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Engineering concept for combined refinery operations with cane sugar milling

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Abstract Most cane sugar factories are in operation for 120 to 160 days, during which time they produce raw sugar or plantation white sugar and, in some cases, refined sugar. Out of season, maintenance and capital project work is typically carried out. The under-utilisation of the plant equipment is generally accepted, but this intermittent use of equipment nevertheless affects the profitability of the factories. This paper looks at process engineering concept for year-round sugar production and their effect on investment and energy consumption. Besides the increased utilisation of equipment, only renewable energy is used during the milling and refinery seasons, which is in line with the goal of sustainable sugar production. A recently completed engineering of a greenfield sugar complex in southeast Asia helped to further develop the concept. The aim is to supply the local market with sulphur-free sugar of consistent quality throughout the year. The entire process is designed to process cane and raw sugar of inferior quality (low polarisation and high colour) and operate with low exhaust steam consumption, with maximum utilisation of the installed equipment in both the milling and refinery seasons.

Key words Sustainable sugar production, equipment downtime, energy consumption, cane sugar, refined sugar

INTRODUCTION

Traditionally, cane sugar factories operate for 120 to 160 days, producing raw sugar or plantation white sugar. Some factories producing raw sugar also operate back-end refineries producing refined sugar. Out of season, cane factories undertake maintenance on existing equipment and capital project work is typically carried out. The under-utilisation of the plant equipment is generally accepted, but this intermittent use of equipment nevertheless affects the profitability of factories.

Few beet sugar factories in Europe and North Africa operate as refineries outside the usual beet processing period. They have an additional melting station (for melting raw sugar) and clarification station (handling raw melt), but the process steps that follow are largely the same. Year-round sugar production and maximum utilisation of the installed equipment would make the business of such factories more sustainable. Braunschweigische Maschinenbauanstalt AG (BMA) has been involved in projects with beet sugar factories in Europe and North Africa which operate as refineries for part of the year and has undertaken engineering projects to retrofit existing beet sugar factories to operate as refineries.

Sustainability for a cane sugar factory implies maximising overall efficiency and optimising the production of a range of products and by-products from the cane feedstock (Avram *et al.* 2004). There is a growing corporate move to address sustainable development. Companies appreciate that there are sound business reasons to adopt more sustainable production and processing practices (Rein 2010).

In 2021, BMA commenced an engineering project for a greenfield sugar factory in southeast Asia. The project specifications demanded year-round production of sugar of a consistent quality. Additionally, the plant would have to process low-quality raw material (cane as well as raw sugar), be energy efficient and have minimal downtimes of the installed equipment. This paper outlines the engineering concepts developed to design a plant operating as a cane sugar factory and sugar refinery at different times of the year. It also discusses the plant engineering in

designing the main process building capable of handling the flow rates for both seasons. The impact of the concept on the capital investment and project feasibility is also discussed.

DESIGN BASIS FOR A CANE SUGAR FACTORY AND REFINERY

The cane sugar factory and the refinery had to be designed for a processing capacity of 6,000 t cane/day (TCD) (250 t/h) and 1,000 t product/day (TPD) RSO (refined sugar output), respectively. A worst-case scenario had to be assumed for the cane and raw juice quality to ensure the final sugar quality would always be achieved. Similarly, the lowest quality of raw sugar was assumed, so the refinery process would be designed to handle poor quality sugar. Table 1 shows the basis for engineering and design calculations.

Table 1. The basis for process engineering and equipment design.

Parameter	Unit	Cane sugar factory	Refinery
Factory capacity	TCD / TPD	6,000	1,000
Cane pol content	%	11	–
Cane fibre content	%	14.5	–
Raw juice purity	%	82	–
Raw juice colour	IU	30,000	–
Operating days	Days	180	160
Exhaust steam consumption	% on cane / t per t RSO	35	0.78
Raw sugar input	t/d	–	1,070
Raw sugar polarisation	%	–	99.06
Raw sugar moisture	%	–	0.22
Raw sugar colour	IU	–	3,500
Plantation white / refined sugar colour	IU	<200	<200
Plantation white / refined sugar output	t/d	535	1,000

The engineering concept had to be designed such that the cane sugar factory would produce plantation white (sulphur-less) sugar from low-quality cane (high colour and low pol content) for 180 days in a year. For the remainder of the year, the factory should be able to produce refined plantation white quality sugar using poor-quality raw sugar (colour up to 3,500 IU). Additional project challenges were reduced steam usage in order to avoid/minimise fossil fuel consumption, and maximisation of equipment utilisation to reduce capital costs.

The engineering was undertaken for the 17 process stations in the cane sugar factory and refinery (Figure 1). Ten of the 17 stations are shared by the milling and refinery seasons and this equipment would be used throughout the year. However, the large difference in the final quantities of sugar obtained in the two seasons made the engineering task more complicated. For example, the sugar drying and cooling station would have to be designed to process refined sugar at 42 t/h and plantation white sugar at 22 t/h, achieving the same final sugar quality parameters (moisture and temperature). The stations highlighted in blue represent the main equipment designed, manufactured and supplied.

PROCESS ENGINEERING

The process engineering involved elaborating mass and energy balances and generating process flow diagrams (PFDs) for the process stations shown in Figure 1. This section describes the process engineering of the project for the milling and refinery seasons.

Cane sugar factory and refinery process concepts

The cane receiving and handling station has a design capacity of 300 t/h for supply of whole-stalk cane. It is planned that the cane will be delivered by trucks or trailers that are suitable for unloading. The cane harvesting and transport management shall supply cane 24 hours a day directly from the fields, eliminating the need for cane storage at the factory and additional equipment for handling of stored cane. Four tipping station with hydraulic rams are planned. These tipping stations weigh the trucks before and after tipping, to calculate the cane weight by difference.

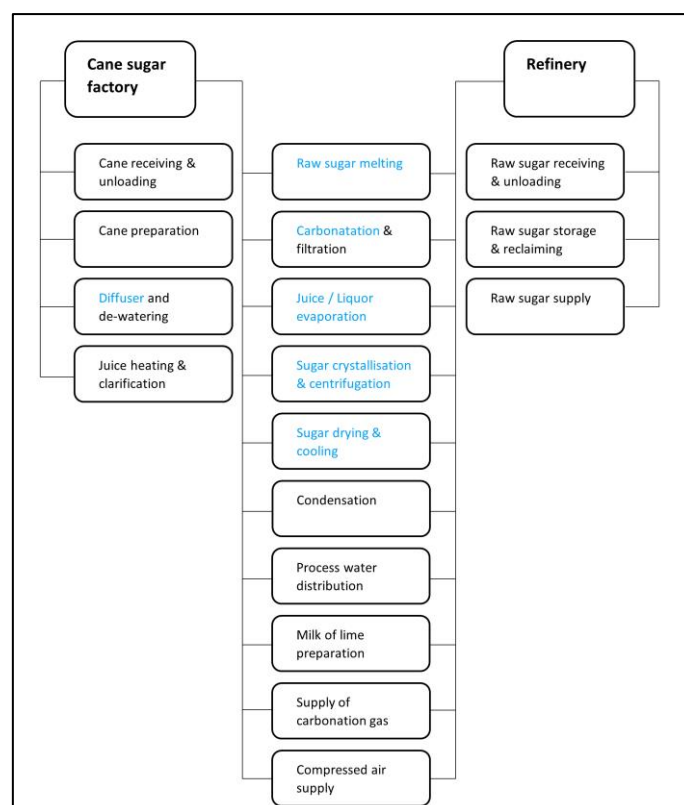


Figure 1. Stations included in the engineering for both the seasons.

The cane preparation equipment includes two set of cane knives and a heavy-duty gravity-fall shredder to achieve a POC (Pol in Open Cells) of 90% (BSES 2001). The shredded cane is transported by belt conveyor to a feeder table, which distributes it along the width of the diffuser. Hot water is added before the last stage and the percolated juice from the last juice trough is pumped to the penultimate stage. This compound imbibition process continues until the first stage. Juice from stages 4 and 5 is heated with vapour (referred to as scalding juice heating) to 82°C to maintain the temperature of the draft juice exiting the diffuser in the range of 40-45°C. The wet bagasse exiting the diffuser has a high moisture content (80 %) and passes through one de-watering mill to reduce the moisture to ~50 %. The press water from the mill is added back to the diffuser just before the second set of lifting screws.

In the clarification station, simple defecation is undertaken. The draft juice from the diffuser is heated to 75°C and milk of lime is added. The limed juice is heated to 103°C and flashed in a tank before it is fed into a SRI-type clarifier. Adding the clarifier underflow to the diffuser eliminates the need of a mud filtration system, and the clear juice is sent to the evaporation station.

While the cane receiving and handling, cane preparation, juice extraction, heating and clarification stations are designed only for the cane season, for obvious reasons, the other stations (melting, carbonation and filtration, evaporation, crystallisation, sugar drying and utilities) are designed for both the milling and refinery seasons.

During the cane season, the crystallisation station is designed to produce sulphur-free sugar with a maximum colour of 200 IU from a high colour syrup (31,500 IU). To achieve this, a modified three-boiling scheme was elaborated, with separate A1 boiling producing the final sugar (Figure 2). The feed solution for A massecuite is syrup and A1-heavy molasses. A-heavy molasses is used as feed solution for B massecuite. The feed solution for C massecuite consists of A-heavy molasses, B-heavy molasses and C-light molasses. The C sugar is double purged (referred to as C after works) to reduce its colour. The A, B and doubled purged C sugar is sent to the melter. The melt passes through carbonation and filtration processes to reduce the colour (by up to 50%) and is evaporated to the desired concentration before being sent to the feed solution tank for A1 massecuite. In all four boiling steps, light molasses (after addition of wash water in the centrifugal machines) is sent back to the feed solution tank of the respective massecuite since its colour is low. This reduces the recycling of liquor going through the carbonation and filtration stations and the energy consumption of the process. All four massecuites are boiled in batch pans.

where the run-off is boiled in three additional steps before the recovered sugar is melted and added back to the melt clarification (carbonatation and filtration).

Figure 4 shows the sugar drying and cooling system designed for both cane and refined sugar. During the refinery season, the wet sugar from the centrifugal machines is sent to the drum dryer via a series of screw conveyors. The dried sugar is then transferred to an elevator which feeds it into a lump sifter (to separate conglomerates) before it passes through the vertical fluidised bed cooler (VFC). This cools the sugar to the final desired temperature and it is then sent forward to the conditioning or packaging station. The air for the VFC is cooled with cold water from the chiller, and the hot air exiting the VFC is used to dry the sugar in the drum dryer. A dust collection system is integrated into the station and the melted dust along with the sugar lumps are sent to a small melter. The sweet water is recycled to the main melter.

During the milling season, the flow rate of the wet sugar is reduced, and the process has to be varied to handle the throughput. The wet sugar from the centrifugal machines is sent to the drum dryer, which, in this case, also acts as a cooler. The sugar exiting the drum dryer and cooler is transferred further through a lump shifter, bypasses the VFC and is sent directly to conditioning and packaging. The air required for drying in the drum dryer can no longer be sourced from the VFC and hence ambient air is used. This, however, needs to be conditioned and is passed through filters and heater before entering the rotary drum.

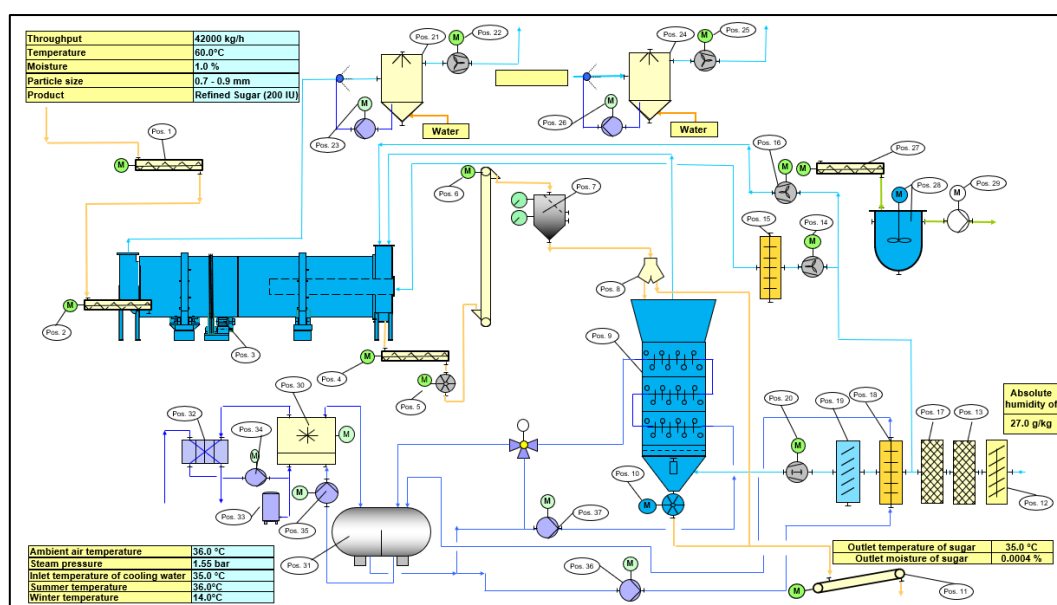


Figure 4. Sugar drying and cooling station for the cane sugar factory and refinery.

Figure 5 shows the heat balance of the cane sugar factory. The evaporator station comprises entirely of falling-film evaporators (FFE) with a final-effect boiling temperature of 82°C. Although not shown in the schematic diagram, a total of 2.11 % on cane (o.c.) (5.27 t/h) flash vapour is generated through the condensate flash system. Exhaust vapour is used for heating 3rd stage clear juice and 4th stage secondary juice (if required). The major consumer of the exhaust vapour is the 1st FFE. Vapour 1 is used for heating 2nd stage clear juice, 3rd stage secondary juice and the seed crystalliser. Vapour 2 is used for heating 1st stage clear juice, 2nd stage secondary juice, molasses, the diffuser bed, and B/C batch pans. Vapour 3 is used for heating 3rd stage primary juice, 1st stage secondary juice, scalding juice for the diffusers, liquor for melt clarification and the A1/A batch pans. Vapour 4 is used entirely for evaporating the filtered melt to a higher concentration prior to sending it to pan boiling. The vapour from the melt concentrator is used for 2nd stage primary juice heating, while Vapour 5 is used for 1st stage primary juice heating. With a condenser vapour loss of 0.3% o.c., the factory heat balance is designed for an exhaust steam consumption of ~35% o.c.

During the refinery season, the filtered liquor is concentrated from 63 Bx to 72 Bx. The vapour generation from evaporation is merely sufficient to undertake some melt and process water heating. An additional FFE is required, which operates on exhaust steam and generates high temperature vapour (usually referred to as transformed

steam) to heat all the batch pans and the remaining heaters. The melt concentrator from the milling season is used as a steam transformer during the refinery season. The last two effects (FFE-4 and FFE-5) from the quintuple set of the milling season are used as a double effect for liquor concentration during the refinery season. The refinery is designed to operate with an exhaust steam consumption of 0.78 t / 1 t RSO.

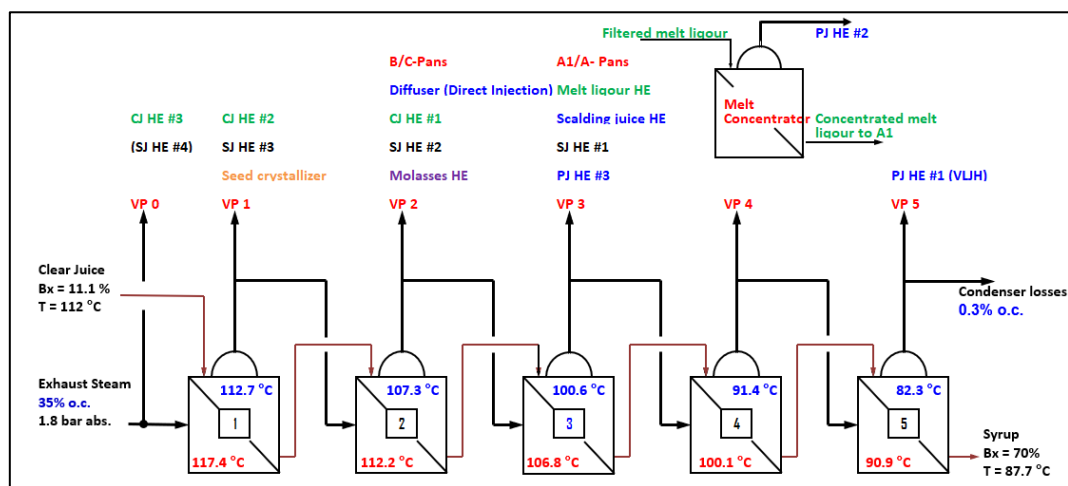


Figure 5. Heat balance for the cane sugar factory.

MAXIMUM UTILISATION OF INSTALLED EQUIPMENT

For this project, the design calculations to be undertaken had to consider the mass flows for both seasons, ensuring that the installed equipment would be capable of handling the throughput and that the target final sugar quality and steam consumption would always be achieved. Included was all main and secondary equipment along with pumps, heaters, tanks and vessels. Table 2 shows the list of main equipment for both the milling and the refinery seasons. In addition to using the main equipment for both seasons, the engineering also ensured that the pumps and heat exchangers were designed to handle both capacities without equipment having to be taken offline or put online.

Table 2. Main equipment for both seasons.

Cane sugar factory stations	Refinery stations	Shared main equipment
Melt clarification	Liquor clarification	Carbonatation towers, membrane press filters
Juice evaporation / melt concentration	Liquor concentration	Falling film evaporators
High-grade crystallisation	Refined sugar crystallisation, raw sugar melting	Vacuum pans, strike receivers, massecuite distribution mixers (pug mills), centrifugal machines, melter
Low-grade crystallisation	Recovery sugar crystallisation	Vacuum pans, strike receivers, massecuite distribution mixers, centrifugal machines, melter
White sugar drying and cooling	Refined sugar drying and cooling	Drum dryer, vertical fluidised cooler, melter

BAGASSE UTILISATION FOR MILLING AND REFINERY PROCESSES

The cane sugar factory burns the final bagasse as fuel for the boiler in order to generate steam and power for the milling process. However, for refineries, bagasse fuel is usually unavailable unless it is a back-end refinery. The project demanded minimal use of fossil fuels for the refinery season. Consequently, higher savings in bagasse during the milling season allows the refinery season to operate only with bagasse as fuel for a longer period.

Based on the operating days of the milling process, the total quantity of bagasse produced was estimated to be 31% o.c. using the calculations detailed by Kent (2010). The steam consumption of the milling process is 35% o.c. and the refinery process consumes 780 kg of steam for each t of refined sugar produced as mentioned earlier. The bagasse required for steam generation during the milling season is determined to be 17.5 % o.c. with assuming a steam/bagasse ratio of 2.0. Figure 6 shows the ratio of bagasse required for the refinery process to the surplus bagasse from the milling process for the different operating days of the refinery and milling processes. If the cane sugar factory is operated for 120 days, the surplus bagasse produced is almost sufficient for the refinery season to operate for 240 days only on bagasse (ratio of bagasse required for the refinery process to the surplus bagasse = 1.0). This calculation is important to understand the minimum tonnes of cane to be processed for the refinery season to operate without burning fossil fuel.

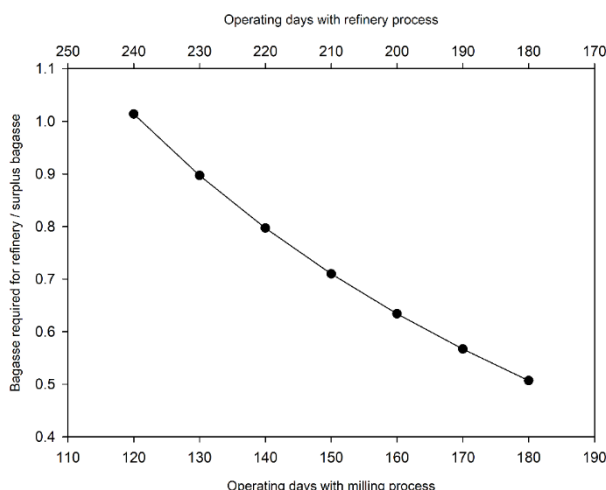


Figure 6. Ratio of bagasse required for refinery process to the surplus bagasse for a range of operating days.

PLANT ENGINEERING

The basic engineering included developing a rough 3D model of the complete sugar complex and generating 2D layout drawings (Figures 7 and 8). The front-end layout was planned such that a new #1 milling unit could be installed in the future to increase the crushing capacity of the factory. The cane diffuser would then be operated as a bagasse diffuser with a higher nominal capacity of 8,500 TCD (40 % higher). The cane receiving, preparation, de-watering milling unit and all other auxiliary equipment were designed accordingly.

Two sets of FFEs (Falling Film Evaporators) were installed, so that the factory can continue crushing when one set requires cleaning. The juice heating and clarification stations are in close proximity to each other. Similarly, the FFEs and all the shell and tubular heaters are installed in a common structure. With this arrangement, the routing of all large pipes for vapour bleeding to the pans and heaters is more convenient and systematic. Pipeline sizing and piping layout will be undertaken during the detailed engineering phase.

The main process building houses all the main equipment for raw sugar melting, raw melt clarification, sugar crystallisation and drying. It has five levels (0, 6, 10, 14 and 21 m). All the batch pans, feed solution tanks, process water tanks and the process control room are located at the 21 m level. The carbonatation and filtration equipment is installed at the 10 and 14 m levels. All the centrifugal machines are installed at the 10 m level. On the 6 m level, most of the screw conveyors are located, transporting the sugar either to the drying station or to the melter. Most of the tanks and pumps are located at the 0 m level, with a central walkway planned to run through the building. The final sugar exits the building from the right corner, as shown in Figure 7. The main process building is 90 m long and 60 m wide.

From the 3D model, 2D layout drawings were generated for each section and for all levels of the main process building. All the equipment items are shown in plan and side views, true to scale and dimensioned, including allocation to the main axes. The plant layout drawing is required to determine the site and space requirements of the factory. In addition, the space requirements for pipelines larger than DN500 are considered in the layout.

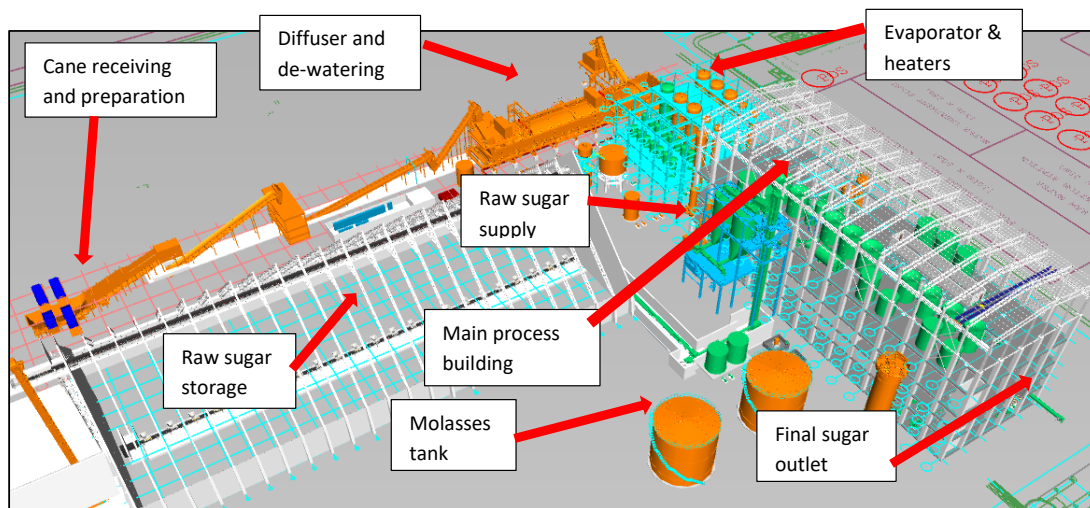


Figure 7. 3D model of the sugar complex (view 1).

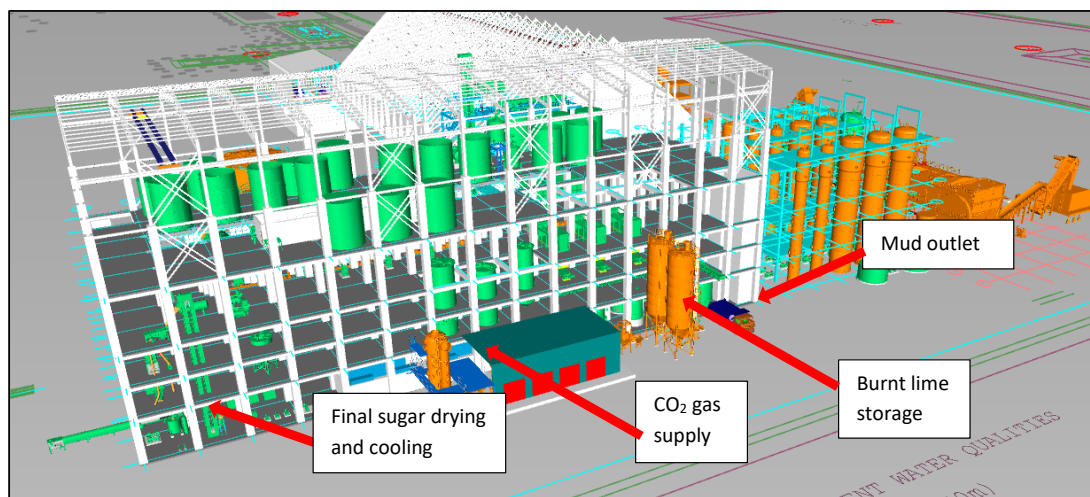


Figure 8. 3D model of the sugar complex (view 2).

ENGINEERING DOCUMENTS

As part of the basic engineering, the following documents were provided for each station of the cane sugar factory and refinery process:

1. Mass, heat and water balances
2. Process flow diagrams
3. Terminal points
4. Short process description
5. Basic equipment list with designations and estimated loads
6. Basic equipment specification with substance and process design information
7. List of sketches of tanks and vessels
8. List of electrical consumers and motors with estimated power consumption
9. Rough 3D model
10. Rough plant layout drawings

IMPACT ON CAPITAL INVESTMENT AND CASHFLOW

In terms of project execution, it was decided that 13 of the 17 factory stations would be installed in Phase 1 so that the refinery process could be operated. This made sense, since the cane cultivation programme would commence at the same time and it would take a few years before the cane would be ready for harvesting and processing. However, in order for the refinery to operate, hybrid boilers would be required which could burn bagasse as well as coal to provide the refinery process with steam and power.

In Phase 2 of the project execution, the cane receiving, handling, preparation, juice extraction, juice heating and clarification stations are to be installed. A bagasse storage system is planned.

The reduction in the number of equipment items substantially affected the capital required for the project. Compared to a standalone cane sugar factory and separate refinery within the same complex, 20 % less capital investment will be needed for the project described in this paper.

Commissioning the refinery first allows the project to generate cashflow while Phase 2 of the project is still under construction/erection, making the entire project financially more attractive. The refinery could be operated for the entire year, until the cane is available for processing.

CONCLUSIONS

An engineering project for a greenfield sugar complex was undertaken, with cane sugar (sulphur-free) and refined sugar production planned to be running all year round. Both types of sugars had to be of similar quality and would be supplied to the local market throughout the year. One challenging task in the project was designing the equipment to handle throughput for both seasons without compromising either the final sugar quality or energy consumption.

Firstly, the process engineering for producing low-colour sugar from high-colour cane juice was undertaken. A modified four boiling scheme was elaborated, which involved the double purging of C sugar, single purging of A and B sugar, and melting of all A, B and C sugar. The melt liquor was clarified in the carbonatation and filtration stations to reduce the colour (by up to 50%). The melt was concentrated and used as feed solution for A1 massecuite producing A1 sugar with colour <200 IU at a rate of 535 t/day. The refined sugar was a mixture of R1, R2 and R3 sugar with colour <200 IU at a rate of 1,000 t/day. The process was designed with a steam consumption of ~35% o.c. for the cane sugar factory and 0.73 t/t of refined sugar output.

Ten of the 17 stations have equipment which was designed to handle flow rates for both seasons. In addition, the main process building (90 m x 60 m) was planned and designed considering the process flows for both seasons.

The capital investment for the project was ~20 % lower compared to a standalone cane sugar factory and a separate refinery within the same complex. The project will be carried out in two phases. In Phase 1, the refinery process will be operated while the cane is growing. This will generate cashflow for the business and make the project financially more attractive.

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Concept d'ingénierie pour les opérations de raffinage combinées avec le broyage des cannes aux moulins

Résumé. La plupart des sucreries de canne fonctionnent pendant 120 à 160 jours, produisant du sucre brut ou du sucre blanc de plantation et, dans certains cas, du sucre raffiné. Pendant l'entrecoupe, des travaux d'entretien et des installations

d'équipements nouveaux sont généralement effectués. La sous-utilisation des équipements de l'usine est généralement admise, mais cette utilisation intermittente des équipements affecte néanmoins la rentabilité des usines. Cet article examine l'ingénierie des procédés pour la production de sucre tout au long de l'année et leur effet sur l'investissement et la consommation d'énergie. Outre l'utilisation accrue des équipements, seules les énergies renouvelables sont utilisées pendant les saisons de broissage et de raffinage, ce qui est conforme à l'objectif de production durable de sucre. L'ingénierie récemment achevée d'un nouveau complexe sucrier en Asie du Sud-Est a contribué à développer davantage le concept. L'objectif est d'approvisionner le marché local en sucre ne contenant pas de soufre et de qualité constante tout au long de l'année. L'ensemble du processus est conçu pour traiter la canne et le sucre brut de qualité inférieure (faible polarisation et couleur élevée) et fonctionner avec une faible consommation de vapeur d'échappement et avec une utilisation maximale de l'équipement installé pendant les saisons de broissage et de raffinage.

Mots-clés: Production durable de sucre, temps d'arrêt des équipements, consommation d'énergie, sucre de canne, sucre raffiné

Concepto de ingeniería para operaciones combinadas de refinería con molienda de caña de azúcar

Resumen. La mayoría de las fábricas de azúcar de caña están en funcionamiento entre 120 y 160 días, tiempo durante el cual producen azúcar sin refinar o azúcar blanco directo y, en algunos casos, azúcar refinada. Fuera de temporada, normalmente se llevan a cabo trabajos de mantenimiento y proyectos de capital. La infrautilización de los equipos de la planta normalmente se acepta; sin embargo, este uso intermitente de los equipos afecta la rentabilidad de las fábricas. Este documento analiza el concepto de ingeniería de procesos para la producción de azúcar durante todo el año y su efecto sobre la inversión y el consumo de energía. Además de la mayor utilización de equipos, solo se utiliza energía renovable durante las temporadas de molienda y refinación, lo que está en línea con la meta de producción sostenible de azúcar. Una ingeniería recientemente completada de un complejo azucarero completamente nuevo en el sureste de Asia ayudó a desarrollar aún más el concepto. El objetivo es abastecer al mercado local de azúcar sin azufre de calidad constante durante todo el año. Todo el proceso está diseñado para procesar caña y azúcar crudo de calidad inferior (baja polarización y alto color) y operar con bajo consumo de vapor de escape, con la máxima utilización de los equipos instalados tanto en la molienda como en la refinación.

Palabras clave: Producción sostenible de azúcar, tiempo de inactividad de equipos, consumo de energía, caña de azúcar, azúcar refinada