การจำลองผลกระทบของการผสมแบบไม่เอกพันธ์ที่มีต่อสมรรถนะของกระบวนการหีบอ้อย

สมชาติ ฉันทศิริวรรณ*
มหาวิทยาลัยธรรมศาสตร์ ศูนย์รังสิต จ.ปทุมธานี 12121

บทคัดย่อ

กระบวนการหีบห้อยประกอบด้วยลูกหีบหลายลูกทำงานต่อเนื่องกัน วัตถุดิบที่เข้าสู่กระบวนการคือ อ้อย และผลผลิตที่ได้คือ ชานอ้อยและน้ำอ้อย วัตถุประสงค์หนึ่งของกระบวนการนี้คือ การดึงน้ำตาลซูโครสในอ้อยออกมาให้มากที่สุดเท่าที่จะมากได้ซึ่งสามารถกระทำได้โดยการผสมน้ำหรือน้ำอ้อยกับกากอ้อยที่กำลังจะเข้าสู่ลูกหีบลูกที่สองและลูกถัดไป ปัจจัยหนึ่งซึ่งส่งผลต่อสมรรถนะของกระบวนการหีบอ้อยคือ การผสมกันอย่างทั่วถึงระหว่างกากอ้อยกับน้ำหรือน้ำอ้อย ในบทความนี้แบบจำลองกระบวนการหีบอ้อยได้ถูกพัฒนาขึ้นเพื่อวิเคราะห์ศึกษาปัจจัยต่างๆ ที่มีผลกระทบต่อกระบวนการหีบอ้อย แบบจำลองนี้ได้พิจารณากรณีที่กากอ้อยอาจผสมกับน้ำหรือน้ำอ้อยอย่างไม่ทั่วถึง แบบจำลองนี้ใช้ในการศึกษาผลกระทบของการผสมกันอย่างไม่ทั่วถึงที่มีต่อการดึงซูโครสออกจากอ้อย ความชื้นของกากอ้อย และความเข้มข้นของน้ำอ้อยที่ได้จากกระบวนการหีบอ้อย ซึ่งเป็นพารามิเตอร์ที่ใช้วัดสมรรถนะของกระบวนการหีบอ้อย

คำสำคัญ : การแยกของเหลวออกจากของแข็ง / การหีบอ้อย / การจำลอง

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* *ศาสตราจารย์ คณะวิศวกรรมศาสตร์*

Modeling Effects of Non-homogeneous Mixing on the Performance of Sugar Cane Milling Process

Somchart Chantasiriwan*
Thammasat University, Rangsit Campus, Pathum Thani 12121, Thailand

Abstract

Sugar cane milling process consists of several mills operating in a tandem. Input to the process is sugar cane, and outputs are final bagasse and mixed juice. An objective of the process is to maximize the extraction of sucrose from sugar cane, which may be accomplished by mixing bagasse entering the second and subsequent mills with either recycled juice from the following mills or imbibition water. An important factor affecting the performance of the sugar milting process is how well bagasse is mixed with recycled juice or imbibition water. In this paper, a model has been developed to simulate the operation of sugar mills. In addition to mass balances of fiber, dissolved solids, and water, this model takes into account non-homogeneous mixing between bagasse and recycled juice or imbibition water. This model is used to investigate how homogeneous mixing affects brix extraction, final bagasse moisture and mixed juice concentration, all of which are important performance parameters of the sugar milling process.

Keywords : Solid-Liquid Separation / Juice Extraction / Modeling

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* Professor, Faculty of Engineering.

1. Introduction

In the sugar industry, milling is the process in which juice is extracted from shredded sugar cane. Sugar cane mills are machinery used to accomplish this task. Juice extraction by a sugar cane mill is effected by squeezing between a floating top roll, which is driven by a power unit, and two bottom rolls known as the feed roll and the discharge roll. An objective of the milling process is to extract as much as sucrose as possible from sugar cane. Because all sucrose is dissolved in juice, maximum sucrose extraction is equivalent to maximum juice extraction. Normally, one mill cannot yield satisfactory juice extraction since bagasse leaving the first mill still contains a lot of juice. Consequently, most sugar factories use at least 5 mills. Since bagasse that is fed to the second and subsequent mills is quite dry, and extraction of dry bagasse is ineffective, water or juice is mixed with bagasse before being fed to the mills. This mixing process is known as imbibition.

Although a variety of imbibition schemes are possible, the sugar industry mostly uses the compound imbibition scheme shown in Fig. 1. In this scheme with five mills in a tandem, imbibition water is mixed with bagasse leaving the fourth mill before being sent to the fifth mill, and juice extracted from the third, the fourth and the fifth mills is sent backward to mix with bagasse that is about to enter the second, the third, and the fourth mills, respectively. Furthermore, juice extracted from the first and second mills are sent to a screen to filter out non-dissolved solids. The filtrate, known as mixed juice, is sent to other processes. The non-dissolved solids laden with residual juice filtrate is known as cush cush. It is sent to the second mill.

Juice extraction is not the only objective of the milling process. The moisture of final bagasse leaving the last mill and the concentration of the mixed juice should also be considered in the evaluation of the performance of the sugar milling process because the bagasse is used as a fuel for the boiler and the mixed juice is sent to subsequent sugar manufacturing processes. Since boiler efficiency increases with the decrease in bagasse moisture, it is desirable from the viewpoint of energy efficiency to minimize the moisture. In addition, high concentration of mixed juice is desirable because less water is needed to be evaporated. Unfortunately, it has been found that increasing the amount of imbibition water in compound imbibition leads not only to increased juice extraction but also increased moisture of the final bagasse and decreased mixed juice concentration. A trade-off among these objectives must, therefore, be considered in choosing the optimum amount of imbibition water.

In order to analyze the performance of sugar mills, a model of the sugar milling process is needed. Black-box models used by Rein [1] and Wienese [2] are unsatisfactory because they ignore the details of sugar mills. A model presented by Loubster [3] takes into account juice recycling and interaction between mills via mass balances. However, it does not contain milling performance parameters required to predict the performance of mills in a different arrangement. A more sophisticated model has been presented by Thaval and Kent [4]. Although this model considers inhomogeneous mixing between bagasse and imbibition water or juice, in addition to mass balances of all components of juice and bagasse, it does not specify how juice extraction from bagasse is modeled. Recently, Chantasiriwan [5] proposes a new numerical model of the sugar cane milling process that takes into account non-ideal mixing between bagasse and water or sugar juice. The model presented in this paper is an improvement over the model by Chantasiriwan [5]. It has been shown to simulate correct behavior of sugar milling process [6]. The explanation of this model and the applications of the model to investigate the performance of sugar milling process with compound imbibition are presented in the following sections.

2. Milling Process Model

There are a large number of variables in the milling process, as can be seen in Fig. 1. Not shown in figure are also many process parameters incorporated in the model. The model development assumes that some variables are given, and attempts to provide a sufficient number of equations so that the equal number of unknown variables can be solved for.

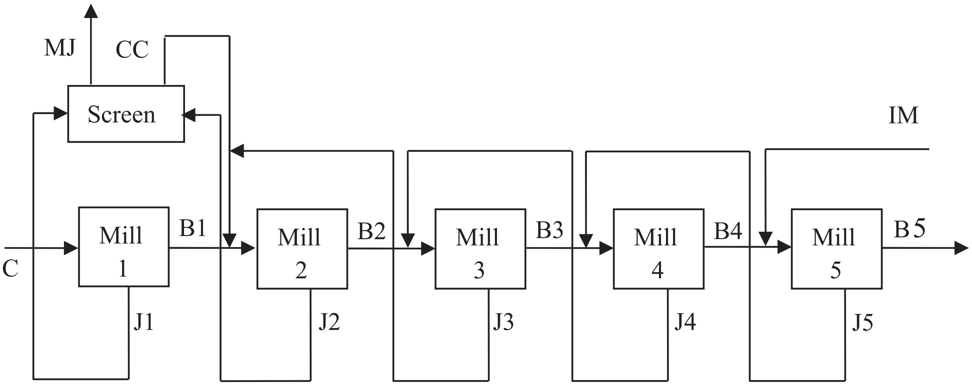

Fig. 1 Sugar milling process with compound imbibition.

2.1 Mass Balances

According to Fig. 1, each of sugar cane, bagasse and juice is composed of 3 components: fiber, dissolved solids and water. Dissolved solids are sucrose and other soluble matters. Water may be divided into free water and bound water. Free water is the solvent in which sucrose and other soluble matters are dissolved. Bound water is water that forms part of cellulosic structure of sugar cane, and is not available as a solvent for sucrose and other soluble matters. Because of this, bound water is not extractable in a milling process. It is therefore more convenient to consider bound water as part of fiber. This means that water will now be referred to only free water. Total mass balance equations are

$$m_{mj} + m_{cc} = m_{j1} + m_{j2} \tag{1}$$

$$m_{j1} + m_{b1} = m_c \tag{2}$$

$$m_{j2} + m_{b2} = m_{b1} + m_{cc} + m_{j3} \tag{3}$$

$$m_{j3} + m_{b3} = m_{b2} + m_{j4} \tag{4}$$

$$m_{j4} + m_{b4} = m_{b3} + m_{j5} \tag{5}$$

$$m_{j5} + m_{b5} = m_{b4} + m_{im} \tag{6}$$

where subscripts can be understood by consulting Fig. 1. Mass balance equations for fiber and dissolved solids can be obtained by replacing m in Eqs. (1) – (6) with m_f and m_b, respectively. It should be noted that there is neither fiber nor dissolved solids in imbibition water. As a result, $m_{f,im} = m_{b,im} = 0$.

2.2 Fiber Separation

Fiber includes not only vegetable fiber (and bound water) but also all water insoluble matters that are not vegetable in nature such as sand and ash. Extracted juice may contain some fiber due to the imperfect juice extraction process that allows some fiber to be extracted along with dissolved solids and water. Wienese [2] defines the fiber separation efficiency (η_f) as the ratio of fiber mass in outgoing bagasse to the fiber mass in incoming cane or bagasse. Analogous definition of fiber separation efficiency can also be used for the screen. These definitions yield the following equations.

$$m_{f,cc} = \eta_{fcc}(m_{f,j1} + m_{f,j2}) \tag{7}$$

$$m_{f,b1} = \eta_{f1} m_{f,c} \tag{8}$$

$$m_{f,b2} = \eta_{f2}(m_{f,b1} + m_{f,cc} + m_{f,j3}) \tag{9}$$

$$m_{f,b3} = \eta_{f3}(m_{f,b2} + m_{f,j4}) \tag{10}$$

$$m_{f,b4} = \eta_{f4}(m_{f,b3} + m_{f,j5}) \tag{11}$$

$$m_{f,b5} = \eta_{f5}(m_{f,b4}) \tag{12}$$

2.3 Juice Extraction

It is well known that the presence of fiber in cane and bagasse impedes juice extraction. Without the presence of fiber in the input to a mill, the extracted juice will be equal to the input juice. To the first approximation, it may be assumed that the difference between the input juice and the extracted juice is proportional to the amount of fiber in the input to the mill. Therefore, a simple model of juice extraction for the screen may be written as

$$m_{mj} - m_{f,mj} = m_{j1} + m_{j2} - m_{f,j1} - m_{f,j2} - x_m(m_{f,j1} + m_{f,j2}) \tag{13}$$

where the fiber obstruction coefficient of the screen (x_m) is a positive number. Similar equations can be written for mills 1 to 5.

$$m_{j1} - m_{f,j1} = m_c - m_{f,c} - x_1(m_{f,c}) \tag{14}$$

$$m_{j2} - m_{f,j2} = m_{b1} + m_{cc} + m_{j3} - m_{f,b1} - m_{f,cc} - m_{f,j3} - x_2(m_{f,b1} + m_{f,cc} + m_{f,j3}) \tag{15}$$

$$m_{j3} - m_{f,j3} = m_{b2} + m_{j4} - m_{f,b2} - m_{f,j4} - x_3(m_{f,b2} + m_{f,j4}) \tag{16}$$

$$m_{j4} - m_{f,j4} = m_{b3} + m_{j5} - m_{f,b3} - mf_{f,j5} - x_4(m_{f,b3} + m_{f,j5}) \tag{17}$$

$$m_{j5} - m_{f,j5} = m_{b4} + m_{im} - m_{f,b4} - x_5(m_{f,b4}) \tag{18}$$

The value of the fiber obstruction coefficient of mill i (x_i) depends on the pressure setting of mill i. It may be expected that a higher pressure setting results in more juice extraction and a lower value of x_i.

The difference between the juice extraction model presented in this paper and the model proposed by Chantasiriwan [5] should be noted. For example, it is assumed that $m_{j1} = y_1 m_c - x_1 y_1 m_{fc1}$ by Chantasiriwan [5]. The present model improves this assumption by replacing mj1 by $m_{j1} - m_{f,j1}$, which is just the amount of juice extracted by mill 1, not the total amount of juice and fiber as assumed by Chantasiriwan [5]. Also, the parameter y_1 in the model proposed by Chantasiriwan [5] becomes unity in the present model under the argument that, without fiber, extracted juice must equal input juice.

2.4 Homogeneous Mixing

For the screen and mill 1, the assumption that the concentration of dissolved solids of output is equal to that of the input leads to

$$\frac{m_{b,cc}}{m_{cc} - m_{f,cc}} = \frac{m_{b,j1} + m_{b,j2}}{m_{j1} - m_{j2} + m_{f,j1} - m_{f,j2}} \tag{19}$$

$$\frac{m_{b,j1}}{m_{j1} - m_{f,j1}} = \frac{m_{b,c}}{m_c - m_{f,c}} \tag{20}$$

Unlike the screen and mill 1, there is mixing between water or juice and bagasse in mills 2 – 5. If the mixing is homogeneous, the concentration of dissolved solids in the extracted juice of each mill will equal the concentration of dissolved solids in the input of the mill.

$$\frac{m_{b,j2}}{m_{j2}-m_{f,j2}} = \frac{m_{b,b1}+m_{b,cc}+m_{b,j3}}{m_{b1}+m_{cc}+m_{j3}-m_{f,b1}-m_{f,cc}-m_{f,j3}} \quad \textbf{(21)}$$

$$\frac{m_{b,j3}}{m_{j3}-m_{f,j3}} = \frac{m_{b,b2}+m_{b,j4}}{m_{b2}+m_{j4}+m_{f,b2}-m_{f,j4}} \quad \textbf{(22)}$$

$$\frac{m_{b,j4}}{m_{j4}-m_{f,j4}} = \frac{m_{b,b3}+m_{b,j5}}{m_{b3}+m_{j5}+m_{f,b3}-m_{f,j5}} \quad \textbf{(23)}$$

$$\frac{m_{b,j5}}{m_{j5}-m_{f,j5}} = \frac{m_{b,b4}}{m_{b4}+m_{im}+m_{f,b4}} \quad \textbf{(24)}$$

If mill inputs (m_c, $m_{f,c}$, $m_{b,c}$, m_{im}) and mill parameters (η_{fcc}, η_{f1}, η_{f2}, η_{f3}, η_{f4}, η_{f5}, x_m, x_1, x_2, x_3, x_4, x_5) are known, the 36 remaining unknowns are m_{mj}, $m_{f,mj}$, $m_{b,mj}$, m_{cc}, $m_{f,cc}$, $m_{b,cc}$, m_{ji}, $m_{f,ji}$, $m_{b,ji}$, m_{bi}, $m_{f,bi}$, and $m_{b,b}$, (i = 1 – 5). These unknowns can be found in a straightforward manner because there are 18 equations from mass balances, 6 equations from fiber separation model, 6 equations from the juice extraction model, and 6 equations from the homogeneous mixing model

3. Non-homogeneous Mixing Model

The assumption that the concentration of dissolved solids in the extracted juice from each of these mills is the same as the concentration of dissolved solids in the input may not be true because the input may not be homogeneous due to incomplete mixing between recycled juice or water and the bagasse. Rein [7] argues that the imbibition juice is more easily extracted than the juice already imbedded in the bagasse. This results in the extracted juice having lower concentration of dissolved solids than the juice imbedded in the bagasse [8].

In order to model non-homogeneous mixing in mill 3, the mixing process between B2 and J4 may be considered as a fiber distribution process. The sum of fiber of B2 and J4 is $m_{f,b2} + m_{f,j4}$. After mixing, some of the fiber accrues to B2, whereas the remaining fiber accrues to J4. If there is no mixing, the amounts of fiber accruing to B2 and J4 are, respectively, $m_{f,b2}$ and $m_{f,j4}$. On the other hand, if B2 is uniformly mixed with J4, the fiber will be distributed according to the relative juice masses of B2 and J4. The actual mixing may be modeled by introducing the mixing coefficient for mill 3 (a_3). The total extracted juice from the first mill (m_{j3}) is considered as the sum of juice extracted from B2 ($m_{j3\alpha}$) and juice extracted from CC ($m_{j3\beta}$). Therefore, the expressions of $m_{j3\alpha}$ and $m_{j3\beta}$ may be written as

$$m_{j3\alpha}-m_{f,j3\alpha} = m_{b2}-m_{f,b2}-a_3x_3(m_{f,b2}+m_{f,j4}) \quad \textbf{(25)}$$

$$m_{j3\beta}-m_{f,j3\beta} = m_{j4}-m_{f,j4}-(1-a_3)x_3(m_{f,b2}+m_{f,j4}) \quad \textbf{(26)}$$

Balance of dissolved solids can now be carried out according to

$$m_{b,j3} = \left(\frac{m_{b,b2}}{m_{b2}-m_{f,b2}}\right)(m_{j3\alpha}-m_{f,j3\alpha})+\left(\frac{m_{b,j4}}{m_{j4}-m_{f,j4}}\right)(m_{j3\beta}-m_{f,j3\beta}) \quad \textbf{(27)}$$

Equations (25) – (27) are now combined and rearranged into an expression for $m_{b,j3}$.

$$m_{b,j3} = m_{b,b2}\left[1-a_3x_3\left(\frac{m_{f,b2}+m_{f,j4}}{m_{b2}-m_{f,b2}}\right)\right]+m_{b,j4}\left[1-(1-a_3)x_3\left(\frac{m_{f,b2}+m_{f,j4}}{m_{j4}-m_{f,j4}}\right)\right] \quad \textbf{(28)}$$

Similar expressions can be obtained for $m_{b,j4}$ and $m_{b,j5}$.

$$m_{b,j4} = m_{b,b3}\left[1 - a_4x_4\left(\frac{m_{f,b3} + m_{f,j5}}{m_{b3} - m_{f,b3}}\right)\right] + m_{b,j5}\left[1 - (1 - a_4)x_4\left(\frac{m_{f,b3} + m_{f,j5}}{m_{j5} - m_{f,j5}}\right)\right] \quad \textbf{(29)}$$

$$m_{b,j5} = m_{b,b4}\left[1 - a_5x_5\left(\frac{m_{f,b4}}{m_{b4} - m_{f,b4}}\right)\right] \quad \textbf{(30)}$$

For mill 2, it is assumed that CC is homogeneously mixed with J3. The non-homogeneous mixing between B1 and CC+J3 can be modeled similarly. The result is the following expression for $m_{b,j2}$.

$$m_{b,j2} = m_{b,b1}\left[1 - a_2x_2\left(\frac{m_{f,b1} + m_{f,cc} + m_{f,j3}}{m_{b1} - m_{f,b1}}\right)\right] + (m_{b,cc} - m_{b,j3})\left[1 - (1 - a_2)x_2\left(\frac{m_{f,b1} + m_{f,cc} + m_{f,j3}}{m_{cc} + m_{j3} - m_{f,cc} - m_{f,j3}}\right)\right] \quad \textbf{(31)}$$

Determination of mixing coefficients ($a_2 - a_5$) must be carried out experimentally. However, there are 2 cases when their expressions can be derived. If mixing is homogeneous mixing, the expression for a_2 can be obtained by equating Eqs. (21) and (31), making use of the expression for $m_{j2} - m_{f,j2}$ in Eq. (15).

$$a_2 = \frac{\left(\dfrac{m_{b,cc} + m_{b,j3}}{m_{cc} - m_{j3} + m_{f,cc} + m_{f,j3}}\right) - \left(\dfrac{m_{b,b1} + m_{b,cc} + m_{b,j3}}{m_{b1} + m_{cc} + m_{j3} - m_{f,b1} - m_{f,cc} - m_{f,j3}}\right)}{\left(\dfrac{m_{b,cc} + m_{b,j3}}{m_{cc} - m_{j3} + m_{f,cc} + m_{f,j3}}\right) - \left(\dfrac{m_{b,b1}}{m_{b1} - m_{f,b1}}\right)} \quad \textbf{(32)}$$

Similarly, expressions for a_3, a_4, and a_5 can be obtained.

$$a_3 = \frac{\left(\dfrac{m_{b,j4}}{m_{j4} - m_{f,j4}}\right) - \left(\dfrac{m_{b,b2} + m_{b,j4}}{m_{b2} + m_{j4} - m_{f,b2} - m_{f,j4}}\right)}{\left(\dfrac{m_{b,j4}}{m_{j4} - m_{f,j4}}\right) - \left(\dfrac{m_{b,b2}}{m_{b2} - m_{f,b2}}\right)} \quad \textbf{(33)}$$

$$a_4 = \frac{\left(\dfrac{m_{b,j5}}{m_{j5} - m_{f,j5}}\right) - \left(\dfrac{m_{b,b3} + m_{b,j5}}{m_{b3} + m_{j5} - m_{f,b3} - m_{f,j5}}\right)}{\left(\dfrac{m_{b,j5}}{m_{j5} - m_{f,j5}}\right) - \left(\dfrac{m_{b,b3}}{m_{b3} - m_{f,b3}}\right)} \quad \textbf{(34)}$$

$$a_5 = \frac{m_{b4} - m_{f,b4}}{m_{b4} + m_{im} + m_{f,b4}} \quad \textbf{(35)}$$

If there is no mixing between B1 and CC+J3 in mill 2, juice will be extracted separately from B1 and CC+J3 according to the juice extraction model. Consequently,

$$a_2 = \frac{m_{f,b1}}{m_{f,b1} + m_{f,cc} + m_{f,j3}} \quad \textbf{(36)}$$

$$a_3 = \frac{m_{f,b2}}{m_{f,b2} + m_{f,j4}} \quad \textbf{(37)}$$

$$a_4 = \frac{m_{f,b3}}{m_{f,b3} + m_{f,j5}} \quad \textbf{(38)}$$

$$a_5 = 1 \quad \textbf{(39)}$$

It can be seen that Eqs. (32) – (35) provide the lower limits for $a_2 - a_5$, whereas Eqs. (36) – (39) provide the upper limits.

The difference between the non-homogeneous mixing model presented in this paper and the model proposed by Chantasiriwan [5] should be noted. Chantasiriwan [5] introduced a parameter defined as the ratio of juice extraction when mixing is non-homogeneous to juice extraction when mixing is homogeneous. Investigation of the parameter reveals the coupling of juice extraction model and mixing model through the parameter xi. The present model improves this assumption by decoupling the mixing model from the juice extraction model with the introduction of mixing coefficients ($a_2 - a_5$). It is believed that this assumption is more fundamental than the assumption made in Chantasiriwan [5].

4. Results and Discussion

Although there are a large number of variables in the solution process, only four variables (m_b, m_j, m_{b5}, $m_{f,b5}$, and $m_{b,b5}$) are of interest because they are involved in the computation of the three performance parameters of the sugar milling process: brix extraction (ε), mixed juice concentration (χ), and bagasse moisture (ω). Brix refers to dissolved solids in cane juice, which consist of sucrose and non-sucrose. In this study, it is assumed to the recovering of all dissolved solids is an objective of the sugar milling process. The recovered dissolved solids or brix is mb,mj, which is the amount of brix in mixed juice (MJ), whereas the available brix in sugar cane is $m_{b,c}$. Therefore,

$$\varepsilon = \frac{m_{b,mj}}{m_{b,c}} \qquad \textbf{(40)}$$

Mixed juice will eventually be sent the evaporation unit, in which water will be evaporated, and the mixed juice becomes syrup of a specified concentration. It is desirable to have a higher concentration of mixed juice because a lower amount of water will have to be evaporated. Mixed juice concentration can be determined from

$$\chi = \frac{m_{b,mj}}{m_{mi} - m_{f,mj}} \qquad \textbf{(41)}$$

Bagasse leaving mill 5 will be used as fuel for the boilers of the sugar factory. Since, bagasse moisture has a negative effect on boiler efficiency, it is desirable for ω to be small. The expression for ω is

$$\omega = \frac{m_{b5} - 0.7894 m_{f,b5} - m_{b,b5}}{m_{b5}} \qquad \textbf{(42)}$$

The coefficient of mf,b5 in Eq. (42) results from the assumption that fiber consists of 27% of bound water [7].

Rein [7] provides typical mill data, which are bagasse masses and juice masses, together with their fiber and brix components at each of the five mills. These data are used to compute mill parameters using the proposed model. The results are shown in Table 1.

Table 1 Mill parameter according to typical mill data.

Parameters	Values
η_{fr}	0.920
$\eta_{f1} - \eta_{f5}$	0.895
x_m	3.32667
x_1	1.29396
x_2	1.17751
x_3	0.88484
x_4	0.72065
x_5	0.57922
a_2	0.53281
a_3	0.69537
a_4	0.64770
a_5	0.71577

Assume that performance parameters of the sugar mill as shown in Table 1 do not change with the amount of imbibition water. Figure 2 compares variations of ε, χ, and ω with the amount of imbibition water, which varies for 50% to 400% of the fiber mass in the input cane, for cases of three degrees of mixing between recycled juice or imbibition water and bagasse: homogeneous mixing, actual mixing, and no mixing. For all 3 cases, ω and ε increase, and χ decreases when the amount of imbibition water increases. The rates of change of ω, ε, and χ are rapid when the amount of imbibition water is small, and decrease as the amount of imbibition water increases. Furthermore, for the same amount of imbibition, ω, χ, and ε increase as mixing becomes more homogeneous.

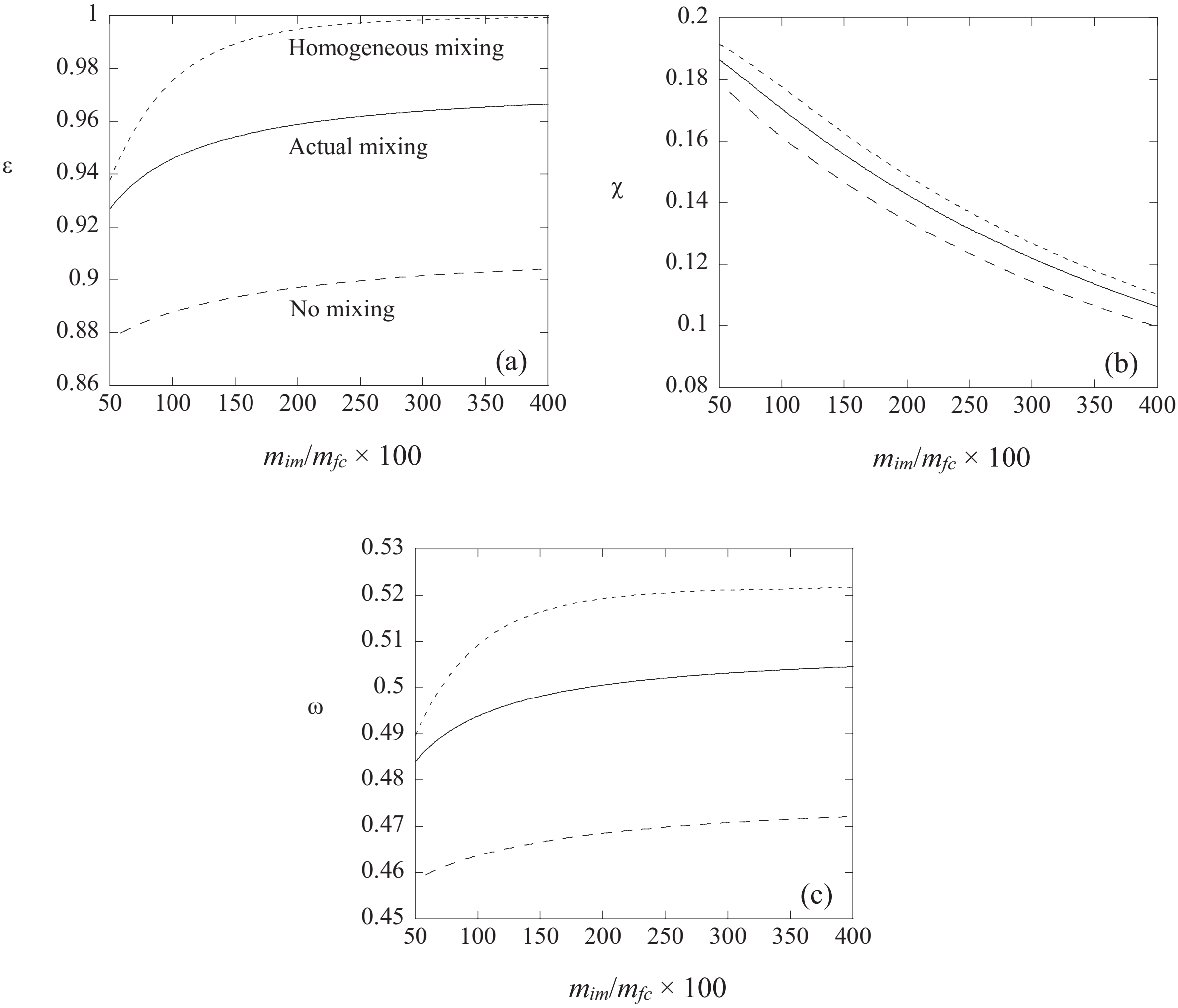

Fig. 2 Effects of the amount of imbibition water and degree of mixing on (a) brix extraction, (b) mixed juice concentration, and (c) final bagasse moisture.

Fig. 3 shows composite curves of variation of ω with ε for all 3 degrees of mixing. It can be seen that ω can be approximated as a single linear function of ε regardless of the degree of mixing. Therefore, the degree of mixing does not affect how ω varies with ε. This means that more brix extraction can only be achieved at the expense of more moisture in final bagasse. Furthermore, the effect of increasing the amount of imbibition is the same as the effect of increasing the degree of mixing as far as the variation of ω with ε is concerned.

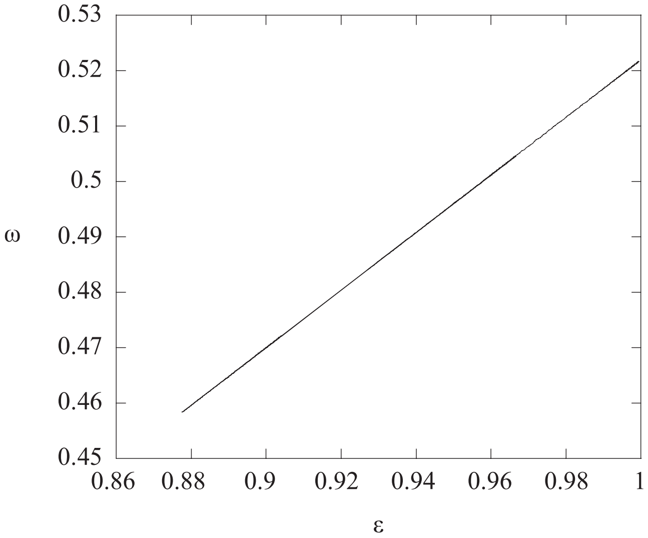

Fig. 3 Variation of final bagasse moisture with brix extraction for all three degrees of mixing.

Fig. 4 shows composite curves of variation of χ with ω for all 3 degrees of mixing. It can be seen that χ decreases monotonically with ω regardless of the degree of mixing. This means that a larger amount of imbibition leads not only to final bagasse with more moisture but also less concentrated mixed juice. More interestingly, Fig. 4 shows that, for the same final bagasse moisture or the same amount of imbibition, the concentration of mixed juice increases as the degree of mixing increases. Since mixed juice requires larger energy in subsequent sugar manufacturing processes as it becomes more diluted, a large degree of mixing between bagasse and recycled juice or imbibition water is advantageous from the viewpoint of energy efficiency.

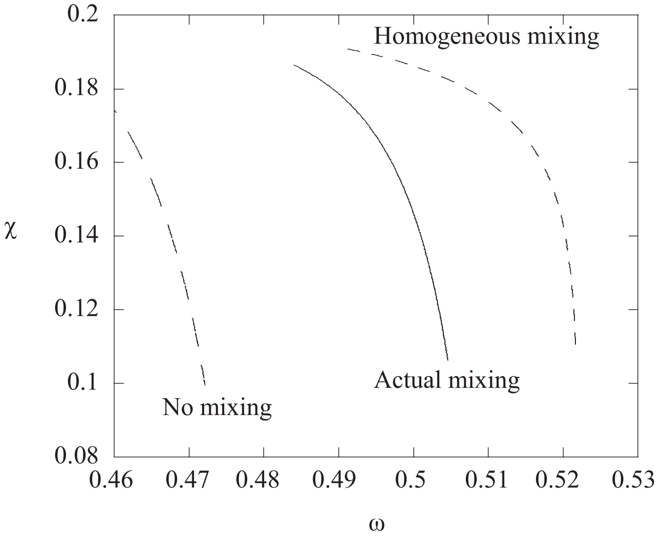

Fig. 4 Variation of mixed juice concentration with final bagasse moisture for three degrees of mixing.

5. Conclusion

A numerical model of sugar milling process is developed in this paper to investigate effects of non-homogeneous mixing between bagasse and recycled juice or imbibition water on three performance parameters: brix extraction, final bagasse moisture, and mixed juice concentration. Required input data for the model are flow rates of sugar cane, fiber, dissolved solids, and imbibition water. Required performance parameters are fiber separation efficiencies of the screen and the mills, fiber obstruction coefficients, and mixing coefficients. This model incorporates mass balances, fiber separation model, juice extraction model, and mixing model. It can be used to analyze the performance of sugar mills with compound imbibition. Results from this model indicate that more homogeneous mixing has the same effect as increasing imbibition water in yielding more brix extraction and causing more moisture in the final bagasse. However, effects of mixing and imbibition water concerning the concentration of mixed juice are different. Increasing the homogeneity of mixing increases mixed juice concentration, whereas increasing imbibition water decreases it.

6. References

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