Options for retrofitting white sugar milling (WSM) technology into existing raw sugar factories†

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abstract

Sugar Mill (WSM) technology produces EEC2 quality white sugar directly from raw cane juice, thereby eliminating the refining process and its associated costs. In addition, the WSM process unlocks the value of the sugars currently found in molasses and produces a liquid fertiliser that is high in nitrogen and potassium. The technology has been piloted successfully in South Africa and Brazil and, in 2005, the first commercial scale WSM plant was built and commissioned at Felixton Mill in South Africa. The technology applies membrane filtration, refrigeration, ion-exchange demineralisation and decolourisation to produce a high quality white juice. The WSM technology can either be applied at a greenfield installation or, as is the case with Felixton, retrofitted to an existing factory. The WSM technology effectively bridges the gap between sugarcane milling and raw sugar refining. However, in doing so it has to make refined quality sugar from a raw material with significantly higher levels of impurities and of variable composition. Sugar factory designs vary from region to region depending on the technology employed, cane quality, season length and market requirements. Similarly, in designing the WSM process for a specific application, these and other factors need to be taken into account. Furthermore, in contrast to the seasonal operation of raw sugar mills, refineries generally operate all year round. This paper presents a generalised WSM flowsheet that allows the back-end of the WSM factory to be decoupled from the juice front-end, thereby facilitating year round operations. Thereafter, various options for incorporating the generalised WSM flowsheet into an existing sugar mill are discussed. The WSM Slipstream plant at Felixton is presented as a specific example.

Keywords: **ion-exchange, ultrafiltration, white sugar mill**

Opciones para introducir la tecnología de azúcar blanco (wsm) en fábricas existentes de azúcar crudo

La tecnología White Sugar Mill (WSM) produce azúcar blanco de calidad EEC2 directamente de jugo de caña crudo eliminando así el proceso de refinado y sus costos asociados. Además el proceso WSM libera el valor de los azúcares encontrados en mieles y produce un fertilizante líquido que es alto en nitrógeno y potasio. La tecnología ha sido evaluada en planta piloto en Suráfrica y Brasil y, en 2005, la primera planta WSM a escala comercial fue construida y puesta en marcha en el Ingenio Felixton en Suráfrica. La tecnología aplica filtración por membranas, refrigerac-ión,desmineralización y decoloración por intercambio iónico para producir un jugo de alta calidad. La tecnología WSM puede ser aplicada en una instalación nueva o adaptada a una fábrica existente como el caso de Felixton. La tecnología WSM cierra efectivamente la brecha entre molienda de caña y refinación de azúcar crudo. Sin embargo para lograr esto tiene que obtener azúcar de calidad refino a partir de materias primas con niveles significativamente altos de impurezas y de composición variable. Los diseños de los ingenios varían de región en región dependiendo de la tecnología empleada, calidad de caña, duración de la zafra, y requerimientos del mercado. Similarmente al diseñar el proceso WSM para una aplicación específica, estos y otros factores deben ser tenidos en cuenta. Además en contraste con la operación por zafra de las fábricas de azúcar crudo, las refinerías operan todo el año. Este artículo presenta un diagrama de flujo generalizado del proceso WSM que permite desacoplar el extremo WSM de la fábrica del lado jugo facilitando la operación todo el año. Se discuten varias opciones para incorporar el diagrama de flujo generalizado WSM en una fábrica existente. Se presenta como ejemplo específico la planta WSM Slipstream de Felixton.

Optionen für die Nachrüstung bestehender Rohzuckerfabriken mit WSM-Technologie

Mit der „White Sugar Mill"-Technologie (WSM) wird direkt aus rohem Rohrzucker Weißzucker von EEC2-Qualität produziert, wodurch das Raffinadeverfahren und die mit ihm einhergehenden Kosten entfallen. Darüber hinaus erschließt der WSM-Prozess die derzeit in der Melasse enthaltenen Zucker und produziert einen Flüssigdünger, der hoch an Stickstoff und Kalium ist. Die Technologie wurde in Südafrika und Brasilien erfolgreich erprobt, und 2005 wurde in der Felixton-Fabrik in Südafrika das erste gewerbsmäßige WSM-Werk gebaut und in Betrieb genommen. Die

Technologie setzt Membranfiltrierung, Kühlung, Ionenaustausch-Demineralisierung und Entfärbung dazu ein, einen hochwertigen weißen Saft herzustellen. Die WSM-Technologie kann entweder in einer Neuinstallation auf der grünen Wiese erfolgen oder, wie in Felixton, in eine bestehende Fabrik eingebaut werden. Die WSM-Technologie bildet einen effektiven Brückenschlag zwischen der Zuckerrohr-Mahlung und der Rohzuckerraffination. Hierbei muss jedoch hochwertiger Zucker aus einem Rohmaterial von signifikant höherem Unreinheitsgrad und von variabler Zusammensetzung produziert werden. Die Bauart von Zuckerfabriken unterscheidet sich von Region zu Region je nach der von ihr benutzten Technologie, der Qualität des Zuckerrohrs, der Länge der Saison und den Erfordernissen des Marktes. Beim Entwurf des WSM-Prozesses für eine bestimmte Anwendung müssen diese und andere Faktoren berücksichtigt werden. Außerdem sind Raffinerien – im Gegensatz zum saisonalen Betrieb der Rohzuckermühlen – normalerweise ganzjährig in Betrieb. Das vorliegende Paper präsentiert ein generalisiertes WSM-Fließschema, das eine Entkopplung des hinteren Teils der WSM-Anlage von Saft-Vorderende erlaubt und so einen ganzjährigen Betrieb ermöglicht. Anschließend werden verschiedene Optionen zur Inkorporierung des generalisierten WSM-Fließschemas in eine bestehende Zuckerfabrik diskutiert. Die WSM-Slipstream-Fabrik in Felixton wird als ein spezielles Beispiel präsentiert.

Introduction

A growing global market for white sugar, coupled with the dismantling of the European Union quota system for beet sugar, is increasing the importance of producing white sugar from sugarcane.

The standard refining process may either be carried out at the raw sugar mill site (back-end refining), or at an autonomous refinery that is closer to the market. The WSM technology (Fechter *et al.*, 2001) is a process that is capable of producing EEC2 grade white sugar directly from raw cane juice. It represents an alternative to installing a back-end refinery to produce white sugar at the sugar mill site.

Sugarcane factories typically operate on a seasonal basis, driven by the agronomic requirements associated with growing and harvesting cane. Furthermore, the composition of raw cane juice can be variable, depending on factors such as the variety of the cane, soil quality, time of the season, rainfall, and cut-to-crush delays. On the other hand, refineries typically operate throughout the year, driven by the market demand for white sugar and the need to maximise the utilisation of the capital equipment. In the case of back-end refineries, raw sugar is stored during the season and refined in the off-season. The variability in the composition of raw sugar supplied to a refinery is very small compared to the variability of raw cane juice.

In considering the WSM technology, it is necessary to marry the operational requirements of a raw sugar mill to the market requirements associated with white sugar production. The first important aspect is one of process robustness: the WSM process is required to produce white sugar that satisfies stringent quality specifications from a highly variable quality feedstock. The demonstration of process robustness has been one of the key deliverables of the WSM Slipstream plant at Felixton.

However, the primary purpose of this paper is to investigate how the standard WSM process can be modified to achieve the operational requirements associated with a typical white sugar production facility. The WSM Slipstream plant represents a specific example of retrofitting the WSM technology to an existing raw sugar mill.

WSM process robustness

By South African standards, the juice quality at Felixton Mill is notoriously poor. Therefore, selecting Felixton as the site to build the first commercial scale WSM plant represents something of a 'torture test' for the technology. The WSM Slipstream plant was commissioned late 2005, and 2006 represented the first full year of operations. Figure 1 shows the colour results from daily composite samples of Felixton clear juice, ion-exchange feed, white juice and white syrup. Clear juice and white syrup analyses were carried out throughout the year, while ion-exchange feed and white juice analyses were carried out towards the beginning and end of the season only.

As is evident in Figure 1, white syrup colours lower than 500 ICUMSA were consistently achieved from clear juices averaging approximately 20 000 ICUMSA. The increase in colour from white juice to white syrup is small, typically 50 to 100 ICUMSA units. It was found that 2 to 3 white sugar boilings were possible from the white syrup.

Demonstrating that the WSM technology is able to achieve the EEC2 white sugar quality specifications consistently at Felixton is an important milestone for the WSM technology. Nevertheless, it is important to note that in designing a WSM plant, consideration needs to be given to the quality and variability of the raw juice for the factory of interest.

Rossiter *et al.* (2002) discuss the issues associated with

Figure 1. Comparison of feed and product colours from the WSM slipstream plant

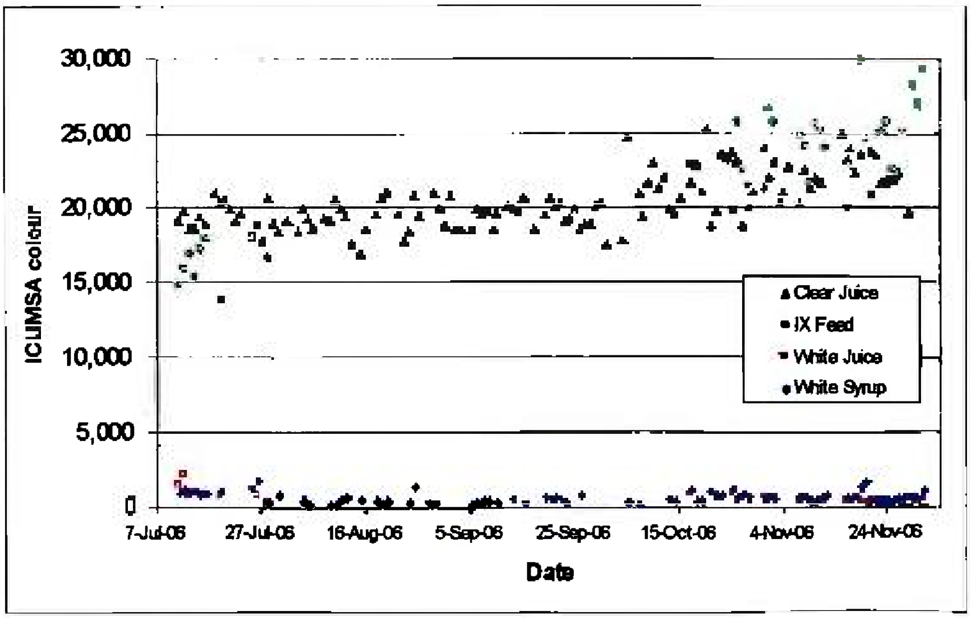
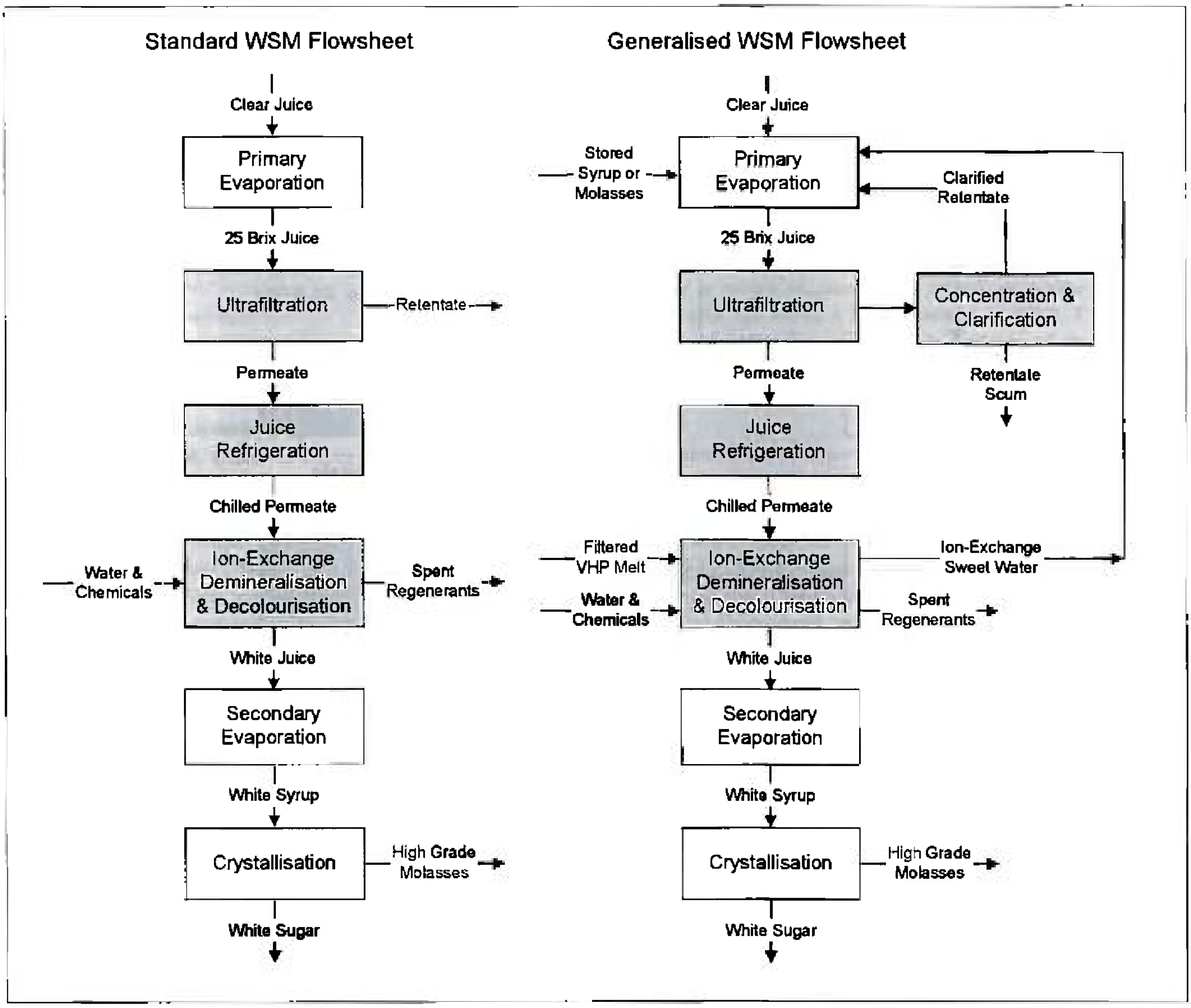


Figure. 2. Comparison of the standard and generalised WSM flowsheets



configuring the WSM unit operations for a specific factory, and present different operating scenarios to show the versatility of the WSM process configuration.

Generalised WSM process flowsheet

The WSM process is easily retrofitted into a standard raw sugar mill (Fechter *et al.*, 2001). Two options for the integration of WSM into the raw sugar mill process are shown in Figure 2 where the shaded blocks represent the core WSM unit operations. By default the standard WSM process produces white sugar during the crushing season only.

Back-end refinery operations are decoupled from the raw sugar mill operations via the production of an intermediate product (raw sugar) that is easily stored. Not only does this permit off-crop refining, but it also allows refinery operations to continue during mill maintenance stops and interruptions in cane supply.

In contrast, the highly integrated nature of the WSM process makes it susceptible to mill stoppages. Furthermore, the fact that sugar juices are not easily stored at low brix rules out the option of creating buffer capacity by installing large tanks. In order to address these issues, a generalised WSM flowsheet is proposed in Figure 2.

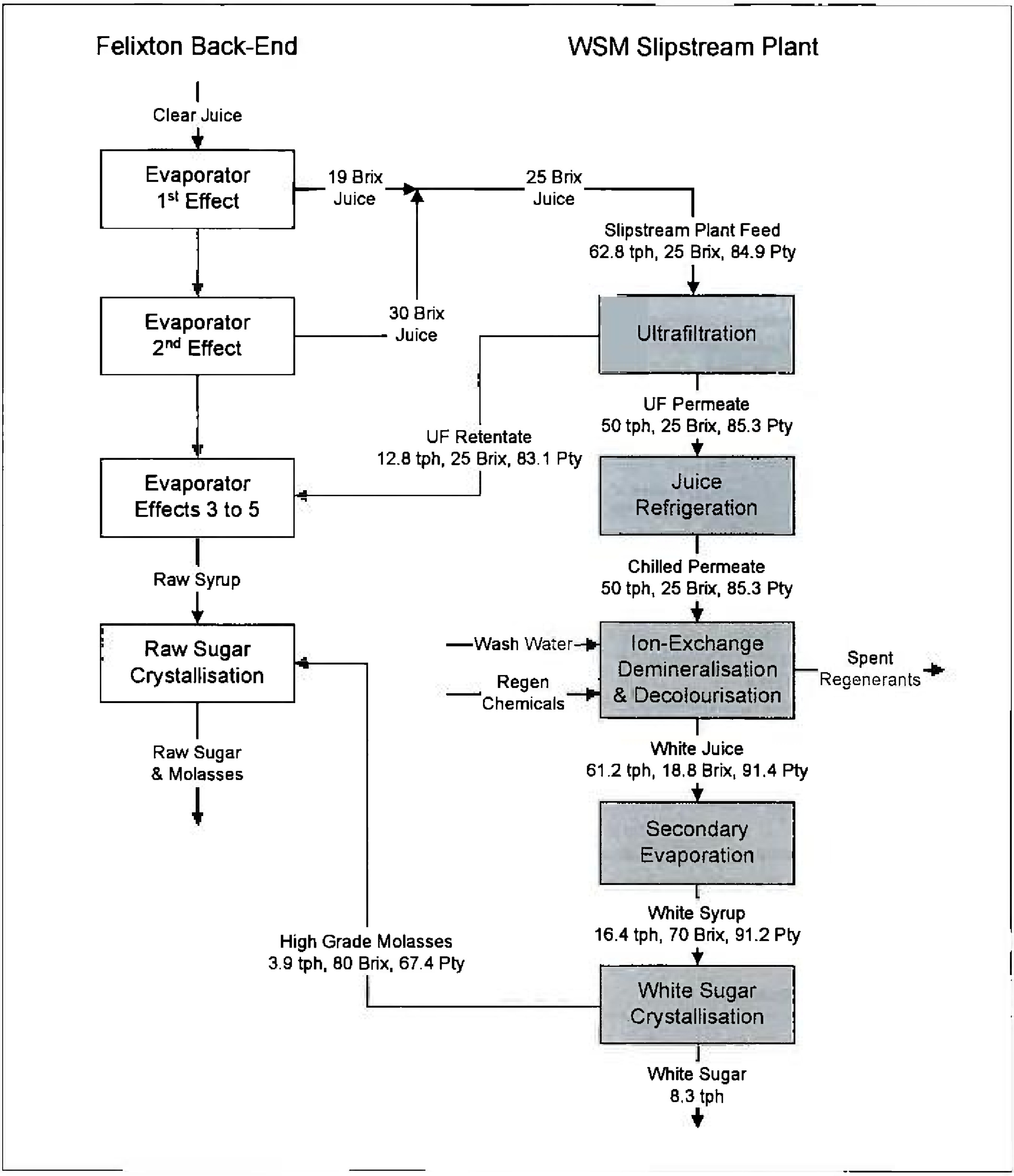
The first aspect of the generalised flowsheet is the feature whereby stored syrup or molasses may be blended with clear juice prior to evaporation to 25 brix. The storage of syrup or molasses provides a means of continuing the WSM process operations during periods of reduced, or no clear juice flow.

As sugar solutions are stable at high brix, large storage tanks may be installed. In this way, it is possible to decouple the back-end WSM operations to some extent from the supply of clear juice. In instances when there is insufficient clear juice to dilute the concentrated products to 25 brix, sweet-water from the ion-exchange section can be used to minimise the use of dilution water.

The second aspect of the generalised WSM flowsheet is the introduction of a VHP melt stream between the ion-exchange demineralisation and decolourisation steps. The brix of the deashed juice is low (~25 brix) and can be used to dissolve the VHP sugar. (Deashed juice is preferable to water as the total evaporation load remains unchanged).

The VHP melt is passed through appropriate processes to

Figure 3. WSM slipstream flowsheet integration with Felixton Mill



remove turbidity (e.g. carbonatation and filtration) before entering the WSM flowsheet upstream of the decolouriser. The VHP melt is then either decolourised and crystallised separately, or blended with the remaining deashed juice prior to decolourisation. VHP sugar may be processed using this flowsheet during both season and off-season operations.

The third aspect of the generalised flowsheet refers to the concentration, clarification and recycling of the ultrafiltration retentate. Concentration by evaporation is important to improve the efficiency by which flotation clarification is able to remove impurities from the juice. The clarified retentate is then recycled to the pre-evaporation stage.

The purpose of the flotation clarification is to remove those impurities from the juice that will not pass through the ultrafiltration membranes. Similarly, the stored syrup and molasses may be subjected to a similar flotation clarification before being introduced into the process (not shown in Figure 2). In this instance, the utilisation of flotation clarification to remove impurities prior to ultrafiltration will improve the ultrafiltration flux rates, thereby reducing membrane area requirements.

The generalised WSM flowsheet as presented in Figure 2 is more comparable with a back-end refinery as it decouples the white end from the raw juice supply and permits factory operations to continue into the off-season. The use of stored syrup/molasses in the off-season is analogous to the 'thick juice campaign' in the beet sugar industry.

WSM plant configuration options

Although the generalised WSM flowsheet is more complex than the standard flowsheet, it introduces greater operational flexibility. For a greenfield WSM plant, additional equipment would be required to achieve this flexibility.

However, when retrofitting the WSM technology to an existing sugar mill, existing sugar mill equipment that may otherwise be made redundant may be re-used to improve the flexibility as described above. This section presents some examples of retrofitting WSM to existing operations.

Partial conversion of an existing factory to WSM

As its name suggests, the WSM Slipstream plant at Felixton falls into this category. Figure 3 shows the process flowsheet for the WSM Slipstream plant.

The plant design is based on 50 tonnes per hour of 25 brix permeate (which represents approximately 15% of the capacity of Felixton mill), producing approximately 8 tonnes of sugar and 4 tonnes of high grade molasses per hour. Figure 3 includes some basic mass balance data: flow (tonnes per hour), brix and sucrose purity, for the WSM Slipstream plant.

Being the first commercial installation of the WSM technology, the rationale for designing the WSM Slipstream plant had much to do with risk mitigation and technology optimisation. It is effectively a plant that can be turned on-and-off at will without affecting Felixton production. The WSM Slipstream plant is designed to use 25 brix juice that is produced by blending first evaporator (19 brix) and second evaporator (30 brix) juices. There is also the facility to run the WSM Slipstream plant using stored syrup that is diluted either with water or first effect juice. The UF retentate is returned to the main process, while the UF permeate continues through the WSM unit operations.

The WSM Slipstream plant includes two strikes of white sugar, thereafter the high-grade molasses, which still contains recoverable sugar, is combined with Felixton A molasses. (Alternatively the high-grade molasses could be exhausted independently of the main factory, but this would require additional equipment.)

While economies of scale point towards the full conversion of a raw sugar factory to WSM, there are a number of benefits associated with a partial conversion to WSM that may make it the option of choice in specific instances. Some of the benefits are as follows:

- Ease of handling of retentate by returning it to the raw sugar process, coupled with enhanced membrane performance.
- Raw sugar and molasses are available for re-processing during offcrop.
- Stored syrup is readily available for maintaining WSM operations during mill front-end stoppages.
- Permits continued use of those raw sugar mill pans and evaporators that do not satisfy food grade specifications.
- Simplifies the start-up and shut-down procedures when compared to a full WSM conversion.

A partial conversion of a factory to WSM may also simply represent a means of phasing the capital expenditure, with the ultimate goal still being a full conversion to WSM. The modular design of the WSM unit operations, in particular UF, facilitates this approach as capital pre-investment for future expansions can be minimised.

Simultaneous factory expansion and partial conversion to WSM

The higher purity, reduced viscosity and low ash content of white juice increases the capacity of the downstream processing equipment (evaporators and pans). On the other hand, a conversion to WSM will make certain equipment redundant, particularly in the panhouse where food grade requirements are an important consideration.

Therefore, a partial conversion to WSM coupled with a factory expansion is perhaps an ideal scenario for adopting the WSM technology: it maintains the flexibility associated with a partial conversion and minimises the redundancy of equipment.

Pairing of a WSM factory and a standard raw sugar mill

In the instance where a complete conversion of a raw sugar mill to WSM is desirable, it makes sense to pair the WSM factory with one or more standard raw sugar mills.

In this instance the WSM plant will produce white sugar from raw cane juice during the season and from a combination of VHP sugar and molasses during the offcrop.

Not only does this provide the flexibility associated with the generalised WSM flowsheet, but it also introduces some benefits at the associated factories. The objective of the sugar campaign at the raw sugar mill that is paired with the WSM factory is to stockpile sugar for the WSM process; either in the form of VHP sugar and molasses, or as a raw syrup.

Table 1 compares three options for storing 100 tonnes of brix at a paired factory. From a WSM perspective, the products will ultimately be blended and therefore it makes little difference whether it is presented with brix in the form of VHP and molasses or as raw syrup.

The primary issue at hand is a trade off between processing costs at the raw sugar mill and transport costs to transfer the products to the WSM factory.

If the paired factory were a new installation that was relatively close to the WSM plant, it would make sense to store the product as raw syrup. Savings in capital and operating expenses would offset the additional storage and transport costs. However, for an existing factory the raw material is best stored as VHP sugar and A-molasses.

Figure 4. Ultrafiltration capital cost and power consumption

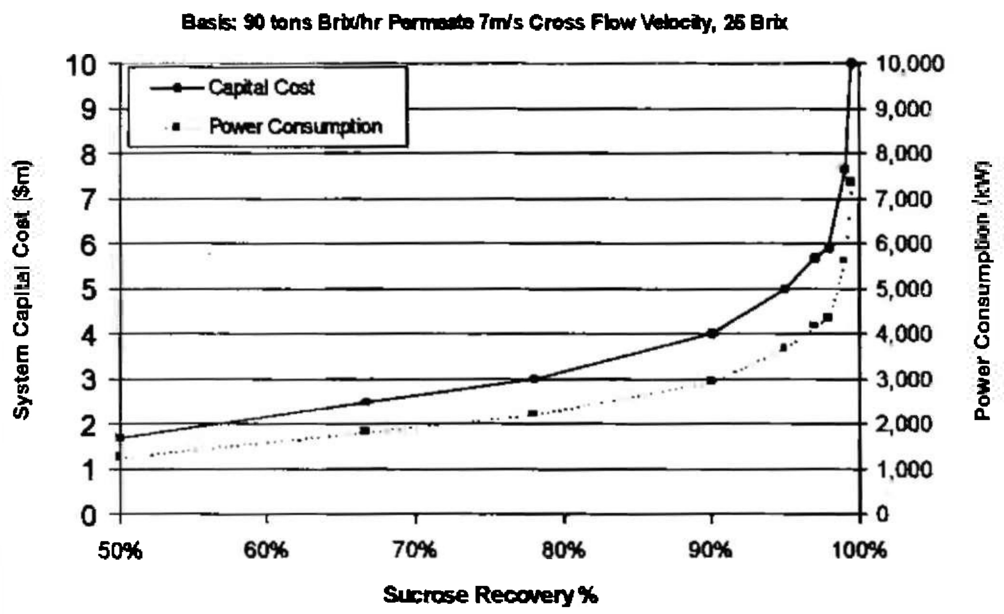


Table 1. Comparison of storage requirements

	VHP & BSM	VHP & A mol	Raw syrup
Tonnes brix	100.0	100.0	100.0
Brix %	80%	80%	70%
Tonnes crystal	79.19	57.23	0
Tonnes syrup/mol	26.16	53.57	142.9
Total tonnes	105.35	110.80	142.86
Increase	0%	5.2%	35.6%

As shown in Table 1, the additional water associated with the molasses only represents 5% increase over the base case of producing VHP sugar and Black Strap Molasses. On the other hand, by only making one strike of sugar, the paired raw factory will enjoy a higher quality raw sugar and reduced steam consumption and operating costs.

Impact of overall plant configuration on the WSM technology

This paper has considered various options for integrating the WSM process streams into the raw sugar process. In practice, it is also important to consider the impact of WSM on factory steam and condensate balances, electrical power load, condenser cooling demand and other utility requirements.

For example, steam generation capacity at a particular factory may influence the WSM plant configuration. Rossiter *et al.* (2002) discuss the requirements for integrating the WSM unit operations into an existing raw sugar mill.

This section focuses on the options associated with the ultrafiltration and ion-exchange unit operations. The impact of the overall plant configuration on these unit operations is discussed.

Membrane filtration system

The WSM membrane plant is inherently a modular design and typically comprises between five and eight membrane stages in series. The number of stages depends on the sizes of the individual modules and the level of product recovery that is targeted. In order to achieve very high product recovery, more stages are needed, with water being added to the latter stages to reduce the product viscosity.

Figure 4 illustrates the impact of product recovery on the ultrafiltration plant capital cost and power consumption (Rossiter *et al.* 2002) for a constant permeate flow rate. A partial conversion of a factory to WSM permits relatively low ultrafiltation recoveries to be targeted, as the raw process is still available to process the retentate.

Once recoveries greater than 90% are required, the ultrafiltration system cost can be expected to increase dramatically.

Cross-flow velocities in the range of 5–7 m/s are recommended. The optimum cross-flow velocity is a trade-off between capital and operating costs. Dropping from 7 to 5 m/s will halve the power consumption of the plant per unit area of membrane, and increase the life of the membranes. However, the total membrane area required at the reduced cross-flow velocity has been found to increase by approximately 20%.

Ion-exchange system

The size of the ion-exchange plant is determined by the ash content and colour of the feed juice. Ion-exchange chemical costs are primarily a function of the ash content of the juice. The stoichiometry of deashing effectively sets the minimum chemical requirements for deashing. By employing continuous ion-exchange technology it is possible to approach the theoretical minimum chemical requirements for deashing while still achieving high deashing efficiency.

Feeding the ion-exchange plant with A-molasses instead of raw juice increases the deashing cost per tonne of sugar produced. However, the higher operational costs are offset by the improved overall recovery benefits compared to raw juice.

The resin and resin vessel costs represent a significant portion of the overall ion-exchange system cost. If a phased implementation of WSMs chosen, it would make sense to pre-invest in the continuous ion-exchange valve and piping, but to install only the volume of resin needed for the current plant capacity. The capacity of the ion-exchange plant may then be doubled or even tripled by connecting the existing ion-exchange vessels in parallel and installing additional vessels as required.

Regenerant selection is an important consideration for the ion-exchange plant design. Recommended regenerants are HNO3, NH3, KOH and KCl as they all have value as a fertiliser. However HCl, NaOH and NaCl may also be used.

In practice, the choice of regenerants represents a trade off between chemical costs, effluent disposal costs, and the value that can be realised from a liquid fertiliser. The best combination of chemicals for the Felixton Slipstream plant was found to be HCl, NH3 and NaOH, based on the above considerations.

Mention has been made of the need for year-round operations in terms of producing white sugar. A similar situation exists when sourcing the regenerant chemicals for ion-exchange. The quantities of chemicals required are significant, and it is likely that the chemical manufacturer would need to dedicate a sizeable production fraction to supplying the WSM plant. A seasonal WSM operation is likely to result in excess capacity for the chemical manufacturer in the off-season, and therefore a higher cost for the regeneration chemicals.

Conclusions

The WSM technology represents a fundamental step-change in sugar milling, allowing EEC2 grade white sugar to be produced directly from raw cane juice without an intermediate raw sugar. In generalising the WSM process to facilitate year-round operations, a different approach to offcrop refining has been presented. Where currently VHP sugar is stockpiled for offcrop refining, a combination of A molasses and VHP sugar are the best products to store for running a WSM plant during the offcrop.

While a greenfield WSM installation remains an option, three categories of options for retrofitting the WSM process to an existing sugar mill were presented; namely a partial conversion to WSM; a partial conversion coupled with a factory expansion; and pairing of a WSM factory with one or more raw sugar mills.

Within each of these categories, a number of options will remain for integrating the WSM process into the specific factory and customising the design of the process according to the composition of the raw cane juice typically processed by the factory. The WSM Slipstream plant at Felixton represents a specific configuration of the WSM technology, which to date has been capable to producing EEC2 grade white sugar from a wide range of juice qualities.

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