BENCHMARKING CONCEPT FOR AN INTEGRATED SUGAR, ETHANOL AND CO-GENERATION PLANT

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Abstract

This paper presents a conceptual design for an integrated sugar, ethanol and co-generation plant employing state of the art technology to create a benchmark for minimised emissions, maximised electricity cogeneration and a wide range of final product streams. The paper gives an overview about selected and applicable technologies that drive the energy demand of an integrated cane processing plant to its minimum and take advantage of a simultaneously increased power export. Further aspects focused on are the minimisation of air and waste water emissions. Nowadays, many cane sugar factories concentrate still on the core business, the production of sugar. Often, energy consumption is rather high, environmental standards are low and air and water pollution are major problems that prevent reaching the status of a sustainable agricultural business. Energy efficient technologies and byproducts like ethanol and surplus electrical power can turn the negative environmental balance. The paper includes a description of the suggested process technologies for an integrated cane processing plant that could serve as a benchmark for reaching sustainable production.

Introduction

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. There is a range of ways in which this objective could be achieved.

The objective of this paper is to outline one possible approach as a basis for considering the elements that must be involved in the design and operation of a sustainable sugar factory. It considers the case of an optimised sugar and ethanol plant as described previously in detail by Avram and Stark (2004).

This was taken as a basis for further refinement and integration with environmentally friendly technologies, such as bagasse drying with steam and incineration of the concentrated vinasse.

In this plant, 50% of the total sugars recovered from the cane go to plantation white sugar production and the other 50% to the production of anhydrous ethanol for blending with gasoline.

Technologies applied in the concept presented in Figure 1 include:

- Energy efficient sugar process including utilisation of vapours from all evaporator bodies.
- Steam drying of bagasse for maximising its heating value.
- High pressure steam boilers and condensing-extraction turbines allowing maximum production of electrical power and satisfying the needs of all steam consumers (at 11 and 2.5 bar).
- Multi-pressure distillation process resulting in minimum steam consumption.
- Concentration of vinasse and burning in a dedicated boiler.
- The required energy for vinasse concentration (steam and power) is produced in a nearly auto-sufficient manner by the vinasse boiler / turbo generator.
In order to reduce the sugar process steam consumption, the evaporator stations commonly found in cane sugar factories and the vapour consumers have to be optimised. Figure 2 shows the result of such an optimisation, whereby the sugar process steam consumption was reduced to 21.9% o.c. (Avram and Stark 2004). The mass quantities presented in Figure 2 relate to a factory crushing 20 000 t/d (833 t/h) and producing 50% white sugar and 50% anhydrous ethanol.

Fig. 2—Evaporation flow scheme for the base case.

The flow scheme in Figure 2 shows an energy efficient connection scheme for the evaporation plant of the sugar factory. Its main features are:
- 60% increase in heating surface over conventional evaporating stations (partially with falling film evaporators in order to shorten residence time and be able to work with lower temperature differences).
- Vapour bleeding from all effects achieving 72° Bx syrup density and reduction in exhaust steam consumption.
- The 3rd effect is split in 2 parallel bodies: vapours from IIIa are bled to juice heaters and vapours from IIIb only to the vacuum pans.
- Clarified juice enters body IIIb without requiring heating with exhaust steam and allowing the body to cope better with fluctuations in vapour demand from pans due to large juice volume.
- Fractioned juice heating with wide-gap plate heat exchangers in order to employ vapours from all effects (including 5th).
- Virtually no ‘condenser loss’ (condenser can be much smaller, only necessary for start-up) meaning significant savings in injection water circulation.
- Step-wise condensate flashing in ‘condensate cigars’ improving usage of flash vapours especially in latter effects.

Fig. 3—Steam and power generation – base case without bagasse drying.

The steam and electrical power plant of the sugar/ethanol plant shall have the following characteristics:
- 3 bagasse boilers rated at 175 t/h steam at 65 bar and 510°C (alternatively 2 of 250 t/h) for burning all of the available bagasse, except for a cautionary reserve for start-up and stoppages.
- 1 condensing turbo generator rated at 60.5 MW max. (specific steam consumption 3.63 kg/kWh).
- 1 backpressure turbo generator with 1 intermediate extraction stage at 11 bar for the distillery with a total power output of 42.5 MW.
- ‘Control steam’ i.e. a small amount of live steam bypassing the turbo generators.
through a pressure reducing valve.

- Desuperheating the 2.5 bar exhaust steam to saturation.
- All factory drives including mills and cooker preparation electrified.
- The surplus electricity (79 MW for the base case without bagasse drying) will be sold to the national (or local) grid.

Steam drying of bagasse

Drying of bagasse in order to lower its moisture content (typically at around 50% when coming from milling tandems and somewhat higher when coming from an extraction plant with a diffuser) has been attempted more or less successfully during the past 30 years. Most bagasse driers employ boiler waste gases by direct contact (flash drier) and they manage to reduce bagasse moisture to figures around 40%. Their drawback is the amount of electrical power used, wear of the fans, choking problems and the danger of the dried bagasse catching fire inside the driers.

A radical new concept, drying bagasse with steam has been investigated on a semi-commercial pilot plant scale in Australia (Morgenroth and Batstone, 2008). The main advantage is the potential to reduce the bagasse moisture from 50% to approx. 10% and thus increase greatly its heating value. Energy lost by burning wet bagasse can be recovered by employing steam drying. Special precautions have to be taken when handling this very light material and feeding it to the boilers, but the benefits regarding increased steam production are significant, as can be seen in Figure 4.

Steam of 11 bar pressure is used for superheating of steam at 2.5 bar pressure. The superheated steam is able to absorb moisture and it is possible to dry the bagasse to approx. 10% moisture content. The vapour generated in the dryer is recovered by employing it in the first effect of the evaporation plant. This vapour is contaminated with volatile components and can of course not be sent back to the boiler or mixed with exhaust steam. The hot condensate from the dryer is flashed to 2.5 bar and the flash vapour is recovered as well in the evaporation plant of the sugar factory.

The amount of live steam produced rises from 485 t/h to 574 t/h, an increase of 18%. Equally the amount of surplus electricity (cogeneration) rises from 341 000 MWh per crop to 402 000 MWh when the whole available bagasse is dried.

![Fig. 4—Steam and power generation - base case with bagasse drying.](image-url)
Effluent-free Ethanol production

Vinasse, a by-product from alcohol production from B-Molasses and secondary juice in cane sugar factories is currently often sprayed on the cane fields. Although widely practised, this increasingly has a negative environmental impact, especially regarding the quality of the ground water and odour emissions. But there are alternative solutions available. The most attractive way is to recover energy and ash for fertilisation. The process scenario is described below.

After the fermentation process, the mash with approx. 10% Vol enters the distillation column. Between 10 and 12 tonnes of vinasse results from the production of 1 m³ of ethanol. This vinasse (see Figure 5) with a dry substance content of about 6% can be concentrated in a five effect evaporator train to about 65% dry substance content. The final condensate arising during the multiple effect evaporation can be used as dilution water in the fermentation. Any excess condensate (with low COD content) can be used for irrigation.

Steam required for the evaporation will be generated in a dedicated boiler especially suited for the burning of the concentrated vinasse, which is injected into the boiler by a high pressure pump. More than 80% of the steam demand for the vinasse evaporation is covered by this method. Auxiliary fuel is added to cover the full demand. The high pressure steam is sent to a steam turbine which generates about 10.5 MW of power. This is more than enough to cover the requirements of the steam dryer, vinasse concentration and pumping equipment as well as the boiler auxiliaries. The clean condensate from the 1st effect evaporation is returned to the feed water system of the boiler.

The flue gas passes an ash scrubber and has almost CO₂ neutral emissions because of the use of a renewable fuel. The potassium containing ash from the burner is being recovered as raw material for fertiliser.

Potential of energy savings in the conventional ethanol distillation process

The feedstock secondary juice and B-molasses from the cane sugar process is used to get an alcoholic mash with about 9–10 Vol% of ethanol after the fermentation, mainly operated as a batch process. Typically the yeast is separated, dried and sold as a by-product.
The alcoholic mash is sent to a mash column, which separates a water-ethanol mixture from the vinasse. The next column rectifies the water-ethanol mixture to a concentration up to 96 Vol%, which is stored as hydrous ethanol after condensation. Ethanol dehydration takes place in the cyclohexane column in smaller units and by using the molecular sieve technology in larger modern plants. Since all columns in the distillery are heated separately, the steam demand is currently between 3.5 and 5 kg/L EtOH in most ethanol plants.

Among other measures, the main possibility of energy optimisation in a distillery is to employ staged pressure systems. This is based on the principle of operating the individual columns at different pressure levels in order to achieve a temperature difference between the columns. As a result, the overhead vapour of the columns can be used to heat one another as discussed in more detail by Seemann (2003).

Figure 6 shows a modern distillation set up (multi pressure distillation) where approximately 800 m³/d hydrous ethanol (associated with a crushing rate of 20 000 t/d) can be produced. It basically consists of two mash columns (MC I and MC II), a separate rectification column (RC I) and a rectification column on top of the mash column II (RC II). The multi pressure distillation uses middle pressure steam at 11 bar and heats the rectification column I only. By the means of the multi usage of this heat down to vacuum it is possible to increase the energy efficiency.

The rectification column I is operated with more than 3 bar at approximately 130°C. The ethanol vapours of this column are used to boil the mash column II, which is operating under atmospheric pressure. Ethanol vapours of rectification column II are used to heat the mash column I, which is operating under vacuum. The employment of this temperature range will decrease the steam consumption down to 1.4 – 1.9 kg/L EtOH. The condensate can also be sent back to the boiler house or be used for further heating of other sources.

Figure 6—Modern multi pressure distillation unit.

Summary

A sustainable production of sugar is of high importance for the future development of the sugar industry. State of the art, environmentally friendly processes and equipment have to be applied to achieve this target. The paper gives an overview about the integration of an energy efficient cane sugar factory linked to a power plant and a distillery considering a maximum reduction of effluents by employing a vinasse concentration and recovery process and bagasse steam drying.

REFERENCES


**LE CONCEPT DE REFERENCES POUR UNE CENTRALE INTEGREE DE SUCRE, D'ETHANOL ET DE COGENERATION**

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**MOTS CLES:** Système (Code) de Référence, Centrale Intégrée, Faible Emission, Production Durable, Séchage à la Vapeur de la Bagasse.

Résumé

CETTE COMMUNICATION présente le plan conceptuel d'une centrale intégrée pour la fabrication du sucre et de l’éthanol et la cogénération, utilisant des technologies de pointe pour créer des codes de référence pour des émissions minimales, une cogénération maximale d’électricité ainsi que pour toute une gamme de produits dérivés de la canne à sucre. L’article donne un aperçu des technologies identifiées – et applicables – qui permettront de réduire au maximum la demande d’énergie d’une telle centrale et de prendre avantage d’une augmentation simultanée de l’énergie exportée. Parmi les autres aspects considérés, figure la minimisation des émissions de gaz et des eaux usées. De nos jours, bon nombre de sucreries se concentrent toujours sur l’activité principale qui est la production du sucre. Dans beaucoup de cas, la consommation d’énergie est assez élevée, les normes environnementales sont faibles et la pollution de l’air et de l’eau représente un problème majeur qui ne permet pas à la production agricole d’atteindre le statut d’une activité durable. Les technologies énergétiques efficaces et les sous produits tels que l’éthanol et le surplus d’énergie pourraient faire basculer cette balance environnementale négative. Cette communication comprend aussi une description des technologies suggérées pour une centrale intégrée pour la transformation de la canne qui pourrait servir de référence pour atteindre une production durable.

**CONCEPTO DE INTER COMPARACIÓN (BENCHMARKING) PARA UNA PLANTA INTEGRADA DE AZUCAR, ETANOL Y COGENERACIÓN**

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**PALABRAS CLAVE:** Inter Comparación (Benchmarking), Planta Integrada, Baja Emisión, Producción Sostenible, Secado de Bagazo con Vapor.

**Resumen**

ESTE DOCUMENTO presenta un diseño conceptual para una planta integrada de azúcar, etanol y cogeneración usando tecnología de punta para crear un punto de inter comparación para emisiones minimizadas, co-generación eléctrica maximizada y un amplio rango de productos finales. Este documento brinda una síntesis sobre tecnologías selectas y aplicables que conducen al mínimo las demandas energéticas de una planta procesadora integrada de caña y toman ventaja de un aumento simultáneo de las exportaciones energéticas. Otros aspectos analizados son la minimización de las emisiones de aire y de aguas residuales. En la actualidad, muchos ingenios azucareros se concentran en el negocio básico, la producción de azúcar. Frecuentemente, el consumo de energía es alto, las normas ambientales son bajas y la contaminación del ambiente y del agua son grandes problemas que impiden alcanzar el status de un negocio agrícola sostenible. Tecnologías eficientes energéticamente y sub productos como etanol y excedentes de energía eléctrica pueden modificar el balance ambiental negativo. Este documento incluye una descripción de los procesos tecnológicos sugeridos para una planta integrada para procesamiento de caña que podría servir como un punto de inter comparación para alcanzar una producción sostenible.