute controls the speed of the main carrier. In the subsequent mills the speed for each mill is controlled by the chute level of that mill. The same is the case for the dewatering mills. Some factories control the mill lift by changing the amount of imbibition and/or maceration juice. The latter is done by the recycling or by-passing of that juice.

Performance indicators

For a tandem as a whole the most common performance indicators are traditionally extraction and moisture % bagasse. The latter may perhaps also be seen as a measure of the performance of the last mill. Column 5 in Table 2 gives the moisture % bagasse for the various factories for the 1991/92 season. With a move towards diffusers it becomes more important to have performance indicators for the individual mills. These indicators are available in the form of brix extraction, reabsorption, imbibition efficiency, juice recycling and separation efficiency (Wienese, 1990). Each of these indicators emphasises a specific aspect. Apart from the first two they are hardly used in the South African sugar industry.

Brix extraction

Although the sucrose extraction is the most important and most widely used performance indicator, brix extraction is a more direct measurement of milling performance. This brix extraction for the first mill in a tandem can be in the eighties. For the other mills this figure varies widely but should not fall below 30%. The brix extraction is defined as:

$$\text{Brix Extraction} = 100 * \frac{\text{Brix in Expressed Juice}}{\text{Brix in Bagasse Feed}}$$

Reabsorption coefficient

Reabsorption is defined as the ratio of the no-void bagasse volume to the escribed volume. In general this factor is different for each mill in the tandem and is mainly a function of speed, preparation, compression, roll roughness and to a lesser extent imbibition level. In particular a decrease in the mill speed and an increase in arcing can lead to substantial improvements in the reabsorption coefficient. Typical values are somewhere between 1,0 and 1,3. A reabsorption factor smaller than 1,0 could be an indication of backward slip or an empty running mill. An alternative definition is:

$$\textit{Reabsorption Coefficient} = \frac{\textit{Fibre \% Bagasse in the Mill}}{\textit{Fibre \% Bagasse Discharge}}$$

Imbibition efficiency

The juice feed to a mill will normally not be homogeneous resulting in a decreased brix extraction. The main reason for this is the incomplete mixing of imbibition juice with the juice in the bagasse. To account for this the imbibition efficiency which is defined as the actual extraction divided by the theoretical extraction was introduced. For the first mill, not affected by imbibition, the imbibition efficiency can be even greater than 100%. For the other mills this factor is normally well below 100%. In equation form the imbibition efficiency is:

$$\textit{Imbibition Efficiency} = 100 * \frac{\textit{Brix \% Expressed Juice} * (100 - \textit{Fibre \% Bagasse Feed})}{\textit{Brix \% Bagasse Feed} * (100 - \textit{Fibre \% Expressed Juice})}$$

Juice recycling

Juice recycling is another interesting performance indicator but is not measured in the South African sugar industry and therefore no real factory data are available. The juice recycling is defined as:

$$\textit{Juice Recycling} = 100 * \frac{\textit{Liquid in Bagasse Discharge}}{\textit{Liquid in Bagasse Feed}}$$

Separation efficiency

The separation efficiency is a direct reflection of the suspended solids in mixed juice and is mainly a function of cane quality and to a lesser extent of cane preparation. In addition the setting of the trash plate affects the separation efficiency. This parameter is also not measured in the South African sugar industry. The definition of the separation efficiency is:

$$\textit{Separation Efficiency} = 100 * \frac{\textit{Fibre \% Bagasse Feed} - \textit{Fibre \% Expressed Juice}}{\textit{Fibre \% Bagasse Feed}}$$

Conclusions

With the increase in diffusers the function of the mill has shifted from an extraction device to a dewatering unit. This has however little effect on the design and operation of the mill which are both well established. Some differences in operation are equipment related while others are indicative that some fine tuning is still required. While the performance of a milling tandem is usually measured in terms of extraction of the tandem as a whole there seems to be a lack of performance measurements of the individual mills. This leaves particularly the dewatering mills without proper assessment.

Acknowledgements

Thanks are due to the staff of the various sugar mills for their quick response on some late requests for information.

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