DIRECT ANALYSIS AND EVALUATION OF SUGARCANE

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ABSTRACT

Formulae are given to be used for estimating the recoverable sugar of a consignment of cane. It compares direct analysis with analysis by means of the factory first mill juice and draws attention to the necessity of taking into account the effect of the fibre in both cases, an effect which is more important in the mill than in the press.

INTRODUCTION

In cane sugar manufacture, one has constantly to determine the quality, or sugar producing value, of the cane delivered to the factory. This is usually cane from growers, who are paid according to the percentage of sucrose or of recoverable sugar in their cane. But, the sugar factory also needs to know the sugar value of the cane grown on its own estates in order to compare different varieties grown, and to determine the influence of the soil, the effect of harvesting time in relation to the season, the age of the cane, the quantity or kind of fertilizer used, etc., upon the sucrose per cent cane. With the same object, experiments are generally systematically carried out, either by the factory itself or by Experiment Stations, to compare the cane from various plots of an experiment.

METHODS

There are several processes for the analysis of sugarcane and they can be classified under two headings:

a) The methods using the primary juice, i.e. the first extracted juice or the first mill juice from a sample of cane passing through this first mill.

b) The so-called direct analysis methods, using a sample taken in the cane consignment to be analysed, the analysis being made in a laboratory.

A. Methods using the Primary Juice

The methods dealing with the first mill juice have some advantages:

a) The sample may be made of almost the total consignment of cane. The juice may be sampled either by hand or automatically the whole time during which the consignment is passing through the first mill. If a consignment is, for instance, of 10 tons of cane and if the factory grinds 120 tch, the juice obtained is sampled during the 5 minutes taken by these 10 tons passing through the mill. No sampling is done during the first few seconds, in order to ensure that the juice of the preceding consignment has been completely washed out, and ceases in the last few seconds of the process to avoid any risk of mixing with the next consignment. At the same time, samples of cane coming from the sets of knives or the shredder are continuously sampled for fibre determination.

b) Such a method ensures an analysis bearing on the actual proportions of clean cane, trash, tops etc. of the consignment.
On the other hand, there are serious drawbacks to these methods:

a) It is not easy to sample the cane so that the sample is representative, because the fan-effect of the knives and of the shredder involves a differential sedimentation of the pieces in the layer on the carrier from the knives. The larger and heavier pieces sink first to the bottom while the lighter ones, including green and dry leaves and dry stems, fall last onto the upper part of the layer. These light pieces are of very high fibre per cent. Therefore, the sample must include in their right proportion all the strata of the bed as otherwise the fibre value found is either erratic or systematically wrong. This difficulty has been overcome by sampling on the rising section of a rake conveyor running over a trap-door which opens to engulf, on its whole width, the whole length of the heap of cane pieces being pushed between two rakes.

b) The Brix and purity of the primary juice depend on the percentage of juice extracted by the mill. This percentage depends on the setting of the mill, on the amount of pressure applied and principally on the immediate volume of cane gripped by the mill, the upper roller of which may lift or be fixed. It follows therefore that, for the same cane, Brix and purity vary from factory to factory, and also in the same factory, from moment to moment. This is why some countries have given up first extracted juice analysis for primary juice analysis, that is to say whole dry pressure juice (first mill juice, or crusher + first mill juice in tandems with a crusher). First extracted juice is much more dependent on the above factors (setting, pressure, ratio between feed and delivery work openings, immediate volume of feed) than primary juice; it contains only about 40 to 50% of the absolute juice sucrose, against 60 to 75% for the primary juice. It is plain that the nearer one comes to 100%, the less is the influence of the error and the inaccuracy factors. This influence would of course fall to zero at 100%, but this maximum is unfortunately out of reach of a mill.

B Methods by Direct Analysis

Lack of comparability and the variations mentioned have prompted some factories and countries to give up even the primary juice analysis method. As far as cane payment on a quality basis is concerned, the obvious drawback for the growers was the discrepancy between the results of various factories, particularly obvious in the case of a grower dividing his canes between two factories. The growers' associations have requested an analytical method not dependent on the factory machines and able to supply comparable results for all factories in a country.

These countries therefore decided on direct analysis, which eliminates some of the difficulties but has others, namely:

a) It allows only very small samples, compared to the total weight of the consignment, with possibilities of error particularly if the consignment is heterogeneous or mixed.

b) It requires special equipment i.e. a laboratory mill or an hydraulic press.

The hydraulic press is to be preferred, because the laboratory mill does not allow for accurate control of the pressure and the general conditions of juice extraction, therefore reproducing the same drawbacks as the big mills. The sample must be thoroughly prepared and always in the same uniform way.
for instance by a "Jeffco" cutter-grinder. The press must have a fixed pressure, a fixed time for reaching that pressure, a fixed time for keeping the sample under pressure, and a fixed diameter and capacity of the press pot in order to obtain comparable results. One may for instance adopt a pressure rising time of 20 seconds, a pressure retaining time of 90 seconds, a pressure of 400 bar and a pot diameter of 145 mm. The pot must be pierced with numerous holes and sample must be of fixed weight. The rise in pressure is carried out by a pump which is automatically stopped at the fixed pressure, this pressure being also automatically broken at the fixed moment by a clockwork switch.

The direct analysis offers some advantages:

a) It is more speedy and thus allows for a greater number of analyses. It is even possible to analyse all consignments.

b) The analyses can be made even when the mill is idle.

c) The cane arriving during daytime and stored for the factory night work can be analysed on arrival.

d) The results are comparable between factories and all along the crop for every factory.

e) The fibre may be determined by weighing the cake coming out of the press, since a correlation may be worked out between its weight and the fibre of the cane sampled, leading to a formula of a very straightforward type: 

\[ f = mb \]

where \( f \) is the weight of the cake of press bagasse, \( m \) is the weight of the cane. This correlation is not perfect, but it is sufficient on account of the great number of analyses made for every grower, and it provides a neat solution to the difficult problem of fibre determination.

Here is a direct analysis process. Let us assume we are dealing with a grower's cane payment and that the cane is sent to the factory by truck, trailer or railway truck. Just after the weighbridge, a core-sampler is placed on rails along the path of the trucks or trailers. There are several types of samplers: the Hawaiian or American core-sampler, the French FAPMO, or the moving sampler fitted tractor. The sampling probe is a 150 or 200 mm diameter tube which can revolve at 450 or 600 rpm while moving forward, with the mouth fitted with a saw all around its edge. The driver, sitting on the seat and driving the sampler, can move it along the rails which are 6 or 8 metres long; he can also lift or lower the tube. He places the sampler where he wants on the rails, sets the tube in motion and cuts off 4 samples: 1 up at the rear, 1 low nearer the middle, 1 up further forwards, and 1 low at the front, taking care not to sample either end of the cane stems, when they are stowed in orderly bundles, but preferably towards the middle, upper or lower third of their length. A piston, set in motion by a push-button or a lever, extracts the core sample from the tube and drops it in a bucket which is taken to the laboratory with a tag giving the analysis weighbridge number. The sample is thoroughly mixed and passed through the Jeffco cutter-grinder. A certain quantity, for instance 1 000 g, is weighed and transferred to the press pot. The piston of the press is set in motion, the pressure reaches 400 bar, remains 90 seconds at this pressure, and the pressure is broken. The juice extracted is collected in two 200 ml settling tubes, one of which is kept only for possible control; the Brix (preferentially refractometric) is taken and, after defecation by Horne's dry basic lead acetate
and filtration, the pol is read on an electronic automatic saccharimeter. The press cake is removed from the pot and weighed. From this are obtained: the fibre, given by the correlation scale or formula; the pol; the Brix and thus the purity. These are the factors which will make possible the calculation of the percentage of recoverable sugar.

RECOVERABLE SUGAR FORMULAE

It is not the sugar per cent which gauges cane quality, but the quantity of sugar the cane will permit an efficient factory to recover. This quantity, reckoned as a percentage, is referred to as RS = recoverable sugar.

The recoverable sugar may be calculated by means of various formulae from the factors given by the analysis.

Ideal or Average Efficiency

The formulae that we are going to study may be derived according to 2 different hypotheses: it may be decided either to compare the factory efficiency to an ideal efficiency matching the best results obtained in the world or to compare it to the average results recorded in the country.

As a matter of fact, the choice is not as important as it might appear at first sight, because these formulae are made up to 2 independent components:
(a) the body of the formula including the 3 quality factors (f, B and S or P);
(b) a numerical coefficient bringing this body to the selected value which may be chosen to correspond to the practical level in the country. It is thus possible to arrive at this practical level either with an ideal efficiency formula admitting a low coefficient, or with an average efficiency formula with a higher coefficient. The discrepancies between these 2 systems are of little importance and the formulae based on an ideal efficiency offer advantages: (1) The determination errors, chiefly those concerning fibre or purity, bear lesser incidence on the exactitude of the results. (2) Being derived from ideal bases, these formulae may be put into general and universal use, making possible comparisons between countries. We strongly advise these ideal efficiency formulae and it is these formulae that we shall study; we will merely quote the average efficiency formulae.

1. PRIMARY JUICE ANALYSIS

Before studying direct analysis, it is useful and interesting to recall the mill juice analysis formulae.

The derivation of the best formula to apply in this case has already been given.\textsuperscript{1} It is based on the following hypotheses:

- a) That it is the RS which is sought for.
- b) That ideal efficiency is adopted, measured by:
  - Reduced extraction = 97.5%.
  - No loss in the filter cake; no undetermined losses.
  - Final molasses exhausted to about 29 purity.
- c) That the factory efficiency is measured by the k coefficient which compares the factory efficiency with the above ideal efficiency.

The formula reads\textsuperscript{3} (see appendix 1):

\[
RS = k(1 - 1.65f)(S - 0.3B)
\]
RS = recoverable sugar to be obtained. It may be reckoned at 94°, at 96°, at 98° or as white sugar, according to the official regulations or to the stipulations between growers and manufacturers.

\[ f = \text{fibre fraction in the cane (0.14 for instance).} \]
\[ S = \text{pol of the primary juice.} \]
\[ B = \text{Brix of the primary juice.} \]

According to the standard sugar agreed on and to the factory efficiency, the coefficient \( k \) varies (as a rule between 1,32 and 1,40, for 98° sugar).

Let us state that the coefficient 1,65 which bears on the factor \( f \) is specific to mill analysis. This formula (1) would apply to direct analysis only on condition that a lower coefficient be substituted for 1,65.

Average efficiency formula.—If the following conditions were substituted for the above ideal ones:
- Reduced extraction = 95%.
- Final molasses exhausted to about 39 purity.
- Losses in cake and undetermined losses kept at zero, to be merely included into the \( k \) efficiency coefficient,

the formula would become (see appendix 3):

\[ RS = k(1-1.8f)(S-0.4B) \] (11)

\( k \) then varies between 1.65 and 1.75.

Formulas (1) and (11) show the big influence of the fibre in the mill analyses. This results, as shown by Michel Hoarau, from the important lowering effect of the fibre on the ratio of sucrose % absolute juice to pol of primary juice. This means that if a mill grinds, all other things being equal, 2 canes of the same juice but of different fibre, the pol of the extracted juice of the high fibre cane will be positively higher than that of the low fibre cane, and not the same, as is often believed. Formulas (1) (11) show how much the fibre must be penalised to counterbalance this effect.

As noted for 1.65 of formula (1), the coefficient 1.8 of (11) is specific to mill juice analysis.

2. DIRECT ANALYSIS — FORMULA OF THE SAME TYPE AS (1)

Having regard for the condition of changing coefficient 1.65, formula (1) may be applied to direct analysis. The fibre lowering effect was denoted in the mill formula by the factor \((1-0.57f)^4\). In the 400-bar press, it is denoted by the factor \((1-0.33f)\). Proceeding as for formula (1) (see appendix 1), we have:

\[ ES = K_2S(1-0.33f)(1-f)(1-0.2f) = K_2S(1-1.53f+0.596f^2-0.066f^3). \]

The term: \( n = (1-0.33f)(1-f) \) may be found by direct determination: \( n = 1-1.285 f \). The polynomial in \( f \) may be replaced, for normal values of \( f \), by \((1-1.45f)\) and the formula becomes:

\[ RS = k(1-1.45f)(S-0.3B) \] (2)

with an approximation of the same order as that of formula (1).

3. DIRECT ANALYSIS — FORMULAE OF TYPE “SUCROSE % CANE MINUS LOSSES”

We strongly recommend formula (2) and the 400-bar press. However, there is another type of formula. The idea is to determine the sucrose % cane and to deduct the normal losses to be expected.

The sucrose % cane \( R \) is easily obtained, thanks to Michel Hoarau's
experiments. Let:

\[ E_J = \text{weight of juice extracted by the press } \% \text{ juice in cane.} \]
\[ E_S = \text{weight of sucrose extracted by the press } \% \text{ sucrose in cane.} \]
\[ S_A = \text{sucrose } \% \text{ absolute juice.} \]
\[ S_E = \text{sucrose } \% \text{ extracted juice.} \]

Let:

\[ C = \frac{S_A}{S_E} \]

We have by definition:

\[ E_S = \frac{E_J \cdot S_E}{1 \cdot S_A} \]

whence:

\[ C = \frac{S_A}{S_E} = \frac{E_J}{E_S} \]

This formula, or Michel Hoarau's formula, is very important in direct analysis. It reads: *the ratio of sucrose \% absolute juice to sucrose \% extracted juice is equal to the ratio of juice extraction to sucrose extraction.* This simple and almost plain relationship had as far as we know, never been stated nor used. Ignoring or neglecting it has led many technologists to admit: \( C = 1 \), an approximation which, in direct analysis, involves a serious error and underestimates the penalty that should be imposed on fibre.

Direct analysis is then quite straightforward and easy: the pol \( S_E \) of the extracted juice is read on the saccharimeter and we have:

\[ R = C(1 - f)S_E. \]

Putting: \( C(1 - f) = n \) \( R = nS_E. \)

For the 400-bar press, \( n_{400} \) is given with good approximation by:

\[ n_{400} = 1 - 1.285f \]

whence:

\[ R = (1 - 1.285 f)S_E. \]

For the 100-bar press, we would have had: \( n_{100} = 1 - 1.375f. \)

Once the sugar \% cane, \( R \), is thus known, we must now find out the recoverable sugar \( R_S \). To this end, we shall split up the manufacturing losses into their components:

a) Sucrose lost in bagasse. The only factor pertaining to cane in the extraction process is the fibre \( f \). All other factors are related to the mill, to imbition, pressure, setting etc. . . . leaving only fibre to characterise the sucrose extractability of the cane. (It is unfortunately true that 2 varieties of the same fibre may sometimes not have the same extractability, but it is not easy to take this property into account). As for the standard extraction to choose, the maximum may be selected, as in formula (1), i.e. 0.975; or 0.95 as in (11). For reasons already explained, we shall choose the first one and decide that the loss in bagasse will be reputed to be: 2.5 \( f \).

b) Sucrose lost in cake, molasses and undetermined losses. Admitting the above assumption, the sucrose obtained after the milling plant is: \( R - 2.5 \ f \). If we assume a sugar purity of 99\%, final molasses of 30\% purity, and a difference of 3 units between the purity of the press extracted juice and the purity of the mixed juice, we have, owing to the loss in final molasses:
Assuming the sucrose lost in the cake and in the undetermined losses to be 2.4\%, we finally have:

\[
R S = 1,435 \left( R - 2.5 f \right) 0.976 \left( 1 - \frac{30}{P - 3} \right) = 1.4 \left( R - 2.5 f \right) \left( 1 - \frac{30}{P - 3} \right)
\]

or:

\[
R S = 1.4 \left[ \left( 1 - 1.285 f \right) S - 2.5 f \right] \left( 1 - \frac{30}{P - 3} \right).
\]

With average efficiency, we would have found:

\[
R S = 1.4 k \left[ \left( 1 - 1.285 f \right) S - 2.5 f \right] \left( 1 - \frac{30}{P - 3} \right)
\]

the coefficient of work being higher in this case (and eventually \( \geq 1 \)).

The systematic errors introduced by the possible but unfortunately frequent shortcomings of the sampling (for instance manual sampling) and/or analysis process sometimes lead to a substitute for \( S \), a term \( x S \), \( x \) being a coefficient which can be of the order of magnitude of 0.9 and even lower, to be accurately determined by practical tests.

Remark. An empirical simplified formula might be substituted for formula (31):

\[
R S = \left[ \left( 1 - 1.285 f \right) S - 5 f \right] \frac{P}{100}
\]

It is easy to verify that:

\[
y_1 = 1.63 \left( 1 - \frac{40}{P - 3} \right)
\]

gives values quite close to those of:

\[
y_2 = \frac{P - 2}{100}
\]

Precision. The theoretical approximations we accepted introduce only a maximum error of 0.25\%, even with \( P \) values as extreme as 80 or 92. But the main drawback of this type of formula comes from the fact that it is liable to a bigger error on extraction loss than is formula (1). This is why we recommend the latter.
CONCLUSION

The formula to be recommended in direct analysis is:

\[ RS = k(1 - 1.45f)(S - 0.3B) \]

the coefficient 1.45 applying to the 400-bar press. It must be modified for other pressures, being higher for lower pressures and lower for higher pressures.

REFERENCES


APPENDIX 1

Primary Juice Analysis — Formula

Let:

- \( R \) = sucrose % of the cane under consideration.
- \( S_A \) = sucrose % absolute juice of this cane.
- \( f \) = fibre per unit of this cane.
- \( X \) = sugar recoverable from this cane (or: “SR”).
- \( B \) = Brix of primary juice furnished by the first mill (or by the combination of crusher and first mill).
- \( S \) = pol % primary juice.
- \( P \) = apparent purity of primary juice = 100 \( S/B \).
- \( P^1 \) = Clerget purity of mixed juice obtained from this cane.
- \( M \) = Clerget purity of the final molasses.

The sucrose entering the factory, % on cane, is:

\[ R = S_A(1-f) \]

Being unable to extract the absolute juice, we must be content to deal with the extracted juice, i.e. the primary juice. We may therefore write:

\[ R = K_S(1-f) \quad \text{with:} \quad k_S = \frac{S_A}{S} \]

The losses in mud and the undetermined losses are small. Besides, we have some discrepancies resulting from the use of pol instead of sucrose, of Brix instead of dry substance, of apparent and Clerget purity instead of true purity, and, in the final result, of sugar instead of sucrose. We shall include those losses and those discrepancies together in a second coefficient \( k_2 \). To obtain the recoverable sugar, it remains to calculate the 2 major losses: loss in bagasse and loss in molasses.

1) Loss in bagasse. Let:

- \( \beta \) = sucrose lost in bagasse % cane.
- \( \sigma \) = sucrose % bagasse.
- \( f^1 \) = fibre per unit of bagasse.

We have:

\[ \beta = \frac{\sigma}{f^1} \]

We must fix the standard efficiency to set as a basis. If the loss in bagasse must correspond to a standard extraction \( e_b \) for a standard fibre \( f_0 \), we shall have:

\[ \frac{\beta}{R} = \frac{f}{f^1} = \frac{1-e}{R} \quad \text{whence:} \quad \frac{R}{f} = \frac{f^1 (1-e)}{R} \]

and we require:

\[ \frac{\sigma}{R} = \frac{f^1 (1-e_b)}{f_0} \]
The following must then hold:

\[ \frac{\beta f}{R} = \frac{f_1 (1-e_0)}{f_0} = \frac{(1-e_0)f}{f_0} \]

The sugar obtained after the milling plant will be:

\[ ES = k_1 k_2 S (1-f) \left( 1 - \frac{(1-e_0)f}{f_0} \right) \]

We must now fix the standard values for \( f_0 \) and \( e_0 \). The classical and standard figure for standard fibre is: \( f_0 = 0.125 \). For \( e_0 \), following the above rule (see "Ideal or average efficiency"), we shall choose: \( e_0 = 0.975 \) since there are tandems exceeding 97\% and since diffusion makes such extractions readily attainable.

Michel Hoarau\(^4\) has shown that \( k_1 \) is a function of \( f \) and he has given the range of variation for all the Réunion factories. The good correlation between the graph obtained and the individual value found for widely different tandems and factories (see Fig. 1 and Appendix 2) allows the results to be generalised and expressed with good precision by the formula: \( k_1 = 1-0.57f \).

Substituting the values of \( k_1 \), \( f_0 \) and \( e_0 \) in the above \( ES \) equation, we have:

\[ ES = k_1 k_2 S (1-0.57f) (1-f) (1-0.2f) \]

or:

\[ ES = k_1 S (1-1.77f + 0.884f^2 - 0.114f^3) \]

\( f \) being small, the terms in \( f^2 \) and \( f^3 \) are still smaller and have little effect compared with the term in \( f \). If we retain only the latter and modify it to give it the same value as the whole polynomial in \( f \) would have for a mean value of \( f \), for instance: \( f = 0.135 \), the sucrose obtained after the milling plant becomes:

\[ ES = k_1 S (1-1.65f) \]

and it is readily shown that the approximation thus adopted involves an error not exceeding 0.4\%, (say: 4 parts per 1 000) for extreme values of \( f \) such as 0.10 and 0.16.

2) **Loss in molasses.** If we take a standard purity \( M \) for the final molasses, the final quantity of sugar recovered from the cane under test will be:

\[ X = k_2 S (1-1.65f) \frac{100 (P_1-M)}{P_1 (100-M)} \]

or:

\[ X = k_2 S \frac{100}{100-M} (1-1.65f) \frac{P_1-M}{P_1} \]

but:

\[ S = \frac{B P}{100} \]

hence:

\[ X = k_2 \frac{B}{100-M} (1-1.65f) \frac{P_1-M}{P_1} \]

Now:

\[ \frac{P_1-M}{P_1} = \frac{P}{P_1} M. \]

If, following the same rule, we choose a standard purity of molasses \( M \) such that:

\[ \frac{P}{P_1} M = 30 \]

which corresponds closely to: \( M = 29 \), a value close to the classical figure \( M = 28.57 \), we shall have:

\[ X = k_2 \frac{100}{100-M} B (1-1.65f) \frac{P-30}{100} \]
E. HUGOT

Putting:

\[ k = \frac{100}{100 - M} \]

and commenting that:

\[ P - 30 \]

\[ B = \frac{S - 0.3B}{100} \]

we finally have:

\[ X = RS - k (1 - 1.65f) (S - 0.3B). \]

APPENDIX 2

Formula (1 - 0.57f)

Michel Hoarau made a great number of press experiments at a pressure of 100 kg/cm² and arranged the various fibres found in the following series:

- Fibres between 0.0975 and 0.1024 = series 0.100
- Fibres between 0.1025 and 0.1074 = series 0.105
- Fibres between 0.1075 and 0.1124 = series 0.110

and calculated by the regression formula the value of the C coefficient for each series. These values are given in columns 2 and 3 of Table 1. He compared the values thus obtained with those given by the chemical control of the 12 factories of the island and established that the sucrose % of the factories tallied quite well with the B, S, f values of the control, provided that the C coefficient used be the one found for the press reduced by 1.85 %; the correlation was equally good with the weekly figures of the various factories. Table 1 gives in column 4 the Cf values = 0.9815 Cp and we added column 5 giving the values of (1 - 0.57 f) and showing the high correlation with column 4.

**TABLE 1.**

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APPENDIX 3

**Primary Juice Analysis — Average Efficiency Formula**

We follow the same procedure as in appendix 1, with the only difference that we substitute
extraction $e_1 = 0.95$ for standard extraction $e_0 = 0.975$ and final molasses purity $M_i$ for $M$,

such that: $M_i = 40$.

It becomes:

$$1 - \frac{(1-e_1)f}{f_0} = 1 - 0.4f$$

and:

$$(1-0.57f) (1-f) (1-0.4f) = 1 - 1.97f + 1.198f^2 - 0.228f^3$$

which, for mean value of $f = 0.135$, gives the same result as: $1 - 1.8f$, this latter expression not departing from the polynomial in $P$ and $P^2$ by more than 0.8% for the extreme values: $f=0.10$ and $f=0.17$.

Taking: $M_i = 40$, we finally have:

$$X = RS = k(1-1.8f) (S-0.4B).$$

**FIGURE 1.** Relation between coefficient $C$ and Fiber $f$ as determined by Michel Hoarau.

**ANALYSIS DIRECTO DE LA CAÑA DE AZÚCAR**

**E. Hugot**

**RESUMEN**

Este artículo da fórmulas para ser utilizadas en la estimación del azúcar aprovechable en una entrega de caña. Compara el análisis directo con el análisis del jugo de primera extracción de la fábrica y llama la atención sobre la necesidad de tomar en cuenta el efecto de la fibra en ambos casos, efecto que es de mayor importancia en el molino que en la prensa.