

Modeling Boiling House Operations with SuperPro Designer®: Effects of Final Molasses Recycle and Double Magma Boiling

The exact calculation of mass and energy balances in industrial sugar operations can be challenging, but it has been greatly facilitated since the widespread use of spreadsheets that can handle the iterative calculations with ease. The setting up of a model is still further assisted with commercial process modeling and simulation software packages, such as Aspen, Chemcad, HYSIM, HYSYS, PROSIM, etc. A commercial sugar industry-specific software, Sugars™ is available to the industry, and has been described in a number of publications (1), with application examples including beet sugar manufacturing, sugar refining and energy optimization. An important extension is the Advanced Monitoring System (AMS) developed more recently by Sugars International, LLC and IPRO Industrieproject GmbH (2, 3) that imports the factory process data, fits the model parameters and provides a balanced simulation model. Despite the obvious benefits, the use of the software in the industry has not become widespread because of its cost and complexity.

SuperPro Designer® (4) is a flexible and easy-to-use software intended primarily for chemical, biochemical and environmental process design and optimization. However, with some limitations the software can as well be applied to modeling sugar industry operations. Its application to modeling the cane sugar “boiling house” operations is presented in this report, and illustrated on two examples to quantify the effects on the process of changes of the final molasses recycle in C-sugar magma, and of switching from a three-boiling to the double-magma boiling. Final molasses recycle – defined here as the mass of final molasses in C-magma percent of mass of final molasses in C-masseccuite – increases the load on the pans and centrifugals, and lowers the effective purity and therefore crystallization rate of sucrose. It needs to

be carefully balanced against the sugar loss in final molasses that tends to increase as the molasses recycle is lowered (or as the C-sugar purity is raised). Double-magma boiling is the standard way to improve the quality of commercial sugar, at the expense of higher load on the pans and centrifugals.

SuperPro Designer® Model

Setting up of the model in SuperPro Designer® starts with choosing the relevant unit operations (such as storage tanks, vacuum pans-crystallizers, centrifugals, mixing or splitting of streams, etc.) from a pull down menu of “unit procedures” and linking them in the “connect mode,” in a manner consistent with the industrial process. The diagram in Figure 1 illustrates the complete model of a boiling house operation. Flexibility of the model is enhanced by specifying multiple optional stream paths; for example, in the model of the boiling house operations in Figure 1, the feed to the A-pans may be any combination of syrup, A-molasses, B- magma or C-magma. Once the model has been set up, the inputs in terms of flow rates and composition must be defined. As a compromise between the ease of use and accuracy, any industrial sugar stream is modeled here as a mixture of five components; water, sucrose, ash, color and reducing sugars. Each of the five components can in turn be either in liquid or solid form.

Therefore, five-component systems are used to model liquid streams (juices, syrup and molasses), and ten-component ones, solid-liquid suspensions (massecuites, magmas and sugars). Each of the unit operations (procedures) that make up the model involves parameters that must be chosen to reflect or match typical industrial data. In the examples presented in this report, laboratory data from a Daily Manufacturing Report of a Louisiana sugar factory was used to obtain the

necessary parameters (“operation data”) for each of the unit operations included in the model. For instance, the model of the vacuum pan requires “evaporation data” and “crystallization data,” that is the percentage of each component evaporated or crystallized, respectively. The differential incorporation of impurities into the sugar crystal can be accommodated with a three-parameter solid-liquid partition equation specific for each component. Once the model has been set up and all procedures and streams defined, the model is “run,” that is the mass and energy balances solved in an iterative fashion until convergence has been achieved. The calculation is complete in less than a second, and can be readily repeated after altering input parameters in order to simulate effects of process changes, changes in syrup composition, changes in evaporation or crystallization yields, etc. The reports are easily exported in Excel or pdf formats. SuperPro Designer® also calculates the energy balance, utilities requirements (steam, electric power, etc.), sizing of the equipment and an economic analysis, but those aspects are not discussed in this brief report.

Application Example: Effect of Final Molasses Recycle

The required input parameters for the model were obtained by matching the model output with sugar factory laboratory data taken from the Daily Manufacturing Report of a Louisiana sugar mill for December 31, 2007. The Brix and purity of syrup, clarified juice, A-, B- and C-masseccuites and molasses, raw sugar and C-footing were used; in all twenty data points. In the table listed in the Appendix A, the most important results are summarized for this so called “base case”, with the factory report data given in parentheses. The agreement between the model and the factory data is quite good, and could still be improved with further

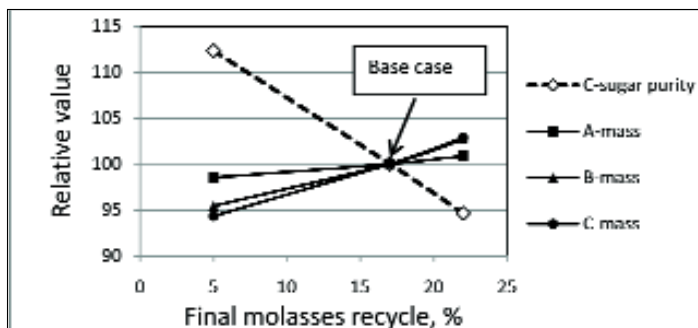


Figure 2: Predicted changes in C-sugar purity and the massecuite flow rates, per cent of the “base case”.

Table I: C-sugar purity and the massecuite volumes predicted by the computer model. The 17% recycle is the so called “base case” that reflects the factory Daily Manufacturing Report of a Louisiana sugar factory.

Molasses recycle, %	C-sugar purity	Flow rate, m ³ /h		
		A-mass	B-mass	C-mass
5	94.0	79.6	25.0	19.9
17	83.7	80.8	26.2	21.1
22	79.2	81.5	26.9	21.7

Table II: Calculated massecuite volumes for the three-boiling and double-magma boiling schemes. Values quoted by Rein (5) are given for comparison.

Case	Flow rate, m ³ /h		
	A-mass	B-mass	C-mass
Three-boiling	80.8	26.2	21.1
Double-magma	91.0	32.8	22.7
Relative increase, %	13	25	8
Relative increase, % (Rein, 2007)	43	31	0

refinement of the model parameters. The model also calculates for each process stream its “Pol” (i.e. polarimetry-determined sucrose concentration) as

$$\text{Pol} = \text{Sucrose concentration} - 0.3 \times \text{Reducing sugars concentration}$$

Some deviations of course are expected as the actual fructose/glucose ratio affects the value of the multiplier in the above equation. Furthermore, factories report so called “apparent purity,” i.e. a Polbased value, while the model’s is the “true purity,” based on sucrose concentration. The difference between the two is small for high purity materials but significant for final molasses. This is correctly reflected by the data presented in the Appendix A. The molasses recycle for this “base case” is about 17%. To evaluate the effects of changing molasses recycle, all model parameters were kept the same, with the exception of the separation efficiency of the C-centrifugal (procedure P-17), specified by the LOD parameter, i.e. loss-on-drying of the C-sugar. In the Appendix B, the stream compositions and flow rates are given for the so called “low recycle” case, i.e. approximately a 5% final molasses recycle and correspondingly a very high C-sugar purity (94%). The Appendix C lists the results for the other extreme, a very high recycle case (22%). In all cases, the syrup flow rate is 100 t/h of dry matter. Crystal content is given in weight per cent, that is in tons/100 tons of the stream.

Overall, for every 1% reduction of molasses recycle, for instance from 17 to 16%, each massecuite’s flow rate will be lowered by about 0.1 m³/h, or in relative terms by about 0.1, 0.5 and 0.5% of the massecuite flow rate, for the A-,

B- and C-massecuite, respectively (Figure 2). Such reduction could be achieved by better separation performance of the C-centrifugals, as a response for instance to increased mean C-massecuite crystal size.

Application Example: Effect of Double-magma Boiling Scheme

The double-magma case was readily modeled by retaining the parameters from the “base case” but re-directing all B-sugar in the split P-15 and adding 1.1 m³/h of clarified juice to the B-sugar mingler P-20 in stream S-106. The massecuite flow rates are tabulated in the Appendix D and Table II.

The calculated increases in A- and B-massecuite volumes are substantially lower than those given by Rein (5). That is because of the higher syrup purity (89.2 vs. 85) as well as quite high Amassecuite crystal yield in our “base case.” The strong dependence of the predicted massecuite volumes on the syrup composition and operational parameters underlines the advantage of a computerized model that allows quick re-calculation if these parameters change.

Conclusions

The SuperPro Designer® model of sugar boiling house operations that has been set up at Audubon Sugar Institute is a useful tool for quick evaluation of the effects of changes in the boiling house process parameters. The relative flexibility and ease-of-use of the software will be utilized to further refine the mass and energy balances as well as extend the model to simulations of other cane sugar industry operations.

Acknowledgments

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References

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- (4) <http://www.intelligen.com>
- (5) Rein, P. W. “Cane Sugar Engineering”, Bartens, Berlin, 2007, p. 367.

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Appendix A – Calculated flow rates and composition of the principle boiling house process streams. The “base case”, 17% final molasses recycle in C-magma. In parentheses are the Daily Manufacturing Report data that were used for determination of the model parameters.

Stream Name	Syrup	Clarif. Juice	Raw Sugar	A mass
Source	INPUT	INPUT	P-19	P-6
Destination	P-3	P-4	OUTPUT	P-8
BRIX	58.5 (58.4)	12.5 (12.5)	99.7 (99.7)	91.7 (91.5)
PURITY	89.2 (89.2)	88.8 (89.0)	99.1 (99.0)	88.8 (88.8)
POL	51.2 (52.1)	10.9 (11.1)	90.9 (90.8)	79.0 (79.4)
CRYSTAL CONTENT	0.0	0.0	99.0	55.2
PURITY MOTHER LIQUOR	89.2	88.8	70.0	72.3
PURITY CRYSTAL			99.6	99.7
TOTAL (MT/h)	170.9	1.0	82.3	116.4
TOTAL (m ³ /h)	137.5	1.0		90.0

Stream Name	A sugar	A runoff	A molasses	B mass
Source	P-8	P-24	P-12	P-5
Destination	P-19	P-12	P-32	P-9
BRIX	99.7	80.7	59.4 (60.9)	94.3 (94.2)
PURITY	99.5	72.3	72.3 (71.3)	73.6 (76.3)
POL	99.1	54.9	40.4 (43.4)	55.6 (71.9)
CRYSTAL CONTENT	99.0	0.0	0.0	41.4
PURITY MOTHER LIQUOR	72.4	72.3	72.3	54.0
PURITY CRYSTAL	99.7			99.0
TOTAL (MT/h)	66.0	53.0	72.0	39.0
TOTAL (m ³ /h)		38.4	57.7	25.2

Stream Name	B sugar	B runoff	B molasses	C footing
Source	P-9	P-30	P-13	P-1
Destination	P-15	P-13	P-14	P-18
BRIX	99.5	84.8	69.0 (66.7)	91.6 (90.8)
PURITY	90.0	54.0	54.0 (55.7)	65.6 (63.9)
POL	98.2	39.6	32.3 (37.2)	55.3 (58.0)
CRYSTAL CONTENT	99.1	0.0	0.0	39.6
PURITY MOTHER LIQUOR	54.1	54.0	54.0	40.4
PURITY CRYSTAL	99.0			99.0
TOTAL (MT/h)	16.3	24.3	29.8	10.4
TOTAL (m ³ /h)		17.3	22.9	12.5

Stream Name	C mass	C sugar	C runoff	Final molasses
Source	P-7	P-17	P-21	P-10
Destination	P-17	P-37	P-10	OUTPUT
BRIX	97.7	97.6	69.0	61.1 (62.3)
PURITY	60.3	63.7	43.3	43.3 (32.4)
POL	52.8	79.4	30.6	27.8 (25.7)
CRYSTAL CONTENT	30.4	72.4	0.0	0.0
PURITY MOTHER LIQUOR	43.3	43.3	43.3	43.3
PURITY CRYSTAL	97.9	97.9		
TOTAL (MT/h)	32.0	13.1	20.1	22.1
TOTAL (m ³ /h)	21.1		14.1	16.2

Stream Name	B magma A pan	B magma B pan	C magma B pan	C magma A pan
Source	P-20	P-20	P-37	P-37
Destination	P-11	P-16	P-16	P-11
BRIX			92.0 (92.4)	92.0
PURITY			83.7 (84.2)	83.7
POL			77.0 (77.8)	77.0
CRYSTAL CONTENT			47.2	47.2
PURITY MOTHER LIQUOR			68.8	68.8
PURITY CRYSTAL			97.9	97.9
TOTAL (MT/h)	0.0	0.0	5.1	9.4
TOTAL (m ³ /h)	0.0	0.0	3.4	6.4

Appendix B – Calculated flow rates and composition of the principle boiling house process streams. The “low recycle” case, 5% final molasses recycle in C-magma.

Stream Name	Syrup	Clarif.Juice	Raw Sugar	A mass
Source	INPUT	INPUT	P-19	P-6
Destination	P-3	P-4	OUTPUT	P-8
BRIX	58.5	12.5	99.6	91.6
PURITY	99.2	99.9	99.1	99.5
POL	51.2	10.9	99.0	90.5
CRYSTAL CONTENT	0.0	0.0	99.0	55.6
PURITY MOTHER LIQUOR	89.2	88.8	71.8	73.8
PURITY CRYSTAL			99.6	99.8
TOTAL (MT/h)	170.9	1.0	61.3	116.6
TOTAL (m3/h)	137.5	1.0	52.9	79.6

Stream Name	A sugar	A runoff	A molasses	B mass
Source	P-8	P-24	P-12	P-5
Destination	P-19	P-12	P-32	P-9
BRIX	99.7	80.3	58.7	94.0
PURITY	99.8	73.0	73.8	75.9
POL	99.2	56.0	40.9	67.8
CRYSTAL CONTENT	99.0	0.0	0.0	42.4
PURITY MOTHER LIQUOR	73.8	73.8	73.8	56.8
PURITY CRYSTAL	99.8			99.1
TOTAL (MT/h)	65.4	51.6	70.8	37.1
TOTAL (m3/h)	42.6	37.6	56.9	25.0

Stream Name	B sugar	B runoff	B molasses	C fooling
Source	P-9	P-30	P-13	P-1
Destination	P-15	P-13	P-14	P-16
BRIX	99.5	83.6	67.3	91.4
PURITY	99.9	56.8	56.8	67.8
POL	99.3	41.8	33.7	57.3
CRYSTAL CONTENT	99.1	0.0	0.0	40.7
PURITY MOTHER LIQUOR	56.8	56.8	56.8	42.7
PURITY CRYSTAL	99.1			99.1
TOTAL (MT/h)	15.9	22.6	26.3	17.6
TOTAL (m3/h)	10.3	16.3	21.9	12.0

Stream Name	C mass	C sugar	C runoff	Final molasses
Source	P-7	P-17	P-21	P-10
Destination	P-17	P-37	P-10	OUTPUT
BRIX	97.8	96.2	89.1	81.5
PURITY	82.0	91.0	15.9	15.9
POL	55.6	91.4	33.3	30.4
CRYSTAL CONTENT	31.7	90.6	0.0	0.0
PURITY MOTHER LIQUOR	45.9	45.9	45.9	45.9
PURITY CRYSTAL	98.1	98.1		
TOTAL (MT/h)	30.2	10.6	21.4	23.4
TOTAL (m3/h)	19.9	6.9	14.8	16.9

Stream Name	B magma A pan	B magma B pan	C magma B pan	C magma A pan
Source	P-20	P-20	P-37	P-37
Destination	P-11	P-16	P-16	P-11
BRIX			90.9	90.9
PURITY			93.9	93.9
POL			85.3	85.3
CRYSTAL CONTENT			57.9	57.9
PURITY MOTHER LIQUOR			86.6	86.6
PURITY CRYSTAL			98.1	98.1
TOTAL (MT/h)	0.0	0.0	4.0	7.5
TOTAL (m3/h)	0.0	0.0	2.8	5.2

Appendix C – Calculated flow rates and composition of the principle boiling house process streams. The “high recycle” case, 22% final molasses recycle in C-magma.

Stream Name	Syrup	Clarif. Juice	Raw Sugar	A mass
Source	INPUT	INPUT	P-19	P-6
Destination	P-3	P-4	OUTPUT	P-8
BRIX	58.5	12.5	99.6	91.8
PURITY	99.2	99.6	99.1	99.1
POL	51.2	10.9	98.9	79.4
CRYSTAL CONTENT	0.0	0.0	99.0	55.0
PURITY MOTHER LIQUOR	89.2	88.8	69.1	71.4
PURITY CRYSTAL			99.6	99.7
TOTAL (MT/h)	170.9	1.0	62.6	119.1
TOTAL (m ³ /h)	137.5	1.0	53.9	91.5

Stream Name	A sugar	A runoff	A molasses	B mass
Source	P-8	P-24	P-12	P-5
Destination	P-19	P-12	P-32	P-9
BRIX	99.7	81.0	59.8	94.4
PURITY	99.5	71.4	71.4	72.5
POL	99.1	54.2	40.0	64.4
CRYSTAL CONTENT	99.0	0.0	0.0	40.7
PURITY MOTHER LIQUOR	71.5	71.4	71.4	52.4
PURITY CRYSTAL	99.7			99.0
TOTAL (MT/h)	66.0	53.7	72.7	10.1
TOTAL (m ³ /h)	43.1	39.9	58.2	26.9

Stream Name	B sugar	B runoff	B molasses	C footing
Source	P-9	P-30	P-13	P-1
Destination	P-15	P-13	P-14	P-18
BRIX	99.5	65.1	69.8	92.0
PURITY	99.9	52.4	52.4	64.4
POL	98.1	38.3	31.4	54.0
CRYSTAL CONTENT	99.1	0.0	0.0	39.0
PURITY MOTHER LIQUOR	52.4	52.4	52.4	39.1
PURITY CRYSTAL	99.0			99.9
TOTAL (MT/h)	16.5	25.2	30.7	10.0
TOTAL (m ³ /h)	10.7	17.8	23.5	12.8

Stream Name	C mass	C sugar	C runoff	Final molasses
Source	P-7	P-17	P-21	P-10
Destination	P-17	P-37	P-10	OUTPUT
BRIX	97.8	97.7	89.0	80.8
PURITY	58.8	79.2	41.8	41.8
POL	51.2	71.2	29.1	28.1
CRYSTAL CONTENT	29.7	65.3	0.0	0.0
PURITY MOTHER LIQUOR	41.9	41.8	41.8	41.8
PURITY CRYSTAL	97.8	97.8		
TOTAL (MT/h)	33.0	15.0	19.8	21.8
TOTAL (m ³ /h)	21.7	9.9	13.7	15.6

Stream Name	B magma A pan	B magma B pan	C magma B pan	C magma A pan
Source	P-20	P-20	P-37	P-37
Destination	P-11	P-16	P-16	P-11
BRIX			92.5	92.5
PURITY			79.2	79.2
POL			73.3	73.3
CRYSTAL CONTENT			12.9	12.9
PURITY MOTHER LIQUOR			63.3	63.3
PURITY CRYSTAL			97.8	97.8
TOTAL (MT/h)	0.0	0.0	5.6	10.4
TOTAL (m ³ /h)	0.0	0.0	3.8	7.1

Appendix D – Calculated flow rates and composition of the principle boiling house process streams. The doublemagma boiling scheme. All other parameters are as in the “base case” for three-boiling scheme in Appendix A. Data from Rein (2007) are given in the parentheses.

Stream Name	Syrup	Clarif. Juice	Raw Sugar	A mass
Source	INPUT	INPUT	P-19	P-6
Destination	P-3	P-4	OUTPUT	P-8
BRIX	58.5	12.5	99.6	81.8
PURITY	89.2	88.8	99.4	88.4
POL	51.2	10.9	98.9	79.4
CRYSTAL CONTENT	0.0	0.0	99.0	55.0
PURITY MOTHER LIQUOR	89.2	88.8	60.1	71.4
PURITY CRYSTAL			99.6	99.7
TOTAL (MT/h)	170.9	1.0	62.8	118.4
TOTAL (m ³ /h)	137.5	1.0	53.9	81.5

Stream Name	A sugar	A runoff	A molasses	B mass
Source	P-8	P-24	P-12	P-5
Destination	P-19	P-12	P-32	P-9
BRIX	99.7	81.0	59.8	94.4
PURITY	99.5	71.4	71.4	72.5
POL	99.1	54.2	40.0	64.4
CRYSTAL CONTENT	99.0	0.0	0.0	40.7
PURITY MOTHER LIQUOR	71.5	71.4	71.4	52.4
PURITY CRYSTAL	99.7			99.0
TOTAL (MT/h)	66.3	53.7	72.7	40.1
TOTAL (m ³ /h)	43.1	38.9	38.2	28.9

Stream Name	B sugar	B runoff	B molasses	C footing
Source	P-9	P-30	P-13	P-1
Destination	P-15	P-13	P-14	P-18
BRIX	99.5	85.1	69.8	92.0
PURITY	99.8	52.4	52.4	64.4
POL	98.1	38.3	31.4	54.0
CRYSTAL CONTENT	99.1	0.0	0.0	39.0
PURITY MOTHER LIQUOR	52.4	52.4	52.4	38.1
PURITY CRYSTAL	99.0			99.9
TOTAL (MT/h)	18.5	25.2	30.7	10.9
TOTAL (m ³ /h)	10.7	17.8	23.5	12.8

Stream Name	C mass	C sugar	C runoff	Final molasses
Source	P-7	P-17	P-21	P-10
Destination	P-17	P-37	P-10	OUTPUT
BRIX	97.8	97.7	80.0	80.8
PURITY	58.8	79.2	41.8	41.8
POL	51.2	74.2	29.1	28.4
CRYSTAL CONTENT	29.7	65.3	0.0	0.0
PURITY MOTHER LIQUOR	41.8	41.8	41.8	41.8
PURITY CRYSTAL	97.8	97.8		
TOTAL (MT/h)	33.0	15.0	19.8	21.8
TOTAL (m ³ /h)	21.7	9.9	13.7	15.8

Stream Name	B magma A pan	B magma B pan	C magma B pan	C magma A pan
Source	P-20	P-20	P-37	P-37
Destination	P-11	P-16	P-16	P-11
BRIX			92.5	92.5
PURITY			79.2	79.2
POL			73.3	73.3
CRYSTAL CONTENT			42.9	42.9
PURITY MOTHER LIQUOR			63.3	63.3
PURITY CRYSTAL			97.8	97.8
TOTAL (MT/h)	0.0	0.0	5.8	10.4
TOTAL (m ³ /h)	0.0	0.0	3.8	7.1