AN APPROACH TO A RELATIONSHIP BETWEEN ROLL SHELL WEAR AND POL EXTRACTION

By

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Abstract

It is widely accepted that worn shells have a negative effect on pol extraction but there are few research reports on the subject. This paper presents research results where wear of roll shells and extraction performance at Manuelita Mill are related using historical data of the milling station and extraction models based on reabsorption coefficient. Some tools that have been developed and a list of economic model components are presented. It was concluded that wear of roll shells is a main factor that affects the performance of milling units. The estimation of loss on brix extraction is between 3.76% and 11.58% for a first mill unit.

Introduction

Wear of roll shells is one of the highest maintenance costs of cane sugar factories. Therefore, continuous evaluation of roll shell technologies is being made worldwide.

Roll shell technologies include a combination of hardfacing materials and geometry such as tooth pitch, angle and surface configurations.

These evaluations have focused mainly on the initial cost of roll hardfacing and how long the roll shell can be used before being changed or hardfaced again.

However, it is recognised that wear of roll shells also affects other factors like energy consumption, pol extraction and time loss, so it is evident that it is necessary to use more general models that account for these losses. This paper presents an estimation of the loss on pol extraction due to wear of roll shells using extraction models and process information from daily reports of the performance of milling units.

Some basics on classic volumetric crushing theory

For this paper, definitions developed and published by Murry and Holt (1967) are used:

Compaction

Compaction relates mill settings and fibre rate passing through the milling unit. It is defined as:

\[ \gamma = \frac{Q_f}{V_e} \]

where

- \( Q_f \) is the fibre rate (kgfibre/s).
- \( V_e \) is the volume escribed by the rolls (m³/s).

Reabsorption

In an ideal situation (without reabsorption), the escribed volume is filled completely by the bagasse and there is no slip, meaning that the escribed volume is equal to the bagasse volume.

If it is assumed that bagasse is fibre, natural juice and hygroscopic water, an expected relationship (without reabsorption) is obtained (Figure 1) between compaction and bagasse composition on the delivery side.
Figure 1 suggests that, if the mill is set at a compaction of 1100 kg/m³ approximately, it would extract all the natural juice having an extraction of 100% on a brix basis. However, the reality is different, and it has been demonstrated and treated extensively by different researchers (Crawford, 1959; Van Hengel and Dekker, 1960) that the performance of the milling unit is limited by reabsorption, leading to an optimal compaction for each milling unit. Therefore, the escribed volume is always smaller than the no void volume of the bagasse on the delivery side. The reabsorption factor is defined as:

\[ k = \frac{V_b}{V_a} \]

where

- \( V_b \) is the volumetric rate of bagasse delivered by the milling unit.

Compaction and reabsorption factor lead to an estimation of volumetric performance of the milling unit.

**Imbibition coefficient**

Imbibition coefficient measures the efficiency of the imbibition process, assuming that maximum performance is achieved when the residual juice is mixed perfectly with the imbibition juice or water.

\[ I = \frac{E}{E_k} \]

where

- \( E \) is the brix extraction of a milling unit, and
- \( E_k \) is the theoretical brix extraction, with a perfect mix of residual and imbibition juices.
With these parameters, the initial composition of the cane and the imbibition rate, it is possible to determine the expected brix extraction of a milling unit with the following expression:

\[
E = I \left[ 1 + \frac{B_i}{B_{i-1}} \frac{f_{i-1} \lambda}{f_i} \frac{1}{d_r} \left( 1 - \frac{d_f}{d_{i-1}} \frac{1}{f_{i-1}} \frac{d_f}{d_i} - 1 \right) \right]^{\frac{k}{1+c}}
\]

where
- \( E \) is the expected brix extraction
- \( I \) is the imbibition coefficient
- \( B_i \) is the brix fraction of the imbibition liquid
- \( B_{i-1} \) is the brix fraction of the bagasse of the previous milling unit
- \( f_{i-1} \) is the fibre content of the bagasse of the previous milling unit
- \( \lambda \) is the weight ratio between imbibition liquid and fibre
- \( d_i \) is the density of imbibition liquid
- \( d_f \) is the no-void density of fibre
- \( d_{i-1} \) is the bagasse density at the exit of the previous milling unit
- \( k \) is the reabsorption factor, and
- \( C \) is the filling ratio (is equal to compaction over fibre density).

So, with dependable models to predict imbibition coefficient and reabsorption factor, the expected extraction performance on a brix basis could be determined.

In order to work with a simpler model, a first mill was focused on, because, usually, it does not have imbibition, its performance is not affected by the performance of other milling units, and the first mill extraction has a major effect on overall extraction.

The simplified extraction formula for a first mill is:

\[
E_k = 1 - \frac{f_c d_c}{d_f - f_c d_c} \left( \frac{k}{1+c} \right)
\]

where
- \( E_k \) is the brix theoretical extraction
- \( d_c \) is the density of cane
- \( f_c \) is the fibre in cane
- \( d_f \) is the density of fibre

There is no imbibition coefficient for this formula, but a brix distribution coefficient is used and considered to be approximately 1.05.

As a prediction model for the reabsorption factor, the expression developed by Loughran and presented in Colombia by Murry (1996) will be used:

\[
k = 1.128 - 0.904 C_r - 0.473 S - 0.496 \hat{a} + 0.310 C_r \hat{a} + 0.560 C_r S
\]

where
- \( C_r \) is the compression ratio of the rolls
- \( S \) is the roll surface speed (m/s), and
- \( \hat{a} \) is Loughran’s ‘treatment number’ which describes the fineness of preparation of the cane

**Wear effect on first mill extraction**

The signs of wear on a first mill are as follows:
- The milling unit moves faster due to a progressive loss of feeding capacity.
The transverse section of the teeth is reduced with the loss of material.
Increase of fibre content in extracted juice with the loss of setting between the rollers and scrapers.

As the increase of fibre content in extracted juice will not affect a first mill without imbition, only the other two signs of wear were used with Loughran's prediction model for reabsorption, so values of expected extraction could be calculated for a first mill.

As basic assumptions, compaction for a first mill of 572 kg/m³ was used for a knifed cane with 16% fibre and 15% brix.

**Effect of increasing the roll shell velocity**

Wear leads to a loss of grip and this loss of grip is corrected by increasing mill velocity. Wear will affect the compression ratio, the reabsorption factor and the unit extraction.

For a monitored milling unit the change in mill velocity was recorded for the life cycle of the roll shells. The variation of this parameter is shown in Figure 2.

**Fig. 2—Increase in mill velocity (week average).**

The velocity of the mill changed from 4.0 to 5.3 r/min approximately, so roller speed increased 33%. Shells have 1.12 m diameter so tangential speed changed from 0.234 m/s to 0.311 m/s. This change in velocity implies a variation in the compaction, reabsorption coefficient and brix extraction.

**Effect of reducing cross-sectional area**

The loss of material causes the escribed volume to increase, affecting compaction and reabsorption factor. A photo of a typical cast steel worn tooth was taken and compared with the original shape (Figure 3).

**Fig. 3—Change of original shape of a tooth with wear.**
The reduction in cross section was 70.36 mm² for this tooth. Taking into account the number of teeth and the opening between the rolls for this mill, the escribed volume increased by 8.31% compared with the original setting.

Wear of teeth could have some compensation by lift reduction so that the only effect will be a higher mill velocity, keeping compaction near to the original figure. Two scenarios with and without lift compensation were explored. Data for this mill and the expected change in parameters are presented in Table 1.

<table>
<thead>
<tr>
<th>Table 1—Parameters and results.</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Treatment number</td>
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<tr>
<td>Surface speed (m/s)</td>
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<tr>
<td>Compaction (kg/m³)</td>
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<tr>
<td>Filling ratio</td>
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<tr>
<td>Brix distribution factor</td>
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<tr>
<td>Reabsorption coefficient</td>
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<td>Expected extraction (%)</td>
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As can be observed, first mill extraction could drop at least 3.8%, affecting overall extraction.

**Factory results**

In order to establish if a noticeable loss of pol extraction because of wear can be detected, data from routine analyses were processed. Data for a whole year (approximately 330 crushing days) were used. A graph of pol extraction vs. time is presented in Figure 4.

**Fig. 4—Variation of pol extraction (January 2003–January 2004).**

Figure 4 shows that there is a real effect of time (and wear) on first mill pol extraction and this is corrected when a worn roll is changed for a new roll. Pol extraction drops up to 10% before the roll change is made. The other milling units showed a similar behaviour.

Some observations were made.

Wear as a function of time has a real effect on pol extraction and it explains part of the progressive loss of extraction. However, there are events of low extraction efficiency where progressive wear of roll...
shells is not the primary cause, such as changes in cane quality, mechanical problems in other elements of the milling unit and lack of careful operation.

Manuelita S.A. has a standard practice of partial mill overhaul which means that mill rolls are not replaced simultaneously and do not have the same life.

This practice is a limitation for an absolute wear effects study, because it is only possible to evaluate combinations of different roll wear status. Many other factors influence mol extraction, such as preparation and cane quality.

These factors were not considered in detail in this study because long periods were studied and these effects are hidden (averaged).

Another major problem for this kind of study is that direct measurement of shell worn surfaces is extremely difficult, because it is not possible to take out the roll from the mill every time.

Available time for measurements is short during a normal continuous crushing season and, furthermore, a roll is never evenly worn and some breakages in random places eventually occur even for a cast steel roll.

**Experimental mill**

Another kind of evaluation tool should be developed, which would enable simulation of operational conditions similar to the milling units at the factory.

It should be able to stop any time without affecting factory performance and evaluation of worn grooving, and its effect on mol extraction should be performed without major difficulties. An experimental mill (Figure 5) is being developed for these purposes.

![Experimental mill](image)

**Fig. 5—Experimental mill.**

**Grip-meter**

Another tool that has been developed to assess wear of roll shells and its effects on milling station performance is the grip-meter (Figure 6), which allows the measurement of the feeding characteristics of a particular topography obtained by arc welding or any other means. This device is attached to the bar that holds the scraper for the feed roll and allows the highest static friction factor between the hardfaced roll and a sample of bagasse to be recorded.

Bagasse is pressed against the top roll and the peak frictional force is measured. Grip performance of different kinds of topographies and different kinds of hardfacing materials, before and after partial wear, can be assessed.
Elements of an economic model

It has been shown that wear of mill roll shells has a real effect on pol extraction, but there are other effects that could be associated with this phenomenon, and all of them have to be accounted for if an economical feasibility for roll hardfacing technology is going to be evaluated. The elements of an economic model for a whole-life cost for a roll shell are:

- **Initial cost of hardfacing**: This is a constant value and has to be distributed over the life of the roll shell. Cost of welding applied during crushing season: This cost is increased progressively with the wear of the roll shell.
- **Down time, due to bagasse on grooves, scraper failures and feeding problems**: This cost is of probabilistic nature and the probability of failure will be higher with the roll shell wear.
- **Energy consumption**: The variation of this cost is not fully understood, as the friction force between bagasse and the roll shell will decrease with time. A lower energy consumption is expected with increased wear but friction losses increase because of fibre sliding on the roll surface. Unfortunately, these combined effects are difficult to measure and besides, they can be mixed with other effects such as bearing and scraper wear.
- **Extraction loss**: As could be seen, a loss of pol extraction is expected due to roll shell wear.

Using optimisation methods, a basic model is being developed to determine an optimal period before roll shell change.

**Conclusions**

- Volumetric theory has been employed as a tool for predicting changes in extraction due to wear.
- The loss in brix extraction was estimated to be 3.8% to 11.6% and factory reports showed a drop of about 10% during the wear period of a milling unit.
- There are additional effects of roll wear that have not been studied such as changes in comminution of bagasse (specific surface) and imbibition efficiency impairing.
- In this analysis, the extraction model was more sensitive to the change in mill velocity, rather than the grooving cross section reduction.

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REFERENCES


UNE RELATION ENTRE L’USURE DU CYLINDRE ET L’EXTRACTION

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MOTS CLEFS: Usure, Extraction, Performance Moulins.

Résume

On accepte facilement que l’extraction aux moulins diminue quand le cylindre est usé, mais cela n’est pas bien documenté dans la littérature. On présente ici des résultats obtenus à la sucrerie de Manuelita concernant la relation entre l’usure et l’extraction ; on donne des résultats actuels et des informations basées sur une modélisation qui se sert d’un coefficient de réabsorption. On a développe des outils et des models économiques ; on peut conclure que la performance aux moulins dépend beaucoup de l’usure ; on perd de 3.76 à 11.58% d’extraction du Brix pour un premier moulin.

UN ACERCAMIENTO A LA RELACIÓN ENTRE EL DESGASTE DE LA CORAZA DE LA MAZA Y LA EXTRACCIÓN DE POL

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PALABRAS CLAVE: Desgaste, Extracción, Desempeño del Molino.

Resumen

Se acepta comúnmente que las corzas desgastadas tienen un efecto negativo sobre la extracción de pol pero existen pocos informes de investigación sobre el tema. Este documento presenta los resultados de una investigación que relaciona el desgaste en la coraza de las mazas y el desempeño de la extracción en el Ingenio Manuelita, empleando datos históricos de la estación de molienza y los modelos de extracción, basados en el coeficiente de reabsorción. Se presentan algunas herramientas desarrolladas y una lista de los componentes del modelo económico. Se concluyó que el desgaste de las corzas de la maza es el principal factor que afecta el desempeño de las unidades de molienza. Se estima una pérdida en extracción de brix de entre 3.76 y 11.58% para la unidad de primera molienda.