M7 AN ENHANCED MILL EXTRACTION MODEL

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Abstract

An enhanced mill extraction model has been developed to calculate mill performance parameters and to predict the extraction performance of a milling unit. The model takes into account the fibre suspended in juice streams and calculates filling ratio, reabsorption factor, imbibition coefficient, and separation efficiency using more complete definitions than those used in previous extraction models. A mass balance model is used to determine the fibre, brix and moisture mass flows between milling units so that a complete milling train, including the return stream from the juice screen, is modelled. Model solutions are presented to determine the effect of different levels of fibre in juice and efficiency of fibre separation in the juice screen on brix extraction. The model provides more accurate results than earlier models leading to better understanding and improvement of the milling process.

Introduction

For the purpose of this paper, an extraction model for a milling train consists of an extraction model for a milling unit and a series of mass balance equations to determine the constituents of bagasse and juice transferred from one mill to another. An extraction model can be used in two modes. In the analytical mode, if bagasse analysis results are available, the extraction model can be used to calculate performance parameters for each milling unit. These performance parameters can then be assessed to determine how well each milling unit is performing. The predictive mode involves defining performance parameters for each milling unit so that the extraction model can predict bagasse analysis for each mill and hence predict extraction for the milling train. Both modes have found application in the sugar industry.

The first and only extraction model to find wide application in Australia, MILSIM (Russell, 1968), uses two performance parameters for a milling unit: reabsorption factor and imbibitions coefficient. Reabsorption factor determines the relative quantities of total juice in the delivery bagasse and expressed juice while the imbibition coefficient determines the split of brix and moisture in the delivery bagasse and expressed juice. The model is based on the assumption that the fibre in juice is negligible so that the fibre rate through each mill is constant and the model is able to focus on brix and moisture only. The assumption is convenient, but incorrect.
The fibre flow model of Kent (2001) includes the actual flow of fibre in the milling train, taking into account the fibre in the return stream from the juice screen. The model determines the fibre processed by each milling unit, but does not describe the relative flows of brix and moisture. A mass balance model of the milling train was presented by Loubser (2004). Loubser’s model determines the mass flows of fibre, brix and moisture taking into account the return stream from the juice screen. However, Loubser’s model does not contain milling unit performance parameters and so cannot be used in a predictive mode.

Wienese (1990) developed a model to predict extraction performance of the milling train. The model defined the performance parameters separation efficiency, reabsorption coefficient and imbibition efficiency from known factory data. The reabsorption coefficient and imbibition efficiency are analogous to the reabsorption factor and imbibition coefficient in the MILSIM model. Wienese allowed some of the fibre to end up in expressed juice and introduced the separation efficiency to account for it. The separation efficiency was defined as \(100 - \frac{\text{Fibre}\%\text{juice}}{\text{Fibre}\%\text{cane}}\). Wienese (1994) changed the definition of separation efficiency to \(100 \times \left(\frac{\text{Fibre}\%\text{cane} - \text{Fibre}\%\text{juice}}{\text{Fibre}\%\text{cane}}\right)\). Wienese’s model did not take into account the return stream from the juice screen and hence ignored a significant flow. Wienese (1995) proposed a mass balance model for the entire milling train, assuming constant ratios of \(\frac{\text{Fibre}\%\text{cane}}{\text{Fibre}\%\text{bagasse}}\), \(\frac{\text{Brix}\%\text{cane}}{\text{Brix}\%\text{bagasse}}\) and \(\frac{\text{Moisture}\%\text{cane}}{\text{Moisture}\%\text{bagasse}}\). The assumptions are not entirely correct, and the model does not determine the individual milling unit mass flows.

Edwards (1995) presented a more sophisticated milling unit extraction model to better represent the split of brix and moisture into delivery bagasse and expressed juice. Edwards replaced the imbibition coefficient with two parameters: crushing factor and mixing efficiency. The crushing factor models the process of opening juice cells by a mill while the mixing efficiency is focussed on the mixing of imbibition with feed bagasse. While this model better represents the physical process in a milling unit, it relies on knowledge of the brix in open cells at each mill which generally is not known. The model has not been widely adopted.

In this paper, an extraction model is described which extends the MILSIM model by accounting for fibre in juice flows, revises the definitions of the performance parameters to account for those flows and includes a separation efficiency term similar to that defined by Wienese (1994). A mass balance model is described to calculate the actual mass flows of cane constituents through the milling train including the return stream from the juice screen. The effects of fibre in juice streams and juice in the return stream from the juice screen on overall brix extraction are determined.

**Milling unit extraction model**

**The MILSIM model**

The MILSIM model (Russell, 1968) defines the following mill parameters for mill \(n:\)
• **Filling ratio** \((C_n)\): The non-dimensional representation of the delivery nip compaction of the mill. It is defined as the ratio of no void volume rate of fibre \((\dot{V}_{\text{BnF}})\) to the escribed volume rate \((\dot{V}_{\text{En}})\).

\[
C_n = \frac{\dot{V}_{\text{BnF}}}{\dot{V}_{\text{En}}} \quad (1)
\]

• **Reabsorption factor** \((K_n)\): The juice extraction performance of the mill. It is defined as the ratio of no void volume rate of bagasse \((\dot{V}_{\text{Bn}})\) to the escribed volume rate.

\[
K_n = \frac{\dot{V}_{\text{Bn}}}{\dot{V}_{\text{En}}} \quad (2)
\]

• **Imbibition coefficient** \((I_{Cn})\): The measure of the performance of the mill in producing uniform brix concentration of juice in bagasse and expressed juice. It is defined as the ratio of the actual brix extraction \((E_n)\) to the theoretical brix extraction \((E_{Kn})\) of the mill if the juice in the feed to the mill (the juice in the delivery bagasse from the previous mill and the applied imbibition) was uniformly mixed.

\[
I_{Cn} = \frac{E_n}{E_{Kn}} \quad (3)
\]

It can be argued that the filling ratio is not strictly a performance parameter since it remains an input to the extraction model whether it is used in analytical or predictive mode.

**Correcting the filling ratio**

Equation (1) shows that the filling ratio is determined from the volume of fibre and the escribed volume. In the MILSIM model, the volume rate of fibre is determined from the cane fibre rate. In this enhanced model, the volume rate of fibre needs to be determined from the fibre rate through mill \(n\).

The fibre rate chosen to calculate the filling ratio and reabsorption factor is the fibre rate in bagasse leaving the mill and not the fibre rate in the feed to the mill. The fibre rate in the feed includes the fibre suspended in the imbibition stream. A significant portion of the juice to be expressed in the mill is expressed before the bagasse reaches the delivery nip (Thaval and Kent, 2011), where filling ratio is calculated, and most of the fibre to be expressed with the juice will have been expressed before this point. Consequently, the delivery bagasse fibre rate is considered a better estimate of milling unit fibre rate than the feed fibre rate for use in the filling ratio calculation.

Using the revised fibre rate, the volume rate of fibre \((\text{m}^3/\text{s})\) is calculated from,

\[
\dot{V}_{\text{BnF}} = \frac{\dot{m}_{\text{BnF}}}{d_F} \quad (4)
\]
where:
\( \dot{m}_{BNF} \) is the delivery bagasse fibre rate of the \( n^{th} \) mill (kg/s),
\( d_F \) is the density of fibre (1530 kg/m\(^3\)) (Pidduck, 1955).

The escribed volume rate is determined from the physical parameters of mill length, delivery nip work opening and top roll surface speed.

The corrected filling ratio \( (C_{On}) \) can be calculated by substituting equation (4) into equation (1),

\[
C_{On} = \frac{\dot{m}_{BNF}}{d_F \times \dot{V}_{En}}
\]  

(5)

Correcting the reabsorption factor

The reabsorption factor is determined from the volume of bagasse, fibre density, corrected filling ratio and bagasse fibre flow.

\[
K_{On} = \frac{\dot{V}_{Bn} \times d_F \times C_{On}}{\dot{m}_{BNF}}
\]  

(6)

where:
\( K_{On} \) is the corrected reabsorption factor of \( n^{th} \) mill,
\( \dot{V}_{Bn} \) is the volume rate of bagasse leaving \( n^{th} \) mill (m\(^3\)/s).

Correcting the imbibition coefficient

The model calculates the brix processed by each milling unit and determines the imbibition coefficient for each mill.

\[
I_{CON} = \frac{\dot{m}_{B(n-1)B} - \dot{m}_{BNB}}{\dot{m}_{B(n-1)B} - \dot{m}_{kBNB}}
\]  

(7)

where:
\( I_{CON} \) is the corrected imbibition coefficient of \( n^{th} \) mill,
\( \dot{m}_{B(n-1)B} \) is the mass flow of brix in bagasse of \((n-1)^{th}\) mill (kg/s),
\( \dot{m}_{BNB} \) is the mass flow of brix in bagasse of \( n^{th} \) mill (kg/s),
\( \dot{m}_{kBNB} \) is the theoretical mass flow of brix in bagasse of \( n^{th} \) mill (kg/s).

Defining the separation efficiency

While the concept of separation efficiency as defined by Wienese (1994) appears suitable, the definition used is not considered ideal, with fibre% juice being subtracted from the fibre% cane (or fibre% feed). The separation efficiency should represent the proportion of total fibre in the feed that is found in the delivery bagasse so that 100% separation efficiency results in no fibre in expressed juice.

The separation efficiency has been redefined here as:
where:

\[ S_n = \frac{m_{F,n} - m_{J,n}}{m_{F,n}} \times 100 \]  

where:

- \( S_n \) is the separation efficiency of the \( n \)th mill (%),
- \( m_{F,n} \) is the mass flow of fibre in the feed to the \( n \)th mill (kg/s),
- \( m_{J,n} \) is the mass flow of fibre in the expressed juice of the \( n \)th mill (kg/s).

**Juice screen model**

The extraction model determines the juice screen efficiency in terms of the proportion of fibre returned to the milling train from the juice screen.

\[ S_{cn} = \left( \frac{m_{JS}}{m_{J1} + m_{J2}} \right) \times 100 \]

where:

- \( S_{cn} \) is the juice screen efficiency (%),
- \( m_{JS} \) is the mass flow of fibre in the return stream from the juice screen (kg/s),
- \( m_{J1} \) is the mass flow of fibre in the expressed juice from the first mill (kg/s),
- \( m_{J2} \) is the mass flow of fibre in the expressed juice from the second mill (kg/s).

**Mass balance model**

Figure 1 shows the flow of products in a milling train with five mills and the denoted parameters for the milling train. In total, there are 14 streams included in the model.

In the following equations, the general form of any parameter is \( q_{pc} \), where \( q \) is a quantity, \( p \) is a product, and \( c \) is a component. In Figure 1, the legend shows all the products used in this model.
Mass must be conserved across each milling unit and across the juice screen.

\[
\dot{m}_c = \dot{m}_{j1} + \dot{m}_{b1} \quad (10)
\]

\[
\dot{m}_{b1} + \dot{m}_{j5} = \dot{m}_{b2} + \dot{m}_{j2} \quad (11)
\]

\[
\dot{m}_{b2} + \dot{m}_{j4} = \dot{m}_{b3} + \dot{m}_{j3} \quad (12)
\]

\[
\dot{m}_{b3} + \dot{m}_{j5} = \dot{m}_{b4} + \dot{m}_{j4} \quad (13)
\]

\[
\dot{m}_{b4} + \dot{m}_{i} = \dot{m}_{b5} + \dot{m}_{j5} \quad (14)
\]

\[
\dot{m}_{j1} + \dot{m}_{j2} = \dot{m}_{j5} + \dot{m}_{jM} \quad (15)
\]

where:
\[\dot{m}_p\] is the total mass flow rate (kg/s) of any product \(p\) listed in Figure 1.

Equations (10) to (15) show only total mass flows (fibre plus brix plus moisture) but conservation of mass also applies to fibre mass flow and brix mass flow individually.

For any stream, the fibre fraction in product \(p\) is determined from:

\[
P_{PF} = \frac{\dot{m}_{PF}}{\dot{m}_p} \quad (16)
\]

where,
\[P_{PF}\] is the fibre fraction in product \(p\),
\[\dot{m}_{PF}\] is the mass flow rate of fibre in product \(p\) (kg/s).

Similarly, the brix fraction is determined from:

\[
P_{PB} = \frac{\dot{m}_{PB}}{\dot{m}_p} \quad (17)
\]

where,
\[P_{PB}\] is the brix fraction in product \(p\),
\[\dot{m}_{PB}\] is the mass flow rate of brix in product \(p\) (kg/s).

For each of the 14 streams, the model accounts for three mass flows: total flow (fibre plus brix plus moisture), fibre flow and brix flow. Hence, there are 42 mass flows in the model. The cane rate, and added water rates are inputs to the model leaving 40 unknown flows. These parameters can be determined by solving equations 10 to 15 for total flow, fibre flow, and brix flow, leaving 22 unknown flows. Fibre and brix content are known for cane and imbibition and are either known for the five bagasse streams or can be calculated from the performance parameters. Using equation (16) and equation (17) for these seven streams reduces the number of unknowns to eight. Separation efficiency is known for the five mills and so equation (8) reduces the number of unknown to three. The juice screen efficiency in equation (9) introduces one further equation leaving two unknowns relating to the juice screen. The juice/fibre ratio of the return stream from the juice screen can be provided as an input, providing another equation. Finally following Loubser (2004), the brix fraction in the return stream from the juice screen and the brix fraction in mixed juice are assumed the same. This assumption seems reasonable in the absence of more detailed
information because the return stream has been saturated by mixed juice in the juice screen.

When calculating the brix fraction in juice, the fibre in juice mass flow is subtracted from the total mass flow of juice, since brix fraction is brix on juice and not brix on total juice material.

**Solving the model**

In analytical mode where bagasse analysis is used to determine mill performance parameters the model solves quite simply in much the same way as the original MILSIM model (Russell, 1968). In predictive mode, however, the solution method is a little more complex.

In both modes, filling ratio is defined according to the MILSIM definition using cane fibre rate. The corrected filling ratio is determined from the calculated mass flows.

Figure 2 shows the flowchart for solving the model in predictive mode. Using the input filling ratio defined according to the MILSIM definition and the defined performance parameters for each mill, the milling unit extraction model is used to determine the bagasse analysis for each mill. Using the bagasse analysis, the mass balance model is solved and, using the calculated fibre flows, the filling ratio is corrected. The corrected filling ratio is then fed back into the extraction model and the process repeated until the calculated corrected filling ratio is sufficiently close in value to the input corrected filling ratio.

![Fig. 2—Flowchart of the calibration model](image)

**Brix extraction**

Without the assumption of constant fibre rate throughout the milling train, the standard definition of extraction no longer applies. Here, brix extraction (%) was calculated as follows:

\[
E = \left( \frac{\dot{m}_{CB} - \dot{m}_{BSB}}{\dot{m}_{CB}} \right) \times 100
\]

(18)

**Exploring the model**

**A base case for testing the model**

To test the model a standard set of input values were adopted (Table 1). The cane and bagasse analysis values were based on a set of routine factory bagasse analysis data. The remaining values were adopted from Kent (2001). These results imply a juice screen efficiency of 92.31%.
Table 1—Input values for the model

<table>
<thead>
<tr>
<th>Product stream</th>
<th>Brix (%)</th>
<th>Fibre (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane (198.47 kg/s)</td>
<td>15.91</td>
<td>14.00</td>
</tr>
<tr>
<td>#1 mill bagasse</td>
<td>11.93</td>
<td>30.16</td>
</tr>
<tr>
<td>#2 mill bagasse</td>
<td>8.43</td>
<td>35.70</td>
</tr>
<tr>
<td>#3 mill bagasse</td>
<td>6.24</td>
<td>40.47</td>
</tr>
<tr>
<td>#4 mill bagasse</td>
<td>4.65</td>
<td>44.45</td>
</tr>
<tr>
<td>#5 mill bagasse</td>
<td>3.19</td>
<td>47.37</td>
</tr>
<tr>
<td>Expressed juice</td>
<td>-</td>
<td>2.00</td>
</tr>
<tr>
<td>Return stream</td>
<td>-</td>
<td>8.00</td>
</tr>
<tr>
<td>Mixed juice</td>
<td>-</td>
<td>0.20</td>
</tr>
<tr>
<td>Imbibition (200% fibre)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Effect of the constant fibre assumption on mill parameters

The corrected mill parameters calculated from the model were compared to their MILSIM values and are shown in Tables 2, 3, and 4.

Table 2—Filling ratio

<table>
<thead>
<tr>
<th>Mill</th>
<th>Filling ratio</th>
<th>MILSIM (C)</th>
<th>Corrected (CO)</th>
<th>(\frac{CO}{C})</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>0.392</td>
<td>0.360</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td>0.444</td>
<td>0.463</td>
<td>1.04</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td>0.492</td>
<td>0.507</td>
<td>1.04</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td>0.542</td>
<td>0.559</td>
<td>1.03</td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td>0.575</td>
<td>0.567</td>
<td>0.99</td>
<td></td>
</tr>
</tbody>
</table>

Table 3—Reabsorption factor

<table>
<thead>
<tr>
<th>Mill</th>
<th>Reabsorption factor</th>
<th>MILSIM (K)</th>
<th>Corrected (KO)</th>
<th>(\frac{KO}{K})</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>1.69</td>
<td>1.55</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td>1.60</td>
<td>1.67</td>
<td>1.04</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td>1.55</td>
<td>1.60</td>
<td>1.03</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td>1.54</td>
<td>1.59</td>
<td>1.03</td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td>1.53</td>
<td>1.51</td>
<td>0.98</td>
<td></td>
</tr>
</tbody>
</table>

Table 4—Imbibition coefficient

<table>
<thead>
<tr>
<th>Mill</th>
<th>Imbibition coefficient</th>
<th>MILSIM (IC)</th>
<th>Corrected (ICO)</th>
<th>(\frac{ICO}{IC})</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>1.05</td>
<td>1.04</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td>0.82</td>
<td>0.87</td>
<td>1.06</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td>0.66</td>
<td>0.67</td>
<td>1.01</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td>0.55</td>
<td>0.57</td>
<td>1.03</td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td>0.53</td>
<td>0.57</td>
<td>1.07</td>
<td></td>
</tr>
</tbody>
</table>

The low bagasse fibre flow in the delivery bagasse of #1 mill shown in Table 2 is an interesting result from the model. The value shows that only 92% of fibre in cane ended up in the delivery bagasse of #1 mill, with the remaining 8% in the expressed juice stream. In other words, 2% fibre in juice equates to 8% fibre in cane. Kent (2001) did not identify this issue because he examined the fibre rate going into each milling unit rather than the fibre rate coming out of each milling unit. The filling
ratios for #1 and #5 mills were less than their MILSIM values while the filling ratios for the remaining mills were greater.

The corrected reabsorption factor differs from the MILSIM value by virtually the same amount as the filling ratio and reflects the importance of the ratio \( \frac{K}{C} \) in the model, rather than either reabsorption factor or filling ratio alone.

The corrected imbibition coefficient is slightly lower than the MILSIM value for #1 mill but higher at the other mills. The largest differences were found for #2 and #5 mills. The return stream from the juice screen is added to #2 mill, increasing the input brix mass flow to #2 mill. The brix (and fibre) flow into the final mill is greater than for the MILSIM model because, for the mass to balance, it contains the brix and fibre expressed in the juice from the final mill. The brix (and fibre) flow in the bagasse from the final mill has less brix and fibre because this flow is missing the brix and fibre in mixed juice. The combination of increased brix flow into the final mill and reduced brix flow out of the final mill in equation (7) causes the large difference in the imbibition coefficient.

Separation efficiency

Table 5 shows the calculated separation efficiency for each mill, resulting from 2% fibre in expressed juice for each mill. The separation efficiencies range from 91.1% at #2 mill to 95.7% at #5 mill. The separation efficiencies are substantially lower for #1 and #2 mills than the other mills.

<table>
<thead>
<tr>
<th>Mill</th>
<th>Separation efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>91.80</td>
</tr>
<tr>
<td>#2</td>
<td>91.11</td>
</tr>
<tr>
<td>#3</td>
<td>94.80</td>
</tr>
<tr>
<td>#4</td>
<td>95.41</td>
</tr>
<tr>
<td>#5</td>
<td>95.65</td>
</tr>
</tbody>
</table>

It follows that, if separation efficiency was assumed constant for each mill, the resulting fibre content in expressed juice differs substantially from mill to mill with relatively much less fibre in the juice from #1 and #2 mills (Table 6).

Table 6—Fibre% juice values for separation efficiency of 95%

<table>
<thead>
<tr>
<th>Mill</th>
<th>Fibre% Juice</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>1.22</td>
</tr>
<tr>
<td>#2</td>
<td>1.33</td>
</tr>
<tr>
<td>#3</td>
<td>1.93</td>
</tr>
<tr>
<td>#4</td>
<td>2.20</td>
</tr>
<tr>
<td>#5</td>
<td>2.32</td>
</tr>
</tbody>
</table>

Effect of including the juice screen in the model

Wienese’s extraction model (Wienese, 1990) does not consider the return stream from the juice screen to the milling train. A case study was undertaken to see if neglecting the juice screen significantly affects the calculation of extraction.
The model was run in analytical mode to calculate reabsorption factor, imbibition coefficient and separation efficiency for two cases. The first case was the base case described earlier in this section. For the second case, the juice screen efficiency was set to zero so that there was no return stream from the juice screen. The results are shown in Table 7.

Table 7—Effect of juice screen on calculated performance parameters

<table>
<thead>
<tr>
<th>Juice screen</th>
<th>( K_0 )</th>
<th>( I_{CO} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1 (With juice screen)</td>
<td>1.55</td>
<td>1.04</td>
</tr>
<tr>
<td></td>
<td>1.67</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>1.60</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>1.59</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>1.51</td>
<td>0.57</td>
</tr>
<tr>
<td>Case 2 (Without juice screen)</td>
<td>1.55</td>
<td>1.04</td>
</tr>
<tr>
<td></td>
<td>1.46</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>1.39</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>1.38</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>1.30</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Although Table 6 shows some significant changes in parameter values, it is difficult to conceptualize their impact and so brix extraction was calculated for the base case model (including the juice screen) using both sets of performance parameters. Using the parameter values calculated with the juice screen in the model, the brix extraction was 94.2%. Using the parameter values calculated without the juice screen in the model, the brix extraction was 95.1%. This analysis shows that the inclusion of the juice screen in the model changes the model parameters to the extent of almost one unit of extraction. Consequently, the juice screen is an important part of the overall model.

Case studies

Effect of separation efficiency and juice in return stream from juice screen on extraction

It is conceivable that, if all the clearances around the mill, such as between scrapers and rolls, were reduced, the amount of fibre in expressed juice could reduce or, in terms of the extraction model, the separation efficiency could increase. Similarly, it is conceivable that, if the juice screen could be continuously cleaned or had a larger screen area, a greater amount of juice would pass through to mixed juice and not be returned to the milling train. The extraction model can examine these concepts.

The model was solved for separation efficiencies in each mill from 93% to 96% and juice/fibre ratio in the return stream from the juice screen of 0 to 12 (a fibre in the return stream of 8% as listed in Table 1 corresponds to a juice/fibre ratio of 11.5). The brix extraction results are shown in Table 8.
Table 8—The effect of mill separation efficiencies ($S_n$) of 93% to 96% and the juice/fibre ratio in the return stream from the juice screen on overall brix extraction (in percent)

<table>
<thead>
<tr>
<th>Juice/fibre ratio</th>
<th>$S_n$ -93</th>
<th>$S_n$ -94</th>
<th>$S_n$ -95</th>
<th>$S_n$ -96</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>94.84</td>
<td>94.83</td>
<td>94.82</td>
<td>94.82</td>
</tr>
<tr>
<td>4</td>
<td>94.61</td>
<td>94.63</td>
<td>94.66</td>
<td>94.69</td>
</tr>
<tr>
<td>8</td>
<td>94.43</td>
<td>94.47</td>
<td>94.52</td>
<td>94.57</td>
</tr>
<tr>
<td>10</td>
<td>94.29</td>
<td>94.34</td>
<td>94.40</td>
<td>94.48</td>
</tr>
<tr>
<td>12</td>
<td>94.18</td>
<td>94.23</td>
<td>94.30</td>
<td>94.39</td>
</tr>
</tbody>
</table>

As separation efficiency increases, brix extraction increases, and as juice/fibre ratio of the return stream from the juice screen increases, brix extraction decreases. Increasing the separation efficiency from 93% to 96% increased extraction by 0.2 units. Reducing the juice/fibre ratio of the return stream from the juice screen from 12 to 10, increased extraction by about 0.1 units.

**Effect of fibre in mixed juice on extraction**

The fibre in mixed juice was varied and the calculated effect on juice screen efficiency and brix extraction is shown in Table 9.

Table 9—Effect of fibre in mixed juice on juice screen efficiency and overall brix extraction.

<table>
<thead>
<tr>
<th>Mixed juice fibre content (%)</th>
<th>Juice screen efficiency (%)</th>
<th>Brix extraction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>92.31</td>
<td>94.16</td>
</tr>
<tr>
<td>0.4</td>
<td>84.48</td>
<td>94.14</td>
</tr>
<tr>
<td>0.6</td>
<td>76.57</td>
<td>94.12</td>
</tr>
<tr>
<td>0.8</td>
<td>68.41</td>
<td>94.10</td>
</tr>
</tbody>
</table>

As shown in Table 9, increasing the fibre content of the mixed juice is achieved by decreasing the screen efficiency. The juice screen efficiency is defined in terms of fibre returned to the milling train from the juice screen. Increasing the fibre content of the mixed juice reduces the fibre flow and total flow in the return stream from the juice screen. The fibre content of mixed juice has little effect on the brix extraction.

**Conclusion**

A more detailed mill extraction model was developed and validated to predict the extraction performance of a milling train. The model explains the effect of changing mass flows of cane constituents through the milling train on mill parameters and brix extraction and eliminates the assumption of zero fibre in juice streams that is used in the existing MILSIM model. A modified separation efficiency parameter has been included to quantify the amount of fibre in expressed juice from a mill.

Although the assumption of equal fibre rate through the milling unit affects extraction predictions, existing models such as MILSIM have already accounted for the variable fibre rates in their mill parameters.

The developed model gives further insight into the milling process. Using the extraction model, it has been possible to quantify the extraction benefit of reducing the amount of fibre in expressed juice and of reducing the amount of juice in the
return stream from the juice screen. Benefits of the order of 0.1 to 0.2 units of extraction seem achievable through such actions.

REFERENCES