M 2. IMPROVING FACTORY PERFORMANCE USING AN INTEGRATED SUGAR FACTORY MODEL

By

AP MANN[1], OP THAVAL[1], R BROADFOOT[1], J McFEATERS[2]

[1]*Queensland University of Technology, Brisbane*
[2]*Kenwalt Australia Pty Ltd, Perth*
o.thaval@qut.edu.au

KEYWORDS: Mass and energy balance, process simulation, extraction model, empirical models.

Abstract

A whole of factory model of a raw sugar factory was developed in SysCAD software to assess and improve factory operations. The integrated sugar factory model 'Sugar-SysCAD' includes individual models for milling, heating and clarification, evaporation, crystallisation, steam cycle, sugar dryer and process and injection water circuits. These individual unit operation models can be either used as standalone models to optimise the unit operation or in the integrated mode to provide more accurate prediction of the effects of changes in any part of the process on the outputs of the whole factory process. Using the integrated sugar factory model, the effect of specific process operations can be understood and practical solutions can be determined to address process problems. The paper presents two factory scenarios to show the capabilities of the whole of factory model.

Introduction

Process modelling of raw sugar factories has been undertaken using different techniques over the years for the purpose of understanding and improving the performance of unit operations. For a mathematical model to be useful, it must be sufficiently complete and accurate to represent the system in the range of variables to be studied. Today, several commercial process modelling packages are available with ability to incorporate various unit operations and integrate them.

Software packages like HYSYS® and SUGARS™ have been used to simulate sugar factory processes. The HYSYS software is general process modelling software and does not contain sugar factory specific operations. The SUGARS package does contain sugar specific unit operations, but does not allow in-house process knowledge to be incorporated into the models (Peacock, 2002).

The use of process modelling software in the South African sugar industry was discussed and demonstrated by Peacock (2002). SIMULINK is a commercial software system overlaid on the MATLAB programming language, which is widely used in modelling, simulation and analysis of steady state and dynamic systems using block diagrams. Peacock (2002) explored the SIMULINK system for a mass and energy balance model in the cane diffuser system (an alternative extraction process to the milling process). The model, which was at an early stage, consisted of a simple material and enthalpy balance.

SysCAD is a commercial process modelling software package developed by Kenwalt Australia (KWA) and extensively used in mineral industries (SysCAD). SysCAD is a powerful and versatile plant simulator. SysCAD offers dynamic simulation and the ability to incorporate in-house models of individual stations. These abilities of SysCAD are favoured for the development of the 'whole of factory' model.

Thaval and Kent (2013) demonstrated the use of the SysCAD process modelling package for modelling the milling process. The mill extraction models proposed by Thaval and Kent (2012a, 2012b) were incorporated into SysCAD and the benefits of using the SysCAD software were discussed.

Thaval and Kent (2015) discuss an updated version of the milling train model in the SysCAD software. The milling train model can be used as a standalone model or in the integrated sugar factory model.

This paper reports the work done in modelling the unit operations of the raw sugar factory and the integration of the models in the SysCAD environment. A complete sugar factory model is presented to demonstrate the features of the model. Some case studies to assess the impact of changes in any part of the factory on the overall factory performance are discussed.

Structure of the SysCAD models

The following steps were undertaken to build the whole of factory SysCAD model:

- Develop the individual unit operation models. A unit operation is the functionality involved in a single item of equipment e.g. turbine, mill, heater or evaporator.

- Upgrade the thermo-physical properties database to incorporate sugar processing parameters. The functional expressions may be either correlations available in public literature (Generic Sugar-SysCAD) or SRI confidential correlations (SRI Sugar-SysCAD). Thermo-physical properties such as enthalpy of steam, saturation steam properties, heat capacity of molasses, solubility of sucrose, viscosity of molasses and density of molasses are used by the unit operation models.

- Incorporate the unit operation models into area models such as a milling train or an evaporator station. The incorporated linkages between unit operation models provide the flexibility to allow modelling of a wide range of configurations of equipment.

- Develop the whole of factory model, in which the individual area models are linked through *ties*, at the appropriate process connections (e.g. link the mixed juice from the milling train model to the mixed juice tank supplying the primary heaters in the heater model).

Unit operation models

Overview

SysCAD has a wide range of unit operation models such as heat exchangers, boilers, evaporators, flash tanks, pumps, turbines, condensers and cooling towers. Additional unit operations for the sugar factory application were developed as part of this work including:

- sugar cane shredder
- milling unit
- juice screen
- sugar vacuum pan
- sugar crystalliser
- sugar fugal
- sugar dryer

All these unit operation models utilise SRI fundamental expressions. The sugar cane shredder and milling unit models were described in detail by Thaval and Kent (2013, 2015). The sugar dryer model is described here to provide an example of a unit operation model developed in the SysCAD software.

Sugar dryer model

The sugar dryer model is a counter flow dryer used to cool and dry sugar crystals in the final stage of processing (Figure 1). The dryer receives hot sugar crystal feed in one end and air enters the other end of the dryer.

The hot sugar crystal feed is coated with a film of molasses and, as the sugar moves through the dryer, heat is transferred from the sugar to the air, and water evaporates from the sugar into the air. As water evaporates the concentration of sugar in the molasses film increases, the solubility of the sugar decreases and some of the aqueous sucrose in the film precipitates onto the existing sugar crystals. The change in the molasses film properties with increasing concentration due to evaporation and decreasing purity as sucrose precipitates affects the partial pressure of water and thus the evaporation rate of water from the film to the air and also the precipitation rate of sucrose from the film to the crystal. These processes are taken into account in the model.

Depending on the temperature and moisture of the feed sugar and the temperature and humidity of the air to the dryer, water may be added to the feed sugar as a model option to control the final moisture content of the sugar to enhance cooling and prevent over-drying.

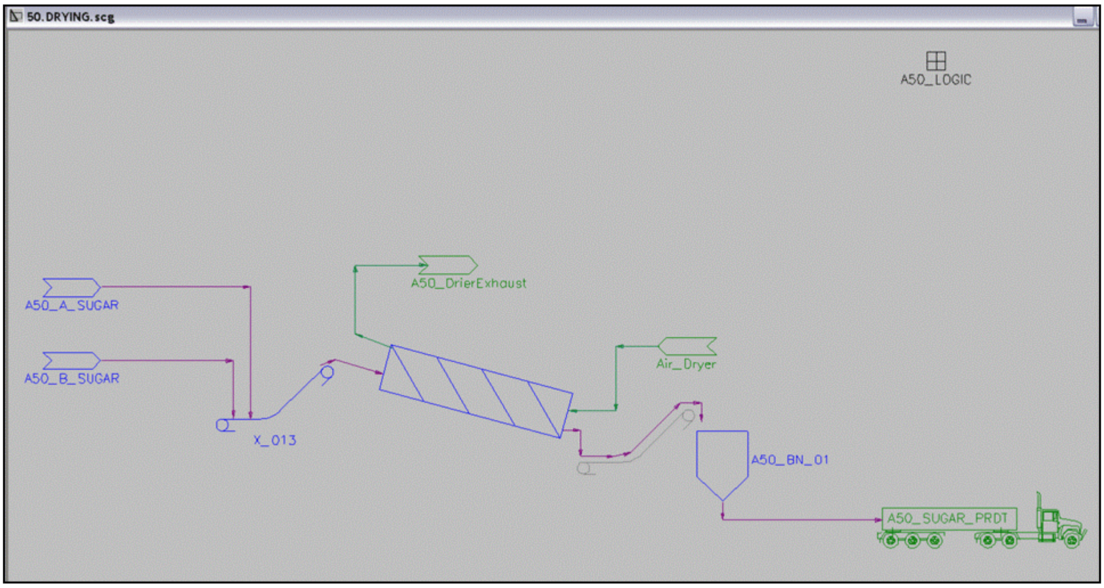

Fig. 1 – Graphics screen for the dryer model

Thermo-physical properties database

A complete species database was developed in SysCAD specifically for developing the sugar industry unit operation models. Most of the properties have been adapted from the Sugar Technologists Handbook (Bubnik *et al* 1995).

The solution properties have been developed so that they default back to pure water properties as sugar concentration goes to zero. This way the properties of solutions are continuous over the whole range of concentrations including down to zero.

Area models

Overview

Standalone area models were developed for different stations of the factory. The standalone models provide flexibility for optimising the operation of process station without requiring information from other stations or considering the effects on other stations of the factory. An example of the standalone model for the milling train is discussed in detail by Thaval and Kent (2013, 2015). The area models developed in SysCAD are as follows:

- crushing and milling
- steam cycle
- water circuit
- heating, clarification and filtration
- evaporation
- crystallisation

The steam cycle model is described to provide an example of the area models developed in SysCAD environment. The area model simulation is described with a pan stage area model example.

Steam cycle area model

The steam cycle model simulates the flows of boiler feedwater, high pressure steam, low pressure (LP) steam and steam condensate through a typical sugar factory. The boiler station is represented as a single boiler and single turbines are used to represent the turbines of the shredder, milling train, boiler auxiliaries and power house. The factory high pressure steam conditions, the pressure of the steam used for process heating, the pressure at which return condensate is flashed, the factory low pressure steam demand and the power requirements and efficiencies of the factory turbines are entered by the user. The model predicts boiler station efficiency and fuel consumption based on flue gas and fuel information supplied by the user. The model calculates the steam requirements of the shredder, milling train, boiler auxiliaries and power house turbines. If the total exhaust steam flow from these turbines is less than the factory LP steam requirements, the model calculates the makeup steam required. Desuperheating of the exhaust steam from the turbines and makeup valve is taken into account with the user specifying target superheats for these streams. If condensation occurs in any of the turbines the model calculates the flow to each of the condensate traps. Figure 2 shows the graphics screen of the steam cycle area model and Figure 3 shows the corresponding Excel input/output screen.

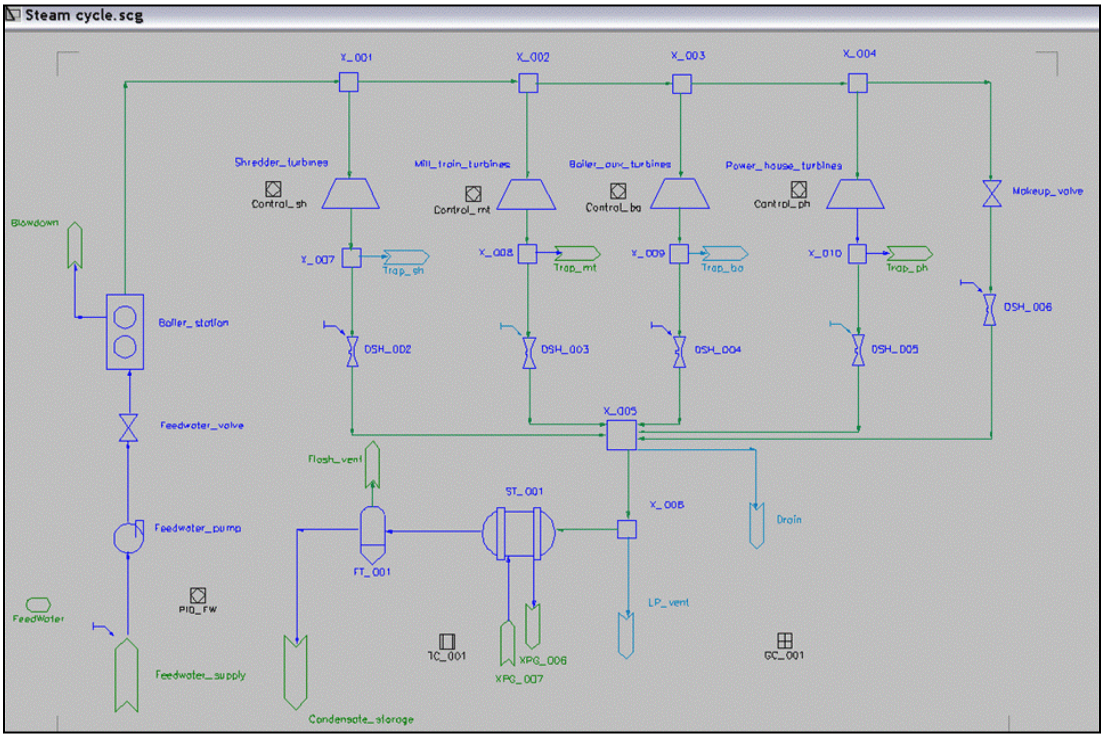

Fig. 2 – Graphics screen for the steam cycle area model

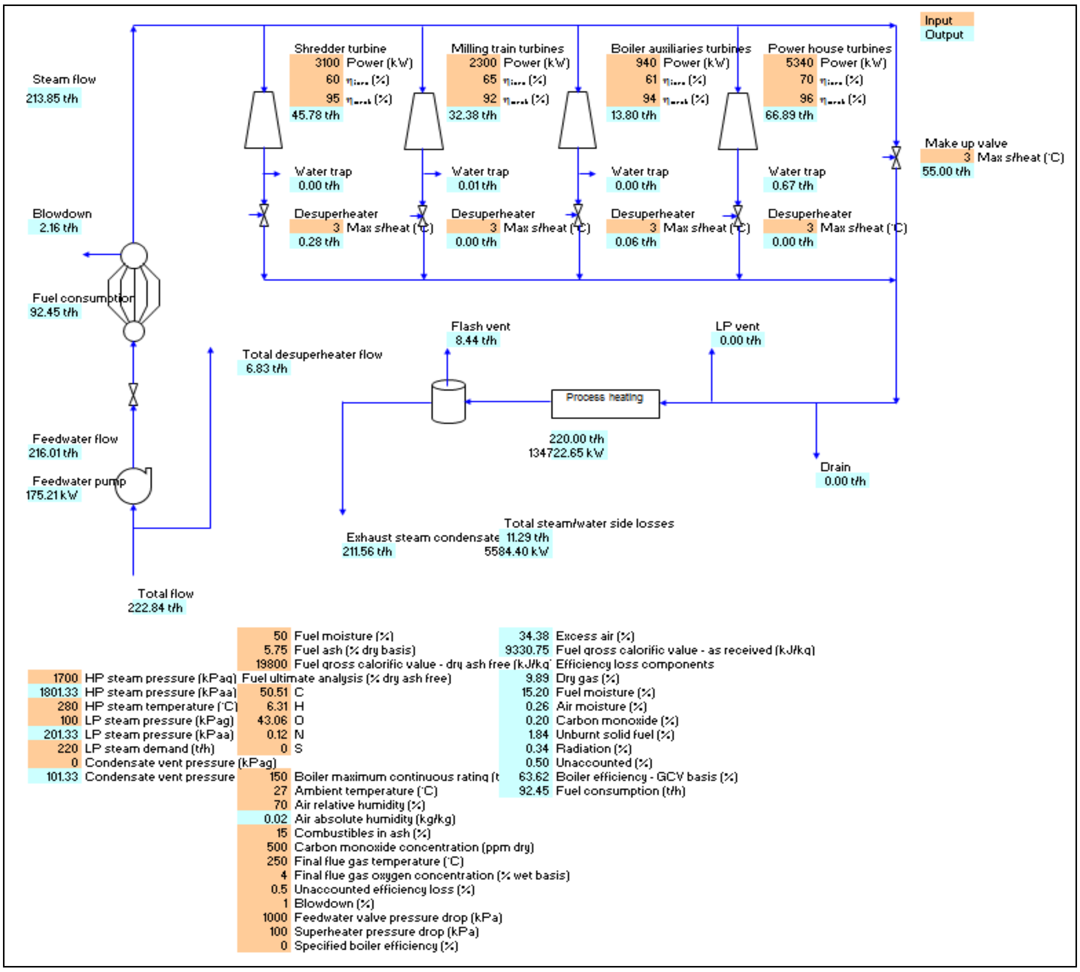

Fig. 3 – Excel input/output screen for the steam cycle area model

Pan stage area model

Different pan boiling schemes are used across the sugar industry, although the Australian sugar factories predominantly use the three massecuite boiling scheme. A CBA boiling scheme was also developed in the SysCAD software. A case study was undertaken where a three massecuite boiling scheme was converted to a CBA boiling scheme. The case highlights the flexibility of SysCAD in modelling different sugar production scenarios.

The case study was undertaken for a sugar factory with a 440 t/h crushing rate and a syrup solids rate of 68.89 t/h (total syrup flow of 101.3 t/h). The required inputs for the model are shown in Table 1. The exhaustion of the A, B and C massecuite are also defined.

Table 1 – Data for simulation of the pan stage for the three massecuite scheme

Parameters	Value
Cane rate (t/h)	440
CCS (%)	13.5
Sugar pol (%)	98.95
PSI[1]	99.5
Syrup purity (%)	90
A massecuite purity (%)	88
B massecuite purity (%)	81
B molasses purity (%)	68
C massecuite purity (%)	68.5
C molasses purity (%)	46.48
C sugar purity (%)	90

[1]Pool Sugar Index

Figure 4 shows a graphics screen for the crystallisation model with the three massecuite boiling scheme and Figure 5 shows the corresponding flows and steam consumptions in the format of an SRI pan stage model spreadsheet. Figure 6 shows a graphics screen for the crystallisation model with the CBA boiling scheme and Figure 7 shows the corresponding flows and steam consumptions. For the CBA scheme it is assumed that B massecuite of lower purity is boiled, allowing better exhaustion of the final molasses to be achieved. The two examples of the crystallisation area model determine the mass balance around the pan stage and calculate the steam flows.

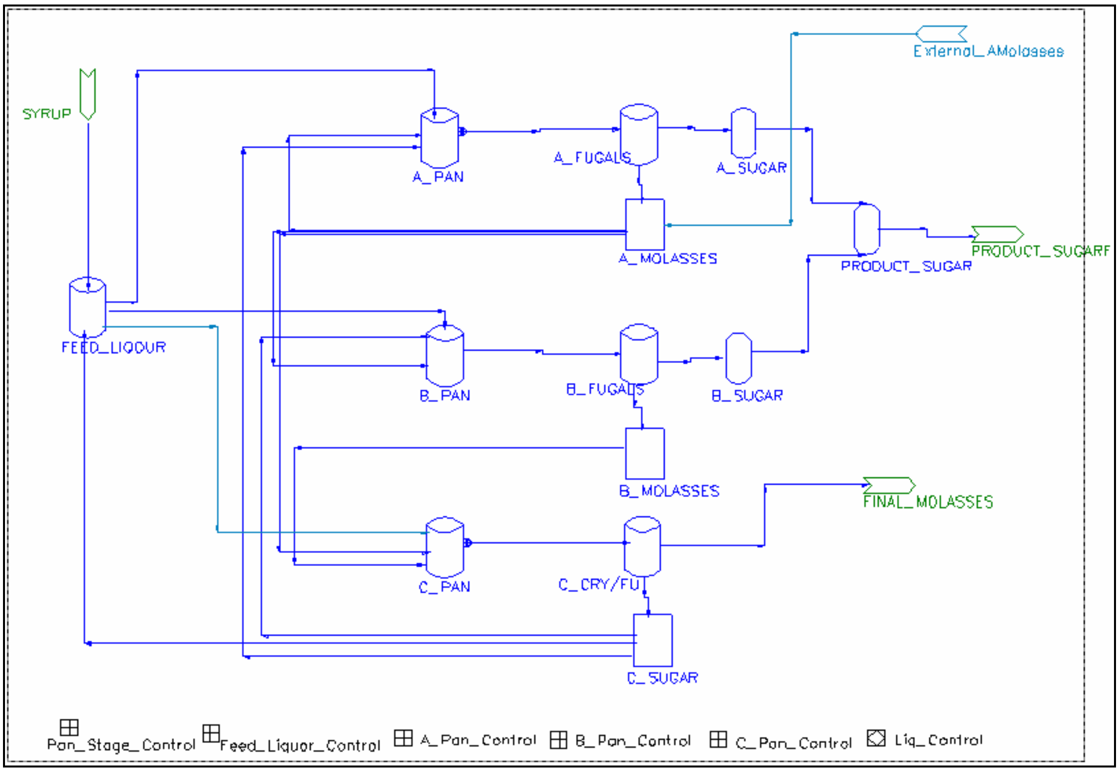

Fig. 4 – Graphics screen for the crystallisation area model (three massecuite boiling scheme)

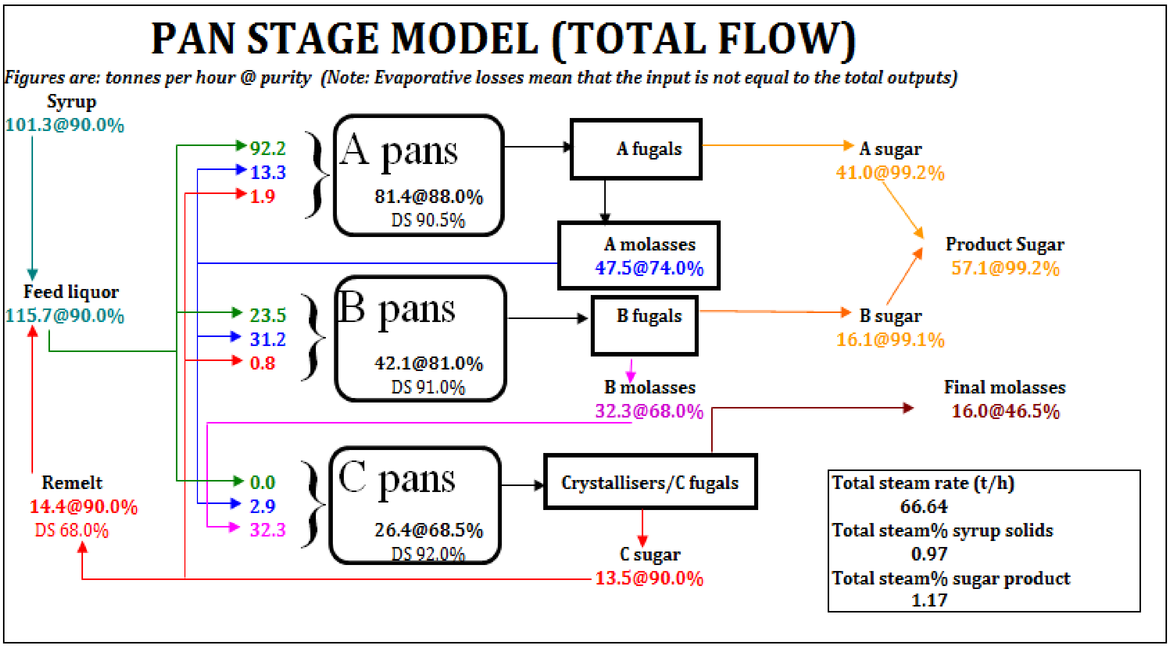

Fig. 5 – Pan stage model total flows and steam consumption (three massecuite boiling)

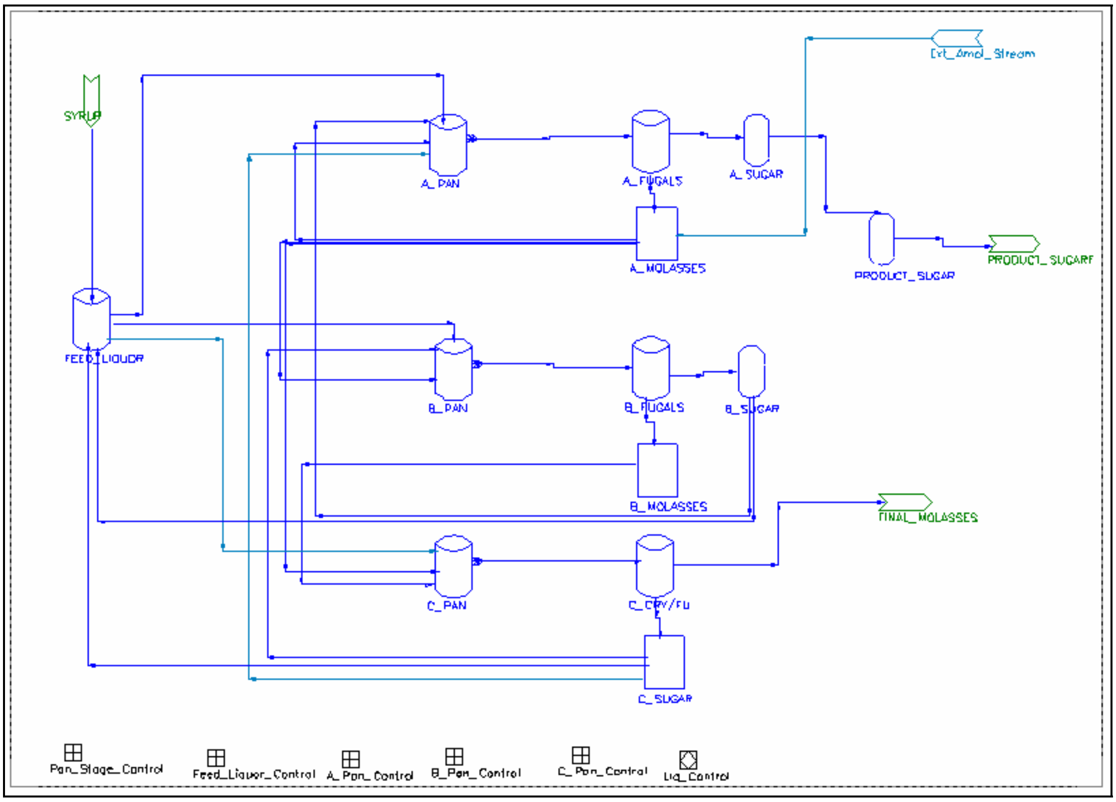

Fig. 6 – Graphics screen for crystallisation area model (CBA boiling scheme)

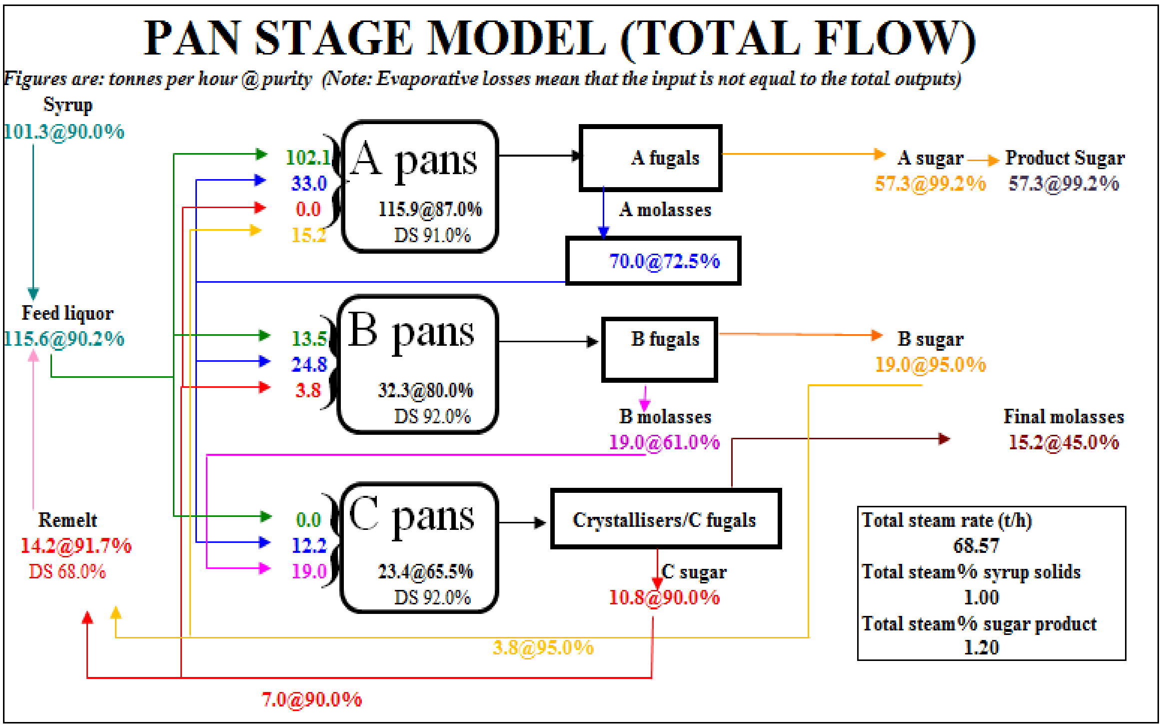

Fig. 7 – Pan stage model total flows and steam consumption (CBA)

When pan boiling operations are converted from the conventional three massecuite boiling scheme to the CBA scheme, the following points are noted:

- Increased A massecuite production rate as now all the shipment sugar is produced from A massecuite. For the case study the increase was about 70%. However the total A and B massecuite production

- Improved sugar recovery from final molasses with the CBA scheme as a result of boiling B and C massecuite at lower purities.

- Increased sugar production of about 0.5 t/h on average is predicted.

- Greater process steam consumption by 2 to 4% for the CBA scheme compared with the three massecuite boiling scheme.

Whole of factory model

The whole of factory model is a combination of the area models and unit operation models described previously. It can be used to simulate a complete sugar factory and assess the impact of changes in the one part of the factory on the operation of other section. The overall model has eight different sections, each with its own graphics page. The sections are:

- crushing and milling
- heating, clarification and filtration
- evaporation
- crystallisation
- drying
- condensate circuit
- injection water circuit
- steam cycle

Modelling factory scenarios

Typical sugar factory

The overall model was used to simulate a ‘typical’ sugar factory with 600 t/h crushing rate, 14% cane fibre level and imbibition rate of 220% fibre. This typical factory has pan stage and secondary juice heating on LP steam and primary juice heating on vapour 1. It has a quintuple evaporator set with syrup brix of 68. There is no ESJ heating or flashing of evaporator condensate. The shredder, milling units and boiler auxiliaries were all assumed to be steam turbine driven. The overall model was used to predict factory performance as the imbibition% fibre is increased. The sections of the overall model substantially affected by changes in imbibition flow are the milling train model, heating and clarification model, evaporation model and steam cycle model.

Figure 8 shows the predicted effect of increasing the imbibition rate to the milling train on pol extraction and steam consumption for this typical factory.

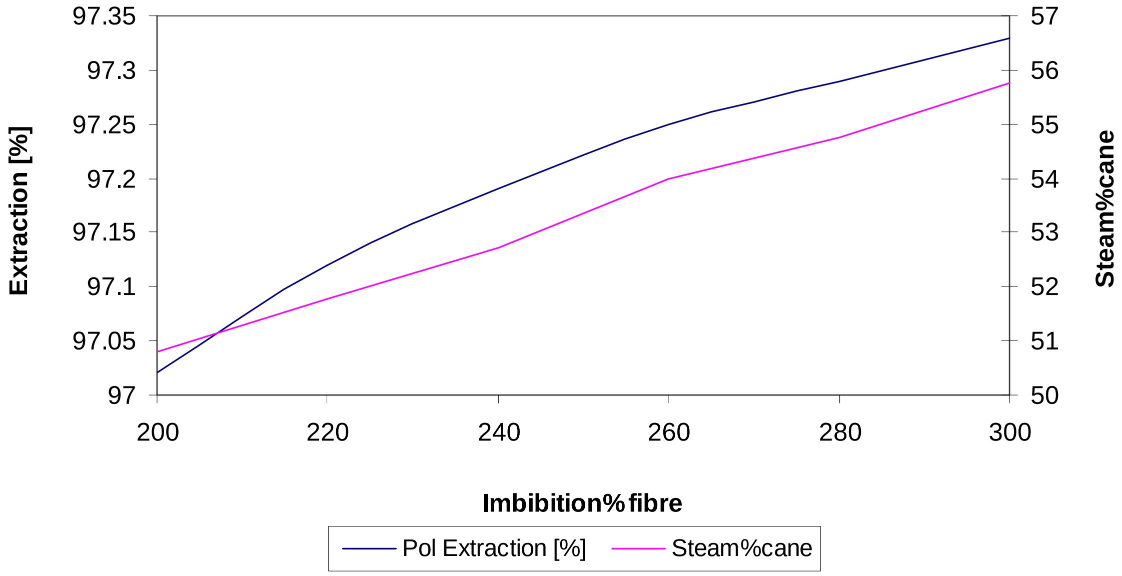

Fig. 8 – Predicted effect of imbibition water rate on pol extraction and factory steam consumption for a typical factory of 600 t/h crushing rate

The empirical model used for predicting the pol extraction was the MILEX-3 model as described by Thaval and Kent (2015). With an increase in imbibition rate from 200% to 300% fibre, the pol extraction was predicted to increase by 0.31 units and the steam consumption (% cane) was predicted to increase by 5 units. The steam consumption was predicted by the overall model.

Factory with changed boiler configuration and vapour bleeding

The overall model was used to model the effects of factory changes to increase electricity export and reduce LP steam demand.

A typical 600 t/h crushing rate sugar factory with 200 t/h and 160 t/h MCR boilers (1.8 MPa g final steam pressure, 270°C final steam temperature, 60% boiler efficiency) was simulated. This factory has a steam requirement of 50.2% on cane. The shredder, milling units and boiler auxiliaries are steam turbine driven. A 10 MW back pressure steam turbine generator (STG) supplies the factory's electricity requirements of 7.8 MW, leaving 2.2 MW for export to the grid.

To increase electricity export the smaller boiler was replaced with a high pressure boiler (7.2 MPa g pressure, 520°C steam temperature, 70% efficiency) of the same capacity, a 30 MW condensing STG was installed and steam economy measures were implemented. The shredder, milling train and auxiliaries for the high pressure boiler are electrically driven. This modified factory set up was simulated and the electricity export and bagasse consumption for the two cases are compared in Table 2.

Table 2 - Comparison between the electricity export and bagasse consumption for a typical 600 t/h factory prior to and after electricity export upgrades

	Typical factory	Typical factory with high pressure boiler and condensing STG, electrification of shredder and mill drives and LP steam economy measures
Electricity generation (MW)	10	40
Factory electricity use (MW)	7.8	14.1
Electricity export (MW)	2.2	25.9
Bagasse use by boilers (t/h)	135.4	148.2
Bagasse surplus (t/h)	39.2	26.4

Further simulations were carried out with the overall model for different vapour bleeding arrangements for a typical 600 t/h crushing rate sugar factory and these are summarised in Table 3.

Table 3 – Vapour bleeding arrangements and heating sources for primary, secondary and ESJ heaters and pans

Vapour bleeding arrangement	Heating source			
	Primary heaters	Secondary heaters	ESJ heaters	Pans
[1]VBA1	Vapour 1	LP steam	LP steam	LP steam
VBA2	Vapour 4	LP steam	LP steam	LP steam
VBA3	Vapour 4	Vapour 1	LP steam	LP steam
VBA4	Vapour 4	Vapour 1	LP steam	Vapour 1
VBA5	Vapour 4	Vapour 1	Vapour 1	Vapour 1

[1]VBA – Vapour bleeding arrangement

The vapour bleeding arrangement VBA1 is typical of many sugar factories while VBA2 uses vapour 4 for primary juice heating. The remaining three vapour bleeding arrangements (VBA3, VBA4 and VBA5) have low pressure steam being progressively replaced by vapour 1 for secondary juice heating, pan heating and clarified juice heating duties. The final arrangement VBA5 has no heating with LP steam. The steam on cane for the different vapour bleeding arrangements is shown in Figure 8. Steam on cane is 10% lower with vapour bleeding arrangement VBA5 than vapour bleeding arrangement VBA1. Changes to the area allocation for the different evaporator stages or total area of the set are required as increased vapour bleed is incorporated. These area changes are not discussed in the paper.

The changes in vapour bleeding arrangements have the largest effects on the heating and clarification, condensate circuit, evaporation station, injection water and steam cycle sections of the overall model.

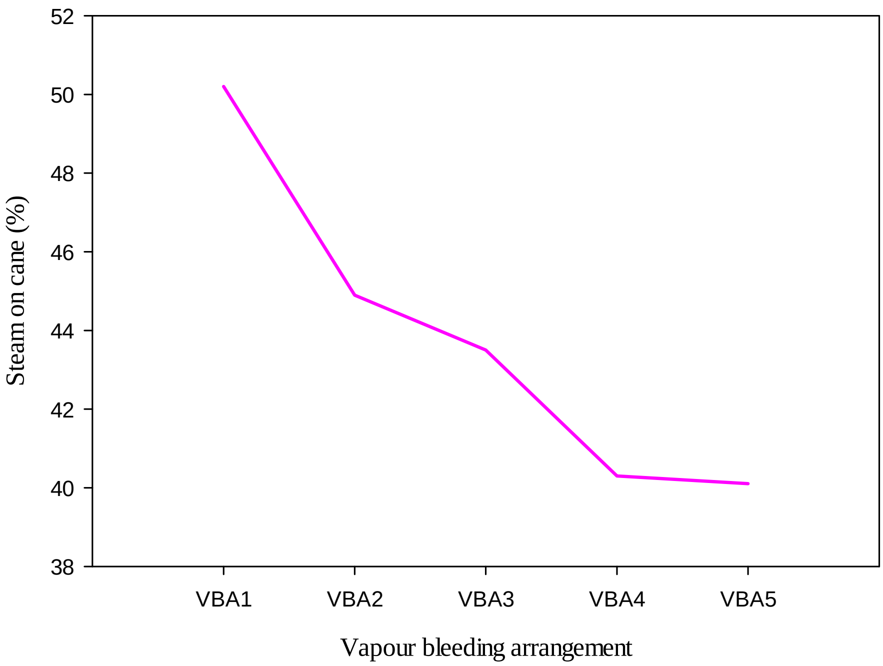

Fig. 8 – Process steam on cane for different vapour bleeding arrangements

Conclusion

A whole of factory model was developed for a raw sugar factory in SysCAD software. The whole of factory model incorporates individual unit operation models and area models and can be accessed through excel spreadsheets. These models can be used as standalone models to optimise the operation of a sugar factory station such as the milling train or in the integrated mode to assess the impact of changes in any part of the process on the operation of the whole factory. The integrated sugar factory model can be used to investigate and provide practical solutions to processing problems.

Two sugar factory scenarios have been modelled to demonstrate the features of the whole of factory model. The first example predicts that increasing the imbibition rate from 200% to 300% fibre increases extraction by 0.3 units and increases steam consumption by 5 units %cane. For a factory that does not generate significant income from electricity export, the increase in steam consumption may be acceptable if there is sufficient bagasse to generate the steam and sufficient evaporator capacity to evaporate the water. For a factory that generates significant income from electricity export, alternative methods for increasing extraction without substantially increasing the steam and therefore bagasse consumption may be more attractive. These options can be explored with the crushing and milling, steam cycle and evaporation area models.

The second example compares a typical sugar factory with a factory set up for cogeneration that incorporates a high pressure boiler, a large condensing STG, electrification of shredder and milling train drives and back end modifications to reduce LP steam usage. The overall model was used to predict the reductions in steam on cane with different vapour bleeding arrangements.

Future work

Further work is being undertaken to incorporate two or three area models to develop factory section models. Modelling of the factory sections will reduce the solution time of the simulation which will be particularly beneficial when multiple scenarios are being examined. An example of a commonly used section model is the evaporator station confined with the injection water circuit and condensate circuit. Any changes in the vapour bleeding arrangement of the evaporator station will mainly affect these other sections of the factory and have minimal impact on section such as milling and pan stage.

Acknowledgement

The authors would like to thank A/Prof Geoff Kent, Dr Floren Plaza, and Dr Thomas Rainey for their efforts in developing the area models. The authors would also like to thank the staff of KWA (Kenwalt Australia Pty Ltd) for providing the training and support for the SysCAD process modelling software. The authors would like to thank SRDC and SRA for the financial support of the project.

REFERENCES

Bubnik Z, Kadlec P, Urban D, Bruhns M (1995) 'Sugar Technologists manual – Chemical and physical data for sugar manufacturers and users'. Verlag Dr. Albert Bartens, Berlin.

Peacock SD (2002) The use of SIMULINK for process modelling in the sugar industry. *Proceedings of the South African Sugar Technologists' Association* **76**, 444-455.

Thaval OP, Kent GA (2012a) An enhanced mill extraction model. *Proceedings of the Australian Society of Sugar Cane Technologists* **34**, (electronic format) 11 pp.

Thaval OP, Kent GA (2012b) Modelling the flow of cane constituents in the milling process. *Proceedings of the South African Sugar Technologists' Association* **85**, 435-453.

Thaval OP, Kent GA (2013) Advanced computer simulation of the milling process. *Proceedings of the International Society of Sugar Cane Technologists* **28**, (1595-1608).

Thaval OP, Kent GA (2015) Modelling milling train performance. *Proceedings of the Australian Society of Sugar Cane Technologists* **37**, (these proceedings).