REFLECTIONS ABOUT ENERGY AND WATER CONSUMPTIONS IN ETHANOL PRODUCTION BY ENZYMATIC HYDROLYSIS – THE INTEGRATION WITH THE CONVENTIONAL PROCESS

Reynaldo Palacios-Bereche, rpalacios@fem.unicamp.br
Faculty of Mechanical Engineering, State University of Campinas, Campinas, Brazil

Adriano Ensinas, adriano.ensinas@ufabc.edu.br
CECS, Federal University of ABC (UFABC), Santo Andre, Brazil

Silvia A. Nebra, silvia.nebra@pesquisador.cnpq.br
Interdisciplinary Center of Energy Planning, State University of Campinas, Campinas, Brazil

Abstract. *Ethanol is produced in Brazil 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. Nowadays, the ethanol production from lignocellulosic materials through hydrolysis process is being researched all over the world, including the installation of pilot plants to test different process types. 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. The aim of this study is to make a diagnosis of the real possibilities of ethanol production increasing through the bagasse hydrolysis process, considering the limiting situation of bagasse use. A simulation in ASPEN PLUS® software was performed, in order to evaluate the mass and energy balances, for both, integrated processes. Thus, in this study, an initial assessment of the possibilities of integration of both technologies is performed, considering first a standard ethanol production plant and an enzymatic hydrolysis process with steam explosion as pre-treatment. In fact, these first results are very modest, so, some improving considerations are also showed, as the use of sugarcane trash to accomplish the energetic needs.*

Keywords: sugarcane, ethanol, enzymatic hydrolysis

1. INTRODUCTION

The conversion of biomass into biofuels represents an important option for the exploitation of an alternative source of energy and the reduction of polluting gases, mainly carbon dioxide. Thus global warming issues have been increasingly a focus of attention and greater use of biofuels, which have been able to compete with (and displace) petroleum-based fuels in the transportation market. However, the extent to which biofuels can displace fossil fuels depends on the way they can be produced due to all processing technologies involved (directly and/or indirectly) in the use of fossil fuels (Cardona and Sánchez, 2006).

Among the biofuels, ethanol is the one that is attracting most attention; it is already produced in large scale (Brazil and USA) and it can be easily blended with gasoline to operate in spark ignition (SI) engines. In Brazil, ethanol is used in 100% alcohol-fuelled passenger cars (hydrous ethanol) or is blended (anhydrous ethanol) with gasoline in proportions of usually about 24% to operate in gasoline engines; or it is still used (as hydrous ethanol) in any proportion in flexible-fuel vehicles (FFV) (Macedo et al. 2008, BNDS and CGEE, 2008).

Ethanol can be manufactured by fermentation and distillation of sugar based raw materials (sugar beet, sugar cane), starch-based raw materials (wheat, rye, corn) and by-products of food industry (molasses) (Lagioia et al. 2005). However another potential feedstock for ethanol production is the "lignocellulosic biomass" which can be converted to ethanol by hydrolysis and subsequent fermentation.

The importance of lignocellulosic biomass is evident due to lignocellulosic complex is the most abundant carbohydrate in the Earth and it is present in abundant materials like sugarcane bagasse, wood chips, sawdust, paper residues and grass. Thus nowadays, the ethanol production from lignocellulosic materials through hydrolysis process is being researched all over the world, including the installation of pilot plants to test different process types.

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. The aim of this study is to make a diagnosis of the real possibilities of ethanol production increasing through the bagasse hydrolysis process, considering the limiting situation of bagasse use. A simulation in ASPEN PLUS® software was performed, in order to evaluate the mass and energy balances, for both, integrated

processes. Thus, in this study, an initial assessment of the possibilities of integration of both technologies is performed, considering first a standard ethanol production plant and an enzymatic hydrolysis process with steam explosion as pre-treatment.

2. SIMULATION OF THE ETHANOL PRODUCION PROCESS

2.1. Conventional ethanol production process from sugarcane

In this study, it was modeled a sugarcane plant with a sugarcane crushing rate of 490.2 t/h for production of anhydrous ethanol.

Sugarcane that arrives to the factory contains some amount of soil that is carried in the harvesting operation, cleaning process upon reception is necessary. Dry cleaning was considered in the simulation with an efficiency of soil removal of 70%.

After dry cleaning operation, sugarcane goes to the extraction system where sugarcane juice and bagasse are obtained. An extraction system with mills was considered. The imbibition water rate considered is 300 kg of water/t of sugarcane and the efficiency of sugar extraction is 97% (Ensinas 2008).

Raw sugarcane juice goes to the physical-chemical treatment which begins with screening operation in order to remove sand and fibers. After that juice goes to phosphatation operation, where small amounts of soluble phosphate may be added to juice to improve simple defecation. It is generally done adding phosphoric acid or other phosphates in a powder or past form. In this simulation, diluted H_3PO_4 (85%) is added in order to increase the amount of phosphates in juice until 0.03% (Rein, 2007). The phosphate juice is heated until 70°C and after that goes to liming operation. In liming operation, milk of lime is added to the juice as a mixture of $Ca(OH)_2$ and water. For the calculation of mass flows of $Ca(OH)_2$ and water, it is considered a lime consumption of 0.9 kg of CaO/t of sugarcane as well as a concentration of $Ca(OH)_2$ of 5°Bé in milk of lime (CTC, 2009). After liming, there is a second juice heating until 105°C. Hot juice is flashed in order to remove air bubbles and subsequently it is sent to decantation stage, where clarified juice and mud are obtained. Clarified juice goes to concentration stage while mud is mixed to bagacillo before to the filtration stage in order to recovery some sugars carried along with the mud. The filtrate is recycled, and a filter cake is obtained in an amount of 36.6 kg/t of sugarcane, as consequence of the juice treatment process.

In order to obtain a sugar concentration in juice adequate to fermentation process, 39% of clarified juice with an original sucrose content of 11.8% is concentrated in an evaporation system of multiple effects until a sucrose content of 55.4%. In the evaporation system, part of vapors that resulted of concentration are used to supply heat duties in the plant and the other part is used in the next evaporator body as heating source, giving as well secondary condensate. Thus, in the simulation vapor bleed of first effect is used for heating of sugarcane juice treatment stage.

Then original clarified juice is mixed with the concentrated juice, resulting in must with a sucrose content of 16.9%. The sterilization of must is done using a treatment type HTST (High Temperature Short Time). In this treatment, must is heated until 130°C, staying in this temperature for approximately 30 minutes. After that, there is a fast cooling until fermentation temperature in the range of 32°C (Dias, 2008).

In this study, fermentation was based on the Melle Boinot process (batch fed fermentation with cell recycle). A conversion yield of 89% from sugars to ethanol is considered. Other fermentation by-products are considered in the simulation such as glycerol, succinic acid, acetic acid, isoamyl alcohol and yeast according conversion data reported in Eijsberg (2006). At the end of the fermentation, the wine is centrifuged to recover most of the yeast. The yeast cream obtained is submitted to an acid treatment with H_2SO_4. An absorption column is considered in order to recovery the ethanol carried in fermentation gases. Final wine has an ethanol content of 6% mass (approximately 7.4 GL).

After that, wine goes to distillation stage. A conventional distillation system was simulated considering the columns A, A1, D and B-B1 according Meirelles (2006). Wine is preheated and fed in column A1 while vinasse is produced at the bottom of column A. Liquid and vapor phlegms are produced with ethanol content of 42% approximately in bottom of column D and near the top of column A respectively. Phlegms are fed in the rectification column were hydrous ethanol and phlegmasse are produced. Ethanol content of hydrous ethanol is 93.7% while ethanol content of vinasse and phlegmasse is 0.02% according Meirelles (2006) and Fingerut et al. (2008). Alcohol of second grade is obtained in column D with ethanol content of 91.3%.

Dehydration of ethanol was simulated considering the extractive distillation with monoethyleneglycol (MEG), which considers the extractive column operating at atmospheric pressure and the recovery column at 20 kPa (Dias, 2008). Anhydrous ethanol is obtained with ethanol content of 99.4% mass basis.

The cogeneration system adopted in this simulation consists of a steam cycle with backpressure steam turbines and parameters of live steam of 67 bar and 480°C. Steam turbines have an extraction at 22 bar for direct driven turbines and at 6 bar for requirements in process of sterilization of must and dehydration of ethanol. The sugarcane boiler was simulated in ASPEN PLUS using a stoichiometric reactor and heat exchangers according studies of Palacios-Bereche and Nebra (2009) and Magnusson (2005).

Figure 1 shows a block diagram of conventional ethanol production process integrated with ethanol plant.
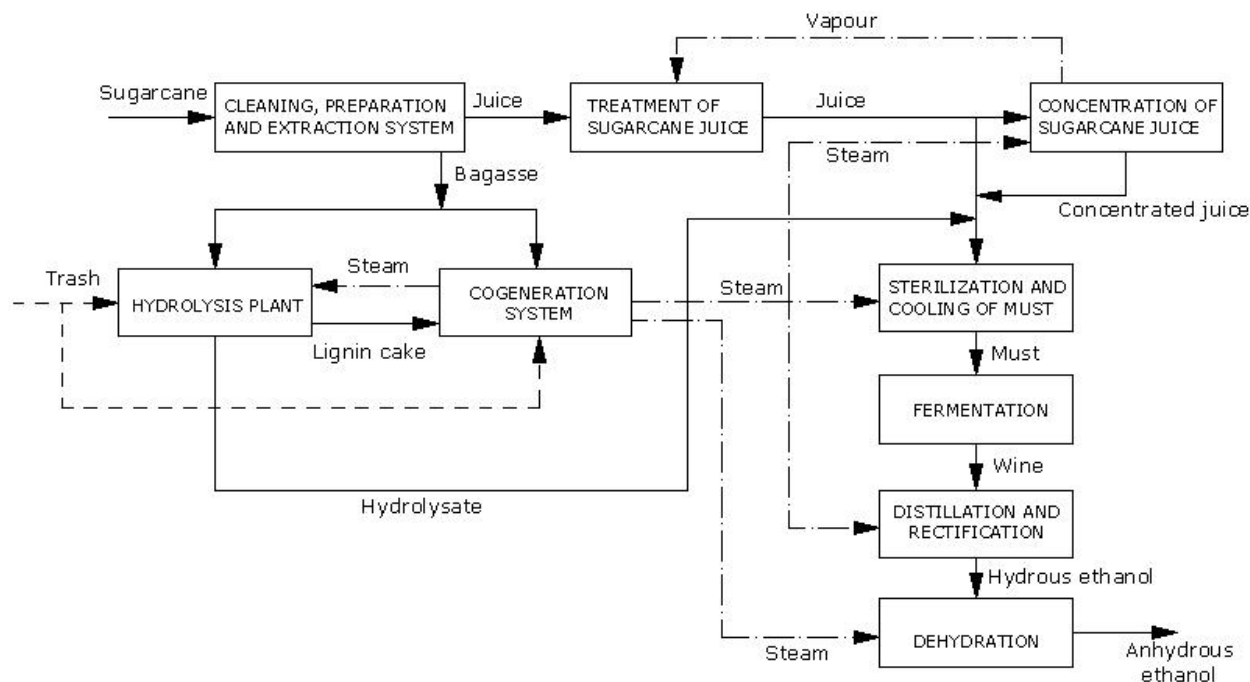
Figure 1. Ethanol production process – Conventional process integrated with hydrolysis process

2.2 Sugarcane residues utilisation

Due to ethanol production process by enzymatic hydrolysis needs energy to operate, the use of lignin cake, which is a byproduct of hydrolysis process, is considered. However, from simulations results, there is still a deficit of energy in the process. For this reason, in this study, the use of sugarcane trash is considered in order to supply all the energy required.

The amount of residues from sugar cane harvesting depends on many factors such as: harvesting system, topping height, cane variety, age of crop, climate, soil and others. In this study it is considered an average trash potential of 140 kg of dry residues per tone of cane stalks (Hassuani et al. 2005; CGEE 2009) and that trash left in field is 50% of total according Michelazzo (2005). The method of trash recovery adopted is baling being the moisture content of trash baled 13% (Hassuani et al. 2005). Thus, considering the mass flow rate of cane, the mass flow rate of trash carried to factory is 39.44 t/h (wet basis).

For simulations, it is considered that trash and lignin cake are burned in boiler with LHV efficiency of 86%. The composition of trash in terms of cellulose, hemicelluloses and lignin used in this study was taken from Pelaez (2007) as well as the HHV of 16.5 MJ/kg (dry basis). The LHV is calculated considering the hydrogen and moisture content in trash. The LHV of trash resulted in 14.2 MJ/kg (wet basis).

Rein (2007) recommend that tops and trash amount, in mass, for boiler should be between 10 and 25% due to trash ashes usually have sufficient sodium an potassium in them to cause boiler fouling if they are burned on their own. From this limitation it is considered that one part of trash is burnt in the boiler and the other part is sent to the hydrolysis process.

2.3. Ethanol production by enzymatic hydrolysis

The degradation of the lignocellulosic materials requires two steps; the first step is the pretreatment for the solubilization of the hemicelluloses and releasing the lignin and the second step is the hydrolysis of cellulose.

The purpose of the pretreatment is to remove lignin and hemicelluloses, reduce cellulose crystallinity, and increase the porosity and contact area of the materials to let the cellulase enzymes gain access to the cellulose molecules (Sun and Cheng, 2002). During the pretreatment of lignocellulosic material the hemicelluloses fraction is also hydrolyzed.

There are several different pretreatment methods proposed by researchers and engineering companies (Efe, 2005). Physical, physical-chemical, chemical and biological treatments have been proposed for the pretreatment of lignocellulosic materials. For example there is mechanical pretreatment (chipping, grinding or milling), the pretreatment by steam explosion, ammonia explosion (AFEX), CO_2 explosion, wet oxidation, ozonolysis, acid hydrolysis, alkaline hydrolysis, organosolv etc. In this study the pretreatment by steam explosion is considered due to data are available in literature and also because use water as working fluid.

In the second step the cellulose chains are broken down in order to produce glucose for the fermentation step. Enzymatic hydrolysis has demonstrated better results during fermentation because no degradation products of glucose are formed although the process is slower.

For the simulation in ASPEN PLUS, new components are defined in simulator such as cellulose enzymes, furfural, hydroxymethylfurfural (HMF), and xylose. Parameters of pure component for cellulase component were obtained from Wooley and Putsche (1996). Properties of HMF are considered the same as furfural component.

Figure 2 shows the flowsheet of the ethanol production process by enzymatic hydrolysis considered in this study. Thus part of the trash that arrives to the mill (TRASH2) is crushed in block MILL-TR and after it is mixed with bagasse for hydrolysis B2. The power of trash crusher is considered 110 HP per a trash flow of 1000 kg/h according data from Hassuani et al. (2005).

The amounts of trash and bagasse for hydrolysis are defined after an iterative process, because the increase of raw material for hydrolysis increases the steam consumption of the plant; thus the amount of bagasse and trash for steam generation should be enough to satisfy the energy requirements of the plant, and so on.

About the raw material for hydrolysis, some authors (Carrasco et al. 2010) indicates the need of cleaning (washing) previous the pretreatment reactor in order to remove impurities. This operation would reduce the amount of reactants in subsequent stages of hydrolysis. As this study is an initial assessment, previous washing of bagasse and trash it is not considered.

After that, stream B2-I is sent to pretreatment reactor PRE-TREA. Some studies indicate that it is not necessary the addition of a catalyst in steam explosion reactor due to it is an autocatalytic process: there is a division of water molecules in their ions H+ and OH- which hydrolyses hemicelluloses and also the formation of acetic acid which catalyzes the reactions. Thus Silva (1995) reports conversions of 73% of xylans in pretreatment with steam explosion without addition of catalyst. On the other hand, some researchers indicate that the addition of acid catalyst such as SO_2 or H_2SO_4 is necessary in order to achieve higher yields of hemicelluloses conversion. In this study it is adopted the addition of catalyst SO_2 in pretreatment reactor in a rate of 2% w/w according the study of Carrasco et al. (2010). In the simulation, the conditions of pretreatment reactor are set in T=190°C and P=12.5 bar.

In the pretreatment reactor, it is considered the formation of xylose ($C_5H_{10}O_5$), acetic acid ($C_2H_4O_2$), furfural and glucose ($C_6H_{12}O_6$) according reactions reported by Dias (2008).

$$C_5H_8O_4 + H_2O \rightarrow C_5H_{10}O_5 \tag{1}$$
$$C_5H_8O_4 + H_2O \rightarrow 2.5\ C_2H_4O_2 \tag{2}$$
$$C_5H_{10}O_5 \rightarrow FURFURAL + 3\ H_2O \tag{3}$$
$$C_6H_{10}O_5 + H_2O \rightarrow C_6H_{12}O_6 \tag{4}$$

Product yields for pretreatment reactor (xylose, acetic acid, glucose and furfural) were calculated from data of Carrasco et al (2010). Tab. 1 shows these yields.

Table 1. Yields considered for the reactions in pretreatment reactor

Product	Yield (%)	From component
Xylose	61.4	Hemicelluloses
Acetic acid	9.2	Hemicelluloses
Furfural	5.1	Xylose
Glucose	4.1	Cellulose

It was not considered glucose formation from hemicelluloses; and the formation of hydroxymethylfurfural (HMF) is neglected. Sulfurous acid H_2SO_3 is formed from catalyst SO_2 and water.

About steam consumption for pretreatment by steam explosion, Kling et al. (1987) inform experimental data of steam requirements for sugarcane bagasse in the range of 0.55 to 0.65 kg of steam /kg moist bagasse on moist bagasse weight basis for the range of moisture content of 38.6 – 65.5%. In this study it is adopted a steam consumption ratio of 0.55 kg of steam/kg of raw material (moisture content 40.5%).

The decompression in pretreatment tank is represented by the expansion valve VE2 and the unitary block FLASH-3 which operates at 1.01bar. Hence there is the steam flashed ST-FLASH and the pretreated material B-PRE1.

In order to remove xylose and other components that could inhibit the posterior process of enzymatic hydrolysis pretreated bagasse is washed in unit block SEPA-XY. After that, two fractions are present: the liquid fraction L-XY (xylose liquor) and the solid fraction CEL-LIG. The efficiency of solids in solution removal is considered 90% and the loss of soluble lignin is considered 6.3%, according data of Carrasco et al. (2010). The amount of water for xylose

washing was estimated in two times the mass flow of pretreated material B-PRE1. The moisture content of solid fraction CEL-LIG is adopted as 60%. In this simulation the use of xyloses liquor is not considered.

For the next stage, water is added to process (stream W-HYDROI) in order to achieve an appropriate concentration of water insoluble solids (in this study 5%) in the hydrolysis reactor. Thus the stream CEL-LIG2 goes to the hydrolysis reactor R-HIDROL where enzymes (stream ENZYME) are added to catalyze the hydrolysis reactions.

The temperature in hydrolysis reactor is adopted as 40°C (Carrasco et al. 2010; Cardona and Sanchez 2006). The amount of enzymes used for hydrolysis is calculated from the ratio of 0.114 g de enzyme/g of dry pulp treated.

The following reactions are specified in hydrolysis reactor with conversion yields of 69.2% and 35.7% for Eq. (5) and (6) respectively (Carrasco et al. 2010).

$$C_6H_{10}O_5 + H_2O \rightarrow C_6H_{12}O_6 \tag{5}$$
$$C_5H_8O_4 + H_2O \rightarrow C_5H_{10}O_5 \tag{6}$$

After hydrolysis stage, the hydrolysate goes to filter in order to separate the lignin cake (CAKE-LIG) of the glucose hydrolysate (LI-GLU). It is considered that solid fraction has a moisture content of 70%. The energy consumption of separators SEPA-XY and SEPA-LT is considered in 0.4 kWh/m^3 according UTS (2009).
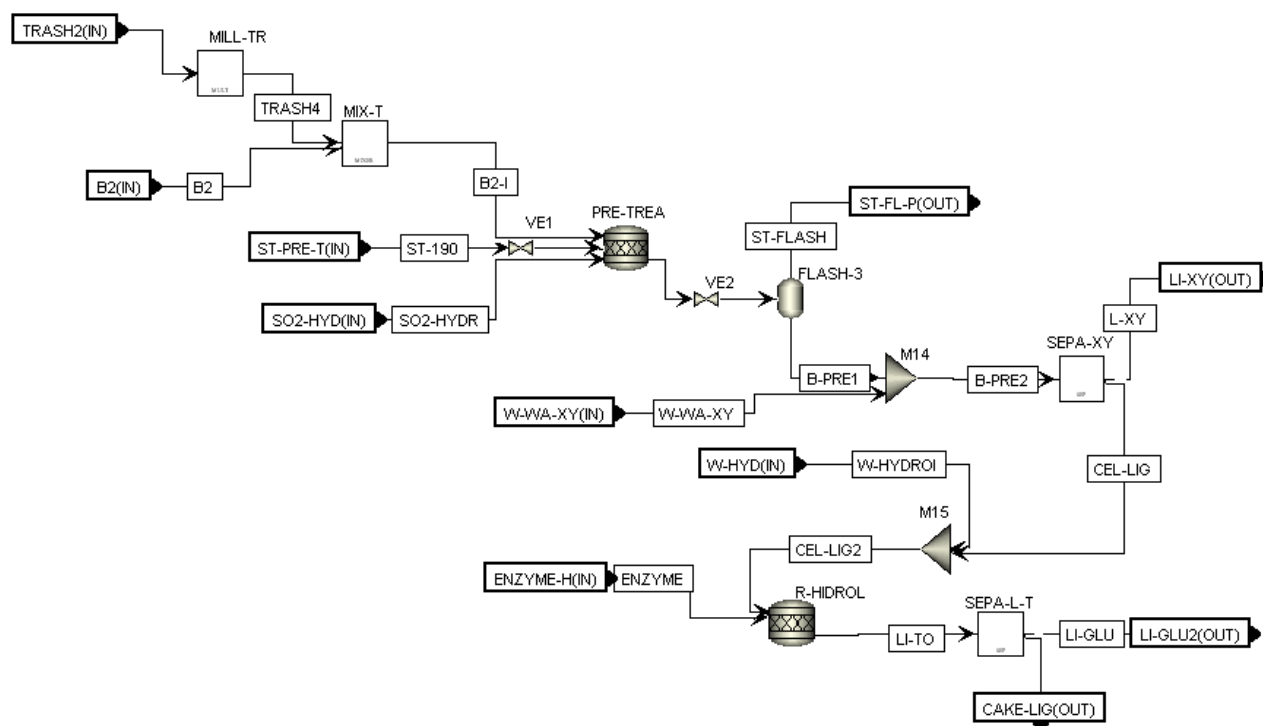

Figure 2. Flowsheet of enzymatic hydrolysis process in ASPEN PLUS ®

3. ENZYMATIC HYDROLYSIS INTEGRATED WITH CONVENTIONAL ETHANOL PRODUCTION PLANT

In order to integrate the ethanol production by hydrolysis process to conventional production process, it is necessary to concentrate the hydrolysate LI-GLU until appropriate Brix content to fermentation process. Moreover steam for steam explosion pretreatment should be supplied from the cogeneration system and lignin cake should be burnt in order to satisfy the heat requirements for steam generation.

In this study steam for steam explosion pretreatment is taken at outlet of desuperheater of direct driving turbines in the cogeneration system. Then, part of the steam at 22 bar 300°C is sent to the hydrolysis process while the other part goes for direct driving turbines. In this study it is considered that steam pass through expansion valve before to get into the pretreatment reactor to reduce its pressure until 12.5 bar adopted in this study. Sanchez and Cardona (2008) indicates conditions of pretreatment by steam explosion with saturated steam in the range of 160-290°C and 6.9-48.5 bar, hence there is a flexibility in relation to the conditions of steam for steam explosion.

Hydrolysate of glucose obtained at the outlet of separator SEPA-L-T has a glucose content of 1.5% wt., thus it is sent to a concentration plant, showed in Fig 3.
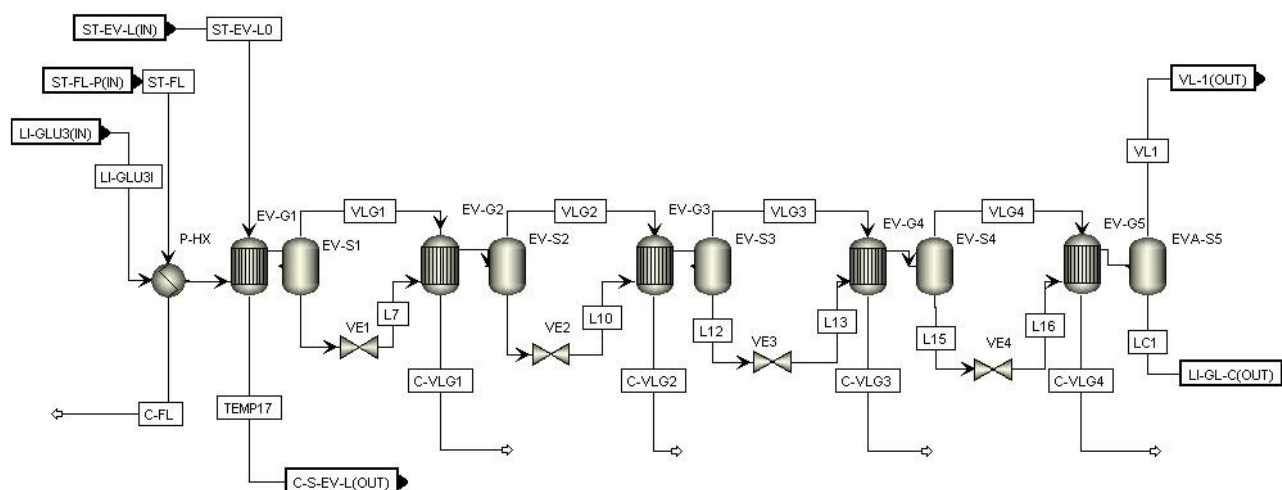
Figure 3. Concentration of hydrolysate of glucose in ASPEN PLUS ®

Hydrolysate of glucose LI-GLU3I is preheated in the heat exchanger PHX with steam flash recuperated from the pretreatment decompression (Fig. 3). After that hydrolysate goes to evaporation system which operates with exhaust steam ST-EV-L0 at 2.5bar. It was considered an evaporation system of five stages in order to reduce the steam consumption. For simulation, each stage is compounded by a unit block heat exchanger and a unit block flash separator in the same way (including operation pressures) that evaporation system considered for concentration of sugarcane juice. The Brix content for concentrated hydrolysate LI-GL-C was specified in 19.8.

Due to possible presence of soluble lignin in glucose hydrolysate as well as phenolic groups (they were not considered in this simulation) it is recommended the detoxification of glucose hydrolysate before its mixture with must of sugarcane juice (Cardona and Sanchez, 2006; Walter and Ensinas, 2008). In this simulation it is considered that the components acetic acid, furfural and sulfurous acid were removed before to mixture with must.

Condensate of exhaust steam from evaporation system C-S-EV-L returns also to cogeneration system in order to evaluate the increase of steam consumption due to hydrolysis process.

In order to recuperate the heat value of lignin cake, stream CAKE-LIG is sent to unit block PRENSA where its moisture content is reduced to 50%. After that lignin cake is sent to unit block BURNER2 (stoichiometric reactor) where it is burned. The stream of exhaust gases EG6 which has a high energetic content is sent to cogeneration system where it is joined to exhaust gases EG0 of mean boiler.

The heat value of lignin cake was estimated in simulator ASPEN PLUS considering that it burns in a stoichiometric reactor at standard conditions T=25°C and P=1.01325 bar. The water content and the molar fraction of water in exhaust gases were taken into account to calculate the lower heating value LHV. From this procedure the HHV resulted in 11219 kJ/kg of lignin cake while the LHV resulted in 9155 kJ/kg of lignin cake.

4. RESULTS OF SIMULATION

Table 2 shows the inputs and products for the analyzed cases being the "Case 1" the conventional ethanol production process and the "Case 2" the ethanol production plant with enzymatic hydrolysis.

From iterative calculation the mass flow of trash necessary to be burnt in boiler was determined according limitations specified in item 2.2. Thus, the amount of bagasse for hydrolysis resulted in 30.95 t/h, which represents 25% of total bagasse produced in the extraction system.

From enzymatic hydrolysis process the mass flow of glucose liquor resulted in 345.3 t/h with a glucose content of 1.5%. The amount of lignin cake resulted in 26.5 t/h with a lignin content of 21.2 %; others components of lignin cake are cellulose, hemicelluloses, water, ashes and cellulase enzyme. It is considered that components of lignin cake are burnt and its released heat represents 22.2% of the energy necessary to steam generation; on the other hand, the heat from trash represents 36.35% and the heat from bagasse represent 57.5%.

The increase of anhydrous ethanol production in Case 2 resulted 2310.3 kg/h which represent an increase of 7.6% in anhydrous ethanol production.

Surplus electricity in Case 2 shows a high increase due to the increase of steam generated in the boiler. The increase of surplus electricity in Case 2 resulted 67.2% in comparison with Case 1.Also, it can be observed an increase of 9.37% in vinasse production.

Table 2. Inputs, products and byproducts in ethanol production process: Case 1 – Conventional ethanol production plant; Case 2 – Ethanol production plant with hydrolysis

Parameter	Case 1	Case 2
Cane input, (t/h)	490.2	490.2
Trash for boiler, (t/h)	0	28.7
Trash for hydrolysis, (t/h)	0	10.7
Anhydrous ethanol, (t/h)	30.5	32.8
Alcohol of second grade	0.9	1.0
Surplus electricity, (MW)	22.83	38.17
Bagasse surplus, (t/h)	8.9	0
Vinasse, (t/h)	447.1	489.0

Table 3 shows the steam consumption in Case 1 and Case 2. It can be observed a slight increase in steam consumption at 6 bar and steam consumption of distillation columns and evaporation of sugarcane juice. On the other hand it can be observed that the highest steam consumption corresponds to the concentration of hydrolysate (glucose liquor) which represents 24.5% of total steam consumption. The steam consumption for steam explosion pretreatment represents 5.8% of total steam consumption. Heat loses of 2% in heat exchangers are considered.

About the steam generated in boiler in Case 1 resulted in 245.7 t/h while in Case 2 resulted in 384.9 t/h.

Table 3. Steam consumptions: Case 1 – Conventional ethanol production plant; Case 2 – Ethanol production plant with hydrolysis

	Case 1 m[t/h]	Case 2 m[t/h]
Sterilization of must - 6 bar	24.3	29.0
Dehydration extractive column - 6 bar	11.7	12.5
Dehydration recuperation column - 6 bar	4.1	4.5
Evaporation system - 2.5 bar	98.0	98.0
Distillation column A - 2.5 bar	73.8	80.2
Distillation column B-B1 - 2.5 bar	48.5	53.0
Concentration of hydrolysate - 2.5 bar	0	97.5
Steam Explosion pre-treatment - 12.5 bar	0	22.9

Finally Tab. 4 shows the water uses in Case 1 and Case 2. In Case 2 there is a significant increase due to hydrolysis operations such as washing of xyloses, dilution of pretreated pulp for hydrolysis reactor and the barometric condenser of evaporation system of glucose liquor concentration. The increase in water use resulted 41.3% in comparison with conventional production process (Case 1).

Results of Tab. 4 shows the water needs of sugarcane plant without any closed circuit. The effective collecting water need is determined taking into consideration the water sources to reuse into sugarcane plant and the closing of water systems. The water sources to reuse consider currents which can be reuse directly, such as condensates of evaporation system, or afterward treatment according their quality. About the closing of water systems the water losses in circuits should be considered (Chavez-Rodriguez et al. 2009; Palacios-Bereche et al. 2010); Chavez-Rodriguez 2010).

Table 4. Steam consumptions: Case 1 – Conventional ethanol production plant; Case 2 – Ethanol production plant with hydrolysis

Water Uses	Case 1 (m³/h)	Case 2 (m³/h)
Imbibition	147.2	147.2
Bearings Cooling	24.5	24.5

Oil of Lubrification Cooling	196.1	196.1
Preparing of milk lime	9.4	9.4
Filter Cake Washing	34.3	34.3
Barometric Condenser of Evaporation	653.7	653.7
Barometric Condensers of Filters	92.5	92.5
Cooling of juice for fermentation	1652.7	1914.3
Dilution of milk yeast	66.2	72.4
Cooling of fermentation vats	1975.4	2126.6
Condenser of Destilation	1228.7	1436.3
Condenser of Rectification	364.1	387.0
Condenser of Extractive Column	306.8	351.0
Condenser of Recuperation Column	49.9	56.9
Cooling of solvent	32.8	32.7
Washing Scrubbers(boiler)	429.9	403.9
Boiler feed water	245.7	384.9
General cleaning	24.5	24.5
Drinkable uses	14.7	14.7
Cooling of Turbogenerators	198.0	290.9
Washing xylose (hydrolysis)	0.0	384.9
Dilution of pretreated pulp (hydrolysis)	0.0	344.0
Barometric condenser of glucose liquor evaporator	0.0	1567.5
Total (m^3/h)	7747.1	10950.2
Ratio (m^3/t of sugarcane)	15.8	22.3

5. CONCLUSIONS

The ethanol production from lignocellulosic materials through enzymatic hydrolysis process is being researched all over the world. Thus this study presents an evaluation in terms of energy, steam and water requirements of hydrolysis process integrated to a conventional Brazilian ethanol production plant.

The conventional ethanol production process considered in this study tried to reflect the real situation of major sugarcane factories in Brazil.

The results show that there was a significant increase in steam consumption in processes due to the pretreatment for steam explosion and the hydrolysis route chosen which are intensive in steam use. For this reason the use of the lignin cake and sugarcane trash was necessary to satisfy energy requirements of the new process joined with the current traditional process.

The total production of anhydrous ethanol in "Case 2", which considers enzymatic hydrolysis process presented results very modest; thus it is necessary to improve the plant as well as to practice thermal integration between streams of process in order to reduce the energy consumption and increase anhydrous ethanol production in order to have more bagasse available for hydrolysis process.

More research and experimental studies are necessary in order to accomplish simulations and potential studies more detailed aiming at the optimization of the process. Some aspects in process have not yet an agreement between researchers or there is not data available for industrial scale; for instance some authors indicates that the use of acid catalyst in pretreatment reactor improve the conversion of hemicelluloses while others indicate that it is not necessary due to reactions are self-catalyst. In this aspect the use of acid catalyst should be done carefully because reactors must be constructed with anti-corrosive alloys, which are more expensive. Other aspect is the need of previous washing of bagasse and trash before the pretreatment with steam explosion. The previous washing would remove some impurities carried by harvesting and milling operation reducing the amount of reactants in subsequent stages such as pretreatment and cellulose conversion, however this washing needs additional capital cost for equipment acquisition as well as additional water consumption. In these cases economic feasibility evaluations should be done.

The water use in "Case 2" presented a significant increase. Operations of hydrolysis process such as washing xyloses, dilution of pretreated pulp and barometric condenser of glucose liquor evaporator represent the 21% of the total water use in "Case 2". The water for washing of xyloses was considered in two times the mass flow of pretreated pulp, a higher amount of water would remove more hemicelluloses but it would do the process more intensive in use of water doing it less sustainable. The amount of water for dilution of pretreated pulp considered a final solid content of 5%, lower concentrations of solid content for hydrolysis process increases the conversion of cellulose to glucose however this process also would consume more water. A careful study of water reuse would be also essential.

Research in boiler project is necessary in order to burning sugarcane trash in higher proportions, leaving more bagasse available for hydrolysis process. Trash would be better to burn due its lower moisture content in comparison to sugarcane bagasse. Due to the high content of soil in trash it is necessary also a system of cleaning and preparation for trash before the burning in boilers.

Other types of pretreatments which will be less intensive in steam use should be simulated and evaluated aiming the increase of ethanol production and the sustainability of the process. Finally some improvements in conventional ethanol production process should be done in order to do the hydrolysis process more competitive, for instance the fermentation at lower temperatures such as 24°C, the dehydration with molecular sieves, or also the concentration of glucose liquor with molecular sieves could be tested.

Finally, it can be observed that the production of ethanol by hydrolysis process joined with the conventional process still is limited; in a future with improvements in process and use of xyloses, the ethanol production can be increased turning this new process competitive economically and environmentally.

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