DEVELOPMENT OF FACTORY PERFORMANCE CURVES USING SUGARS^{TM} FOR WINDOWS

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ABSTRACT

Sugar mills and refineries involve a series of complex, interconnected processes. Feed material properties and process parameters in one part of the factory have cascading effects throughout the rest of the facility. It is necessary to gain a full understanding of these relationships between process inputs and process outputs in order to optimize the process as a whole and maximize profitability. This can be a very difficult and time-consuming task, especially considering the non-linearity of many process relationships.

A novel approach to this task has been developed using the Sugars^{TM} for Windows mass and energy balance simulation software. "Performance Curves" can be generated by running a series of balances on an established factory model, varying one input parameter over a range of possible values. Two examples are presented: varying cane sugar content, and varying cane diffuser draft. Comparisons are made between responses of parameters such as overall extraction, steam demand, molasses purity, etc.

The applications of this technique to production planning, financial forecasting, and capital improvement planning are also discussed.

INTRODUCTION

One of the greatest challenges of operating a sugar processing facility is presented by the nature of the process itself: a change to one parameter or condition can lead to a whole host of effects throughout the rest of the process. Understanding these cause-effect relationships is critical to economically optimizing the factory's performance.

Unfortunately, many of the interactions between factory variables are complex and difficult to predict. In some cases, historical data can be empirically analyzed to look for "average" process responses over a period of years. However, this method is subject to the quantity and quality of historical data available and can become obsolete if major physical changes or upgrades are made to the factory itself.

METHODS

A novel approach to this problem involves utilizing Sugars™ for Windows, a PC-based mass and energy balance software package developed specifically for the sugar and ethanol industries. An accurate process model of an entire factory can be developed using Sugars™. This model represents all the process inputs, internal unit operations within the factory, and the resulting process outputs. Figures 1 through 5 below are images of a Cane Factory with Diffuser model, one of the example models provided with Sugars^{TM} for Windows. This model was utilized for the work described throughout the rest of this paper.

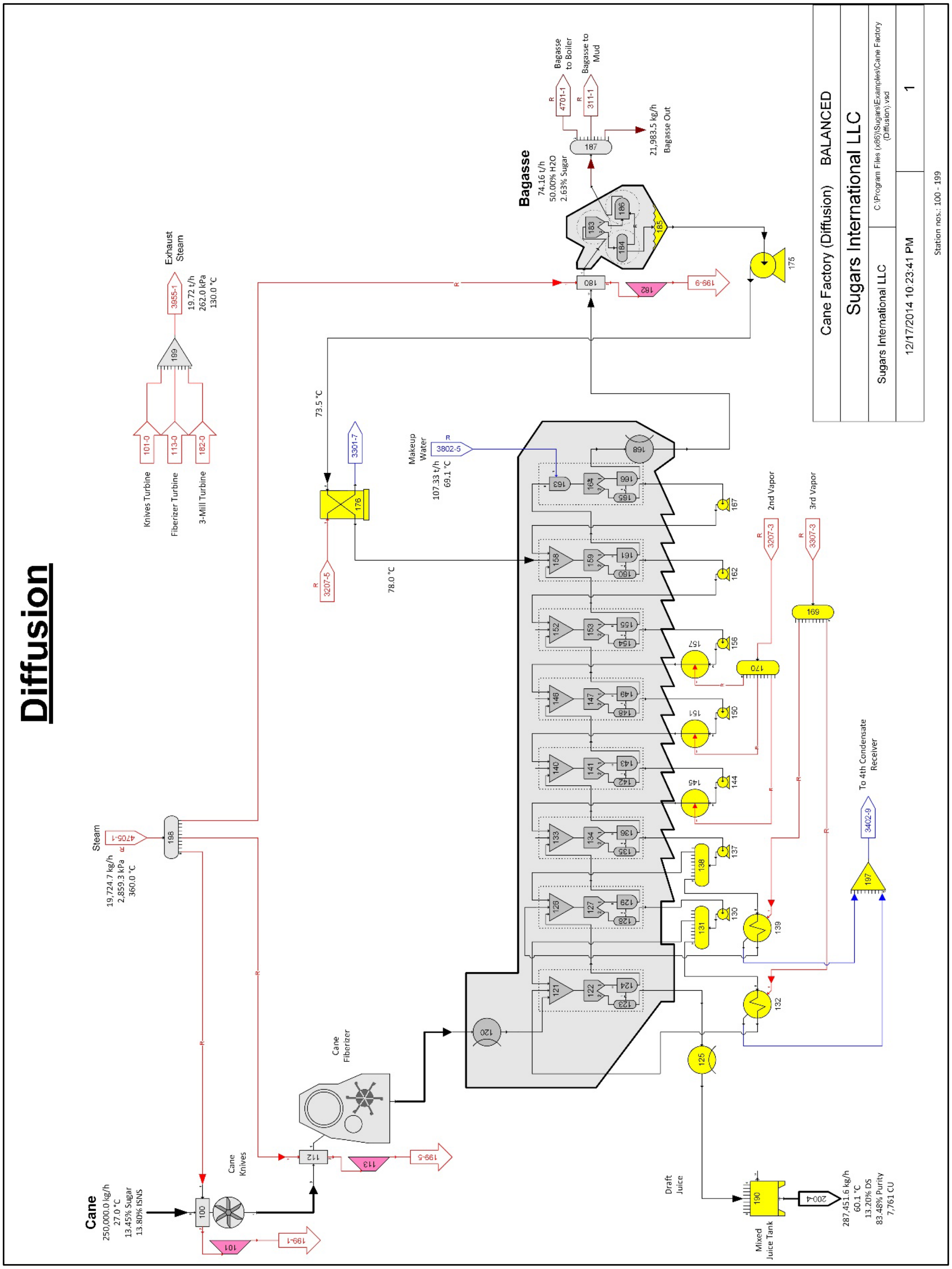


Figure 1: Cane Factory (Diffusion) model, Diffuser Area

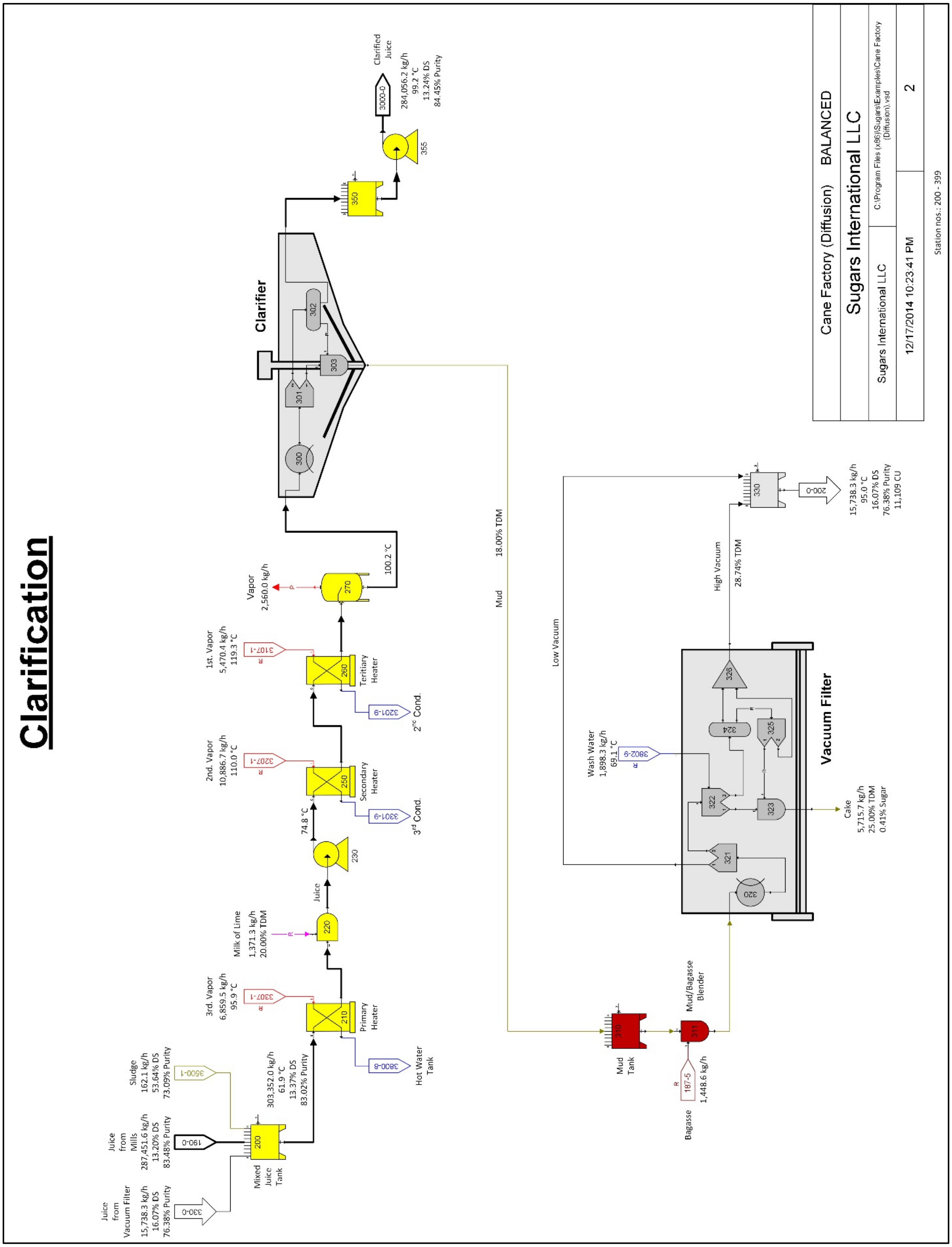


Figure 2: Cane Factory (Diffusion) model, Clarification Area

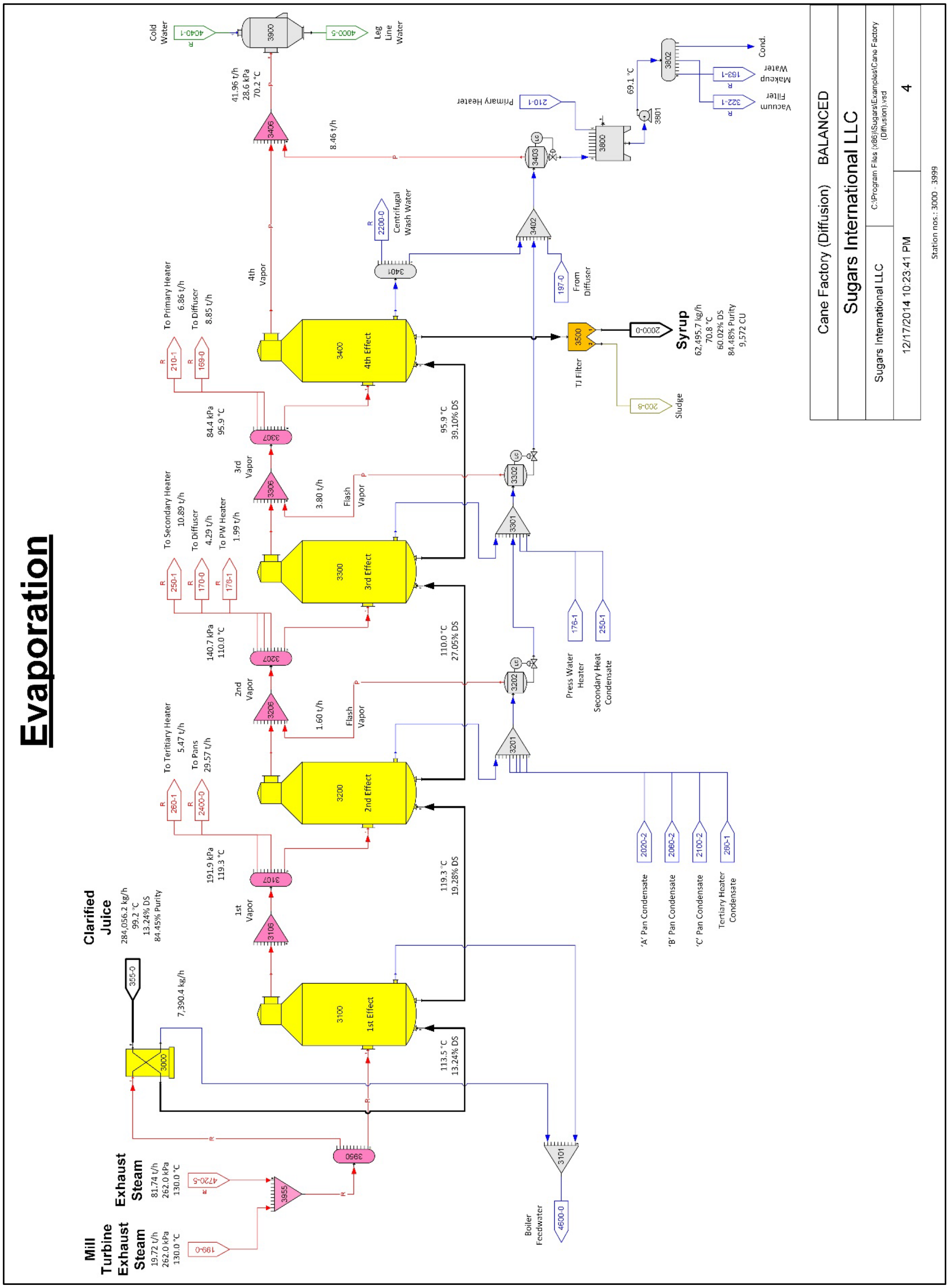


Figure 3: Cane Factory (Diffusion) model, Evaporation Area

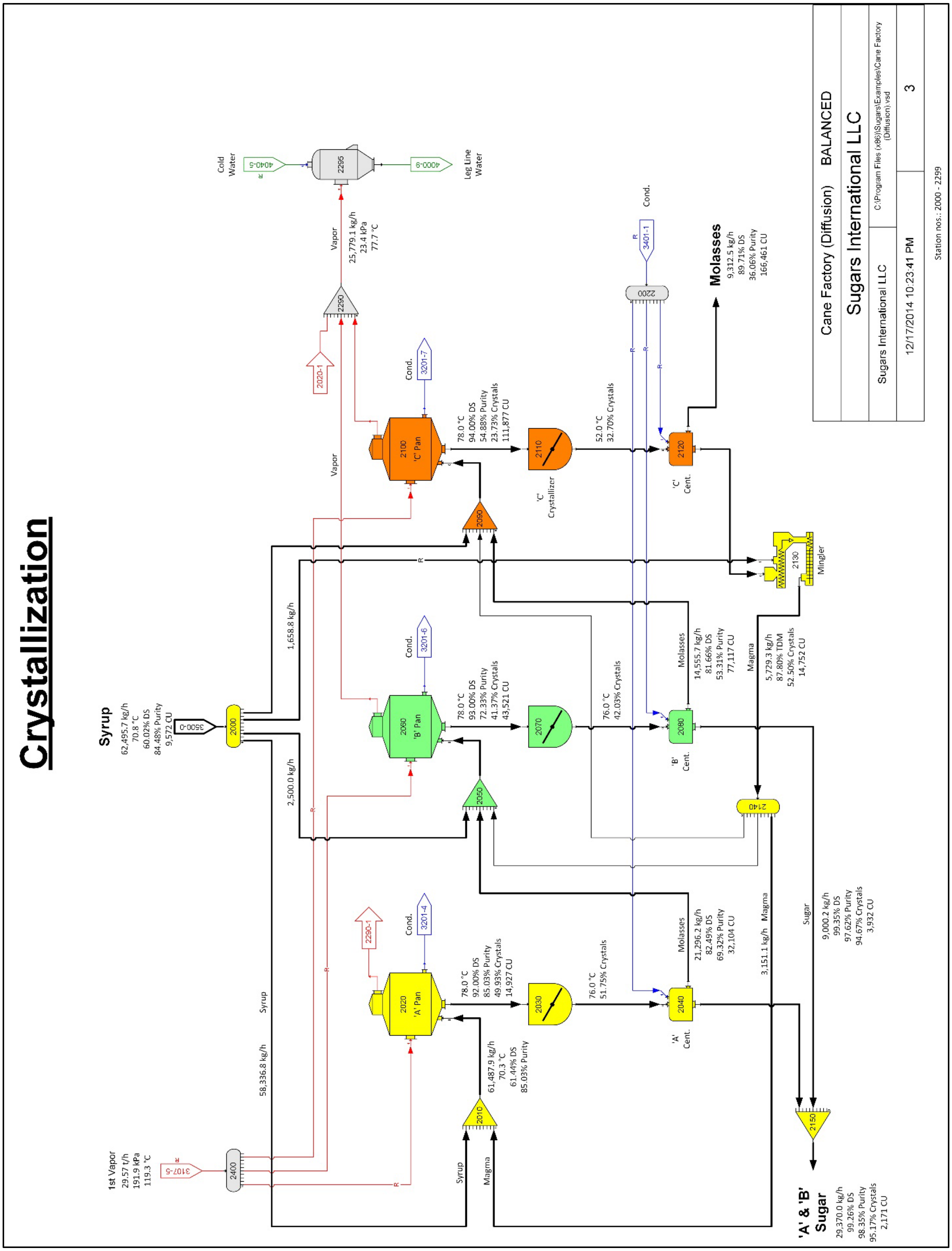


Figure 4: Cane Factory (Diffusion) model, Crystallization Area

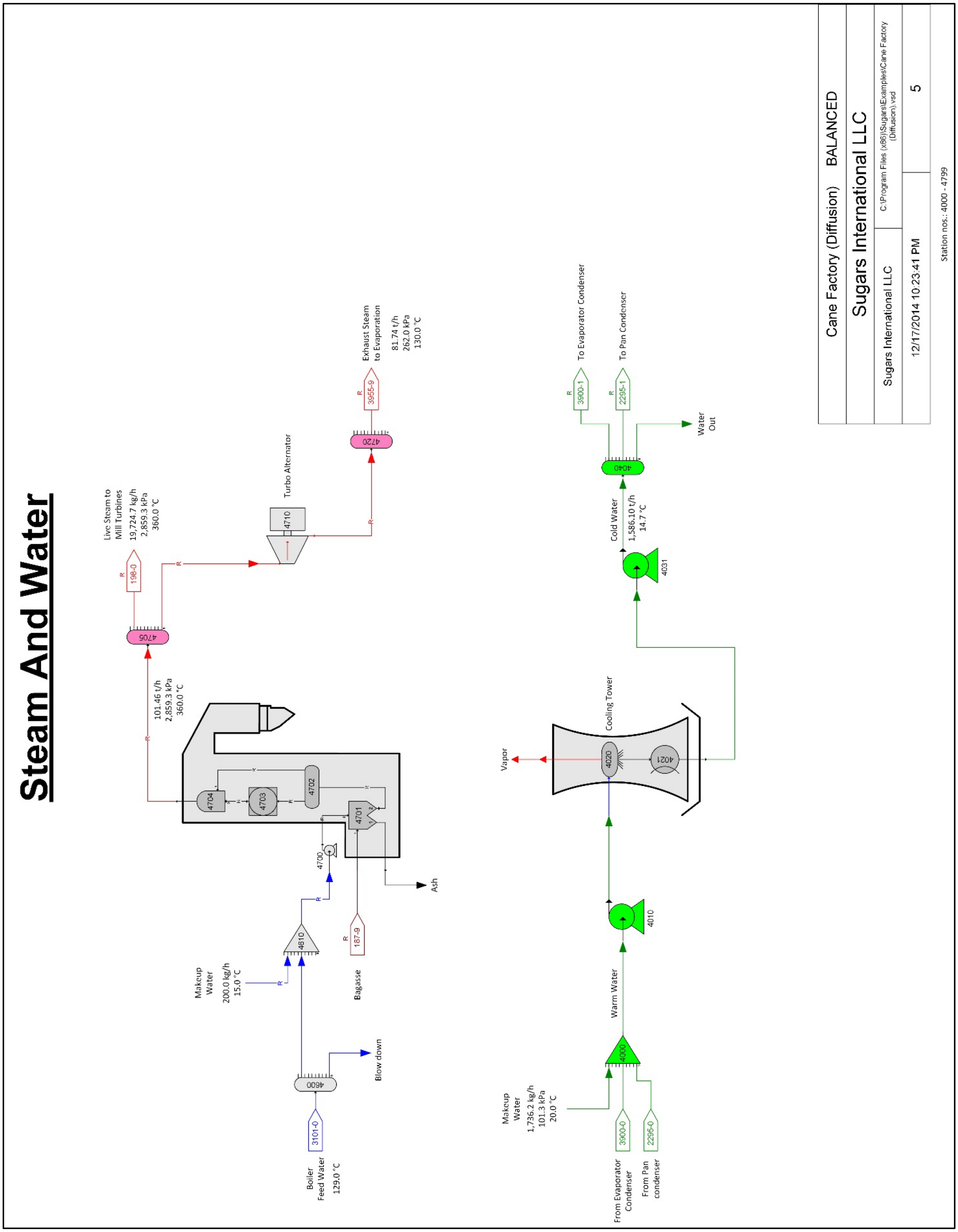


Figure 5: Cane Factory (Diffusion) model, Steam and Water Area

The first step in developing Performance Curves is to determine for which process input variable we desire to gauge process responses against. Sugar factories are affected by hundreds of inputs which may vary slowly throughout the processing season, or as quickly as minute-by-minute. Performance Curves relative to all types of input variables can provide value; for this study, two inputs were chosen to illustrate their methods of development and usefulness: cane sugar content and diffuser draft.

For each input, a table of values, spanning a typical operating range, was generated, and a set of process outputs of interest was selected. The input values for each row of the table were entered into the Sugars^{TM} Cane Factory (Diffusion) model and the model was balanced for each case. The model's output variable results were then added to the table.

RESULTS AND DISCUSSION

The first process input that was tested was the sugar content of the raw sugar cane feeding the factory. This parameter may vary gradually throughout a processing season, or more rapidly as different sources of cane are fed to the mill. The sugar content was varied from 12.0% to 15.0%, in 0.2% increments. The water content was held constant, and the soluble non-sugar and fiber content were adjusted proportionally so that the total of all components was always 100%. These are represented by the green-shaded columns in Table 1. All other factory process parameters were held constant for each model run.

The component fractions for each row of the table were entered into the Sugars^{TM} Cane Factory (Diffusion) model's incoming cane flow stream specifications for each case and the balance results were entered for each output. Table 1 below shows the completed version.

Cane Factory Diffusion Model Sugar Content Performance Curve Data

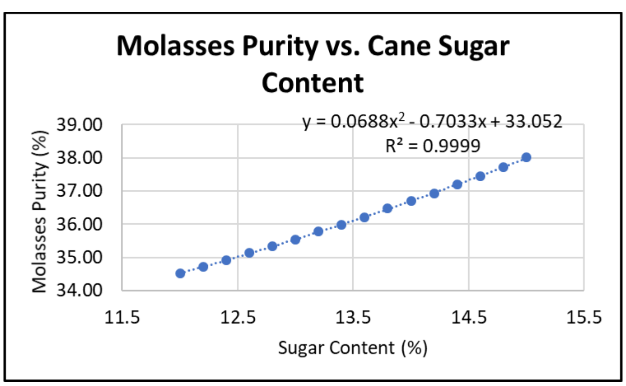
Cane Flow: 250,000 kg/hr

Cane Sugar Content (%)	Cane Sol. Non-Sugars (%)	Cane Fiber (%)	Cane Water (%)	Sugar Produced (kg/hr)	Extraction (%)	Molasses Produced (kg/hr)	Molasses Purity (%)	Steam Demand (T/hr)
12.0	3.00	15.01	69.99	25,985	86.6%	10,113	34.53	102.17
12.2	2.97	14.84	69.99	26,443	86.7%	10,014	34.71	102.08
12.4	2.94	14.67	69.99	26,913	86.8%	9,913	34.91	101.98
12.6	2.90	14.51	69.99	27,390	87.0%	9,783	35.13	101.89
12.8	2.87	14.34	69.99	27,855	87.0%	9,681	35.33	101.79
13.0	2.84	14.17	69.99	28,317	87.1%	9,579	35.54	101.69
13.2	2.80	14.01	69.99	28,788	87.2%	9,449	35.78	101.60
13.4	2.77	13.84	69.99	29,246	87.3%	9,346	35.99	101.49
13.6	2.74	13.67	69.99	29,699	87.3%	9,244	36.21	101.39
13.8	2.70	13.51	69.99	30,159	87.4%	9,113	36.47	101.29
14.0	2.67	13.34	69.99	30,607	87.4%	9,010	36.70	101.19
14.2	2.64	13.17	69.99	31,051	87.5%	8,906	36.93	101.08
14.4	2.60	13.01	69.99	31,501	87.5%	8,775	37.21	100.98
14.6	2.57	12.84	69.99	31,938	87.5%	8,670	37.45	100.88
14.8	2.54	12.67	69.99	32,371	87.5%	8,565	37.71	100.77
15.0	2.50	12.51	69.99	32,813	87.5%	8,431	38.01	100.66

Table 1: Cane Factory (Diffusion) model results of varying cane sugar content

The yellow-shaded columns in Table 1 represent modeling results. The Sugar Produced, Molasses Produced, Molasses Purity, and Steam Demand are all direct results of the Sugars™ model balance. Extraction is calculated as the Sugar Produced divided by the mass of sucrose in the Cane feed to the factory.

Plots were generated comparing each output variable to the cane sugar content, including best-fit regression curves that mathematically represent the relationships.



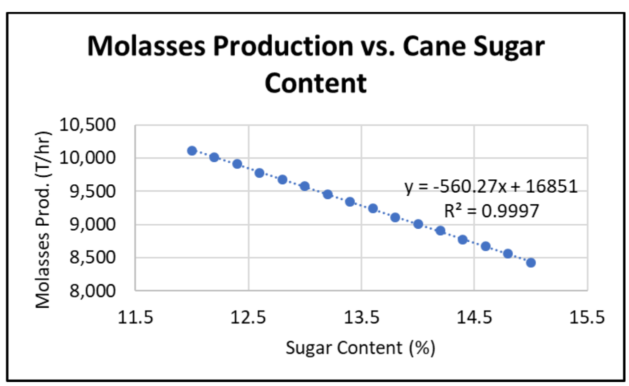


Figure 6: Molasses Purity and Production vs. Cane Sugar Content

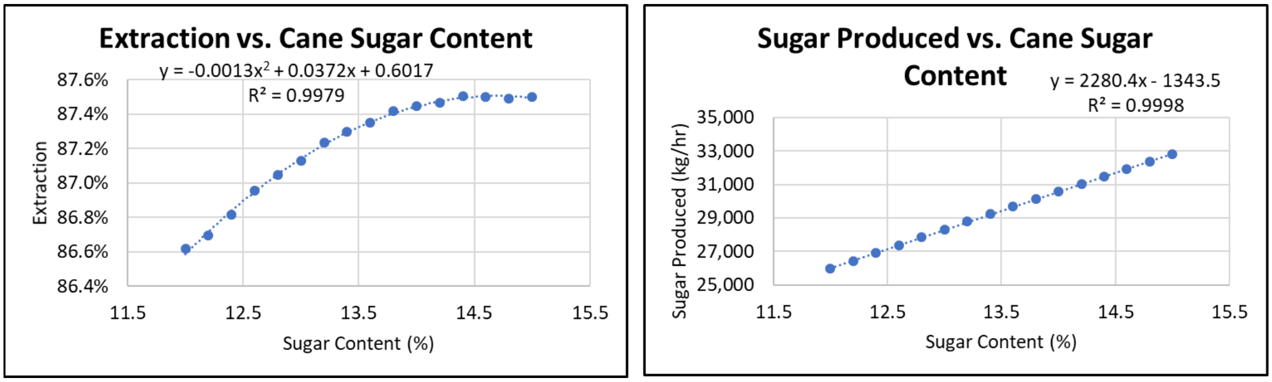


Figure 7: Extraction and Sugar Produced vs. Cane Sugar Content

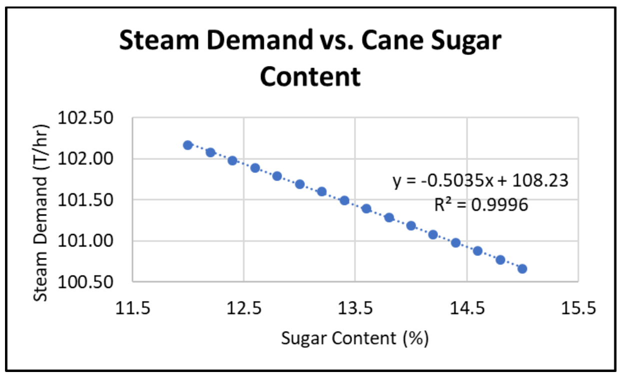


Figure 8: Steam Demand vs. Cane Sugar Content

Interesting to note is that while molasses production, sugar production, and steam demand are linear with respect to cane sugar content, molasses purity is slightly non-linear, and extraction (sugar produced/sugar in cane) is severely non-linear.

The regression equations shown on each plot can be used as a simple tool for predicting changes in each output parameter based on changes in cane sugar content. Using this example, if the factory's cane supply were switched to one of known, lower sugar content, the Sugar Produced vs. Cane Sugar Content curve could be used to predict the reduction in sugar production rate. This provides needed information to sugar storage managers for inventory predictions as well as financial planners regarding the amount of sugar available for sale.

Diffuser draft (draft juice mass flow/cane mass flow) was the second input variable tested using the Performance Curve method. It was varied from 0.97 to 1.31 in increments of 0.03. Table 2 illustrates the results of balancing the model at each draft value, including a simple calculated net revenue column based on the following values:

Sugar: $0.30 /kg

Molasses: $0.10 /kg

Steam: $15.00 /ton

Cane Factory Diffusion Model Draft Performance Curves

Cane Flow: 250,000 kg/hr

Cane Sugar Content (%)	Draft (Ratio)	Sugar Produced (kg/hr)	Extraction (%)	Molasses Produced (kg/hr)	Steam Demand (T/hr)	Sugar in Bagasse (%)	Net Revenue ($/hr)
13.5	0.97	26,496	78.8%	8,082	88.45	6.28	$ 14,018
13.5	1.00	27,150	80.7%	8,336	90.89	5.53	$ 14,371
13.5	1.04	27,747	82.5%	8,579	93.29	4.81	$ 14,694
13.5	1.07	28,284	84.1%	8,809	95.65	4.12	$ 14,985
13.5	1.10	28,759	85.5%	9,021	97.97	3.49	$ 15,243
13.5	1.13	29,171	86.8%	9,214	100.23	2.92	$ 15,467
13.5	1.16	29,523	87.8%	9,386	102.44	2.42	$ 15,657
13.5	1.19	29,816	88.7%	9,537	104.61	1.99	$ 15,816
13.5	1.22	30,058	89.4%	9,666	106.73	1.62	$ 15,945
13.5	1.25	30,254	90.0%	9,776	108.80	1.32	$ 16,049
13.5	1.28	30,411	90.4%	9,869	110.85	1.08	$ 16,132
13.5	1.31	30,536	90.8%	9,946	112.86	0.88	$ 16,196

Table 2: Cane Factory (Diffusion) model results of varying diffuser draft

Plots were again generated to visualize and quantify the relationship between each output variable and diffuser draft.

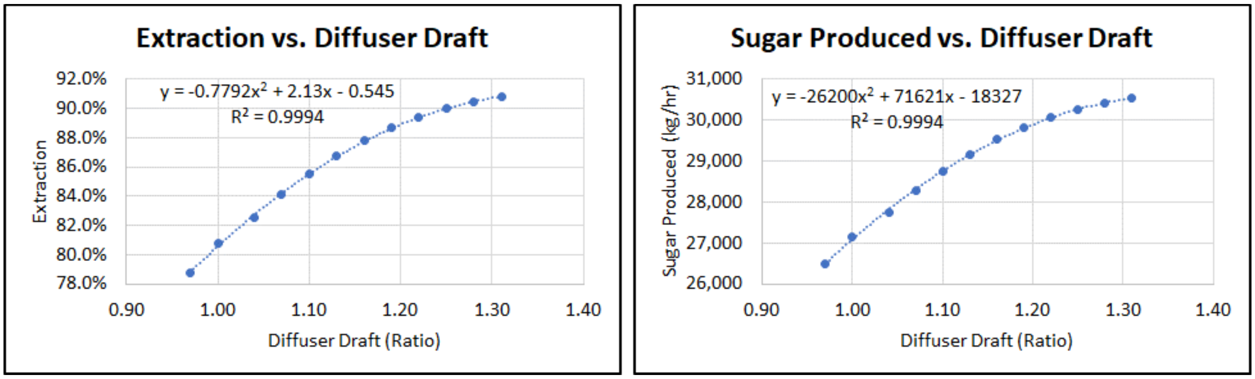


Figure 9: Extraction and Sugar Produced vs. Diffuser Draft

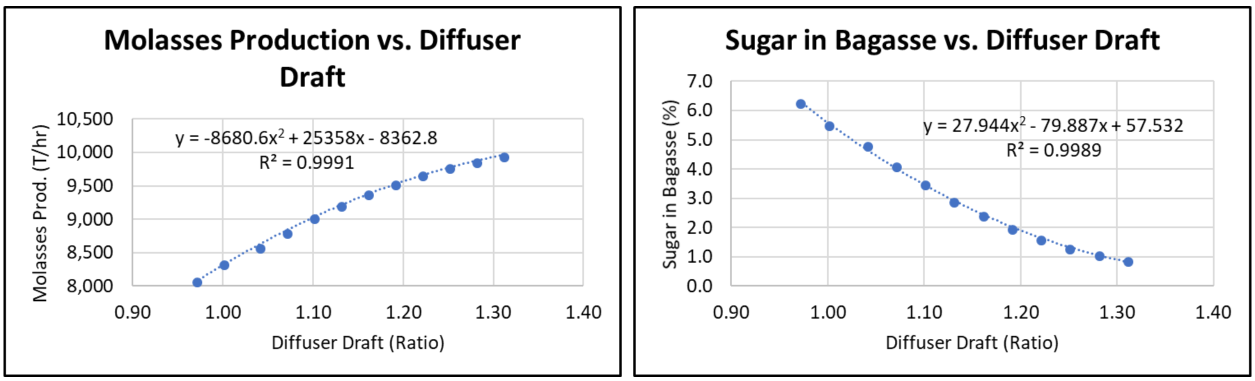


Figure 10: Molasses Production and Sugar in Bagasse vs. Diffuser Draft

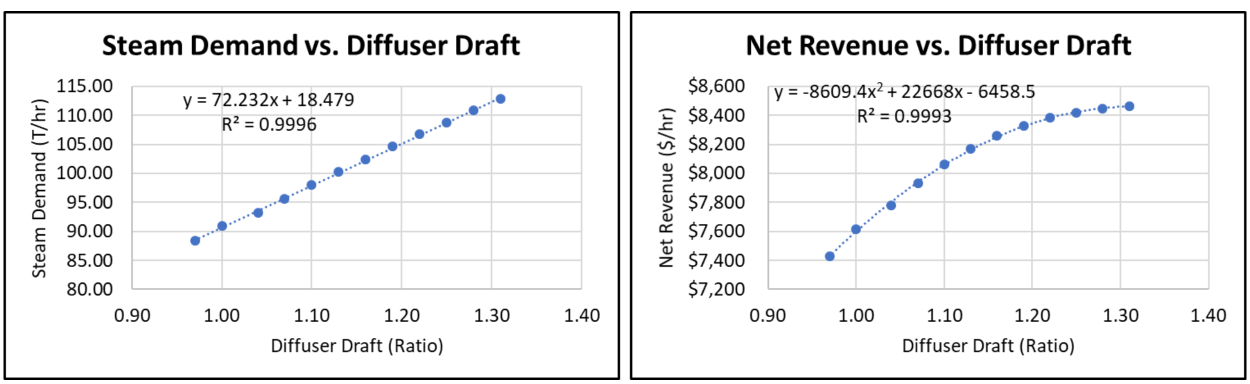


Figure 10: Steam Demand and Net Revenue vs. Diffuser Draft

Steam demand is the only parameter showing a linear relationship vs. Diffuser Draft. In fact, net revenue is so strongly non-linear, it indicates that any draft values over 1.30 do not increase revenue any further. This is extremely valuable information when making factory process optimization decisions. In this case, adjusting the draft target from 1.0 to 1.2 could yield an additional $750 /hr in net revenue! (Note that the shape and position of this curve will vary significantly from factory-to-factory.)

This example could also be applied to capital planning efforts if, for instance, a mill were considering installing a larger cane diffuser. The Sugars™ model would be updated with the parameters and performance characteristics of the new diffuser. This new model could be run through the same series of draft scenarios as the "baseline" model, yielding a new set of performance curves. The gap between the two curves represents the anticipated process change over the entire range of draft rates. The Net Revenue curve is shown as an example below, showing the varying economic benefit of the new diffuser across the draft range.

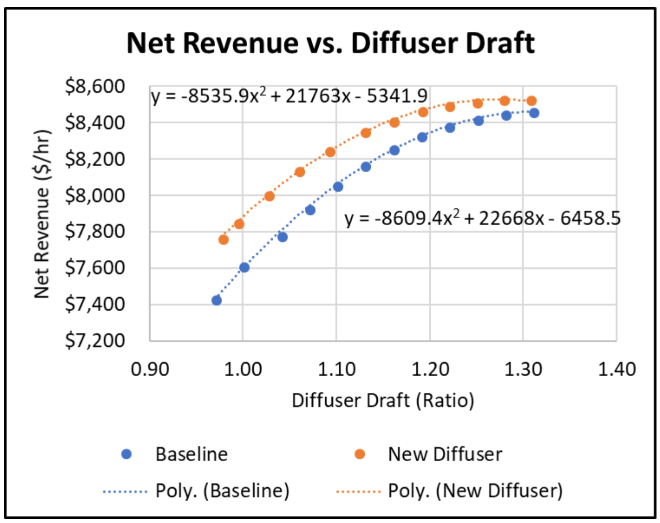


Figure 11: Net Revenue vs. Diffuser Draft, Baseline and New Diffuser Curves

CONCLUSIONS

Utilizing a factory-wide Sugars™ mass and energy balance model, Performance Curves can be developed showing the responses of multiple process outputs to changes in process inputs. This mass and energy balance-based method allows isolation of a single process input, holding all others constant. This is an advantage over empirical modeling in which there are virtually always multiple input variables changing simultaneously. Simple mathematical regressions can be built to represent the Performance Curves, providing easy-to-use equations for production planning, sugar storage management, financial forecasting, process optimization, and more. Major economic benefits are possible when decisions are made based on the information provided by Performance Curves.