WEAR IN CANE PREPARATION MACHINERY—SOME TECHNICAL
AND ECONOMIC CONSIDERATIONS

By

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and Costs Modelling, Hammer Wear.

Abstract
AN IMPORTANT part of programmed downtime in a sugar mill originates from hammer tip
wear in cane preparation machines. Similarly, a major component of maintenance costs is the
labour and material cost dedicated to this subject. The use of measurements in Colombian
mills and pilot plant equipment allowed the authors to capture data related to performance,
energy consumption and costs. Research results of interactions between operational
parameters, extraneous matter in cane, equipment design, wear rates, hammer materials,
energy consumption and overall operational costs of cane preparation are reported, together
with an optimisation oriented model based on the operational costs of a cane preparation
installation. Increase in power consumption during hammer edge wear was measured and
loads in a shredder anvil were related to different amounts of wear. It was found that the costs
related to sugar losses and increased energy consumption resulting from operating with worn
hammer tips are much higher than the direct maintenance costs.

Introduction
Impact between shredder hammers (or knives) and cane in the crushing process expose the metal
parts to contact with extraneous matter. This generates a progressive wear phenomenon that decreases the
useful life of the element. This wear negatively influences cane preparation, energy consumption and the
rotordynamic behaviour of the machine.

As the knives and hammers lose material, rotor settings against conveyors or anvils increase up to
values in which the preparation of the cane is not enough to guarantee an efficient extraction. Evidence of
this efficiency deterioration is measured by indices such as pol in open cells (POC) of the prepared cane
and first mill extraction.

The loss of material is not uniform along knives and hammers, generating an imbalance which
often increases gradually due to the forces in different directions that are generated by the new attack
profiles of these elements. Any imbalance in a rotating machine is an undesirable phenomenon. On the
other hand, an important increase has been observed in the power consumption as soon as wear begins to
progress. This multiple factor problem implies that applied and fundamental research must be done in a
controlled and comprehensive way.

Extraneous matter in cane
Soil in cane is blamed as the main cause of abrasive wear in preparation and milling equipment. Its
direct measurement is not an easy task and historically different approaches have been taken to assess the
amounts of mineral extraneous matter entering the factory. A typical Colombian sugar mill crushes cane all
year round working 320–330 days/year. Therefore, it is not possible to have all the milling units in an even
state of wear at any one time. Gomez et al. (2003) present the results of an evaluation of soil in cane
entering the factory. A material balance oriented approach was chosen, and the following conventional
methods were used to measure soil in cane, bagasse and juice. A granulometric analysis was conducted to
determine the characteristics of a sample of fine particles retained from mill juice. These fine particles
represent the typical abrasive material circulating in the milling tandem. In order to compare the
performance of different hammer materials, it is necessary to have a measure of the amount of soil processed with the cane and how abrasive it is. Reported results show that it is possible to estimate the approximate crushed soil content in cane with an ash measurement of either final bagasse or mixed juice. Table 1 shows the typical distribution of mineral extraneous matter in cane between juice and bagasse. These measurements were taken during rainy days when different harvesting techniques were being evaluated and show that 52–65% of the soil entering with the cane ends up in the final bagasse. These results agree with those reported by Wright (2003) who reported that the fraction of soil in final bagasse is 60–64% of that entering with the cane supply.

Table 1—Ash in juice % ash in cane.

<table>
<thead>
<tr>
<th>Ash % cane</th>
<th>Ash in bagasse % ash in cane</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.33</td>
<td>58.7</td>
</tr>
<tr>
<td>4.33</td>
<td>52.4</td>
</tr>
<tr>
<td>2.17</td>
<td>60.6</td>
</tr>
<tr>
<td>2.42</td>
<td>64.7</td>
</tr>
<tr>
<td>2.46</td>
<td>54.0</td>
</tr>
</tbody>
</table>

Analysis of soil in mill juice showed that 87% is retained in a 90 μm sieve (Gómez et al., 2003). The material retained in the 90 μm sieve is considered to be fine sand (60 to 200 μm). Gordillo (2004) reported that the most abrasive range of particle size, using a non-standard high stress abrasive test, is between 90–127 μm. This information is relevant in the development of more wear-resistant alloys and hardfacings because of the relationship between abrasive size and microstructure.

Maintenance costs and operation parameters

From the point of view of the contribution of cane preparation maintenance to the total cost of raw sugar production (not including packing), a detailed cost benchmarking is under way in the Colombian sugar industry (CENICANÁ, 2004).

Figure 1 shows maintenance costs (labour and materials) for cane preparation per tonne of fibre and per tonne of extracted pol in six Colombian factories. These costs include the costs associated with feeding and conveying devices.

A wide variation of costs is observed among the different factories. Table 2 gives a brief description of the preparation devices at each evaluated factory. Factories 1 and 5 have 2 milling tandems. Maximum POC values attained and installed power in kW/TFH are also reported:

![Preparation machinery maintenance cost and installed power](image)

Fig. 1—Preparation machinery maintenance cost and installed power.
Table 2—Description of cane preparation equipment.

<table>
<thead>
<tr>
<th>Factory</th>
<th>1st Machine</th>
<th>2nd Machine</th>
<th>3rd Machine</th>
<th>Max. POC*</th>
<th>Total installed power kW/TFH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Conventional</td>
<td>Conventional</td>
<td>Conventional</td>
<td>70</td>
<td>40</td>
</tr>
<tr>
<td>1b</td>
<td>Conventional</td>
<td>Swing back</td>
<td>Swing back</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Swing back</td>
<td>Swing back</td>
<td>Swing back</td>
<td>76</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>Conventional</td>
<td>Shredder 60m/s</td>
<td>Swing back</td>
<td>85</td>
<td>47</td>
</tr>
<tr>
<td>4</td>
<td>Swing back</td>
<td>Swing back 78 m/s</td>
<td>Swing back</td>
<td>79</td>
<td>69</td>
</tr>
<tr>
<td>5a</td>
<td>Swing back</td>
<td>Swing back</td>
<td>Swing back</td>
<td>74</td>
<td>43</td>
</tr>
<tr>
<td>5b</td>
<td>Swing back</td>
<td>Swing back</td>
<td>Swing back with anvil</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Swing back</td>
<td>Swing back</td>
<td>Swing back with anvil</td>
<td>80</td>
<td>55</td>
</tr>
</tbody>
</table>

Note: Preparation level (POC) of knifed cane is an approximate figure.

Cane quality (pol, fibre, extraneous matter) contributes to maintenance costs as shown in Figure 1. Factory 3, the only factory with a conventional shredder, ranks third but it crushes cane with the highest fibre content. A high capability to maintain preparation and milling equipment geometry must be developed especially during long periods of crushing and high levels of extraneous matter.

High imbibition % cane seems to partially compensate for a low preparation level (Factory 1).

Table 3 shows cane quality and levels of insolubles in juice (2003) for the evaluated factories.

Table 3—Crushing performance.

<table>
<thead>
<tr>
<th>Factory</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pol % cane</td>
<td>13.70</td>
<td>13.39</td>
<td>12.1</td>
<td>13.38</td>
<td>12.74</td>
<td>12.95</td>
</tr>
<tr>
<td>Fibre % cane</td>
<td>15.33</td>
<td>13.98</td>
<td>16.02</td>
<td>13.75</td>
<td>14.80</td>
<td>13.89</td>
</tr>
<tr>
<td>Insolubles in mixed juice</td>
<td>1.09</td>
<td>1.14</td>
<td>1.99</td>
<td>1.80</td>
<td>1.55</td>
<td>0.84</td>
</tr>
<tr>
<td>Imbibition % fibre</td>
<td>230</td>
<td>189</td>
<td>198</td>
<td>195</td>
<td>197</td>
<td>218</td>
</tr>
<tr>
<td>Pol % bagasse</td>
<td>1.71</td>
<td>2.01</td>
<td>1.63</td>
<td>1.89</td>
<td>1.75</td>
<td>1.99</td>
</tr>
<tr>
<td>Pol extraction</td>
<td>96.23</td>
<td>95.82</td>
<td>96.18</td>
<td>96.43</td>
<td>96.37</td>
<td>95.83</td>
</tr>
</tbody>
</table>

From the point of view of a specific energy consumption index in cane preparation, Factories 2 and 4 with the highest indices of installed power are also the ones with the highest maintenance costs. The additional energy (when more power is available) appears to contribute to the wear process, without increasing cane preparation beyond the threshold determined by machine design.

Wear tests

Hammer edges are commonly hardfaced with high chromium cast irons. Some Colombian factories are beginning to use inserts of high chromium cast irons bonded to mild steel blocks as widely used in the Australian industry (Lakeland et al., 1992; Dolman, 1983).

No technical or economic analyses have been reported about the performance of these hammer tip designs.

Scanning electron microscope (SEM) analysis of a worn surface of a hardfaced shredder hammer showed that the wear mechanism was partly abrasive but also some fracture mechanism was observed. In a worn surface of a cast high-chromium insert, the wear mechanism was clearly abrasive.

Some trials have shown that hardfacings are more prone to fail by combined abrasion-fracture especially if they have been re-surfaced after the initial service. If a fracture occurs after a short service period, heavy metal losses can result because the wear often reaches the base metal.

Research must be done looking for materials and application procedures with adequate wear and impact performance. To identify an increased service life of preparation machine elements, two types of tests were carried out to determine material performance.
First, an operational medium duty shredder currently installed as the final preparation device for a 1.82 m x 1.07 m six mill tandem was used as a test bench. Five different hardfacing consumables were applied to hammers, which were located randomly along the machine rotor.

The shredder had a peripheral speed of 60 m/s, with an installed power of 1500 HP for a crushing rate of 36.9 TPH. The shredder used 99 hammers with an approximate weight of 30 500 g each.

New hammers were used for the test and each hammer was hardfaced on both sides (see Figure 2), weighed, used to process 82 000 tonnes of cane on one side, turned and used to process an additional 53 000 tonnes of cane. After these two periods of service, all the hammers were weighed to within 10 g.

Second, a standard low-stress abrasion test (ASTM G65) was used to provide wear results for comparison with the results from the actual shredding service. It was hoped that the standard low-stress abrasion test would be proven a dependable wear performance predictor for the shredder environment. Some additional specimens were tested in order to provide information on a wider range of available wear resistant technologies. Specimens below 100 g were weighed within 0.0001 g before and after the abrasion test. The additional reference samples (> 200 g) were weighed within 0.001 g.

**Analysis of results**

Wear of shredder hammers is a low-stress abrasion process. No significant size reduction in typical mineral particle size has been found especially within the more abrasive size distributions (Gordillo, 2004). Nevertheless, impacts with stones of various sizes and tramp iron can affect the hard and brittle weld deposits. Some of the edges seemed to have lost some material by fracture combined with progressive wear, and the reported results represent an average of the individual hammer performance within each technology tested. Material lost from the shredder hammer edges and results of standard low-stress abrasion test (ASTM G65) are reported in Figure 3.

![Fig. 2—Hardfaced hammer.](image)

![Fig. 3—Material lost in the shredder hammer edges and low-stress abrasion test (ASTM G-65).](image)
Figures 4, 5 and 6 present the microstructures of the three highest performing materials. Material G (Primary M7C3 carbides in a eutectic matrix) was not tested in the shredder but behaved as the most wear resistant material in the standard laboratory tests due to the size and density of the primary carbides. Cabra and Jaramillo (1997) reported this material as very fragile under impact when used in hardfaced inserts. Primary carbide sizes in materials A and B are smaller than in material G. A high chromium cast iron insert (material F), showed a good performance in lab tests (third place) and should be considered as an alternative in a more comprehensive approach that includes cost considerations.

An optimisation approach to preparation machinery wear

In the search for the best solutions to a problem, a comprehensive approach is needed that takes into account all the indices associated with the process. Preparation machinery must provide the optimum combination of geometric and operational conditions. Wear is the main maintenance focus for this type of machinery. In addition to wear, the following maintenance costs need to be considered, refurbishing hammer edges, programmed and not programmed downtime, increases in the energy consumption as well as increased losses in pol extraction.

Controlling these costs has explained the search for more wear resistant materials and geometries (Koen, 1980). Many trials have been performed in the Colombian sugar industry with this objective, but economic support has not been available to evaluate alternatives from the cost-efficiency point of view.

Accurate determination of maintenance costs is affected by different manufacturing processes and maintenance procedures. In an economic analysis, costs should include a detailed description of the repair and/or substitution of each one of the elements, including labour costs. This will change with the applied technology (Flanders, 1978).
In a typical Colombian sugar mill, worn edges are changed after two continuous crushing weeks unless crushing rate is impaired by power consumption increases.

There is a need to adopt a program involving all the aspects and consequences related to the wear of elements in preparation machines, in order to achieve a maximum utilisation of resources at minimal cost. An increase in pol losses because of a preparation level decrease must be assessed using a dependable preparation level technique, and direct analysis of cane and bagasse. A decrease on first mill extraction as a result of POC decrease can be used to estimate a global extraction decrease.

Wear problems and the associated costs can be approached by a compound equation of costs, adding the different functions, where each of the variables might have a weight or influence considered in the general equation. Gomez et al. (2003) presented a methodology to determine the optimum service time of the interchangeable elements of cane preparation machines. A function, cost model, must be configured to be optimised and to apply sensitivity tests. A general equation is:

\[ C_t = C_n + C_{mm} + C_{pe} + C_e + C_d \]

- \( C_t \): Total cost.
- \( C_n \): Cost of new elements.
- \( C_{mm} \): Cost of repair and labour.
- \( C_{pe} \): Cost of increased pol losses
- \( C_e \): Cost of energy consumption increase
- \( C_d \): Cost of mechanical effects (imbalance)

After every time dependent variable has been determined and particular equation \( C_t \) for a factory has been obtained, a new equation \( U = C_t / t \) is derived on \( t \) and equated to 0 in order to find relative optimum \( t \), or the best service time.

\[ d(Ut)/dt = 0 \]

A model was developed and applied to cane preparation in a 400 TCH crushing mill with swing back knives as preparation devices. One of the components for definition of cost equation (steam consumption increase) is shown in Figure 7. Energy cost was estimated assigning a value for high-pressure steam.

![Steam consumption increase](image)

Fig. 7—Steam consumption increase.

The cost equations were:

\[ C_t = C_n + C_{mm} + C_{pe} + C_e \]

\[ C_t = 10286640 +200*t +37.899*t^{1.81} + 324.64*t^2 + 196.56*t^3 \]

\[ U = C_t / t = 10286640*t^{-1} +200 +37.899*t^{0.81} + 324.64*t + 196.56*t \]
Recommended service time was $t = 139$ hours or approximately 6 continuous crushing days, well below the typical 14 day period.

![PREPARATION COSTS](image)

Fig. 8—Preparation costs.

Total costs, as well as the individual contribution of each term in the general equation are shown in Figure 8. For this specific sugar mill, increases in total costs are mainly affected by additional energy consumption and pol losses.

**Conclusions**

High capability to maintain preparation and milling equipment geometry must be developed, especially during long crushing periods and high amounts of extraneous matter. Size and density of primary M7C3 carbides (high volume fraction) was found as related to high wear resistance. Some materials with high wear resistance can not be adopted for shredder use because of their poor impact response. High chromium cast iron inserts showed a good performance in lab tests and should be considered as an alternative against hardfacing alloys in a more comprehensive approach that includes cost considerations. ASTM G65 resulted in a useful prediction tool to rank wear resistant materials for cane preparation. Optimisation model developed for a specific sugar mill was more sensitive to additional energy consumption and pol loss increases rather than direct maintenance costs.

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**REFERENCES**


USURE DE L'ÉQUIPEMENT DE PRÉPARATION DES CANNES—POINTS TECHNIQUES ET ÉCONOMIQUES

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MOTS CLÉFS: Préparation, Coûts, Model, Marteaux, Usure.

Résumé

L'usure des marteaux pour la préparation des cannes est à la base des arrêts programmes des sucreries; les coûts de maintenance et de main d'œuvre ne sont pas négligeables. On a mesuré ces coûts, l'énergie et les performances dans des sucreries colombiennes et en se servant d'équipements à l'échelle pilote. On a aussi étudié les interactions entre l'opération, l'énergie, les pailles, l'usure, les matériaux de construction et les coûts associés à la préparation. On a pu donc optimiser la préparation de la canne. L'énergie consommée et la charge au shredder ont pu être associées à l'usure. On a trouvé que le coût des pertes de sucre et de la demande additionnelle d'énergie résultant de l'usure des marteaux, est plus fort que celui de la maintenance pour réparer les marteaux.

EL DESGASTE EN LA MAQUINARIA DE PREPARACIÓN DE LA CAÑA—ALGUNAS CONSIDERACIONES TÉCNICAS Y ECONÓMICAS

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PALABRAS CLAVE: Equipo de Preparación de la Caña y Modelado de Costos, Desgaste del Martillo.

Resumen

Parte importante del tiempo fuera de servicio en un ingenio azucarero se origina a partir del desgaste de la punta del martillo en las máquinas de preparación de la caña. De manera similar, un componente importante de los costos de mantenimiento son los costos en trabajo y materiales que se dedican a esta tarea. El uso de las mediciones en los ingenios colombianos y de equipo piloto en las plantas, permitió a los autores capturar datos relacionados con el rendimiento, consumo de energía y costos. Se reportan aquí los resultados de la investigación sobre las interacciones entre los parámetros de operación, las materias extrañas en la caña, el diseño de equipos, las tasas de desgaste, los materiales de los martillos, el consumo de energía y los costos generales de operación de la preparación de la caña, junto con un modelo orientado hacia la optimización, el cual se basa en los costos operativos de una instalación para la preparación de la caña. Se midió el incremento en el consumo de energía conforme al desgaste del extremo del martillo y se relacionaron las cargas en el yunque de la trituradora con las distintas cantidades de desgaste. Se encontró que los costos relacionados con las pérdidas de azúcar y el aumento en el consumo de energía resultantes de la operación con puntas de martillo desgastadas, son mucho mayores que los costos directos de mantenimiento.