MOLASSES DESUGARIZATION IN THE U.S. BEET SUGAR INDUSTRY: RECENT UPDATE

Vadim Kochergin*, Erin Johnson, Matthew Morrow, and Steve Peacock
Amalgamated Research LLC, 2531 Orchard Dr. E., Twin Falls, ID 83301

Introduction

Molasses desugarization (MDS) through simulated moving bed chromatography has been used in the United States beet sugar industry since 1988, when the U.S. saw its first commercial system installed at the Amalgamated Sugar factory in Twin Falls, ID.[1] Chromatographic separation proved to be an effective and efficient method for recovering sucrose from beet molasses, and the technology was widely adopted in the industry.[2] Today, most U.S. sugar beet companies operate some type of molasses desugarization system.

Early MDS technology used a batch process to perform the separation. The first industrial-scale batch system in the U.S., consisting of a single column with 22 m^3 of resin, was installed in 1973 at the Utah-Idaho Sugar factory in Moses Lake, Washington.[3] However, the use of batch separation was short-lived in the beet sugar industry and was soon replaced by simulated moving bed (SMB) technology. Continuous SMB operation requires less water and less resin to achieve the same separation, greatly improving the efficiency of the process.[2,4] Adaptations of the SMB process were soon introduced in the U.S. by Amalgamated Sugar, Illinois Water Treatment, and Applexion.[5,6]

Initially, MDS systems were used only to separate sucrose from non-sugars.[7,8] The process flow of this two-component separation is shown in Figure 1. The feed molasses is separated into two product streams: the sucrose-rich extract, which is sent to the sugar end for crystallization, and the non-sucrose-rich raffinate.

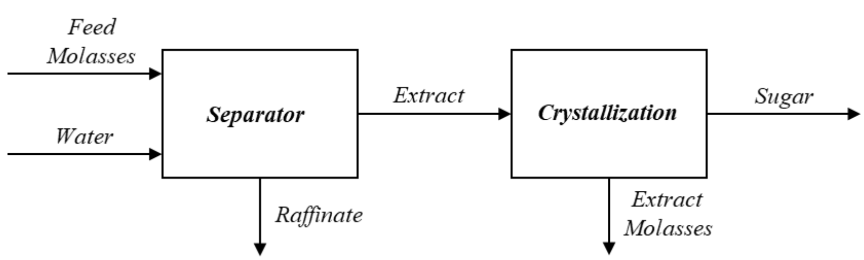

Figure 1. Process flow of an MDS system separating two components.

Multicomponent separations soon became possible, allowing molasses to be separated into sucrose-, non-sucrose-, and betaine-rich streams. In 1989, Finnsugar introduced a sequential SMB process that was capable of multicomponent separation using a semi-continuous operating strategy.[9] Variations on the sequential SMB process were also developed by Mitsubishi, Japan

Organo, and Applexion.[10-12] In 1997, Amalgamated Research (ARi) introduced coupled-loop chromatography, where two separators are operated in series using approximately the same amount of total resin and water as a traditional separator.[13] This allowed for improved separation of sucrose from non-sugars, as well as the recovery of purified betaine from the feed molasses, without the expense of additional resin or water use. The process flow of a coupled-loop system is shown in Figure 2. Through the first loop separator, the feed molasses is separated into a purified betaine stream and a sucrose-rich upgrade stream. The upgrade stream is sent to the second loop separator, where a majority of the remaining non-sugars are removed in the raffinate to yield highly pure extract. The extract from the second loop is sent to the sugar end for crystallization.

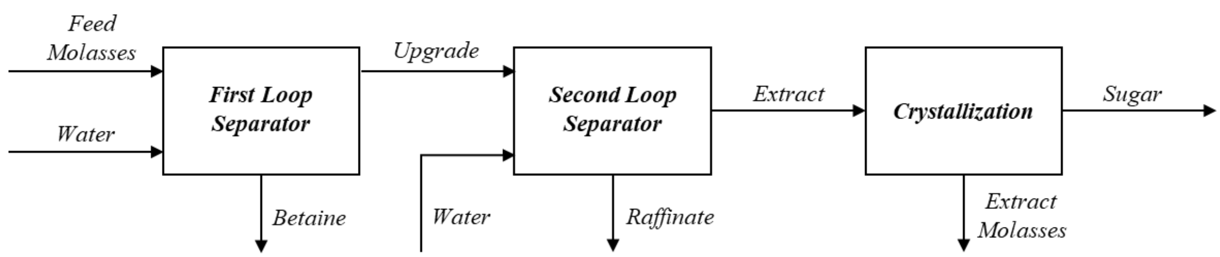

Figure 2. Process flow of a coupled-loop MDS system.

In early MDS systems, it was expected that with efficient operation, 75 – 78% of the sucrose in the feed molasses could be recovered as crystallized sugar in the bag.[13] However, the performance targets of MDS separators have evolved considerably in recent years. The achievable purities and recoveries are higher in modern systems, and an overall recovery of 81 – 88% of sucrose in molasses can be expected.

Reviewing available literature on MDS technology shows that most discussions are 20 – 30 years old.[2,4-6,9-12] Recent performance improvements have received little attention in the literature, and there are few discussions surrounding the proper tuning and analysis required to achieve these results. There is significant variation among existing MDS installations, and the lack of published industrial data makes it difficult to compare various process configurations. This paper will summarize current achievable separation targets, explain the necessary analysis for achieving and maintaining performance, and discuss variations for integrating an MDS system into a factory.

Current Achievable Separation Targets

In the sugar beet industry, the performance of a chromatographic separator is often evaluated by the overall recovery of sucrose from molasses after crystallization. This is the amount of crystallized sugar obtained from the extract relative to the amount of sucrose in the feed molasses. ARi refers to this recovery as the Z-factor recovery.[14] The Z-factor is calculated according to Equation (1), where R represents the sucrose recovery across the separator, E represents the sucrose purity of the extract, and M represents the sucrose purity of the resulting molasses after extract crystallization.

$$Z = R\left(1 - \frac{M(100-E)}{E(100-M)}\right) \qquad (1)$$

The Z-factor was introduced to objectively quantify the separator performance by differentiating between various combinations of purity and recovery. For example, Table 1 shows two cases of possible separator performance. From the purities and recoveries alone, it may be difficult to gauge which case is superior, but the Z-factor allows the two cases to be easily compared. It is assumed in the calculations that the final molasses purity will be 60%, and the Z-factor is therefore referred to as Z60.

Table 1. Comparing two cases of separator performance.

	Case 1	**Case 2**
Extract Sucrose Purity (%)	90	92
Sucrose Recovery (%)	92	90
Z60 Recovery (%)	76.7	78.3

Note that there are multiple combinations of extract purity and separator recovery that can result in the same Z-factor. This demonstrates that the same amount of sugar can be produced through different modes of separator operation.

When MDS systems were first adopted in the beet industry, a Z-factor of 75% might have been expected from efficient operation. However, newer resins and updated operation strategies have improved separator performance in recent years, leading to greater efficiency in modern systems. Purities and recoveries have increased, and Z-factors above 80% are commercially achievable. Table 2 shows current expectations from modern separator systems, assuming 60% molasses purity after extract processing.

Table 2. Current separator targets.

Extract Sucrose Purity (%)	95.0
Sucrose Recovery Across Separator (%)	91.0
Z60 Recovery (%)	83.8

These advances in SMB efficiency have allowed satisfactory performance to be achieved with less resin, decreasing the required size and cost of MDS systems. The capacity of a chromatographic separator can be represented through the loading, which quantifies the amount of feed material that can be processed through the system. ARi typically expresses loading in terms of lbs. non-sugars per cubic foot of resin per day. At higher non-sugar loadings, the size of the system can be reduced because less resin is required to achieve the separation. ARi has studied the performance of SMB separators at various non-sugar loadings, and process improvements have allowed the loading to be increased over time while simultaneously improving performance. This increased efficiency has decreased the resin requirements for commercial systems and reduced the overall capital costs. Figure 3 shows how the loading of ARi systems has increased over time relative to a baseline of 100% loading in 1988. ARi is now operating systems at up to 800% of the loading used in early systems, while simultaneously achieving better performance.

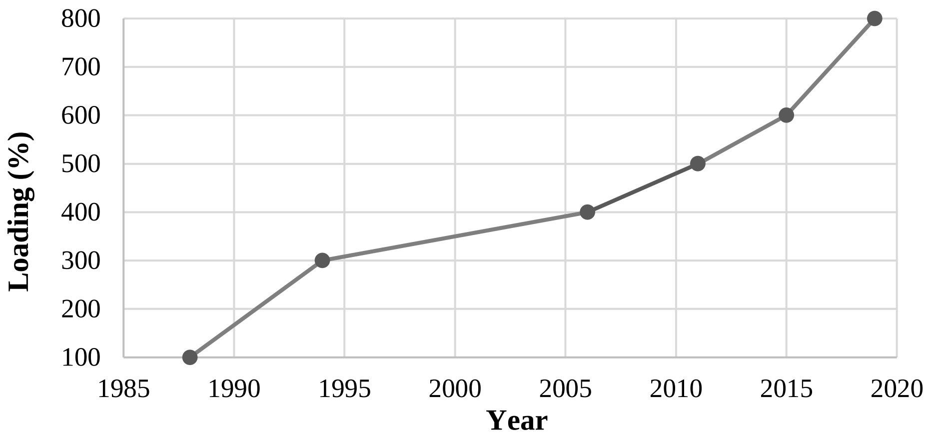

Figure 3. Increase in non-sugar loading of ARi separator systems over time.

Another development in the MDS process is second-pass separation, a method recommended and developed by ARi to increase the overall sucrose recovery from feed molasses. After extract is processed through the sugar end, the remaining extract molasses contains significant amounts of sucrose that could not be recovered as crystallized sugar. It is possible to recover some of this sugar by recycling the extract molasses back to the feed to the separator; however, this tends to negatively affect SMB performance through the accumulation of non-sugars and color. ARi found that this can be avoided by storing the extract molasses and processing it through the SMB separately in a second-pass campaign. This prevents the build-up of impurities and allows the separator to be properly optimized for both first-pass and second-pass feed material.

In 2017, second-pass chromatography was tested in an industrial trial at the Amalgamated Sugar factory in Nampa, ID. Approximately 6,000 tons of extract molasses were processed in the MDS unit, producing extract with a purity above 90% and recovering 2,550 additional tons of sugar after crystallization. After both passes, the overall Z-factor recovery was 87.7%. Results from the trial are shown in Table 3. It should be noted that this trial was relatively short and used an older separator system; it is likely that with newer equipment and more time for optimization, the performance could be improved further.

Table 3. Results from industrial second-pass trial.

Sucrose Purity of Extract Molasses (%)	66.9
Sucrose Recovery Across Separator (%)	88.1
Z-Factor Recovery (%)	87.7

Separator Optimization

The results above demonstrate that overall sugar recoveries of up to 88% can be expected at a commercial scale. However, to achieve these results, the separator must be properly tuned and integrated within the factory. This requires regular system monitoring and accurate analytical techniques.

The performance of an SMB is heavily influenced by the properties of the feed material, and accurate analysis is needed to track any changes in feed and extract quality. Many factories rely on apparent purities to measure sucrose content, but this is not always an appropriate method. In systems that process extract molasses, either through second-pass separation or recycle schemes, non-sugars such as raffinose tend to accumulate since they are not easily eliminated through chromatography. Raffinose rotates light in the same direction as sucrose, and its presence interferes in polarimetry readings and elevates the measured apparent purity.[15] The difference between true purity and apparent purity of beet molasses in the presence of raffinose is illustrated in Figure 4 below.

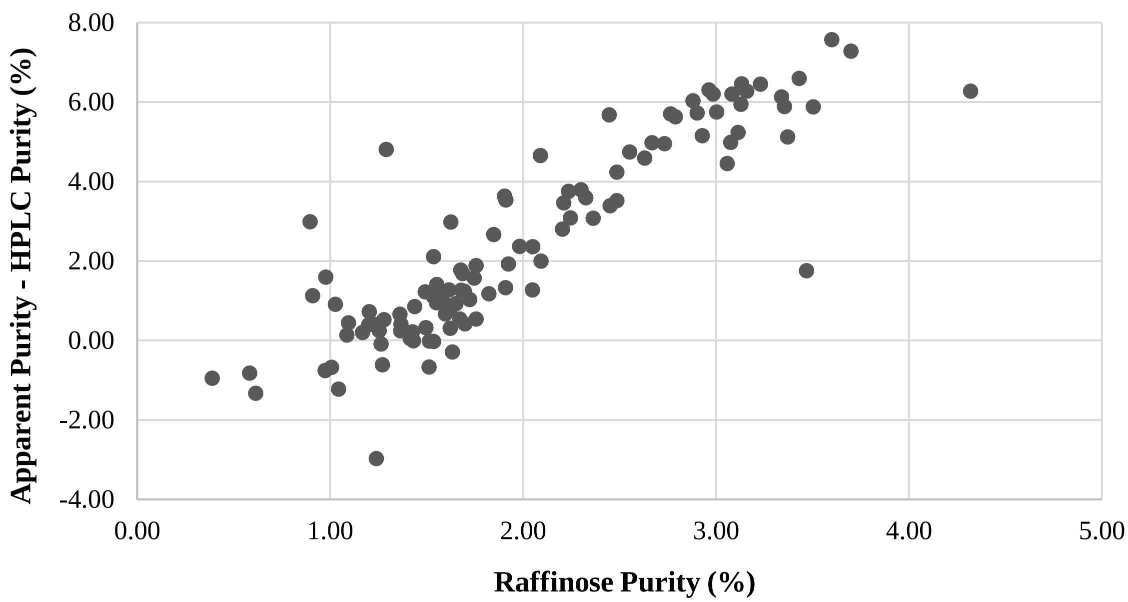

Figure 4. Difference between apparent purity and HPLC purity of beet molasses in the presence of raffinose.

Since the optical rotation of raffinose is known, it is possible to correct the apparent purity for the influence of raffinose. However, even after accounting for raffinose, there is often still significant error between the true and apparent purity. Therefore, to accurately monitor the separator, it is necessary to measure true sucrose purities using a method such as HPLC or NIR.

It should be noted that when MDS systems were first adopted in the beet industry, apparent purity was the standard method of analysis used to measure performance. In modern systems, true purities are used to set separation targets. Since the apparent purity is frequently higher than the true purity by 2 – 6 percentage points, this suggests that the gap between early separation targets and current separation targets is even larger.

Tuning of the MDS unit should also depend on how it is integrated into the factory. The Z-factor recovery quantifies the amount of sugar produced from feed molasses, and as given in Equation (1), it depends on both the extract purity and the separator recovery. The result of this relationship is that there are multiple combinations of purities and recoveries that give the same Z-factor.[14] Figure 5 shows the extract purities and separator recoveries that yield Z-factors of 75%, 80%, and 85%, assuming that the purity of the extract molasses is 60%.

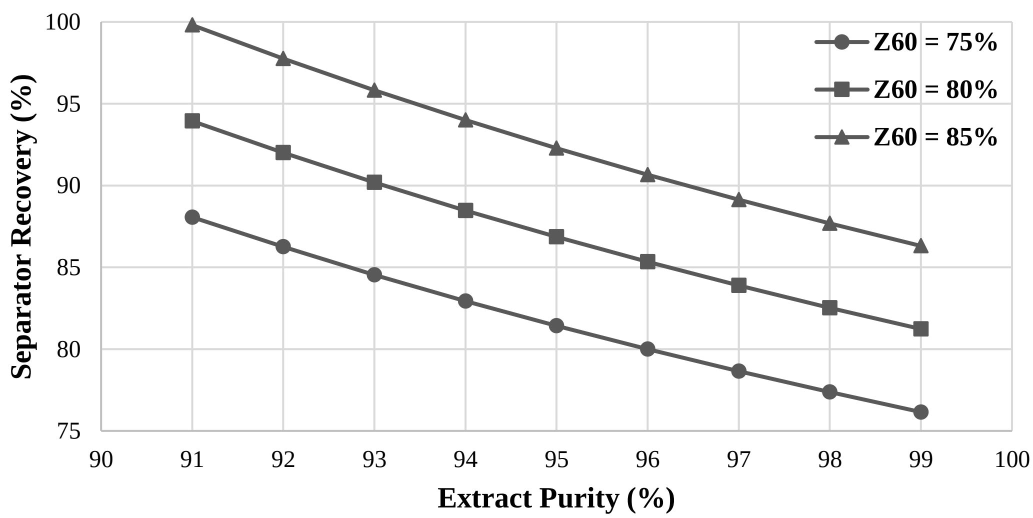

Figure 5. Combinations of separator recovery and extract purity that yield Z60 = 75%, 80%, and 85%.

The proper combination of separator recovery and extract purity should be influenced by how the extract is processed in the factory. For example, producing high-purity extract may be beneficial since it decreases the amount of non-sugars processed in the sugar end; however, if the extract purity is too high, it requires more than three boilings to achieve full molasses exhaustion in the sugar end. In factories with limited sugar end capacity, separator recovery may be more important than extract purity because high purity extract cannot be fully exhausted.

Integration of Extract Processing

There are various ways to incorporate extract processing into a factory, and the MDS unit should be optimized according to this integration. Since extract is typically higher in color than thick juice, extract crystallization through the standard three-boiling scheme can be problematic due to the high color of the sugar produced.[16] Modifications to the crystallization process, such as the addition of a fourth boiling or blending the extract with thick juice in a recycle campaign, are necessary to obtain high-quality sugar from extract. This section will discuss some of the extract processing schemes that have been used in the beet sugar industry, and a theoretical sugar end material balance will be used to calculate the purities, recoveries, and colors resulting from each scenario. The material balance assumes for each case that 500,000 tons of thick juice is processed over 330 total days of operation. In each scenario, expected separator performance is assumed, and extract purity and recovery are used as inputs to the model.

Single-Pass Extract-Only Processing in Factories with One Sugar End

In this crystallization scheme, the extract from the MDS unit is stored to be processed in the sugar end after thick juice processing is complete. The extract is crystallized separately and not blended with the thick juice, and the extract molasses is not processed in a second-pass campaign. This crystallization scheme may be implemented with three or four boilings. Due to the high extract color, saleable sugar may not be produced directly through the white pan, and it is recommended to instead feed the extract to the second boiling. A schematic of the three-boiling configuration is shown in Figure 6.

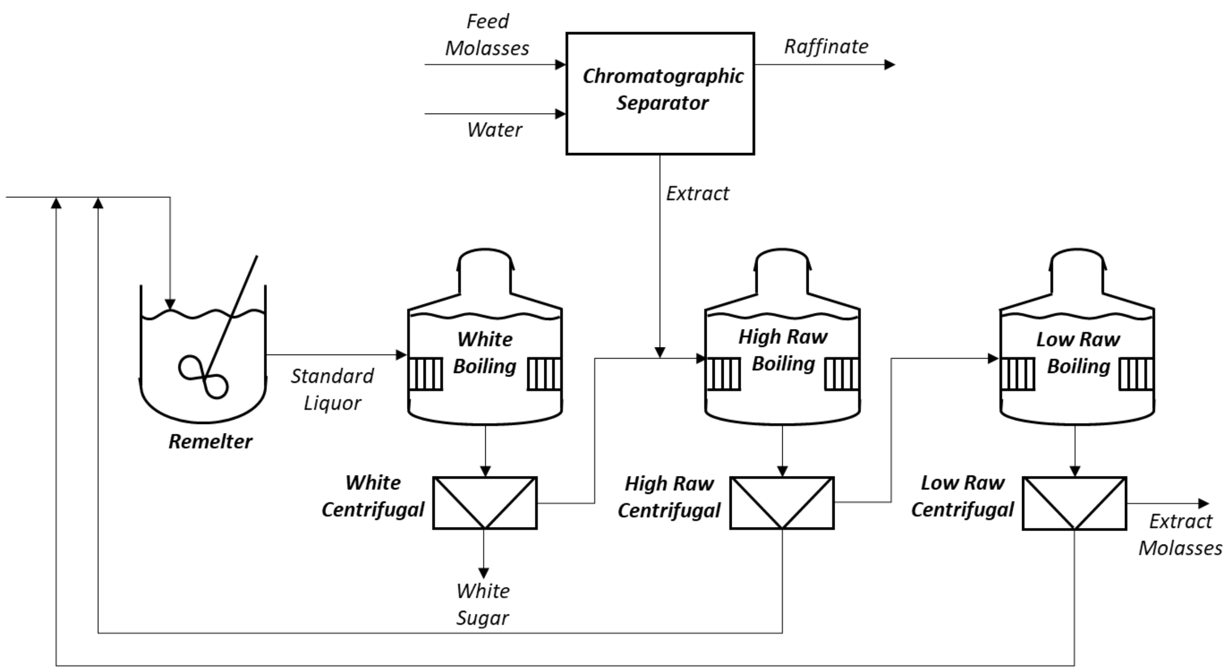

Figure 6. Diagram of three-boiling crystallization for single-pass, extract-only processing.

Table 4 shows key results from modeling this extract processing scheme. Full results can be found in the Appendix. In Table 4, the feed molasses purity represents the sucrose purity of the virgin molasses that is fed to the separator. The separator is assumed to achieve 93% extract purity and 92% sucrose recovery based on conservative targets, and this performance yields a Z60 recovery of 81.6%. However, the predicted extract molasses purity is elevated since the extract is added to the second boiling. It is possible to reduce this final molasses purity by recycling extract molasses onto the low raw boiling, but this requires additional pan capacity or a reduction in the processing rate in the sugar end. Two white sugar colors are shown in the table; the first represents the sugar produced from the crystallization of thick juice, while the second represents the sugar produced from the crystallization of extract. Over the entire 330-day operation, the model predicts that 97.6% of the sucrose in the thick juice can be recovered as white sugar.

Table 4. Results from modeling single-pass extract-only processing with one sugar end.

Feed Molasses Purity (%)	Separator Extract Purity (%)	Separator Recovery (%)	Z60 Recovery (%)	Extract Molasses Purity (%)	White Sugar Color (IU)		Sugar Recovery from Thick Juice (%)
					Thick Juice	*Extract*	
60.2	93.0	92.0	81.6	72.2	19.8	29.9	97.6

Second-Pass Extract-Only Processing in Factories with One Sugar End

As in the scenario above, the extract is processed separately after the thick juice run. In this case, the extract molasses produced after crystallization is stored and later sent through the separator to recover additional sucrose. The resulting second-pass extract is processed in the sugar end in a separate campaign. It is again recommended that the second-pass extract be fed to the second pan due to high color. A diagram of this process with three boilings is shown in Figure 5.

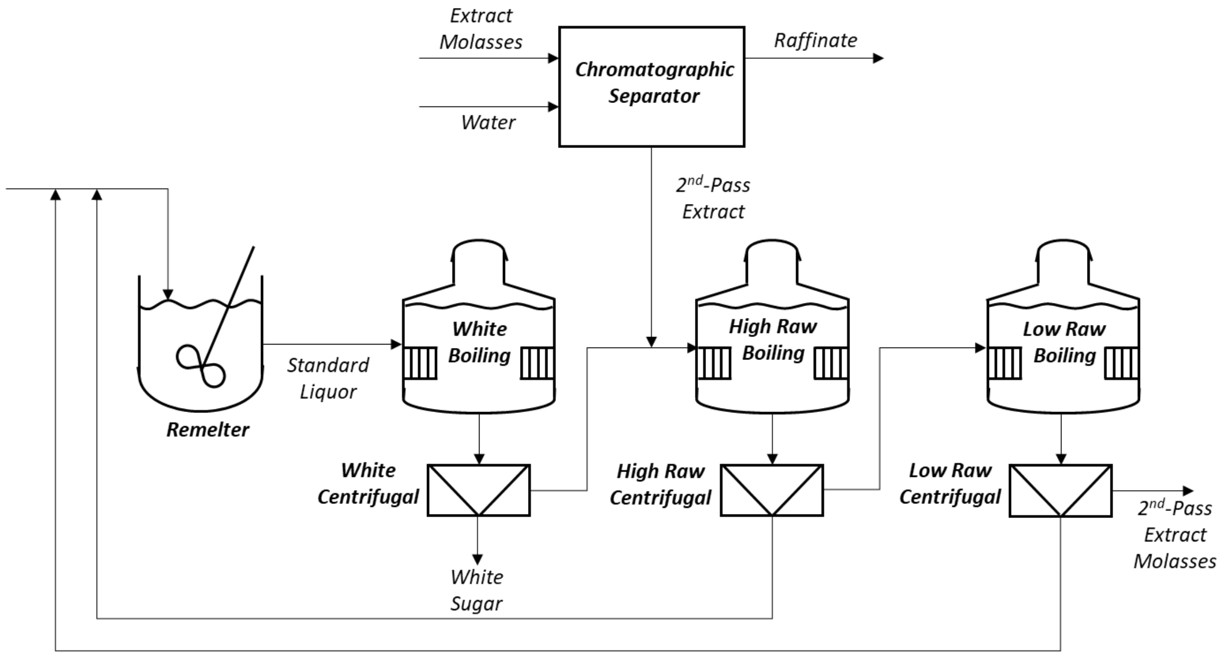

Figure 5. Diagram of three-boiling crystallization for second-pass, extract-only processing.

Table 5 shows the results from modeling this extract processing scheme. The feed molasses purity again represents the molasses fed to the separator, which in this case is the extract molasses produced in the first pass. The separator is assumed to achieve 91% extract purity and 89% recovery, based on industrial second-pass data. The final Z60 recovery including both the first-pass and second-pass operation is 87.5%. However, as in the above first-pass case, the final molasses purity is elevated since the first- and second-pass extract are added to the second boiling. It is again possible to recycle the final molasses back to the third boiling to reduce the purity, if the pan capacity is sufficient or if the sugar end processing rate can be reduced. Overall, 99.1% of the sugar in the thick juice is recovered as sugar in the bag after both passes.

Three white sugar colors are shown in Table 5; the first is sugar produced from crystallizing thick juice, the second is from crystallizing first-pass extract, and the third is from crystallizing second-pass extract. The sugar produced from the second-pass extract is 74.1 IU, which may be too dark to be salable. It may be necessary to increase washing in the high and low raw boilings to decrease the color, or this sugar may need to be blended with stored white sugar before sale.

Table 5. Results from modeling second-pass extract-only processing with one sugar end.

Feed Molasses Purity (%)	**Separator Extract Purity (%)**	**Separator Recovery (%)**	**Final Z60 Recovery (Both Passes) (%)**	**2nd-Pass Extract Molasses Purity (%)**	**White Sugar Color (IU)**			**Sugar Recovery from Thick Juice (%)**
					Thick Juice	***Extract***	***2nd-Pass Extract***	
72.2	91.0	89.0	87.5	69.0	19.8	29.9	74.1	99.1

Single-Pass Extract-Only Processing in Factories with an Extract Sugar End

In this case, extract can be processed at the same time as thick juice, but the extract crystallization takes place in a separate extract-only sugar end. Instead of feeding the extract to the second boiling, it can be added to the first pan for a conventional three-boiling process. Although the sugar produced may have high color, it is remelted and sent to the first pan of the standard sugar end, which provides sufficient decolorization. The extract molasses is not processed in a second-pass campaign. This process flow is shown in Figure 6.

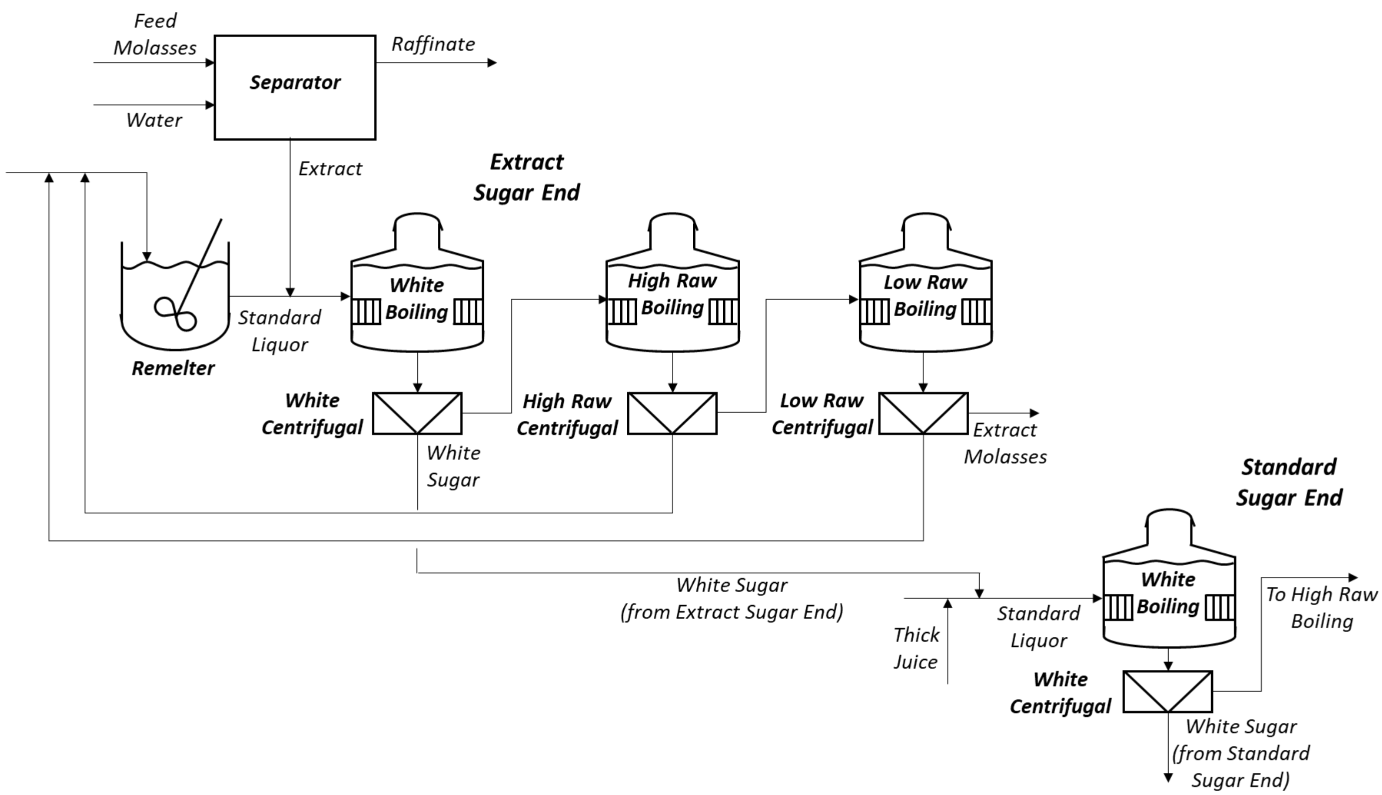

Figure 6. Diagram of single-pass, extract-only processing with a separate extract sugar end.

Table 6 shows the results from modeling this extract processing scenario. The separator is assumed to achieve 93% extract purity and 92% recovery, which corresponds to a Z60 of 81.6%. In this case, since the extract can be added to the first boiling of the extract sugar end, the extract molasses purity is lower than the previous cases and is closer to 60%. Since the white sugar produced in the extract sugar end is sent through the standard sugar end for further decolorization, the final white sugar from both thick juice and extract are produced together and only one sugar color is shown in Table 6. Overall, 98.3% of the sugar in the thick juice is recovered as crystallized sugar.

Table 6. Results from modeling single-pass extract-only processing with an extract sugar end.

Feed Molasses Purity (%)	Separator Extract Purity (%)	Separator Recovery (%)	Z60 Recovery (%)	Extract Molasses Purity (%)	White Sugar Color (IU)	Sugar Recovery from Thick Juice (%)
61.6	93.0	92.0	81.6	61.6	18.3	98.3

Infinite Extract Recycle

In this crystallization scheme, extract from the separator is blended with thick juice, and the combined stream is processed in a single three-boiling configuration. A portion of the extract stream is sent to the second boiling to control the white sugar color. The molasses produced after crystallization serves as the feed molasses to the separator. Since the entire molasses stream is routed back to the MDS unit, this scenario is referred to as "infinite" recycle.[16] A diagram of this process is shown in Figure 7.

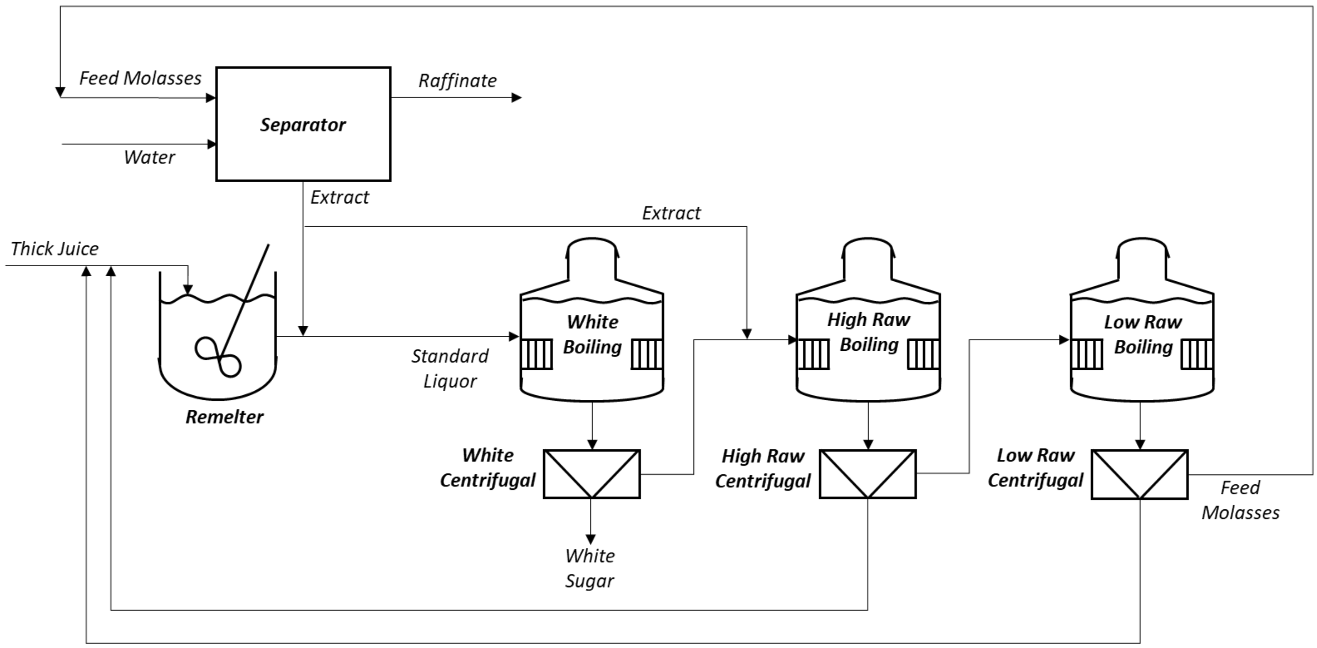

Figure 7. Diagram of infinite extract recycle.

Infinite recycle is logistically simple since it does not require molasses storage or additional crystallization campaigns. However, infinite recycle reduces separator throughput, and it may lead to the accumulation of non-sugars that are not easily eliminated through chromatography. These non-sugars can build up in the molasses and negatively impact the separator performance.[16] In addition, extract recycle results in ever-changing molasses quality, which makes it difficult to properly tune the separator.

The results from modeling infinite extract recycle are shown in Table 7. Based on industrial data, the separator was assumed to achieve 91% extract purity and 87.2% sucrose recovery, resulting in a Z60 of 74.2%. Overall, it is predicted that infinite recycle recovers 98.9% of the sugar in the thick juice as sugar in the bag.

Table 7. Results from modeling infinite extract recycle.

Feed Molasses Purity (%)	Separator Extract Purity (%)	Separator Recovery (%)	Z60 Recovery (%)	White Sugar Color (IU)	Sugar Recovery from Thick Juice (%)
60.9	91.0	87.2	74.2	25.0	98.9

Extract Recycle with Molasses Purge

In this scenario, the extract from the separator is again blended with thick juice to be processed through a single sugar end with three boilings. To control the white sugar color, a portion of the extract stream is again added to the second boiling. However, unlike the infinite recycle case where all of the molasses produced is sent back to the separator, a portion of the molasses is discarded as a purge. This helps reduce the accumulation of non-sugars and can improve the separator and sugar end performance. Figure 8 illustrates this process. The discarded molasses may be stored to be processed in the sugar end at a later time.

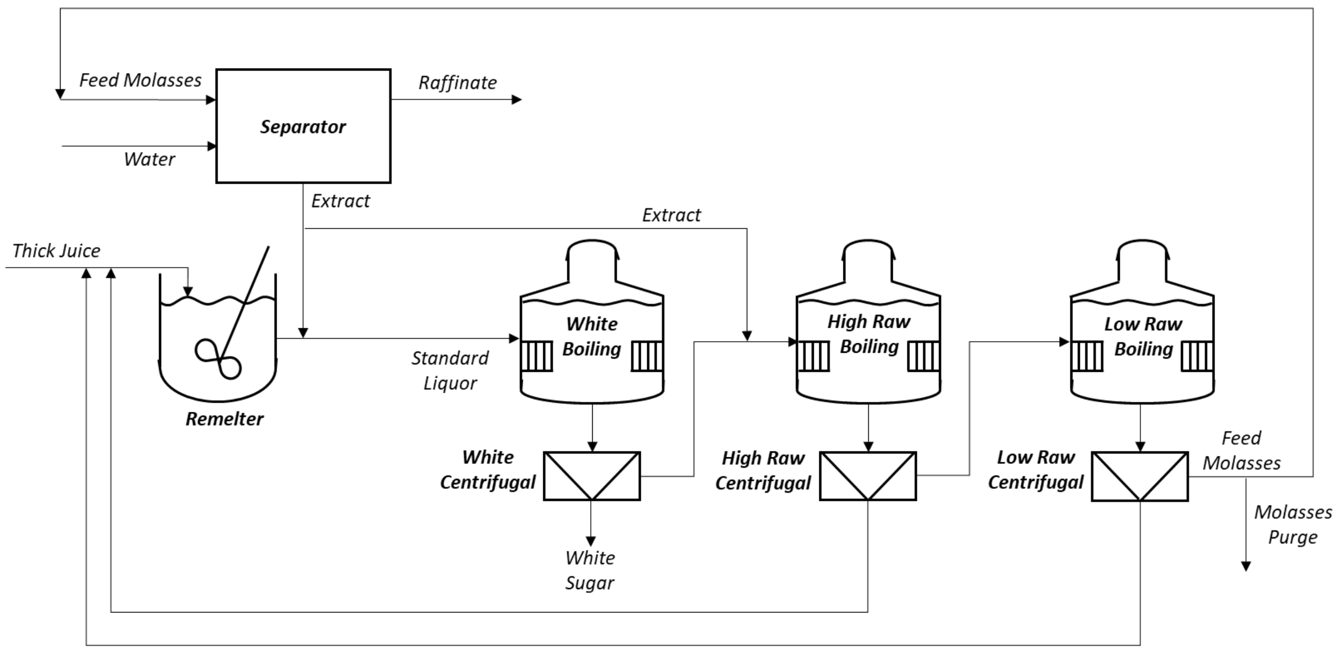

Figure 8. Diagram of extract recycle with molasses purge.

The results from modeling extract recycle with a molasses purge are shown in Table 8. The model is configured so that the molasses purge is 5% of the total molasses stream. Based on industrial data, it is assumed that the separator recovery achieves 91% extract purity and 87.5% sucrose recovery, resulting in a Z60 of 74.5%. This slight improvement over the infinite recycle case is expected due to the reduction in non-sugar accumulation. Overall, the model predicts that 98.3% of the sugar in the thick juice is recovered as white sugar in the bag.

Table 8. Results from modeling extract recycle with molasses purge.

Feed Molasses Purity (%)	Separator Extract Purity (%)	Separator Recovery (%)	Z60 Recovery (%)	White Sugar Color (IU)	Sugar Recovery from Thick Juice (%)
60.7	91.0	87.5	74.5	25.1	98.3

Single-Pass Extract-Only Processing with One Sugar End and Extract Decolorization

In this crystallization scheme, the extract from the MDS unit is sent through a decolorization process before crystallization. It is assumed that the decolorization process removes 60% of the extract color. The decolorized extract is stored until after the thick juice run, and the extract is crystallized separately and not blended with the thick juice. The extract molasses is not processed in a second-pass campaign. Due to the reduced color, the extract can be added to the first pan for a conventional three-boiling process. A schematic of the three-boiling configuration is shown in Figure 6.

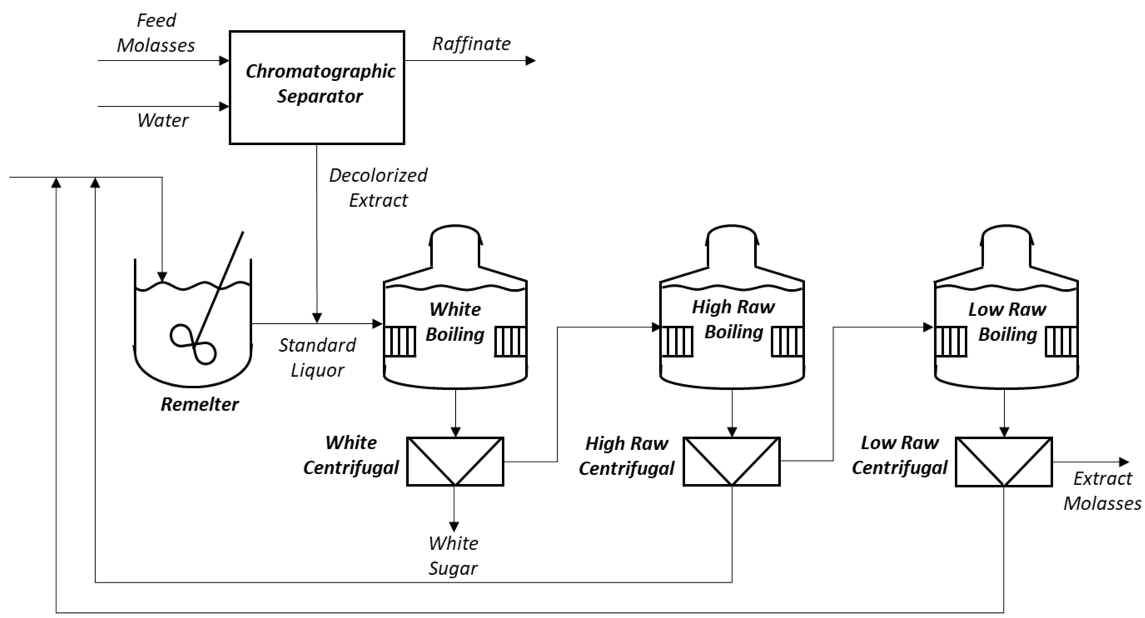

Figure 9. Diagram of single-pass extract-only processing with extract decolorization.

The results from modeling this crystallization scheme are shown in Table 9. The separator is assumed to achieve 93% extract purity and 92% sucrose recovery, resulting in a Z60 of 81.6%. Since the extract can be added to the first boiling, the molasses purity is significantly lower than the single-pass case without decolorization. Overall, the model predicts that 98.4% of sugar in the thick juice will be recovered as sugar in the bag.

Table 9. Results from modeling single-pass extract-only processing with extract decolorization.

Feed Molasses Purity (%)	Separator Extract Purity (%)	Separator Recovery (%)	Z60 Recovery (%)	Extract Molasses Purity (%)	White Sugar Color (IU)		Sugar Recovery from Thick Juice (%)
					Thick Juice	*Extract*	
60.2	93.0	92.0	81.6	61.6	19.8	28.9	98.4

Extract Processing Summary

Table 11 shows a summary of the results from modeling each extract processing scenario. For a baseline, the extract processing scenarios are compared to a standard sugar end with no molasses desugarization. This base case assumes that the thick juice is processed in a standard three-boiling crystallization scheme, and the resulting molasses is sold. There is no extract processing in this base case. The feed molasses purity reported for each scenario is the purity of the molasses being fed to the separator, or, in the case of no extract processing, the purity of the molasses resulting after thick juice crystallization. The white sugar color reported for each case is an average color, taking into account the white sugar produced from thick juice, extract, and second-pass extract when applicable.

Table 11. Performance comparison of various extract processing schemes.

Extract Processing Scheme	Feed Molasses Purity (%)	Separator Extract Purity (%)	Separator Recovery (%)	Z60 Recovery (%)	Extract Molasses Purity (%)	Average White Sugar Color (IU)	Sugar Recovery from Thick Juice (%)
Standard Sugar End, No MDS (Baseline)	60.2	-	-	-	-	19.8	88.2
Single-Pass, Standard Sugar End	60.2	93.0	92.0	81.6	72.2	20.8	97.6
Second-Pass, Standard Sugar End	72.2	91.0	89.0	87.5	69.0	21.6	99.1
Single-Pass, Extract Sugar End	61.6	93.0	92.0	81.6	61.6	18.3	98.3
Infinite Recycle	60.9	91.0	87.2	74.2	-	25.0	98.9
Recycle with Purge	60.7	91.0	87.5	74.5	-	25.1	98.3
Single-Pass, Extract Decolorization	60.2	93.0	92.0	81.6	61.6	20.8	98.4

The modeling predicts that extract-only processing with a second-pass campaign will result in the highest overall sugar recovery, closely followed by infinite recycle. The improvement over infinite recycle found through second-pass operation is mostly due to the improved separator performance. Infinite recycle results in non-sugar accumulation and unstable molasses quality, which causes difficulties in separator tuning. Second-pass operation sends a stable feed through the SMB, allowing the separator to be properly optimized throughout the entire campaign.

Table 12 shows the required separator and pan capacities for each extract processing scenario. The SMB molasses feed rate indicates the required separator size, the total tons of DS processed is an approximate measure of the steam requirements to perform the crystallization, and the tons DS/day through each pan is indicative of the required pan capacity. A standard sugar end with no extract processing is again taken to be the baseline, and this scenario is given a value of 100% for every indicator except the separator feed rate. Single-pass extract processing with a standard sugar end is assumed to be the baseline for the separator capacity.

Table 12. Comparison of factory sizing with each extract processing scheme.

Extract Processing Scheme	Molasses Feed Rate to Separator	Total Tons DS Processed	Tons DS/Day White Pan	Tons DS/Day High Raw Pan	Tons DS/Day Low Raw Pan
Standard Sugar End, No MDS (Baseline)	-	100%	100%	100%	100%
Single-Pass, Standard Sugar End	100%	116%	110%	272%	237%
Second-Pass, Standard Sugar End	115%	119%	112%	286%	258%
Single-Pass, Extract Sugar End	104%	122%	111%	110%	108%
Infinite Recycle	120%	117%	111%	126%	124%
Recycle with Purge	112%	116%	112%	124%	122%
Single-Pass, Extract Decolorization	100%	111%	111%	112%	112%

Table 12 demonstrates that recycle schemes and second-pass operation require greater separator capacity than single-pass operation. It also shows that adding extract to the second boiling, as modeled in the single-pass and second-pass scenarios with a standard sugar end, requires substantially increased capacity in the high raw and low raw pans.

Conclusions

Achievable separation targets for MDS units have changed significantly over the past thirty years. Higher extract purities, higher sucrose recoveries, and improved sugar production are possible through modern chromatographic systems. However, proper separator optimization is necessary to achieve these targets. This requires accurate analytical methods; in particular, the use of true purity is strongly recommended over apparent purity to measure sucrose content. Separator optimization also depends on the integration of the MDS unit in the factory. There are multiple combinations of extract purity and separator recovery that will yield the same sugar production, and the ideal combination should be determined by how the extract is processed in the sugar end.

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Appendix

Table A.1. Model predictions of the overall performance during each extract processing scenario.

	Single-Pass	Second-Pass	Infinite Recycle	Molasses Purge	Single-Pass Extract Decolorization	Single-Pass Extract Sugar End
Overall Sugar Recovery (%)	97.6	99.1	98.9	98.3	98.4	98.3
Z_{60} Recovery						
First Pass	81.6	81.6	-	-	81.6	81.6
Second Pass	-	75.8	-	-	-	-
Recycle	-	-	74.2	74.5	-	-
White Sugar Produced (tons)	311678	316661	315922	314115	314419	313987
White Sugar Color (IU)						
Virgin	19.8	19.8	-	-	19.8	-
First Pass	29.9	29.9	-	-	28.9	18.3
Second Pass	-	74.1	-	-	-	-
Recycle	-	-	25.0	25.1	-	-
Average	20.8	21.6	25.0	25.1	20.8	18.3
SMB molasses feed (tons/day)						
First Pass	251	288	-	-	251	260
Second Pass	-	288	-	-	-	-
Recycle	-	-	295	277	-	-
SMB Operating Days						
First Pass	330	287.3	-	-	330	330
Second Pass	-	42.7	-	-	-	-
Recycle	-	-	330	330	-	-
Sugar End Operating Days						
Virgin	299.2	294.6	-	-	296	-
First Pass	30.8	30.3	-	-	34	330
Second Pass	-	5.1	-	-	-	-
Recycle	-	-	330	330	-	-
Extract Sugar End Operating Days						
Virgin	-	-	-	-	-	-
First Pass	-	-	-	-	-	330
Second Pass	-	-	-	-	-	-
Recycle	-	-	-	-	-	-
% of Extract Stream fed to High Raw Pan						
First Pass	100	100	-	-	0	0
Second Pass	-	100	-	-	-	-
Recycle	-	-	52	45	-	-
Separator Recovery (%)						
First Pass	92.0	92.0	-	-	92.0	92.0
Second Pass	-	89.0	-	-	-	-
Recycle	-	-	87.2	87.5	-	-
Extract Purity (%)						
First Pass	93.0	93.0	-	-	93.0	93.0
Second Pass	-	91.0	-	-	-	-
Recycle	-	-	91.0	91.0	-	-
Thick Juice Purity (%)	92.3	92.3	92.3	92.3	92.3	92.3
Extract Decolorization (%)	0	0	0	0	60	0

Table A.2. Model predictions of the performance and capacity of the standard sugar end during each extract processing scheme.

	Single-Pass	Second-Pass	Infinite Recycle	Molasses Purge	Single-Pass Extract Decolorization	Single-Pass Extract Sugar End
High Green Purity (%)						
Virgin	87.1	87.1	-	-	87.1	-
First Pass	92.4	92.4	-	-	88.0	88.0
Second Pass	-	92.5	-	-	-	-
Recycle	-	-	87.3	87.2	-	-
Inter Green Purity (%)						
Virgin	75.2	75.2	-	-	75.2	-
First Pass	85.2	85.2	-	-	76.7	76.7
Second Pass	-	82.9	-	-	-	-
Recycle	-	-	76.0	75.8	-	-
Molasses Purity (%)						
Virgin	60.2	60.2	-	-	60.2	-
First Pass	72.2	72.2	-	-	61.6	61.6
Second Pass	-	69.0	-	-	-	-
Recycle	-	-	60.9	60.7	-	-
Average	61.7	61.9	60.9	60.7	60.3	61.6
White Fillmass Purity (%)						
Virgin	93.8	93.8	-	-	93.8	-
First Pass	96.5	96.5	-	-	94.3	94.3
Second Pass	-	96.5	-	-	-	-
Recycle	-	-	93.9	93.9	-	-
High Raw Fillmass Purity (%)						
Virgin	87.1	87.1	-	-	87.1	-
First Pass	92.8	92.8	-	-	88.0	88.0
Second Pass	-	91.6	-	-	-	-
Recycle	-	-	87.6	87.5	-	-
Low Raw Fillmass Purity (%)						
Virgin	75.2	75.2	-	-	75.2	-
First Pass	85.2	85.2	-	-	76.7	76.7
Second Pass	-	82.9	-	-	-	-
Recycle	-	-	76.0	75.8	-	-
White Pan Capacity (tons DS)						
Virgin	535549	535549	-	-	535549	-
First Pass	55052	55052	-	-	61534	593730
Second Pass	-	9202	-	-	-	-
Recycle	-	-	599679	596432	-	-
High Raw Pan Capacity (tons DS)						
Virgin	255649	255649	-	-	255649	-
First Pass	64887	64887	-	-	29216	281962
Second Pass	-	11202	-	-	-	-
Recycle	-	-	309561	303700	-	-
Low Raw Pan Capacity (tons DS)						
Virgin	124569	124569	-	-	124569	-
First Pass	27542	27542	-	-	13979	134979
Second Pass	-	4938	-	-	-	-
Recycle	-	-	149486	146953	-	-

Table A.2 (continued).

White Pan Capacity (tons DS/day)						
Virgin	1790	1818	-	-	1809	-
First Pass	1790	1818	-	-	1809	1799
Second Pass	-	1818	-	-	-	-
Recycle	-	-	1817	1807	-	-
High Raw Pan Capacity (tons DS/day)						
Virgin	854	868	-	-	864	-
First Pass	2109	2142	-	-	859	854
Second Pass	-	2213	-	-	-	-
Recycle	-	-	938	920	-	-
Low Raw Pan Capacity (tons DS/day)						
Virgin	416	423	-	-	421	-
First Pass	895	909	-	-	411	409
Second Pass	-	975	-	-	-	-
Recycle	-	-	453	445	-	-

Table A.3. Model predictions of the performance and capacity of the extract sugar end during each extract processing scheme.

	Single-Pass	**Second-Pass**	**Infinite Recycle**	**Molasses Purge**	**Single-Pass Extract Decolorization**	**Single-Pass Extract Sugar End**
High Green Purity (%)						
Virgin	-	-	-	-	-	-
First Pass	-	-	-	-	-	88.0
Second Pass	-	-	-	-	-	-
Recycle	-	-	-	-	-	-
Inter Green Purity (%)						
Virgin	-	-	-	-	-	-
First Pass	-	-	-	-	-	76.7
Second Pass	-	-	-	-	-	-
Recycle	-	-	-	-	-	-
Molasses Purity (%)						
Virgin	-	-	-	-	-	-
First Pass	-	-	-	-	-	61.6
Second Pass	-	-	-	-	-	-
Recycle	-	-	-	-	-	-
White Fillmass Purity (%)						
Virgin	-	-	-	-	-	-
First Pass	-	-	-	-	-	94.3
Second Pass	-	-	-	-	-	-
Recycle	-	-	-	-	-	-
High Raw Fillmass Purity (%)						
Virgin	-	-	-	-	-	-
First Pass	-	-	-	-	-	88.0
Second Pass	-	-	-	-	-	-
Recycle	-	-	-	-	-	-

Table A.3 (continued).

Low Raw Fillmass Purity (%)						
Virgin	-	-	-	-	-	-
First Pass	-	-	-	-	-	76.7
Second Pass	-	-	-	-	-	-
Recycle	-	-	-	-	-	-
White Pan Capacity (tons DS)						
Virgin	-	-	-	-	-	-
First Pass	-	-	-	-	-	64745
Second Pass	-	-	-	-	-	-
Recycle	-	-	-	-	-	-
High Raw Pan Capacity (tons DS)						
Virgin	-	-	-	-	-	-
First Pass	-	-	-	-	-	30740
Second Pass	-	-	-	-	-	-
Recycle	-	-	-	-	-	-
Low Raw Pan Capacity (tons DS)						
Virgin	-	-	-	-	-	-
First Pass	-	-	-	-	-	14708
Second Pass	-	-	-	-	-	-
Recycle	-	-	-	-	-	-
White Pan Capacity (tons DS/day)						
Virgin	-	-	-	-	-	-
First Pass	-	-	-	-	-	196
Second Pass	-	-	-	-	-	-
Recycle	-	-	-	-	-	-
High Raw Pan Capacity (tons DS/day)						
Virgin	-	-	-	-	-	-
First Pass	-	-	-	-	-	93
Second Pass	-	-	-	-	-	-
Recycle	-	-	-	-	-	-
Low Raw Pan Capacity (tons DS/day)						
Virgin	-	-	-	-	-	-
First Pass	-	-	-	-	-	45
Second Pass	-	-	-	-	-	-
Recycle	-	-	-	-	-	-