DRI - WHAT IS IT?

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Abstract

For many years, the preparation of cane has been measured in terms of the ratio of brix in open cells in prepared cane to the total brix in an equivalent sample. The process involves gently washing a fixed mass of sample in a fixed mass of water for a specified time. A second sample is prepared further in a cold digester. The preparation is expressed as the ratio of the brix washed from the prepared cane to the total brix in the sample from the cold digester as a quantity known as preparation index or PI. Although theoretically sound, the process has some practical difficulties, which can cause large errors in the values reported. The causes of these errors include effects such as the washing time and temperature of the water. This, together with the time taken to measure a single sample, has led to the method falling into disfavour.

This paper describes an alternative method of expressing preparation as a function of how easily the brix can be extracted from the open cells rather than the fraction of open cells. The concept uses the theory of mass transfer and diffusion through concentration gradients to define the quantity, which has been called the 'diffusion rate index' or DRI. DRI is the time constant associated with the process of washing the brix out of a particular preparation.

A machine incorporating the theory and several practical innovations has been designed and manufactured. The main focus has been on automation and reducing the inputs required from the operator. Several of these machines have been installed in the South African industry. Some comparisons between DRI and the cane preparation are discussed.

Keywords: cane preparation, diffusion rate index, brix, extraction

Introduction

It has long been recognised that the degree of preparation of cane prior to extraction has a marked influence on the performance of the extraction plant (Markham, 1969). There have been many methods proposed for the measurement of preparation. Murray (1960) used sieving and bulk density as a measure of preparation. A method of washing the sucrose out of the prepared cane and comparing the extract to the total sucrose in the sample, known as displaceability index (DI) was documented by Payne (1960). Markham (1969) reported an evaluation of the approach for use in the South African sugar industry. This method moved from using sucrose to brix and became known as preparation index. The Australian sugar industry adopted pol in open cells as a measure of preparation.

The measurement of brix or pol in juice washed from prepared cane is time consuming and it is consequently an expensive measure of preparation. Often the errors associated with the measurement are also high, reducing the usefulness of the results.

Several attempts have been made to automate the process such as that by Bachan *et al.* (1988). The machines developed were mechanically complex and did not reach commercial viability.

Reid and Hastie (1994) used a different approach where the cane was washed in a constant volume of water and the conductivity rise in the water was measured as a function of time. They attempted to relate the result that was achieved to the preparation index (PI) technique that was in use at the time. The machine consisted of two containers. A lower container contained a volume of water. The water was pumped into the bottom of an elevated container through the cane sample. The water then overflowed back into the lower container. This was repackaged into a single box with the upper container placed concentric to the lower container (Gooch *et al.*, 1999). A dedicated microprocessor board replaced the personal computer. A pump to empty to machine was added in the current implementation.

Unlike the technique proposed by Reid and Hastie (1994), which tried to derive a reading comparable to the PI technique using curve fits and statistical techniques, DRI is a directly measured value, namely the time constant for the process of washing the brix out of the prepared cane. DRI is a measure of how easily brix can be removed from open cells in the prepared cane whereas PI indicates the number of open cells.

Mass transfer – the background to the value of DRI

The cane is held in a container while water is pumped through it, as shown in Figure 1. The conductivity of the water indicates how much of the salts have been washed out of the sample. The process can be modelled using a concentration difference approach.

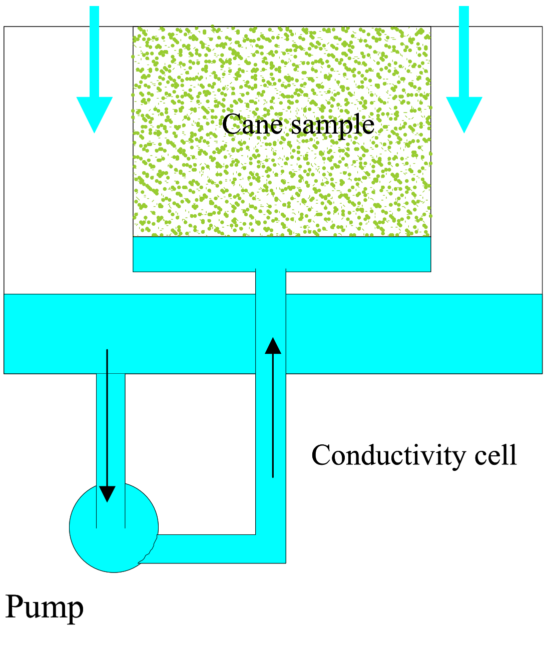

Figure 1. DRI machine layout.

The juice in the cane has a high brix concentration and the water circulating has a low brix concentration. The pump provides a forced flow through the cane bed. The brix will migrate from the high concentration area to the low concentration area. In other words, the concentration of the brix in the cells will decrease while the concentration in the water increases to a point where a uniform concentration exists throughout the system.

At the moment the washing starts, no migration of brix has occurred from the cells to the water.

The initial conditions are shown below:

$$m_0 = initial\ mass\ brix\ in\ broken\ cells$$
$$c_0 = initial\ average\ concentration\ of\ brix$$
$$v_w = volume\ of\ water\ added$$

To build a model, it is necessary to define the volume from which the brix migrates and the volume to which it migrates. The destination volume is simply the water added, namely v_W. The source volume is slightly more difficult to define since the shape of the broken cells is irregular and the concentration of brix is not necessarily homogeneous. It is useful to define an apparent cell volume, v_c, which is the volume required to contain the juice from broken cells at the average concentration of the brix in the cells.

This apparent volume of open cells can be calculated:

$$v_c = \frac{m_0}{c_0}$$

Once the washing starts, the mass of brix in the cells is transferred to the water, giving rise to the following time dependent functions:

$$m_c(t) = mass\ of\ brix\ in\ broken\ cells$$
$$c_c(t) = concentration\ of\ brix\ in\ broken\ cells$$
$$m_w(t) = mass\ of\ brix\ in\ water$$
$$c_w(t) = concentration\ of\ brix\ in\ water$$

The brix in the cells at time t, is the difference between the initial mass of brix and the amount that has migrated to the water.

$$m_c(t) = m_0 - m_w(t)$$

Concentration of the brix in the cells is

$$c_c(t) = \frac{m_c(t)}{v_c} = \frac{m_0 - m_w(t)}{v_c}$$

Concentration of brix in the water is

$$c_w(t) = \frac{m_w(t)}{v_w}$$

From mass transfer theory it is reasonable to assume that the mass flow rate of brix from the high concentration in the cells to the low concentration in the water is proportional to the difference in concentration between the two regions.

Using h as the proportionality constant gives:

$$\begin{aligned}
\dot{m}_w = -\dot{m}_c &= h\left[c_c(t) - c_w(t)\right] \\
&= h\left[\frac{m_0 - m_w(t)}{v_c} - \frac{m_w(t)}{v_w}\right] \\
&= h\left[\frac{m_0}{v_c} - m_w(t)\left(\frac{1}{v_c} + \frac{1}{v_w}\right)\right] \\
&= h\left[\frac{m_0}{v_c} - m_w(t)\frac{v_w + v_c}{v_c v_w}\right]
\end{aligned}$$

Which has the solution:

$$m_w(t) = \frac{m_0 v_w}{v_w + v_c}\left[1 - e^{-h\left(\frac{v_w + v_c}{v_w v_c}\right)t}\right]$$

Since:

$$v_w >> v_c$$

$$\left(\frac{v_w + v_c}{v_w v_c}\right) \approx \frac{1}{v_c} \text{ and } \frac{v_w}{v_w + v_c} \approx 1$$

The mass flow equation then becomes:

$$\begin{aligned}
m_w(t) &= m_0\left[1 - e^{-\frac{h}{v_c}t}\right] \\
&= m_0\left[1 - e^{-\frac{t}{\tau}}\right]
\end{aligned}$$

The machine measures conductivity of the water and not the mass. The equation may be divided by v_w, adjusted for the cell constant and rewritten as:

$$C(t) = C_\infty\left[1 - e^{-\frac{t}{\tau}}\right]$$

where:

$$\begin{aligned}
&C(t) = \textit{conductivity at time t} \\
&C_\infty = \textit{conductivity after an infinite time}
\end{aligned}$$

The time constant, τ, determines or describes the shape of the curve. A small value of τ results in the conductivity rising rapidly towards its final value whereas a large value indicates a slow rises in concentration. In other words, the smaller the value of τ, the easier it is to remove the brix from the prepared sample. It is the time constant that has been given the name diffusion rate index or DRI.

Figure 2 shows a trace that would be expected for conductivity as a function of time. If one time constant has passed, then the concentration equation becomes:

$$\begin{aligned} C(\tau) &= C_\infty(1-e^{-1}) \\ &= 0.63C_\infty \end{aligned}$$

In other words, when the conductivity becomes 63% of the final value, one time constant has passed. This can be used to calculate DRI.

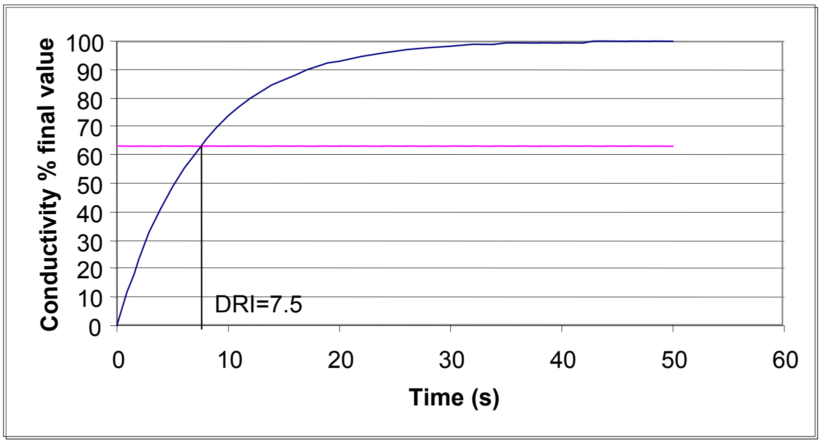

Figure 2. Typical conductivity curve with DRI=7.5 s.

Implementation

The measurement of PI has fallen out of favour because it is time consuming, can be subject to operator error and suffers from poor repeatability. These considerations had to be taken into account when the technology was packaged into a machine. The process had to require minimum user involvement and training. Relatively short measurement times were desirable. Maintenance had to be kept to a minimum.

The machine was packaged in a powder coated metal box that would fit on a 450 mm wide × 550 mm deep shelf.

It consisted of five main components:
- Sample holder
- Circulation
- Conductivity cell
- Emptying
- Controller.

The sample holder was constructed from standard PVC pipe sections. Sheet PVC was used for blanking the ends to form the necessary pots.

Circulation was achieved using a commercially available centrifugal pump. Care has to be taken to ensure that all the machines have equivalent pumps to avoid different circulation rates. The performance of the pump is checked before each run using the volume of water displaced in a certain time.

Stainless steel electrodes were used in a temperature compensated conductivity cell. The compensation algorithms were coded into the controller.

Previous attempts at automating the measurement of PI had run into problems resulting from fibres jamming the control valves. To avoid this problem, a second pump was used to empty the tank instead of a valve.

The control strategy was coded on a single chip microprocessor. The program instructs the operator on what actions to take via a liquid crystal display (LCD) visible on the front panel in Figure 3.

Routine operation would involve a few simple steps:

- Rinse the machine
- Install the cane sample
- Measure DRI
- Empty the cane basket
- Rinse the machine.

Figure 3. DRI Machine.

If the machine detects that the water supply has failed a message is sent to the display for the operator to take corrective action.

During the factory trials of the machine, one thing that came clear was that the way in which the sample was packed in the basket was important to the reliability of the measurement. The sample had to be broken up and mixed thoroughly. This was best achieved by breaking up the matted sample by hand and placing it on a piece of plastic. The sample was then mixed by rolling it back and forth using the plastic. Failure to do this would result in channelling of the sample by the water and the conductivity curve would become distorted. This distortion could be detected to some extent by examining the correlation parameters and poor samples could be rejected with a message on the LCD.

Another problem that arose was biological fouling of the pipe work. This was solved by introducing an option to wash the machine out with bleach. Once the bleach cycle was activated, the operator would be asked to pour a small amount of bleach into the machine. The machine could then alternate between circulating the bleach solution and allowing it to stand to ensure maximum effect.

Verification

When a new technique is introduced, it is often useful to compare it to the results from existing techniques. Rein (1970) studied the relationship between brix based displaceability index (DI), now known as preparation index (PI), and diffuser performance. With this relationship already established, it was decided to use PI as a measure against which to compare DRI. Since it is difficult to achieve repeatable PI results under factory conditions, a second measure was required. Shredding time in a mini shredder was chosen as the second measure of preparation in the laboratory.

Shredder time

Five hundred gram samples of cane stalks were billeted and placed in a mini-shredder. The shredder was run for times ranging from 5 s to 25 s in increments of five seconds. Two runs were done at each preparation time. The DRI for each sample was measured and the mean values for each preparation time are shown in Figure 4.

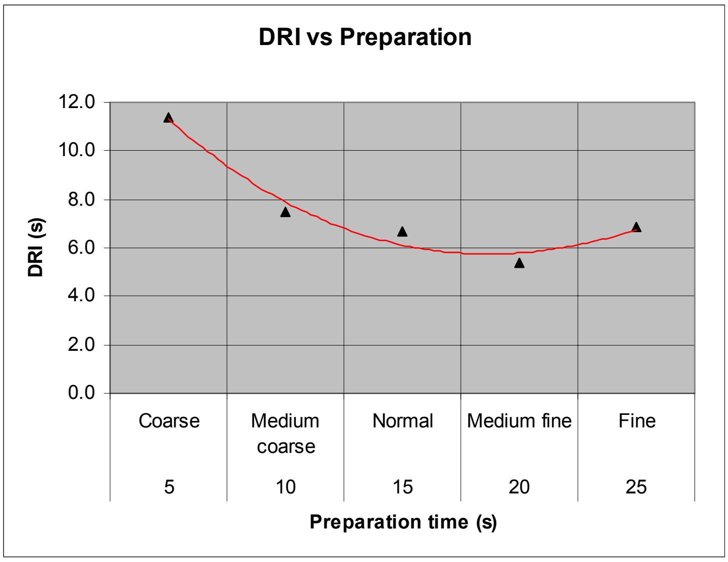

Figure 4. Comparison of DRI with preparation time.

It can be seen from the figure that the rate of removal of brix from the prepared cane increases with increasing preparation time until a point is reached where too many fine particles result in blinding of the screens. This is analogous to the flooding that will occur in a diffuser if the cane is over-prepared.

It was difficult to control the shredding time precisely because of the motor switch reaction time and the inertia of the shredder rotor.

Comparison with PI

A prototype DRI unit was installed at Eston mill. DRI and PI measurements were performed in parallel. The results of this exercise are shown in Figure 5. Although the trend is clearly visible, the correlation is extremely poor (r^2=0.21).

Under research laboratory conditions it is possible to keep factors such as temperature and test time constant. One difficulty experienced in factory use of PI is that ambient conditions vary considerably as a function of location and time of day. Often duration of the test can also vary as a result of pressures on staff preventing the termination of the test at the right time. It is this variation that contributes to the reduction in the accuracy of the PI test.

Further tests were conducted by SRI under strictly controlled laboratory conditions. (Using Pol in Open Cells instead of PI.) The correlations obtained were much closer and the results were published at the 2004 ASSCT conference (Kent *et al*., 2004)

Whereas PI is the ratio of brix released to total brix in cane, DRI is a measure of how quickly the brix can be removed from a particular preparation. It follows that, although a correlation will exist between PI and DRI, it need not be a strictly linear relationship.

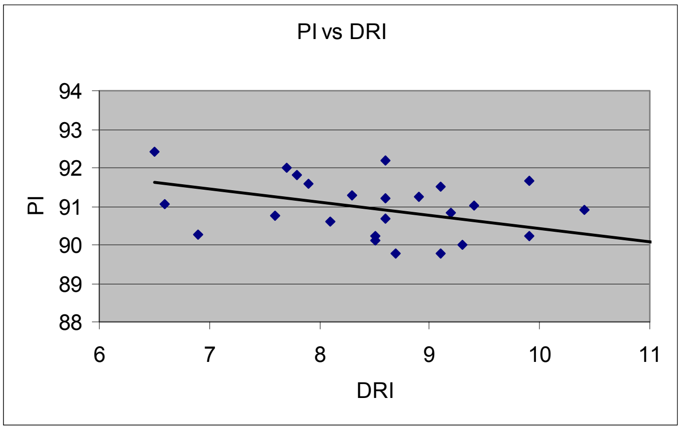

Figure 5. Comparison of PI and DRI in factory laboratory.

Typical values

The sample used must be representative of the cane that is prepared. If the sample preparation technique was followed, then a typical value for a well-prepared cane would be 6.5 to 7 seconds. Coarsely prepare cane obtained from Noodsberg during the time when energy consumption was to be minimised showed a value of 12 seconds. Values as low as 5 seconds have also been reported by Umzimkulu.

Table 1 summarises the values that have been identified in the units installed in various sugar mills.

Table 1. Typical DRI values.

DRI	Comment
5	Fine preparation
6.5-7	Well prepared cane – a good target value
12	Coarse preparation

Conclusion

This contribution reports on a new technique for the measurement of cane. This technique washes the brix from a sample. Conductivity is used to measure the amount of brix washed out of the sample as a function of time. The quantity reported is the time constant associated with the process of washing the brix out of the sample. This time constant has been given the name: 'Diffusion Rate Index' or DRI.

It takes less than ten minutes to complete a DRI test, where earlier techniques can take in excess of half an hour. The DRI machine is controlled by a microprocessor, thereby removing much of the scope for operator error. The only responsibility on the operator is to ensure that a homogeneous, representative sample is placed in the sample basket.

Acknowledgements

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