PROPOSAL FOR THE EVALUATION OF CANE AND SUGAR IN IDENTICAL UNITS AT STANDARDISED FACTORY EFFICIENCY

A. Van Hengel
Smithtech (Pty) Ltd, Durban, South Africa.

ABSTRACT

A method is proposed for expressing the commercial value of consignments of cane in terms of a recoverable standard sugar. A conversion method for different grades of sugar, is explained, including white-end refined sugar into this standard sugar. The conversion of recoverable sugar in cane into actual sugar in the bag is dependent on factory efficiency and a method for standardisation is given. Although calculations are largely based on conditions prevailing in the South African Sugar Industry, the methods are universally applicable. Evaluation of cane in terms of sugar is dealt with but not cane payment.

GENERAL

Historical background

The Java Sugar Industry was probably the first in the world to introduce evaluation of cane, sugar products and sugar with the concept of “recoverable crystal”.1,2 The Australian Sugar Industry introduced its CCS concept in 19153 and many countries4-7 thereafter adopted “recoverable sugar” as the basis of cane evaluation and cane payment, with or without additional incentives.

In South Africa there has been a gradual development in this direction. Interest in direct testing of cane has increased during the last decade and this has culminated in the introduction of Direct Analysis of Cane (DAC) in all twenty mills in South Africa from the beginning of the 1973-1974 season. The analytical system, originally aiming at the determination of pol only, requires the determination of soluble and insoluble solids as well and, when the Government appointed a Commission of Inquiry into the affairs of the Sugar Industry, the milling section was quick to point out that the knowledge of pol, non-pol and fibre contents of cane consignments, as established by DAC, would permit the computation of “recoverable standard sugar”. A cane evaluation system, coupled with a new cane payment system was proposed. This cane evaluation system is the subject of this paper.

The analytical methods

The method is fully described in the official “Manual of Cane Sampling and Analysis for the South African Sugar Factories, compiled by the Direct Cane Testing Implementation Committee of the South African Sugar Association”.

In rough outline the procedure is as follows:

A continuous sample, by means of a hatch, is taken over the full width of the carrier feeding shredded and/or knifed cane to the first mill.
The sample is further disintegrated and subsampled. In 2 different portions of the sample the total solids are determined by drying and pol and brix are determined after cold extraction at 7 000 rpm in approved equipment. Simple formulac will lead to the pol, non-pol and fibre contents of the sample.

Choice of standard sugar

Many different “standards” for sugar have been proposed through the years. The concept of “crystal” originally proposed and still used in the Java Sugar Industry, is very suitable as it supposes each sugar to be composed of a quantity of pure, crystallised sucrose, associated with a quantity of exhausted final molasses. As will be seen in Section 3, the conversion of sugars, raw and refined, into “crystal” is simple.

Choice of Factory Efficiency Standard

Any system will eventually have to make an assumption as to factory efficiency. In South Africa this was, until recently, a fixed Overall Pol Recovery, but variations, as a result of cane quality and/or manufacturing skill, in excess of 7% have been recorded. If the variation on account of cane quality is to be excluded, no meaningful performance comparisons can be made unless referred to a standard factory efficiency level. Then, if “crystal” is chosen as the standard sugar, it is logical to specify the Factory Performance Index (FPI) as:

\[
FPI = \frac{\text{crystal in sugar produced}}{\text{crystal in cane}} \times 100
\]

THE STANDARD SUGAR — “CRYSTAL”

Crystal in sugar

Any commercial sugar is normally evaluated by its polarisation (P) and moisture content (M). The non-pol content (N) is then found by:

\[
N = 100 - P - M
\]  

(1)

It is further acceptable to assume that the non-pol content will eventually lead to losses of pol in the refinery process as each part of non-pol will render a quantity of pol non-crystallisable.

Here a difference between conversion of raw sugars into one another and the conversion of raw sugar into refined sugar must be made. In the first case different types of sugar can be considered to consist of crystals of 100% purity with varying quantities of “final molasses” attached to them. During the refining process considerable change in the nature of the molasses will take place with, as a result, a different “exhaustibility” of the molasses.

In South Africa only one central refinery (Huletts in Rossburgh) is operating and the average purity of its molasses is taken as a basic parameter. The average molasses purity of the rest of the industry is taken as the basis for the “standard molasses”.

The following average figures are acceptable for the explanation of the principles put forward. It is recognised that revisions of the assumed values, due to improved technology, may be necessary from time to time. It is stressed that the proposed values are valid for South Africa, but that other countries may have to adopt other values.
<table>
<thead>
<tr>
<th>True purity</th>
<th>True solids</th>
</tr>
</thead>
<tbody>
<tr>
<td>standard molasses</td>
<td>42.0</td>
</tr>
<tr>
<td>refinery molasses</td>
<td>52.0</td>
</tr>
</tbody>
</table>

It is further found that on average only 90% of the non-pol entering the central refinery is recovered in the molasses and that 0.6% of the pol is lost.

If R stands for molasses purity, then it follows that the crystal content of raw sugar (C) is defined by:

$$C = P - \frac{R}{100 - R} (100 - P - M)$$  \hspace{1cm} (2)

or for purity R = 42.0 by

$$C = 1.724 P + 0.724 M - 72.4$$  \hspace{1cm} (3)

With the use of this equation (3) any raw sugar of which P and M are known can be brought back to a common denominator.

It is now necessary to look again at directly refined sugar which is produced in South Africa by the factories: Sezela, Gledhow, Entumeni, Pongola and Malelane in varying percentages of total production.

It will be shown that it is convenient to express refined sugar as a fraction of crystal originally in raw sugar.

Consider 100 parts of a raw sugar with $P\%$ pol and $M\%$ moisture and $C\%$ crystal. The non-pol content of this sugar is $N\%$ and therefore 0.9 $N$ parts of non-pol will end up in refinery molasses as the non-pol content of refined sugar is negligible. Also, of the $P$ parts of pol only 0.994 $P$ parts of pol will be recovered in either refined sugar or molasses on account of the 0.6% loss.

$$52 \times 0.9 \times 0.975 N = 0.975 N$$

parts of pol are going to be associated with the non-pol in refinery molasses the recovery of pol in refined sugar will be 0.994 $P - 0.976 N$. In South Africa the average crystal content of refined sugar is 99.88% and thus the recovery of refined sugar, expressed as parts per 100 raw sugar will be:

$$0.994 P - 0.976 N$$

$$0.9988$$

$$= 0.9952 P - 0.9762 N$$

$$= 1.9714 P + 0.9762 M - 97.62$$

As the original crystal in raw sugar is defined by:

$$C = 1.724 P + 0.724 M - 72.4$$  \hspace{1cm} (3)

then:

Refined sugar % crystal in raws =

$$\frac{1.9714 P + 0.9762 M - 97.62}{1.724 P + 0.724 M - 72.4} \times 100$$  \hspace{1cm} (4)
For different values of P and M this percentage can be computed. The results are shown in the following table:

<table>
<thead>
<tr>
<th>% H₂O</th>
<th>98,0</th>
<th>98,2</th>
<th>98,4</th>
<th>98,6</th>
<th>98,8</th>
<th>99,0</th>
<th>99,2</th>
<th>99,4</th>
<th>99,6</th>
<th>99,8</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>99,34</td>
<td>99,39</td>
<td>99,44</td>
<td>99,49</td>
<td></td>
</tr>
<tr>
<td>0,3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>99,39</td>
<td>99,44</td>
<td>99,49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0,5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>99,39</td>
<td>99,44</td>
<td>99,49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0,7</td>
<td></td>
<td>99,23</td>
<td>99,28</td>
<td>99,33</td>
<td>99,39</td>
<td>99,44</td>
<td>99,49</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0,9</td>
<td>99,28</td>
<td>99,33</td>
<td>99,39</td>
<td>99,44</td>
<td>99,49</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,1</td>
<td>99,33</td>
<td>99,39</td>
<td>99,44</td>
<td>99,49</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,3</td>
<td>99,39</td>
<td>99,44</td>
<td>99,49</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,5</td>
<td>99,44</td>
<td>99,49</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,7</td>
<td>99,49</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>99,49</td>
</tr>
</tbody>
</table>

When interpreting the values in this table it must be borne in mind that the central refinery in South Africa will normally refine VHP sugar of 99,3-99,6 pol with 0,05 to 0,15% moisture. The percentage for that type of sugar varies between 99,39 and 99,44.

Direct refineries may be expected to melt raw sugar of much lower pol but with much higher moisture contents and here again the value of the percentage will vary between 99,39 and 99,44. If the direct refineries melted sugar with, say 98,0 pol and only 1,1% moisture, the ratio would come down to 99,28 but it would be their own fault.

In view of the foregoing arguments, and as later it will be seen that the figure has little or no commercial meaning, it is fair to assume that in South Africa: One ton of crystal in raw sugar will render 0,994 tons of refined sugar under "normal" conditions of efficiency.

**Crystal in cane**

All sugars, raw or refined, consist mainly of sucrose. Conversely, by no means all sucrose in cane will crystallise as sugar. The large variations in sugar/sucrose in cane ratio, normally expressed as Overall Recovery are well known and are dependent on:

a) factory efficiency

b) fibre in cane, affecting quantity of bagasse and thus loss of pol in the extraction process

c) non-pol in cane, leading to larger or lesser quantities of final molasses, thus varying the recovery for any given molasses purity.

The factory efficiency is measured by a number of generally accepted parameters, viz:

1) Extraction, by means of comparing pol to fibre ratios in both cane and bagasse.

2) The losses in molasses.
3) The losses in filter cake.
4) The undetermined losses.

The first two losses are influenced by a combination of raw material quality and operational skill, whereas the last two losses are largely dictated by and dependent on average process conditions. It is therefore logical to group these losses together as in the following formula:

$$C = aS - bN - cF$$

in which:

- $C = \text{per cent pure crystallisable pol in cane (crystal)}$
- $S = \text{per cent pol in cane}$
- $N = \text{per cent non-pol in cane}$
- $F = \text{per cent fibre in cane}$
- $a = \text{unit fraction of recovery of pol in sugar, molasses and bagasse combined}$
- $b = \text{the loss of pol in molasses per unit of non-pol in cane}$
- $c = \text{the loss of pol in bagasse per unit of fibre in cane}$

Criticism has been levelled against this simple concept. Not only the total quantity of non-pol will effect the loss in molasses but the composition of the non-pol will influence the molasses exhaustibility. The reducing sugar/ash ratio and viscosity are well known as factors influencing practical exhaustibility. Also, the concept of extraction losses being tied up with original juice composition is universally accepted.

The above arguments are not disputed as the facts are too well known, but they in no way invalidate the overall usefulness of this highly practical formula.

In general it is accepted that fibre and non-pol influence the extraction and boiling house recovery. Cognisance is taken of that by the formula. Furthermore, the whole system of factory control in use today recognises only pol, non-pol (brix minus pol) and fibre as the main variants. Also, the system of direct analysis of cane samples, so far, is only concerned with pol, purity of juice and fibre content. So, with a number of reservations it can be said that in broad terms the formula (5) takes into consideration all basic materials normally used in factory control.

But, even if it were accepted that the factor $b$ in the formula not only depends on average factory efficiency, but is also dependent on specific components in molasses, then still it should be argued that the formula is a vast improvement on the customary Overall Recovery, in which not only the composition of non-pol is totally ignored, as in formula (5), but the quantity as well. So, where in South Africa cane evaluation is done by the formula:

$$C_1 = \frac{O}{S}$$

in which:

- $C_1 = \text{recoverable pol % cane}$
- $O = \text{Industrial Average Overall Recovery}$
- $S = \text{pol % cane}$

the introduction of formula (5) would be at least a vast improvement.

Moreover, in the long run, with the improvement of analytical techniques, there would be no reason if found practical not to expand the formula to:

$$C = sS - bN - cF \pm dK$$
in which:

\[ K = \text{constituent of cane, found by direct analysis, to improve (+) or decrease (−) the recovery of sugar.} \]

\[ d = \text{the loss or gain of pol per unit of constituent.} \]

**THE STANDARD EFFICIENCY (FPI)**

Efficiency is normally expressed as:

\[ \% \text{ efficiency} = \frac{\text{obtained}}{\text{obtainable}} \times 100 \]

For a factory this efficiency could be expressed as the Factory Performance Index (FPI).

Then:

\[ \text{FPI} = \frac{\text{Crystal in sugar}}{\text{Crystal in cane}} \times 100 \]

and, logically, the standard efficiency should be 100%. This is difficult to predict as technological progress would tend to gradually increase this ratio to well over 100%, whereas conditions affecting cane quality and delivery, e.g. prolonged droughts or bumper crops would cause considerable variations. Also, if cane is of very poor quality millers may not be able to attain the targets set by the formula.

On the other hand, during a bumper crop millers may even have to let efficiency slip for higher throughput to obtain an overall industrial advantage.

It is therefore logical to set the efficiency each year at 100% and to measure cane quality against this average industrial efficiency.

It is immaterial whether this efficiency is set at 100% for one factory or a whole industry. The principle remains the same. The aim is to distribute a part of the returns from sugar manufacture to growers who contributed proportionally to this production in the form of recoverable sugar in cane.

**THE CANE EVALUATION FORMULA**

The derivation of this formula is easiest explained by setting a simple example. Assume an industry to consist of 3 factories, each crushing different canes in varying quantities and with varying efficiency:

<table>
<thead>
<tr>
<th>Factory</th>
<th>Tons</th>
<th>Cane</th>
<th>Pol</th>
<th>Non-Pol</th>
<th>Fibre</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1 000 000</td>
<td>135 000</td>
<td>25 000</td>
<td>140 000</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>500 000</td>
<td>70 000</td>
<td>12 000</td>
<td>65 000</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>1 500 000</td>
<td>195 000</td>
<td>39 000</td>
<td>230 000</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3 000 000</td>
<td>400 000</td>
<td>76 000</td>
<td>435 000</td>
<td></td>
</tr>
</tbody>
</table>
This table corresponds with the following cane qualities:

<table>
<thead>
<tr>
<th>Factory</th>
<th>%S</th>
<th>%N</th>
<th>%F</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>13.5</td>
<td>2.5</td>
<td>14.0</td>
</tr>
<tr>
<td>B</td>
<td>14.0</td>
<td>2.4</td>
<td>13.0</td>
</tr>
<tr>
<td>C</td>
<td>13.0</td>
<td>2.6</td>
<td>15.33</td>
</tr>
<tr>
<td>Industrial Average</td>
<td>13.33</td>
<td>2.53</td>
<td>14.50</td>
</tr>
</tbody>
</table>

Assume further that these factories would show the following production records (see following table):

<table>
<thead>
<tr>
<th>Factory</th>
<th>In Cane</th>
<th>In Raw Sugar</th>
<th>In Refined Sugar</th>
<th>In Final Molasses</th>
<th>In Final Bagasse</th>
<th>Unaccounted for*</th>
<th>Crystal</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>S 135</td>
<td>80</td>
<td>35</td>
<td>12</td>
<td>6</td>
<td>2</td>
<td>78.4</td>
</tr>
<tr>
<td></td>
<td>N 25</td>
<td>1</td>
<td>0</td>
<td>19</td>
<td>4</td>
<td>1</td>
<td>35.2</td>
</tr>
<tr>
<td></td>
<td>F 140</td>
<td>0</td>
<td>0</td>
<td>139</td>
<td>1</td>
<td></td>
<td>113.6</td>
</tr>
<tr>
<td>B</td>
<td>S 70</td>
<td>0</td>
<td>0</td>
<td>61</td>
<td>5</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>N 12</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>3</td>
<td>1</td>
<td>61.4</td>
</tr>
<tr>
<td></td>
<td>F 65</td>
<td>0</td>
<td>0</td>
<td>65</td>
<td>0</td>
<td></td>
<td>61.4</td>
</tr>
<tr>
<td>C</td>
<td>S 195</td>
<td>162</td>
<td>0</td>
<td>17</td>
<td>12</td>
<td>4</td>
<td>160.6</td>
</tr>
<tr>
<td></td>
<td>N 39</td>
<td>1</td>
<td>0</td>
<td>25</td>
<td>10</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>F 230</td>
<td>0</td>
<td>0</td>
<td>228</td>
<td>2</td>
<td></td>
<td>160.6</td>
</tr>
<tr>
<td>Industrial Average</td>
<td>N 76</td>
<td>52</td>
<td>17</td>
<td>5</td>
<td>239.0</td>
<td>96.6</td>
<td>335.6</td>
</tr>
<tr>
<td></td>
<td>F 435</td>
<td>0</td>
<td>0</td>
<td>432</td>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Allowing for pol in filtercake, undetermined pol loss, suspended solids in mixed juice, etc.

The further treatment is now very simple:

As it is assumed that the industry operates at 100% FPI, the 3 million tons of cane contain $335,6 \times 10^3$ tons crystal or —

$$C = \frac{335,600}{3,000,000} \times 100 = 11.186 \text{%}$$

The factor $c$ is also easily found because

$$c = \frac{\text{tons pol in bagasse}}{\text{tons fibre in cane}} = \frac{21}{435} = 0.0483$$
The factor $b$ is equally easily found as

$$b = \frac{\text{tons non-pol in molasses and sugar}}{\text{tons non-pol in cane}} \times \frac{\text{tons pol in molasses}}{\text{tons non-pol in molasses}}$$

or $b = \frac{52 + 2}{76} \times \frac{34}{52} = 0.4646$

Applying the above values to the average S, N and F contents, we obtain:

$$11,186 = a \times 13,33 - 0.4646 \times 2.53 - 0.0483 \times 14.50$$

and $a = 0.9799$

Therefore the recovery formula would have the following constants for the year under review:

$$C = 0.9799 \, S - 0.4646 \, N - 0.0483 \, F$$

The individual factory performance indices for the three factories would be:

<table>
<thead>
<tr>
<th>Factory</th>
<th>Overall Recovery</th>
<th>FPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$\frac{80 + 35}{135} \times 100 = 85.18$</td>
<td>$\frac{113 , 600}{113 , 909} \times 100 = 99.73$</td>
</tr>
<tr>
<td>B</td>
<td>$\frac{61}{70} \times 100 = 87.14$</td>
<td>$\frac{61 , 400}{59 , 878} \times 100 = 102.54$</td>
</tr>
<tr>
<td>C</td>
<td>$\frac{162}{195} \times 100 = 83.08$</td>
<td>$\frac{160 , 600}{161 , 800} \times 100 = 99.25$</td>
</tr>
<tr>
<td>Industrial Average</td>
<td>$\frac{242 + 96}{400} \times 100 = 84.50$</td>
<td>$\frac{335 , 600}{335 , 588} \times 100 = 100.00$</td>
</tr>
</tbody>
</table>

**DISCUSSION**

A simple formula has been derived, which will each season again cover the total industrial production of the chosen standard sugar for exactly 100%, which no other formula will do unless based on the same assumptions. This formula will then enable an industry to determine, with adequate accuracy, the contribution of each cane consignment towards the total production of the industry in terms of this standard sugar. How a consignment is then to be paid for is a matter of legislation, but the basis, recoverable sugar, is well founded and meaningful.

An evaluation system is not acceptable, when used for payment, if it contains negative incentives. Although this paper does not intend to deal with payment, it is nevertheless useful to see whether the proposed formula offers the right incentives to the sellers and buyers (growers and millers) of “crystal”.

The following points are therefore of importance:

i) Each consignment will be evaluated exactly proportionally to its con-
tribution to the industrial total output, irrespective of which miller
 crushes the cane.

ii) Therefore a grower is paid precisely according to his industrial con-
tribution. He can increase the value of his cane by good trashing, fast
transport, etc, and will reap the benefits of his actions.

iii) If, on the contrary, cleaning and trashing is considered uneconomical
the receiving individual miller is not penalised.

iv) The individual miller receives for processing a certain quantity of
recoverable crystal. If he operates more efficiently than average, he
will produce more sugar than average and his profit margin will
increase.

v) If each miller takes this attitude, sugar production will increase, the
formula will adjust itself and a new industrial average efficiency will
be established.

vi) If, as a result of the incentives, the average cane quality improves,
sugar manufacture will be easier and a new average cane quality will
be established. Again the formula will adjust itself.

vii) The system proposed adjusts itself continuously to the conditions
appertaining to the industry. Many cane payment systems, which do
not have built-in automatic annual adjustments are non-negotiable
between the parties after a certain lapse of time.

A small disadvantage of the proposed system is that the final formula is
only known after all consignments have been sampled and all sugars have
been made. It is obvious that a procedure of provisional payment, as operated
in most industries, can be associated quite easily with a provisional evaluation
formula, e.g. the formula of the previous year, which may be out by about 1%.

Another disadvantage is that a direct refiner will never know exactly
from how much raw sugar he commenced. However, it has little financial
significance as he can only sell the sugar he is actually producing. The crystal
conversion approximation could, at the most, slightly and quite insignificantly
alter some of the factors in the cane evaluation formula.

It is therefore concluded that the proposed system, though suffering from
a few very minor disadvantages, contains a number of major advantages on
which a fair and just cane payment system could be built.

REFERENCES
2. Prinsen Geerligs, H. C. (1911). Tabellen voor de berekening van de winbare suiker en
het winbaar kristal en voor de berekening van het kristal gehalte van suikers van vers-
schillende samenstelling, Archief, 1469.
6. Hugot, E. (1955). Cane payment on quality basis, an extractable sugar formula in
PROPOSICION PARA LA EVALUACION DE LA CAÑA Y EL AZUCAR EN UNIDADES IDÉNTICAS A UNA EFICIENCIA DE ELABORACION ESTANDARIZADA

A. Van Hengel

RESUMEN

Este trabajo propone un método para expresar el valor comercial de entregas de caña en términos de un azúcar aprovechable estándar. Además explica un método de conversión para distintas clases de azúcar, incluyendo azúcar refinada a este azúcar estándar. La conversión de azúcar efectivamente ensacado depende de la eficiencia de la elaboración y aquí también se da un método para la estandarización. Aunque los cálculos se basan fundamentalmente en las condiciones que prevalecen en la industria azucarera de Sud Africa, los métodos son de aplicación universal. El trabajo se ocupa de evaluar la caña en términos de azúcar pero no cubre el pago de la caña.