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Energy Consumption in Ethanol Production by Enzymatic Hydrolysis – The Integration with the Conventional Process Using Pinch Analysis

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The aim of this study is to make a diagnosis of the possibilities of ethanol production increasing through the bagasse hydrolysis process, considering the limiting situation of bagasse use. Simulations in ASPEN PLUS® software were performed, in order to evaluate the mass and energy balances, for both, integrated processes, considering the pre-treatment by steam explosion. The use of sugarcane trash is considered in order to accomplish the energetic needs of the overall process. Four cases are evaluated which include the conventional ethanol production plant without hydrolysis (Case I), the conventional plant joint with hydrolysis process without thermal integration (Case II), and the conventional plant joint with hydrolysis process considering thermal integration (Case III and IV). Results showed that Case IV has an ethanol production increase of 13.8% in comparison with Case I.

1. Introduction

In Brazil, ethanol is produced in large scale using sugarcane as raw material by fermentation of sugars and distillation. The sugarcane bagasse is the major by-product in sugar and ethanol production, it is burnt in boilers to attend the steam and power requirements of the process. Moreover sugarcane bagasse, as well as other lignocellulosic materials, can be also used for ethanol production but, 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. Thus simulations in ASPEN PLUS® software were performed, in order to evaluate the mass and energy balances, for both, integrated processes. The use of sugarcane trash is considered in order to accomplish the energetic needs of the overall process. Pinch Analysis is used to determine the minimum hot and cold utilities required by the integrated process in order to increase the ethanol production as well as the electricity surplus.

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2. Simulation of the ethanol production process

2.1 Conventional ethanol production process from sugarcane

The simulation of the conventional production process was accomplished according the study of Dias et al. (2010). Figure 1 shows the block diagram of the conventional ethanol production integrated with the ethanol production process by enzymatic hydrolysis while Table 1 shows the mean parameters adopted for the simulation of conventional ethanol production process.

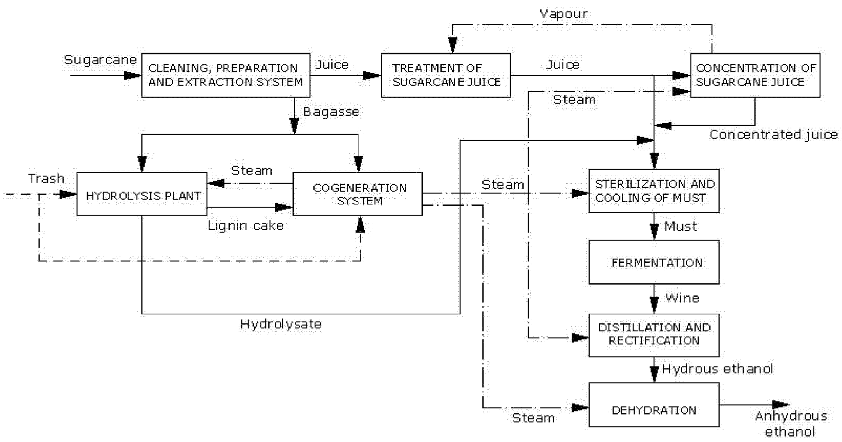

Figure 1: Ethanol production process-Conventional process integrated with hydrolysis process.

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

Parameter	Value
Sugarcane crushing rate, t/h	490.2
Efficiency of sugar extraction in extraction system, %	97
Conversion yield from sugars to ethanol, %	89
Ethanol content in vinasse and phlegmasse, %	0.02
Ethanol content in anhydrous ethanol, wt %	99.4

The conventional process begins with the cleaning operation. After that sugarcane goes to the extraction system where sugarcane juice and the bagasse are obtained. Raw juice goes to the physical-chemical treatment while part of bagasse goes to the cogeneration system. In order to obtain a juice sugar concentration adequate to fermentation, one part of clarified juice is concentrated in an evaporation system of multiple effects. The sterilization of must is done using a treatment type 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 monoethyleneglycol (MEG). The cogeneration system adopted in the simulation 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 and at 6 bar for requirements in the processes of sterilization of must and dehydration of ethanol.

2.2 Sugarcane residues utilization

Sugarcane trash and lignin cake, which is a byproduct of hydrolysis process, are considered in order to satisfy the energetic requirements of the integrated process. For simulations, it is considered that trash and lignin cake are burned in the boiler with efficiency of 86% (LHV base).

The available amount of sugarcane trash and its LHV is calculated from literature data (Hassuani et al. 2005). The values obtained were 39.4 t of trash/h getting into the factory and LHV of 14.2 MJ/kg (wet basis; moisture content of 13%).

Case II and Case III of this study consider that one part of trash is burnt in boiler (according Rein, 2007, share of 25% of the bagasse in mass) while the other part is sent to hydrolysis process, considering the current technology of sugarcane boilers and the problems of fouling due to the high amount of mineral impurities in trash. On the other hand Case IV considers that all trash is burnt in the boiler while only bagasse is used in the hydrolysis process, considering a prospective study where problems produced by ash are solved using, perhaps, fluidized bed boilers.

2.3 Ethanol production by enzymatic hydrolysis

The simulation of the ethanol production process was accomplished according Palacios-Bereche et al. (2010). Figure 2 shows the flowsheet of the ethanol production process by enzymatic hydrolysis considered in this study. Table 2 shows the reactions and conversion yields considered in pre-treatment reactor according Carrasco et al. (2010).

Table 2: Yields considered for the reactions in pretreatment reactor

Equation	Product	Yield	From
$C_5H_8O_4 + H_2O \rightarrow C_5H_{10}O_5$	Xylose	61.4	Hemicelluloses
$C_5H_8O_4 + H_2O \rightarrow 2.5\ C_2H_4O_2$	Acetic acid	9.2	Hemicelluloses
$C_5H_{10}O_5 \rightarrow$ FURFURAL + 3 H_2O	Furfural	5.1	Xylose
$C_6H_{10}O_5 + H_2O \rightarrow C_6H_{12}O_6$	Glucose	4.1	Cellulose

The following reactions are specified in hydrolysis reactor with conversion yields of 69.2% and 35.7% for Eq. (1) and (2) respectively (Carrasco et al. 2010).

$$C_6H_{10}O_5 + H_2O \rightarrow C_6H_{12}O_6 \quad (1)$$

$$C_5H_8O_4 + H_2O \rightarrow C_5H_{10}O_5 \quad (2)$$

In filter SEPA-L-T (see Fig. 2) is obtained the lignin cake (CAKE-LIG) and the glucose hydrolysate (LI-GLU). The glucose hydrolysate, with a glucose content of

1.5%, is concentrated until appropriate glucose content to fermentation process in an evaporation system of five stages.

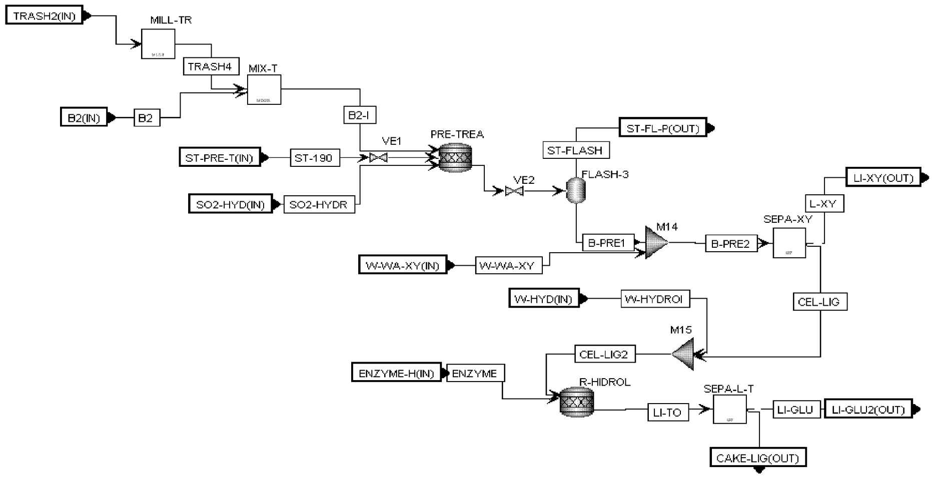

Figure 2: Flowsheet of enzymatic hydrolysis process in ASPEN PLUS.

3. Thermal integration using Pinch Analysis

The Pinch Point Method was used to analyze the streams of the process which are available for thermal integration. The minimum approach difference of temperature (Δtmin) adopted in this study was 10°C for process and 4°C for evaporation system. Due to the characteristic of the process the procedure is accomplished following the sequence:

Step 1. Calculation of the amounts of trash and bagasse for boiler from an initial assumption of the steam consumption of overall process.

Step 2. Thermal integration of the streams of process available for thermal integration; excluding the evaporation systems (sugarcane juice and glucose liquor).

Step 3. Integration of the evaporation systems and calculation of the appropriate vapor bleeding demand according procedure of Westphalem and Wolf Maciel, (2000).

Step 4. Re-calculation of the steam consumption of overall process until to achieve the convergence.

4. Results and Discussion

Table 3 shows the streams considered for thermal integration while Fig. 3 shows the Grand Composite Curve integrated with the evaporation systems (of sugarcane juice and glucose liquor). Fig. 3 also indicates that only vapor bleed of 1st and 2nd effect are appropriated for the integration with the system. The vapor bleed calculated from graphical method was almost the same for Case III and IV being 86.3 t/h and 16.9 t/h in 1st and 2nd effect respectively (Case III). Table 4 shows the distribution of bagasse, trash and lignin cake for boiler and hydrolysis. LHV of lignin cake is calculated from its composition by enthalpy balance. The increase in ethanol production, in comparison to Case I, was 9.4%, 13.3% and 13.8% for cases II, III and IV respectively while the steam consumption increases 53.7%, 35.8% and 38% for cases II, III and IV respectively.

Table 3: Streams considered for thermal integration – Case IV

Hot streams	$T_{initial}$	T_{final}	Q	***Cold streams***	$T_{initial}$	T_{final}	Q
	°C	°C	MW		°C	°C	MW
Sterilized juice	130	32	45.4	Raw juice	30	70	22.4
Fermented wine	32	28	13.4	Limed juice	70	105	24.2
Phlegmasse	104	35	3.3	Juice for sterilization	95.5	130	17.9
Condensate of Vapors[1]	97.3	35	33.3	Reboiler column A	109	109	48.4
Condenser column B	81.6	81.6	28.7	Reboiler column B	104	104	34
Condenser Ext[2]	78.3	78.3	8.3	Reboiler Ext[2]	112	137	7.6
Condenser column D	85.1	35	32.3	Reboiler Rec[3]	150	150	2.8
Cooler of vapor SE	101	99.6	11	Treated sugarcane juice	99.1	115	1.9
Anhydrous ethanol cooling	78.3	35	9.6	Pre - heating celu-lignin	30.7	40	5.6
				Hydrolysis reactor	40	40	3.5
				Heater of glucose liquor	40	115	45.3
				Imbibition water	25	50	4.4

[1] Condensate vapors of evaporation systems of multiple effect (sugarcane juice and glucose liquor); [2] Extractive column; [3]Recovery column

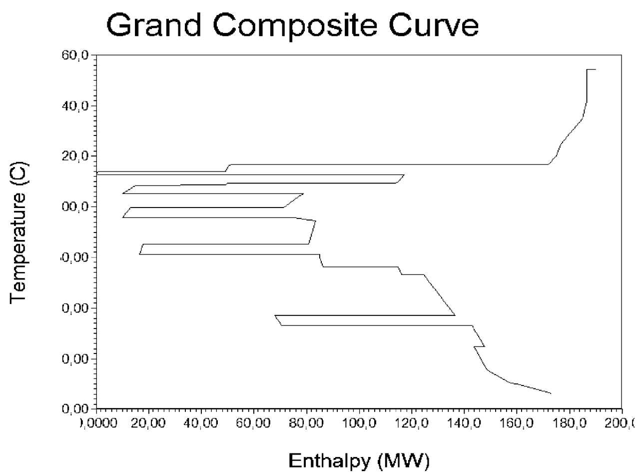

Figure 3: Grand Composite Curve including the evaporation systems – GCC Case IV.

The ratio of steam consumption for Case III and IV resulted 719.8 and 732.1 kg of steam/ t of sugarcane respectively.

Table 4: Inputs for cogeneration system and products of the plant for each case

	Case I	Case II	Case III	Case IV
Bagasse for boiler[1], (t/h)	109.5	96.0	79.5	43.8
Bagasse for hydrolysis[1], (t/h)	0	21.1	37.6	73.3
Trash for boiler[2], (t/h)	0	24	19.9	39.4
Trash for hydrolysis[2], (t/h)	0	15.4	19.6	0
Lignin cake[3], (t/h)	0	25.6	34.6	32.3
Products				
Anhydrous ethanol, (t/h)	30.5	33.1	34.3	34.5
Surplus electricity, (MW)	22.83	37.2	31.55	31.98
Steam consumption				
Steam generated in boiler, (t/h)	248.3	387.1	348.4	355.8
Direct steam for pre-treatment, (t/h)	0.0	20.1	31.4	40.3

1LHV of bagasse: 7448 kJ/kg; [2]Moisture 13%; [3]Moisture 50%.

5. Conclusions

An evaluation of energy consumption for the ethanol production process by enzymatic hydrolysis was accomplished. Case IV showed the highest ethanol production; however it is a prospective study and pilot plant/industrial data would be necessary in order to adjust the modeling of the plant. The Pinch analysis showed to be a useful tool to evaluate the thermal integration potential for the cases considered.

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