COMPARISON STUDY: ETHANOL PRODUCTION INCREASE THROUGH THE INTRODUCTION OF BAGASSE ENZYMATIC HYDROLYSIS & SURPLUS ELECTRICITY INCREASE, IN ETHANOL DISTILLERIES

Reynaldo Palacios-Bereche, reynaldo.palacios@ufabc.edu.br
Marcelo Modesto, marcelo.modesto@ufabc.edu.br
Adriano Ensinas, adriano.ensinas@ufabc.edu.br
Center of Engineering, Modeling and Social Sciences, Federal University of ABC (CECS/UFABC), Avenida dos Estados, 5001, Santo André, SP, 09210-580, Brazil.

Silvia A. Nebra, silvia.nebra@pq.cnpq.br
Center of Engineering, Modeling and Social Sciences, Federal University of ABC (CECS/UFABC), Avenida dos Estados, 5001, Santo André, SP, 09210-580, Brazil.

Interdisciplinary Center of Energy Planning, University of Campinas (NIPE/UNICAMP), Cidade Universitária Zeferino Vaz, Rua Cora Coralina 330, P.O. Box 6166, Campinas, SP, 13083-896, Brazil.

Abstract*. The aim of this study is to evaluate the potential of ethanol production increase, and the impacts in electricity surplus of the cogeneration plant due to the introduction of enzymatic hydrolysis of bagasse in a conventional distillery. Moreover a comparison of these results is performed with another scenario, where all available bagasse and trash are used in the distillery cogeneration system, in order to maximize electricity surplus, considering a steam cycle provided with extraction-condensing turbines. Simulations in ASPEN PLUS® software were performed, in order to evaluate the mass and energy balances, for the studied processes. For the case of enzymatic hydrolysis, it was assumed that sugarcane trash and lignin cake, which is a residue of the hydrolysis process, are available as fuel in the cogeneration system in order to achieve a significant ethanol production increase. In the electricity surplus study, an adequate higher pressure in the boiler and turbine has been considered. Ethanol production increase resulted 12.3% and 15.1% for the hydrolysis cases evaluated, while surplus electricity increase was 236.5% and 267.5% for the cases where condensing-extraction steam turbines were adopted without enzymatic hydrolysis.*

Keywords*: sugarcane, ethanol, electricity, enzymatic hydrolysis, cogeneration*

1. INTRODUCTION

The conversion of biomass into biofuels represents an important option for both the exploitation of an alternative source of energy and the reduction of polluting gases, mainly carbon dioxide. Among the biofuels, ethanol is the one that is attracting most attention. It is produced in large scale in Brazil using sugarcane as raw material through sugar fermentation and distillation. However, the ethanol production can be increased through the introduction of enzymatic hydrolysis of lignocellulosic biomass such as sugarcane bagasse and trash. Nowadays, the ethanol production from lignocellulosic materials through the hydrolysis process is being researched all over the world, including the installation of pilot plants to test different types of processes. Nevertheless, the introduction of the bagasse hydrolysis process in the current ethanol production system is a real challenge, being bagasse the fuel of the current process and at the same time, raw material for the new one. On the other hand, electricity is another product in ethanol distilleries and its production can be increased, in steam cycles, adopting steam generators with higher levels of pressure and temperature, as well as condensing-extraction steam turbines. Moreover, sugarcane trash can be used as fuel in cogeneration system aiming to maximize the electricity surplus.

Therefore, the aim of this study is to evaluate the potential of ethanol production increase and the impacts in electricity surplus due to the introduction of enzymatic hydrolysis of bagasse in a conventional distillery and compare these results with another scenario, where all the available bagasse and trash are used in the cogeneration system, in order to maximize electricity surplus, taking into account a steam cycle provided with extraction-condensing turbines. Both of the considered scenarios present technological bottlenecks which must be solved in order to make these processes feasible.

2. METHOD

Simulation and modelling of the conventional ethanol distillery, enzymatic hydrolysis of bagasse and cogeneration system was carried out using the software Aspen Plus® and according the studies of Palacios-Bereche (2011); Dias (2008), Palacios Bereche et al. (2011) and Palacios-Bereche and Nebra (2009).

In order to evaluate the potential of ethanol production increase as well as the potential of electricity surplus increase, five cases were evaluated in this study:

I: Base - Conventional distillery
II: H-10%E - Enzymatic hydrolysis of bagasse incorporated to the conventional distillery and concentration of glucose liquor in a multiple-effect evaporator of 5 effects.
III: H-10%M - Enzymatic hydrolysis of bagasse incorporated to the conventional distillery and concentration of glucose liquor in membrane system.
IV: EE-67 bar - Conventional distillery and cogeneration system with condensing-extraction steam turbines and steam generation at 67 bar and 480°C.
V: EE–100 bar - Conventional distillery and cogeneration system with condensing-extraction steam turbines and steam generation at 100 bar and 530°C.

2.1 Conventional ethanol distillery

The conventional process begins with the cleaning operation. After that, the sugarcane goes to the extraction system where the sugarcane juice and bagasse are obtained. Raw juice goes to the physical-chemical treatment, while part of the bagasse goes to the cogeneration system. In order to obtain a juice sugar concentration adequate to fermentation, one part of the clarified juice is concentrated in a multiple effect evaporator of 5 effects. Must sterilization is carried out by a HTST-type treatment (High Temperature Short Time). The fermentation process adopted in the simulation is based in batch fed fermentation with cell recycle (Melle Boinot process). A conventional distillation system was simulated, considering distillation and rectification columns. Dehydration of ethanol was simulated considering the extractive distillation with monoethylene glycol (MEG). The cogeneration system adopted for the conventional ethanol distillery consists of a steam cycle with backpressure steam turbines and parameters of steam of 67 bar and 480°C. Steam turbines have a bleed at 22 bar for direct driven turbines of the extraction system and at 6 bar for must sterilization and ethanol dehydration.

2.2 Conventional ethanol distillery coupled with enzymatic hydrolysis of bagasse

The modelling and simulation of enzymatic hydrolysis of bagasse was accomplished according the studies of Palacios-Bereche (2011) and Palacios Bereche et al. (2011). Enzymatic hydrolysis begins with the pretreatment of lignocellulosic material; the steam explosion pretreatment was adopted because of its efficiency and low cost relative to other chemical pretreatments. The following operation is the washing of pretreated material, in order to remove the soluble xylose. The next step is the hydrolysis of cellulose, where cellulose chains are broken down in order to produce glucose for the fermentation step. Water is added to the process, in order to achieve an appropriate concentration of solids in the hydrolysis reactor. In this study a solids content of 10% was adopted. After hydrolysis stage, the hydrolysate goes to a filter in order to separate the lignin cake from the glucose hydrolysate. The glucose hydrolysate obtained has very low glucose content (3.4%). To reach the concentration values needed in the fermentation step, this study examines two alternatives for concentration. The first considers a multiple-effect evaporator of 5 effects (H-10%E), while the second considers a concentration system by membranes (H-10%M). Figure 1 shows the block diagram of the hydrolysis plant inserted in the conventional ethanol production process proposed.

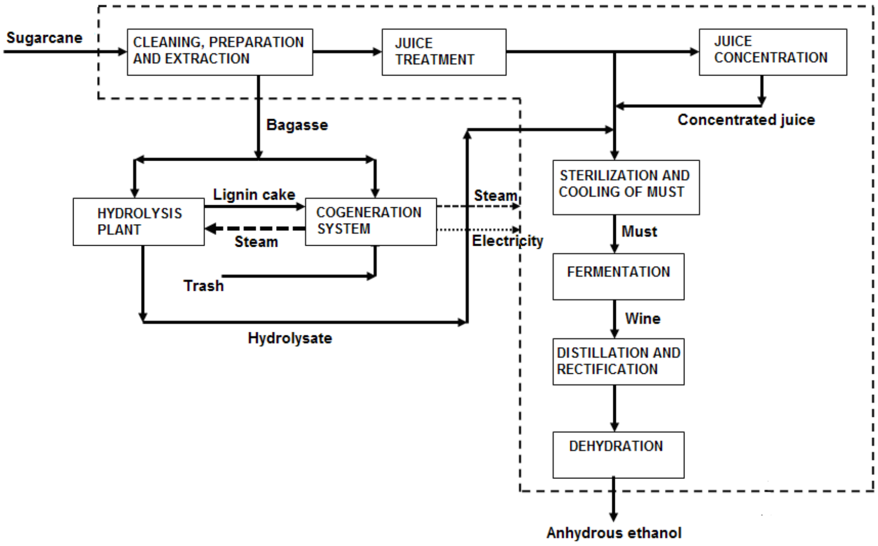

Figure 1. Ethanol production process-Conventional process integrated with hydrolysis process.

Sugarcane trash and lignin cake are considered, in order to satisfy the energetic requirements of the integrated process, freeing a larger amount of bagasse to be used in the hydrolysis process. Nevertheless, it is still necessary to burn part of the bagasse in the boilers to cover the energy requirements. The amount of bagasse for hydrolysis is defined after an iterative process, because the increase of raw material for hydrolysis increases the steam consumption of the plant. Data of trash potential and composition were adopted from Hassuani et al. (2005)

2.3 Conventional distillery adopting condensing-extraction steam turbines in cogeneration system

Figure 2 shows the cogeneration system for cases IV and V, where the objective is to maximize the electricity surplus. As in the previous cases, it is considered that trash is used as fuel in the boilers. The modelling of the steam boiler brings into account the combustion chamber and the heat exchangers: superheater, evaporator, air preheater and economizer. Steam turbine has the first extraction at 22 bar to direct driving turbines, the second at 6 bar for must sterilization and ethanol dehydration and the third at 2.5 bar for the others process requirements. In Fig. 2, block TGB represents the condensing stages of turbine while block CONDEN represents the condenser, which operates at 10 kPa.

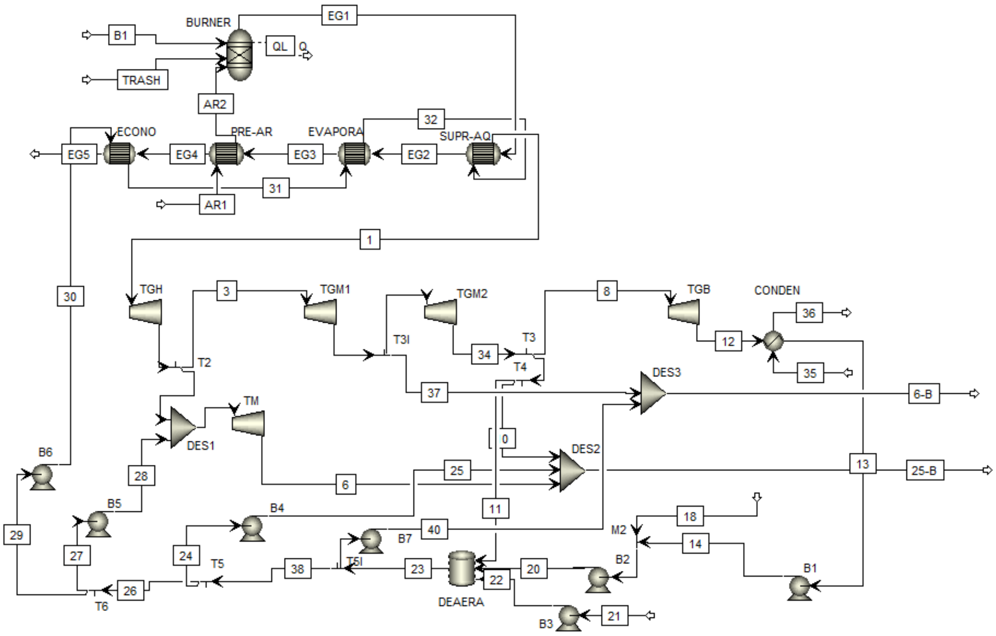

Figure 2. Cogeneration system for cases IV and V.

Table 1 shows the main parameters for modelling and simulation of the ethanol and electricity production process.

Table 1. Parameters adopted for the simulation of conventional ethanol production process

Parameter	Value
Sugarcane crushing rate, t/h	500
Efficiency of sugar extraction in extraction system, %	97
Conversion yield from sugars to ethanol, %	89
Ethanol content in anhydrous ethanol, wt %	99.4
Cogeneration system	
Isentropic efficiency of electricity generation in steam turbines, %	80
Isentropic efficiency of direct driven steam turbines, %	50
Boiler thermal efficiency, % (LHV base)	86
Hydrolysis process	
Solid content at hydrolysis reactor, %	10
Hydrolysis time, h	48
Yield conversion from cellulose to glucose, %	55.8
Steam consumption at pretreatment, kg of steam/kg of raw material	0.55

3. RESULTS AND DISCUSSION

Figure 3 shows the results of anhydrous ethanol and electricity surplus produced. The ethanol production increase was 12.3 % and 15.1% for cases H-10%E and H-10%M respectively while the increase in electricity surplus for these cases was 21.3% (increase) and -15.2% (decrease). This last value is due to an increase in electricity consumption in the hydrolysis process and a reduction of the steam generated, caused by the use of membranes in the glucose liquor concentration.

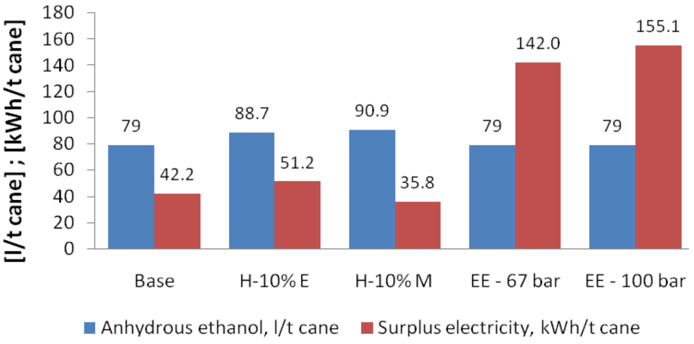

Figure 3. Main products of the distillery: Anhydrous ethanol and electricity surplus.

On the other hand, cases where electricity generation is prioritized showed high electricity surplus increases. Case EE-67bar presented an increase of 236.5%, while Case EE-100bar presented 267.5% in comparison with Case I (Base). It can be observed that the difference in electricity surplus between these cases is low (13.1 kWh/t cane), thus the increase obtained to pass from Case EE-67bar to EE-100bar resulted in 9.2%. Figure 4 shows the balance in electricity generated for all the cases.

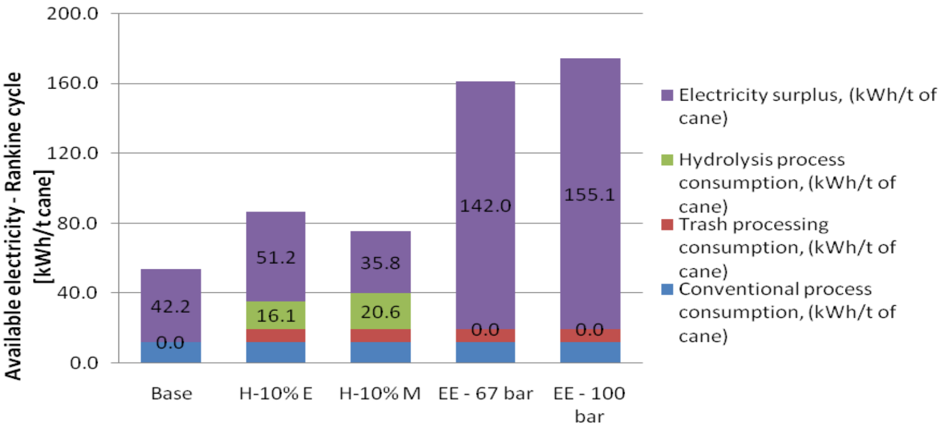

Figure 4. Balance of electricity generated (kWh/t cane)

These results show that surplus electricity increases in cases EE-67bar and EE-100bar are higher than ethanol production increases in cases H10%-E and H10%-M. However, further exergetic and economic evaluations should be performed; in order to determine what is better, an increase in the steam parameters in cogeneration system or maximizing the ethanol production.

It is important to point out that steam parameters (pressure and temperature) adopted for the simulation of electricity generation are within the parameters currently offered by manufacturers of boilers and turbines in Brazil. Better results can be obtained through advanced cogeneration systems, for instance, with supercritical boilers or cycles IGCC (Integrated Gasification Combined Cycle).

Moreover, the reduction of steam consumption in process might improve the ethanol production by enzymatic hydrolysis and the surplus electricity through condensing-extracting steam turbines. Among the improvements that can be cited there is the multiple effect distillation, vacuum extractive fermentation and thermal integration between process streams.

In the literature there are several studies where both ethanol production and electricity generation from sugarcane biomass are evaluated.

Pellegrini (2009) and Pellegrini et al (2010) accomplished a thermoeconomic evaluation for the production process of sugar, ethanol and electricity. In these studies, several technologies of cogeneration systems were evaluated. Among these technologies there are: cogeneration systems with condensing extraction steam turbines, supercritical boilers and cycles IGCC. The steam cycles with condensing extraction turbines presented surplus electricity of 64 kWh/t of cane, adopting boilers of 67 bar and 515°C without utilization of sugarcane trash while the cogeneration system with a supercritical boiler (300 bar and 600°C) presented a surplus electricity of 142 kWh/t of cane, and the IGCC cycles presented surplus electricity in the range of 152 to 205 kWh/t of cane without the utilization of sugarcane trash.

Dias (2011) and Dias et al. (2012) carried out simulations of the production process of ethanol and electricity from sugarcane including the enzymatic hydrolysis of bagasse and trash. These authors adopted an improved plant with steam consumption in process of 373 kg of steam/t of cane in base case, and a boiler with steam parameters of 90 bar and 520°C. In base case (plant without hydrolysis) the results of this study presented a surplus electricity of 34 kWh/t of cane when a steam cycle with backpressure steam turbines is adopted. On the other hand a surplus electricity of 173 kWh/t of cane is achieved when condensing extracting turbines are adopted assuming the use of trash as fuel (50% of total potential). For cases where enzymatic hydrolysis is adopted the surplus electricity is in the range of 77 to 86 kWh/t of cane. About the ethanol production increase, these authors indicate increases in the range of 24 to 41%, however this high increase is because of the fermentation of pentoses is taking into account by these authors.

4. ACKNOWLEDGEMENTS

The authors wish to thank CNPq (Process 304820/2009-1), FAPESP (Process 11/05718-1) and FINEP (Contract FINEP - FUNCAMP No. 01/06/004700) for providing financial support.

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