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A Methodology for Sugarcane Industry Analysis: Technical, Economical and Environmental Approach

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Abstract

In this paper, it is exposed an analysis methodology specific to the sugarcane industry, dealing with technical, economical and environmental aspects.
Sugarcane bagasse has different utilizations, even in cogeneration. Also, bagasse might be the unique fuel for a sugarcane factory, its emission factors of greenhouse effect gases being significantly smaller than the one of the fossil fuels.
For the selection of a variety able to produce minimum residue for the maximum energy output a mathematical model is proposed.
A thermoeconomic analysis is developed in order to evaluate streams inside the sugar production process. By this approach, a standard sugarcane factory is assessed from technical, economical and environmental point of view, in order to face nowadays challenges.
Key words: *sugarcane, bagasse, cogeneration, exergy*

Introduction

Sugarcane represents one of the most important cash of the world, the sugarcane industry being one of the oldest industries of mankind. This industry is based on three main processes: the cultivation of cane, the milling of the cane in order to extract the juice and the rendering of the juice into crystal sugar.

In the world there are 200 countries involved in the grow of the crop in order to produce 1,324.6 million tons.

Data delivered by the Food and Agricultural Organization of the United Nations (Economic and Social Department / The Statistical Division), indicate that Brazil is the leader among the world's sugarcane producers (514,079,729 tones), followed by India (355,520,000 tones) and China (106,316,000 tones). The world's sugarcane production is 1,557,664,978 tones.

Sugarcane exploitation has an important socioeconomic aspect due to the fact that it supplies the raw material for three sectors: sugar, spirits and alcohol. The sugarcane industry does not need any kind of fuel for its production because the sugarcane processed is sufficient to fulfil the fuel demand by mean of a by-product of the milling process, the sugarcane bagasse. Figure 1 depicts the standard process flow sheet for a typical sugar factory.

Governments all over the world pay attention to the use of cleaner fuels and renewable sources in the context of the energy matrix diversification.

The bagasse is the biomass (the sugarcane waste) that remains after sugarcane is crushed for the juice extraction. It is currently used as renewable.

The main goal is the introduction of new energy sources, independent or together with those already existing, for making the energy matrix more flexible.

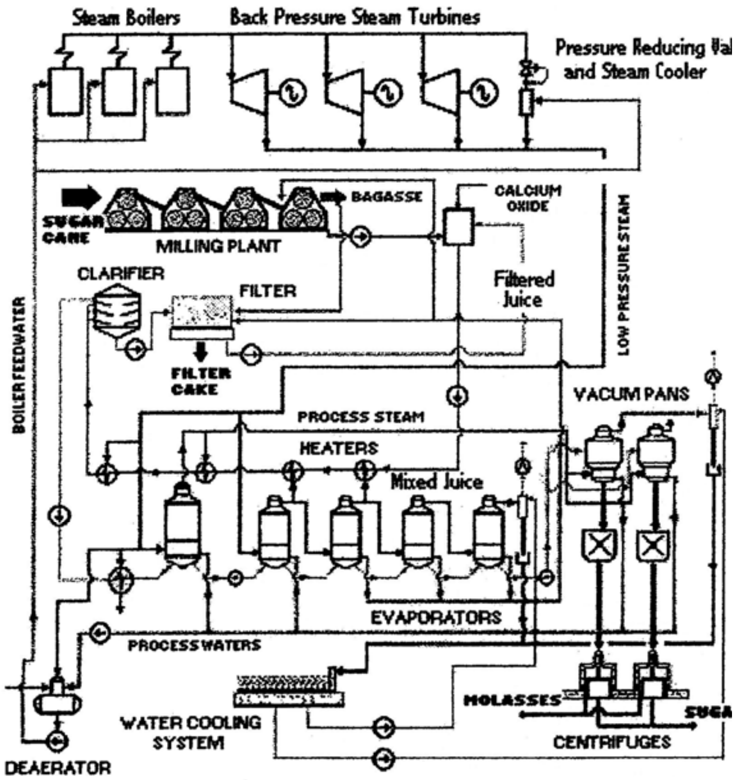

Fig.1. Typical layout of a sugarcane factory

About Sugarcane Bagasse

The use of sugarcane bagasse is motivated by the yearly increase of electricity consumption and the annual availability of sugarcane bagasse in regions with intense sugarcane production.

It is known the fact that a sugarcane factory can cover all its technological demands of energy (thermal and electrical) using bagasse as the unique fuel.

Sugarcane bagasse is utilised for bricks production, for the production of cellulose pulp and cellulose derivates, as reinforcement in polymer composites, but also in cogeneration.

The cogeneration of stream and electricity has become the norm in the sugarcane industry all over the world. This process has been brought at a level where sugar companies can export an important amount of energy to the grid.

Cogeneration from the bagasse represents one of the best examples of renewable based cogeneration, its benefits having environmental, social and economical aspects.

Biomass cogeneration is the way to satisfy the increased need of energy consumption by an environmental friendly technology, while it emits less carbon gases than fossil fuels.

In Table 1, the emission factors for sugarcane bagasse and some other fuels are shown, the drawback of fossil fuels being obvious.

Table 1. Emission factors of greenhouse effect gases for the main fuels

Fuel	Emission factors (t/TJ)			
	C	CO	CH_4	NO_x
Fuel oil	21.10	0.015	0.003	0.161
Diesel oil	21.81	0.990	0.220	0.990
Firewood	0.00	0.002	0.015	0.115
Coal	26.80	0.093	0.002	0.329
Sugarcane bagasse	0.00	0.002	-	0.088

After the crop, sugarcane is prepared and introduced in mills, the juice extraction taking place. This juice will be used for the production of sugar and alcohol. The bagasse obtained after the grinding process, in the proportion of 30% in weight, contains 50% humidity and presents lower heating value of 10.470 kJ/kg of bagasse.

Choosing of the Sugarcane Variety with a Mathematical Model

In order to use the residual biomass of the sugarcane in the context of the clean energy generation, the use of a mathematical model is needed [2]. It will allow the selection of the variety able to produce minimum residue for the maximum energy output.

$$\text{Minimize} \quad \sum_{i=1}^{n} P_i x_i \tag{1}$$

with the following constraints:

$$\sum_{i=1}^{n} x_i = s \tag{2}$$

$$\sum_{i=1}^{n} p_{fi} x_i \geq s\overline{p}_f \tag{3}$$

$$\sum_{i=1}^{n} e_i x_i \geq s\overline{e} \tag{4}$$

$$x_i \geq 0 \tag{5}$$

where:

$i = 1,2,...,n$ are the varieties;

P_i – the production of crop residue for variety „i” [t/ha];

x_i – variable which determines the surface to plant with each variety „i” [ha];

s – the total surface for planting [ha];

p_{fi} – the average production of the fermentable sugar for each variety „i” [t/ha];

$\overline{p}_f$ – the average production of fermentable sugar for considered varieties [t/ha];

e_i – the average energy production for each variety „i” [kJ/ha];

$\overline{e}$ – the average energy production for considered varieties, [kJ/ha].

$$\text{Maximize} \qquad \sum_{i=1}^{n} E_i x_i \tag{6}$$

with the following constraints:

$$\sum_{i=1}^{n} x_i = s \tag{7}$$

$$\sum_{i=1}^{n} p_{fi} x_i \geq s\overline{p}_f \tag{8}$$

$$\sum_{i=1}^{n} p_{ri} x_i \leq sp_r \tag{9}$$

$$x_i \geq 0 \tag{10}$$

where:

E_i – the energy of the crop residue for the variety „i” [kJ/ha];

p_{ri} – the average production of crop residue for each variety „i” [t/ha];

$\overline{p}_r$ – the average production of crop residue for considered varieties [t/ha].

The Use of Thermoeconomics

The production process depicted in figure 1 can be structured on economic reasons, in seven units working independently: the milling plant, the steam generation plant, the electricity generation plant, the purification plant, the boiling plant, the cooking and crystallisation plant and the solids separation plant (see figure 2).

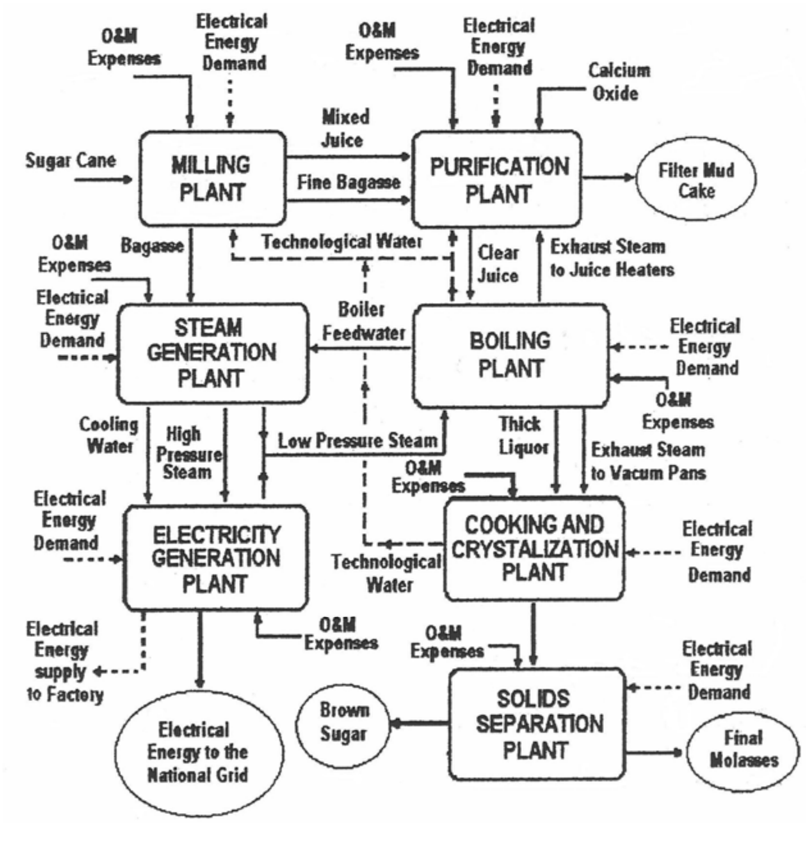

Fig. 2 Thermoeconomic environment for a sugarcane factory

A technical improvement of the process is justified by a decrease of the sugar production cost. To make a cost evaluation and technical improvement evaluation, simultaneously, is a difficult task. That is why the concept of thermoeconomic environment of a sugarcane factory was introduced; such concept permits the calculation of exergy and expenses.

The money balance of a plant is given by:

$$Z_{OM} + \sum C_i E_i = \sum C_0 E_0 \tag{11}$$

where:
Z_{OM} – invested capital considering operation and maintenance [Euros/s];
C – monetary cost per energy [Euros/kJ];
E – exergy flow [kW];
i – input;
o – output.

The exergy flow balance:

$$\sum E_i = \sum E_0 + D \tag{12}$$

where:
D – destruction of exergy, [kW].

The production cost of any flow of matter, final or intermediate, C_p, is given by:

$$C_p = \frac{C_j E_j}{\dot{m}_j} \tag{13}$$

where:
$\dot{m}_j$ – mass flow [kg/s].

Conclusions

Sugarcane is a significant crop, supplying raw material for different agro industries.

The use of the residual biomass of sugarcane in cogeneration is a viable alternative to satisfy the energy need, being a renewable source of energy.

A mathematical model is proposed in order to solve agronomic, economic or environmental issues related to sugarcane crops. This model minimizes the harvest residue as a function of cane varieties and maximizes residue energy as part of the production system.

Introducing thermoeconomic analysis, it is offered to engineers a powerful tool for the estimation of the technical improvements of a sugarcane factory. By defining the thermoeconomic environment it is possible to value the unitary costs of each stream met in a standard sugar factory.

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O metodologie de analiză a industriei de producere a zahărului din trestia de zahăr: punct de vedere tehnic, economic şi ecologic

Rezumat

În această lucrare este prezentată o analiză a industriei de producere a zahărului din trestia de zahăr, fiind abordate aspecte tehnice, economice şi ecologice specifice.
Celuloza din trestie de zahăr are diferite utilizări, fiind întâlnită chiar şi în cogenerare. De asemenea, celuloza din trestia de zahăr poate fi singurul combustibil utilizat într-o fabrică producătoare de trestie de zahăr, având în vedere că noxele şi efectulde seră sunt semnificativ inferioare celor date de combustibilii solizi
Pentru alegerea soiului capabil să producă minimum de reziduu şi maximum de energie, este propus un model matematic.
Pentru evaluarea fluxurilor din cadrul procesului de obţinere a zahărului, este prezentată o analiză tehnicoeconomică.
Prin această abordare, o fabrică standard de obţinere a zahărului din trestia de zahăr este evaluată din punct de vedere tehnic, economic şi ecologic, pentru a răspunde provocărilor din zilele noastre.