Energy consumption in ethanol production by enzymatic hydrolysis – The integration with the conventional process using Pinch Analysis

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INTRODUCTION

- Ethanol is produced in Brazil in large scale using **sugarcane** as raw material by fermentation of sugars and distillation.

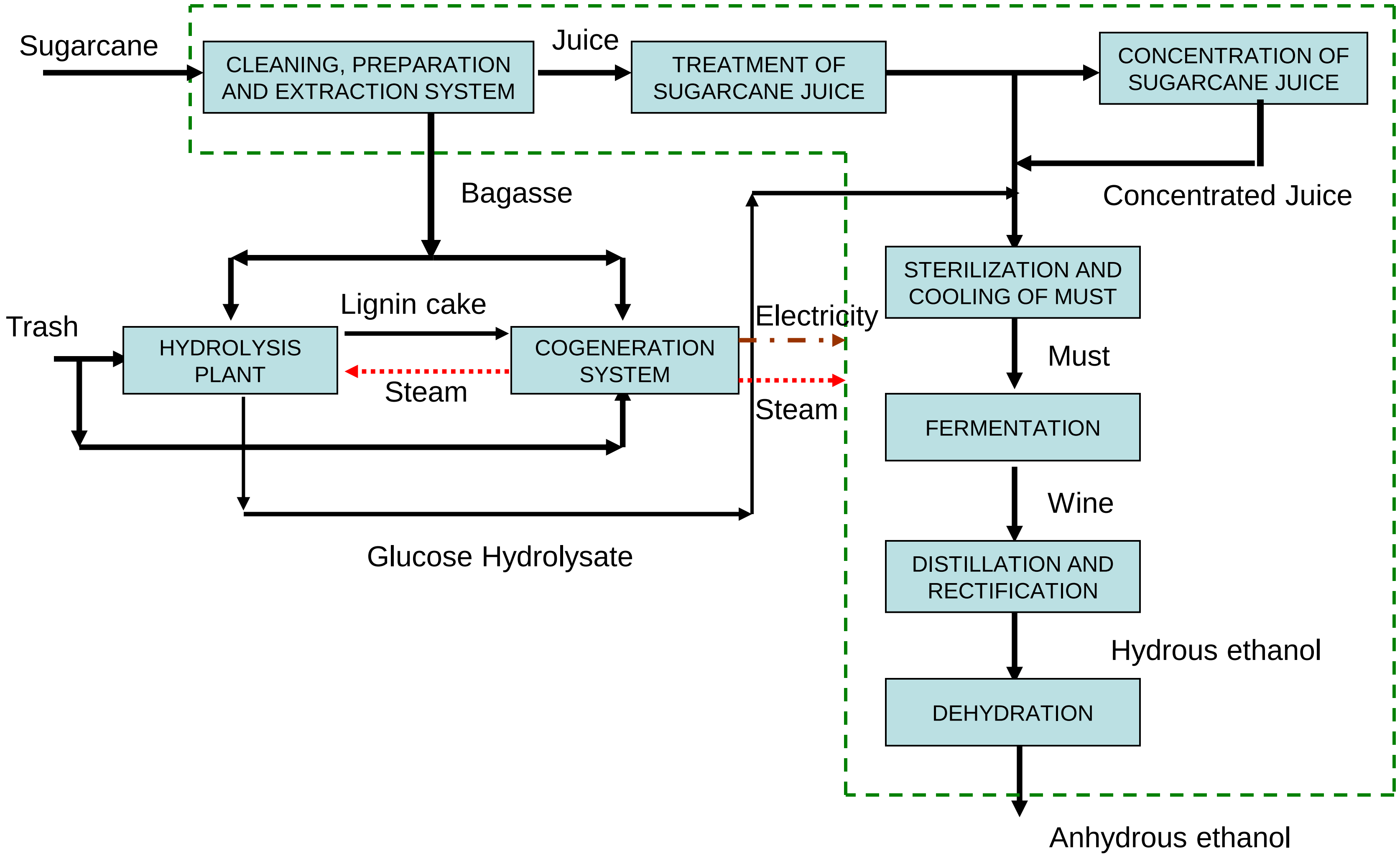
- Nowadays, the ethanol production from **lignocellulosic materials (such as sugarcane bagasse and trash)** through **hydrolysis process** is being researched all over the world including the installation of pilot plants to test different process types..

- 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.

OBJECTIVES

- **Main**
- The aim of this study is to accomplish a diagnosis of the possibilities of ethanol production increase and the consequences in electricity production due to the introduction of enzymatic hydrolysis process of sugarcane bagasse in conventional ethanol production process.
- **Specific:**
- Modeling the ethanol production process (conventional and hydrolysis) in Aspen Plus simulator.
- Research of different options in process aiming the ethanol production increase.
- Thermal integration of process using Pinch-Point method.

ETHANOL PRODUCTION PROCESS



Ethanol production process

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

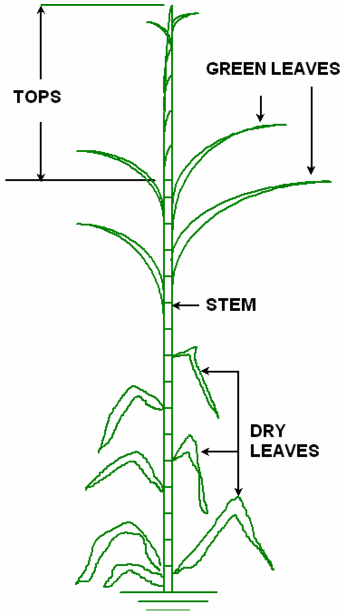
Parameter	Value
Sugarcane crushing rate, t/h	490.2
Efficiency of sugar extraction in extraction system, %	97
Conversion yield from sugars to ethanol, %	89
Ethanol content in vinasse and phlegmasse, %	0.02
Ethanol content in anhydrous ethanol, wt %	99.4

Cogeneration System, it was assumed:

- **Boiler can burn bagasse, trash and lignin**
- **back pressure turbine: the process electric energy produced depends on the steam produced by the boiler**
- **thermal match: the process thermal demand are fulfilled by the boiler steam**

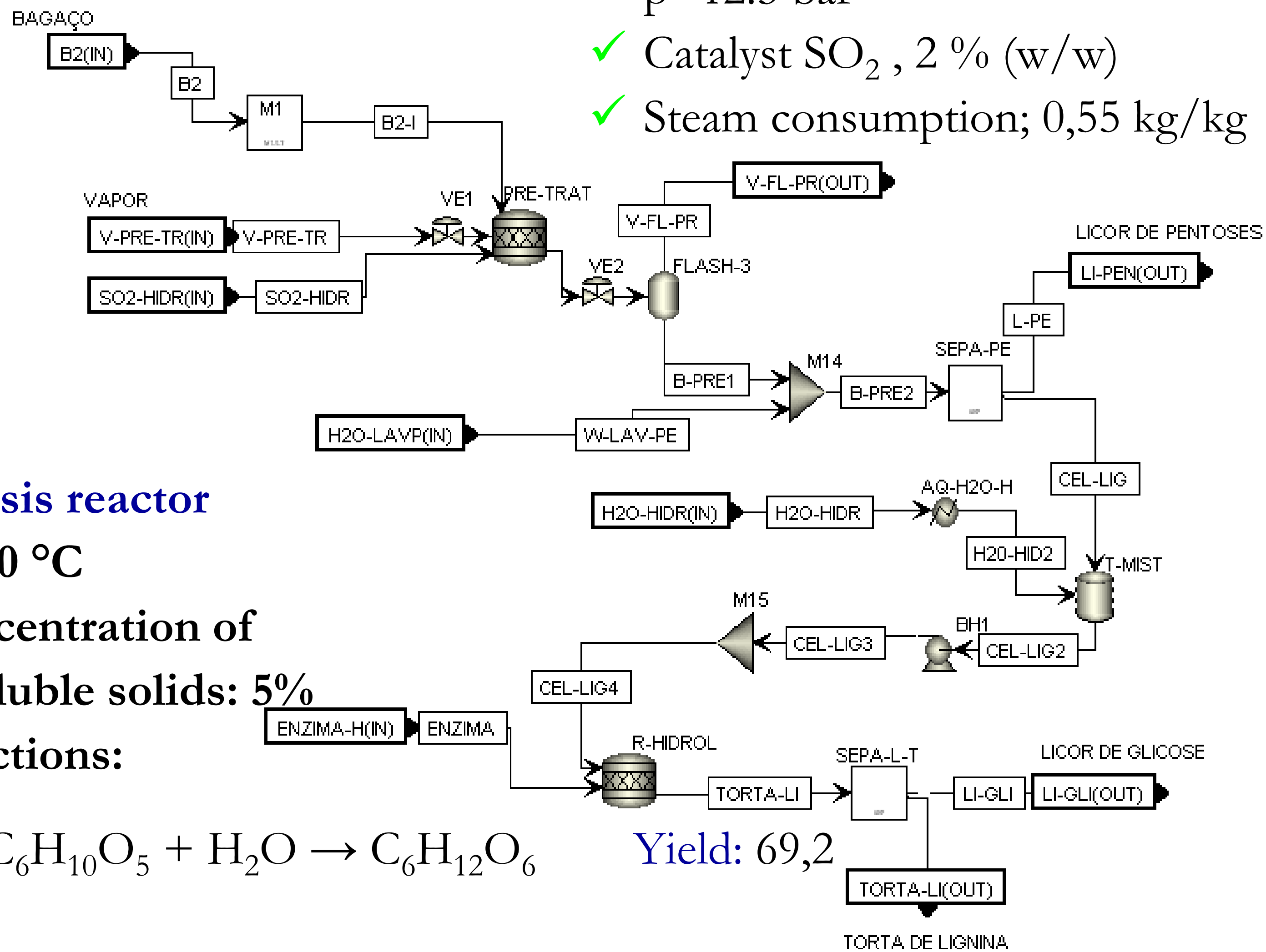
Sugarcane residues utilization

- Average trash potential 140 kg of dry residues per tone of cane stalks.
- Trash left in field: 50% of total
- Moisture content 10%.
- HHV 16,98 MJ/kg (dry basis).
- LHV 13,9 MJ/kg (wet basis).
- It is assumed that trash and lignin cake are burnt in boilers with efficiency of 86% LHV basis.
- Pentose liquor was considered as a useless reject.



Ethanol production by enzymatic hydrolysis

- Pre-treatment reactor
  - ✓ p=12.5 bar
  - ✓ Catalyst SO_2 , 2 % (w/w)
  - ✓ Steam consumption; 0,55 kg/kg

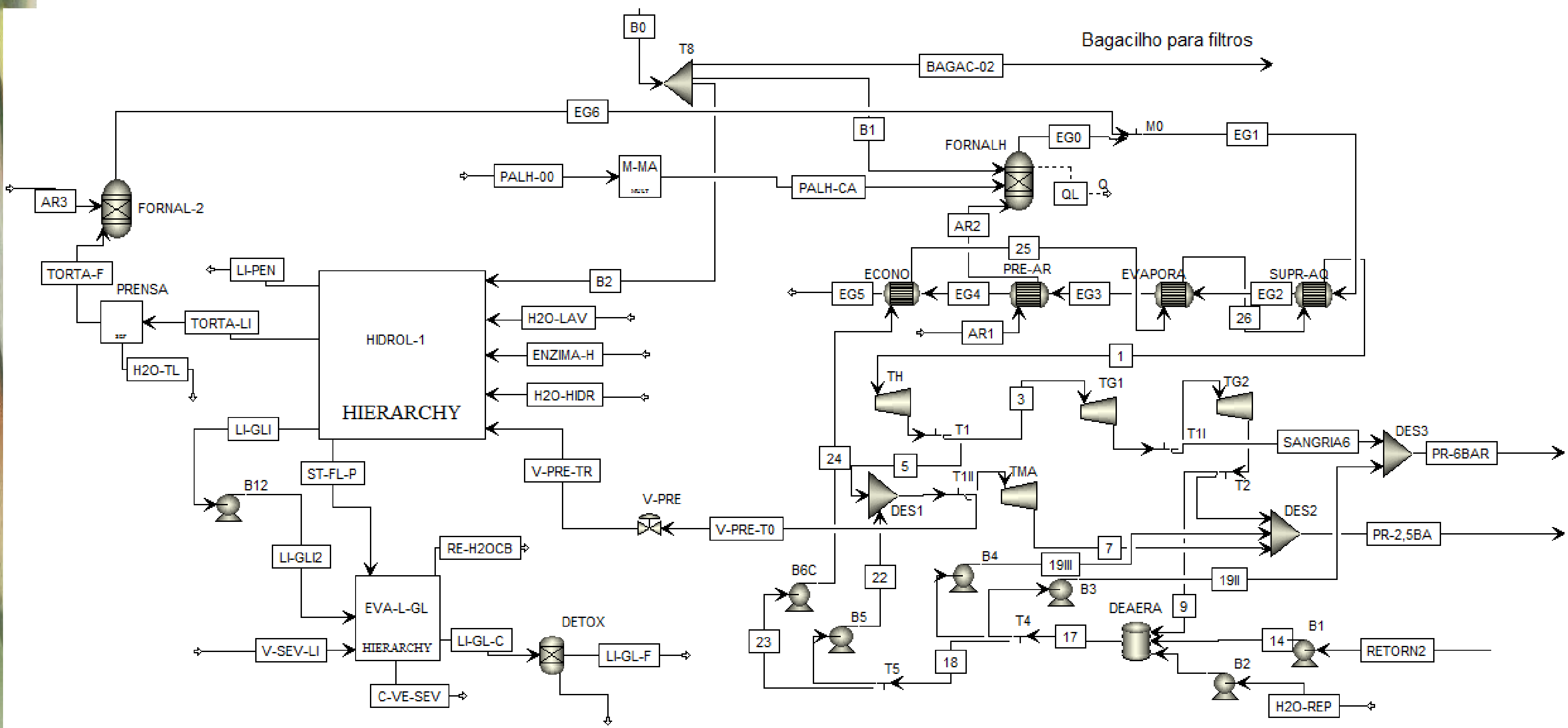


- **Hydrolysis reactor**
  - ✓ **T=50 °C**
  - ✓ **Concentration of**
  - ✓ **insoluble solids: 5%**
  - ✓ **Reactions:**

• $C_6H_{10}O_5 + H_2O \rightarrow C_6H_{12}O_6$ Yield: 69,2

Flowsheet of enzymatic hydrolysis process in ASPEN PLUS ®

Enzymatic hydrolysis process coupled to conventional production process



Flowsheet of enzymatic hydrolysis process integrated to cogeneration system

Enzymatic hydrolysis process coupled to conventional ethanol production process

- **Cases evaluated**
  - ✓ 5% of solid content in hydrolysis reactor
  - ✓ 8% of solid content in hydrolysis reactor
  - ✓ 10% of solid content in hydrolysis reactor

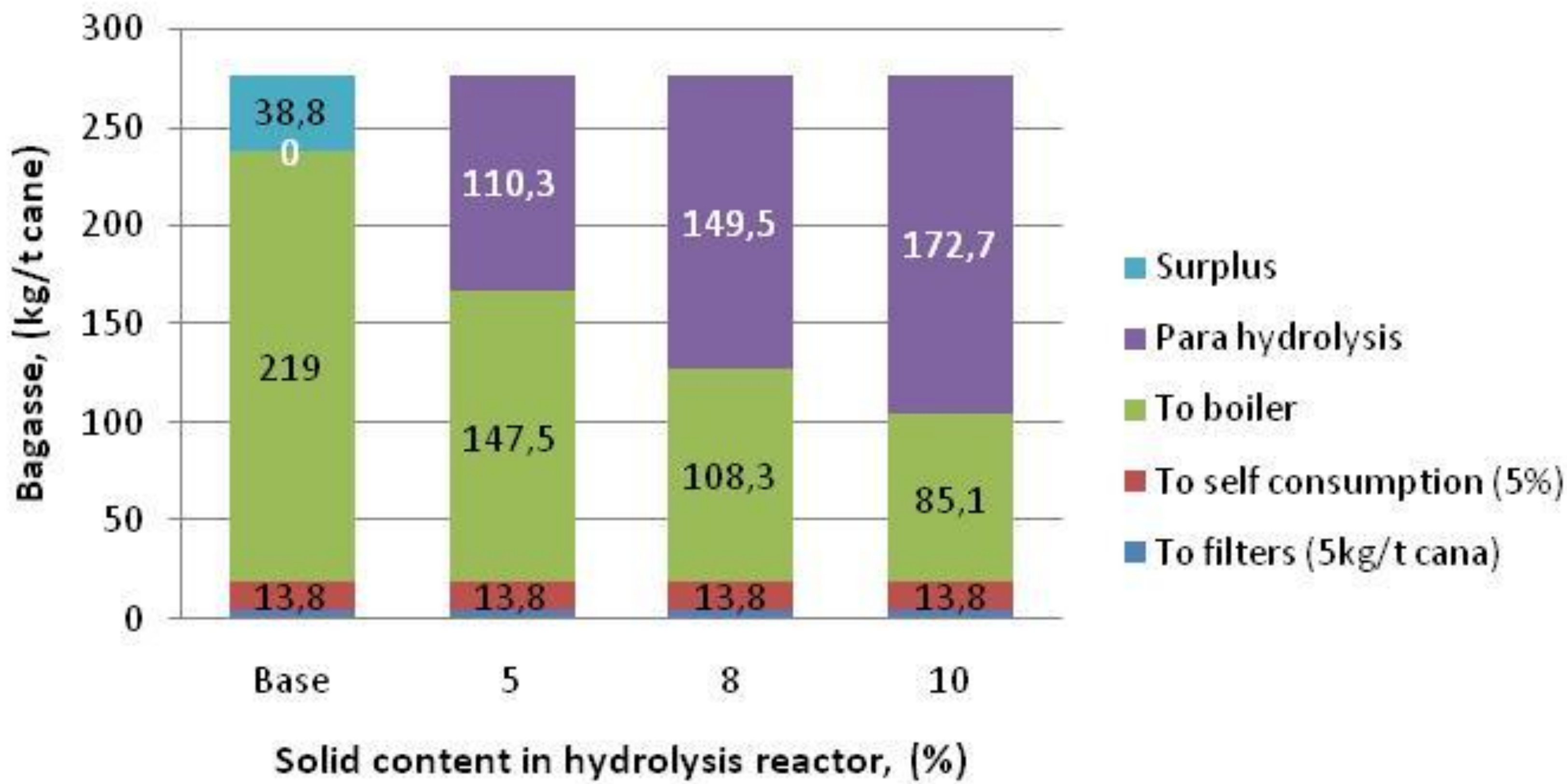
- **Concentration of glucose liquor**
  - ✓ Concentration of glucose liquor using evaporation system
  - ✓ Concentration of glucose liquor using membrane system (reverse osmosis membranes)

RESULTS

Results of simulation – Products and by-products for cases that consider **evaporation system** of 5 effects to concentrate glucose liquor

Parameter	Case I	Case II	Case III	Case IV
Cane crushed, (t/h)	500	500	500	500
Solid content in hydrolysis reactor, (%)		5	8	10
Bagasse to enzymatic hydrolysis (kg/t cane)	0	110.3	149.5	172.7
Bagasse to enzymatic hydrolysis, (%)		39.9	54.1	62.4
Products and by-products				
Anhydrous ethanol , (l/t cane)	79.0	86.7	88.1	88.7
Alcohol of second grade, (l/t cane)	2.3	2.6	2.7	2.7
Surplus of electricity, (kWh/t cane)	42.3	62.5	54.6	51.3
Vinasse (t/t cane)	0.88	0.98	1.00	1.01
Ethanol production increase, (%)		9.7	11.5	12.3
Ethanol production increase, (l/t cana)		7.7	9.1	9.7

RESULTS



Balance of bagasse (kg/t cane) for cases that consider concentration of glucose liquor through **evaporation system**

RESULTS

Electric Energy Consumption –
considering glucose liquor concentration through 5 effects evaporation system

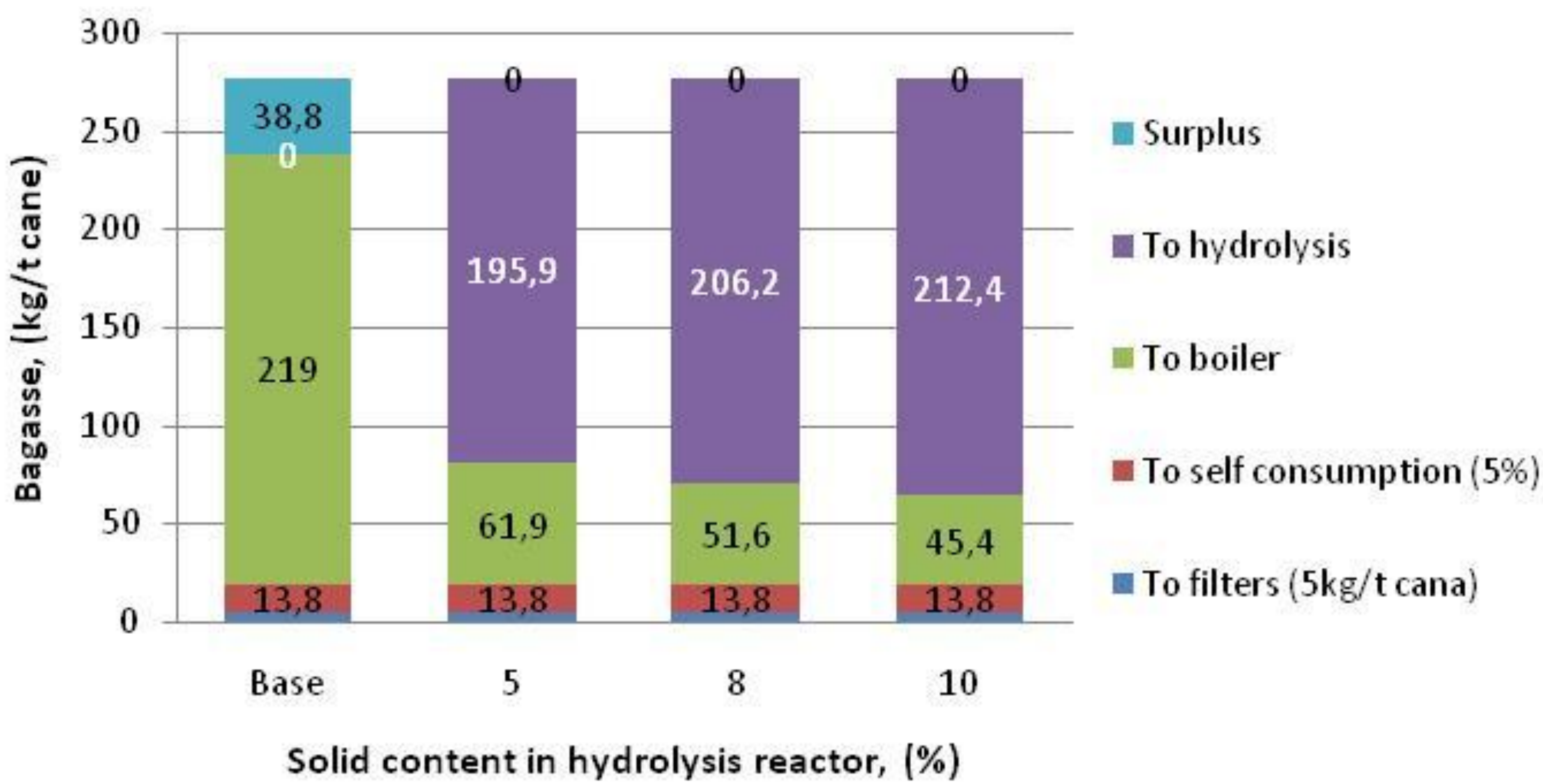
	CASE II	CASE III	CASE IV
CONSUMPTION			
CONVENTIONAL PROCESS, (kW)	6000	6000	6000
TRASH			
TRASH CRUSHER, (kW)	3191	3191	3191
CONVEYORS + FAN, (kW)	529	529	529
HYDROLYSIS			
FEEDER TO PRE-TREATMENT REACTOR, (kW)	25.3	34.3	39.6
BAGASSE CONVEYOR TO CHUTE, (kW)	6.2	9.0	9.8
XYLOSE WASHING – CELULIGNIN SEPARATOR, (kW)	1191.1	1614.1	1864.6
PUMP OF HYDROLYSIS REACTOR, (kW)	24.9	20.4	18.4
AGITATOR OF HYDROLYSIS REACTOR, (kW)	6182.4	5277.7	4825.3
SEPARATOR OF LIGNIN CAKE, (kW)	171.0	143.0	131.1
PRESS OF LIGNIN CAKE, (kW)	658.2	962.1	1163.7
CONVEYOR OF LIGNIN CAKE, (kW)	3.0	4.2	4.6
NON CONCENTRATED GLUCOSE LIQUOR PUMP, (kW)	10.6	8.2	7.1
CONCENTRATED GLUCOSE LIQUOR PUMP, (kW)	4.0	4.9	5.2
CONSUMPTIONS			
TOTAL HYDROLYSIS, (kW)	8 277	8 078	8 069
TOTAL HYDROLYSIS + TRASH PROCESSING (kW)	11 998	11 799	11 790
TOTAL, (kW)	17 998	17 799	17 790
TOTAL HYDROLYSIS (kWh/t bagasse to hydrolysis)	150.0	108.1	93.4
TOTAL, (kWh/t cane)	36.0	35.6	35.6

RESULTS

Results of simulation – Products and by-products for the cases that consider glucose liquor concentration by **membrane system**

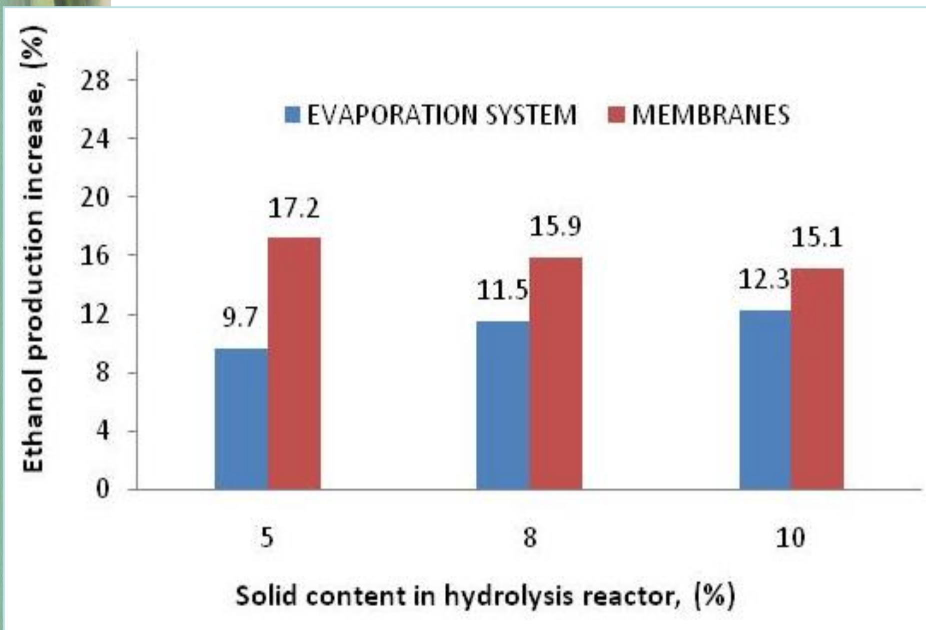
Parameter	**Case I**	**Case II**	**Case III**	**Case IV**
Cane crushed, (t/h)	500	500	500	500
Solid content in hydrolysis reactor, (%)		5	8	10
Bagasse to enzymatic hydrolysis, (kg/t cane)	0	195.9	206.2	212.4
Bagasse to enzymatic hydrolysis, (%)		70.8	74.6	76.8
Products and by-products				
Anhydrous ethanol, (l/t cane)	79	92.6	91.5	90.9
Alcohol of second grade, (l/t cane)	2.3	2.8	2.8	2.8
Surplus electricity, (kWh/t cane)	42.3	25.3	32.9	35.7
Vinasse (t/t cane)	0.88	1.07	1.06	1.05
Ethanol production increase, (%)		17.2	15.9	15.1
Ethanol production increase, (l/t cane)		13.6	12.5	11.9

RESULTS

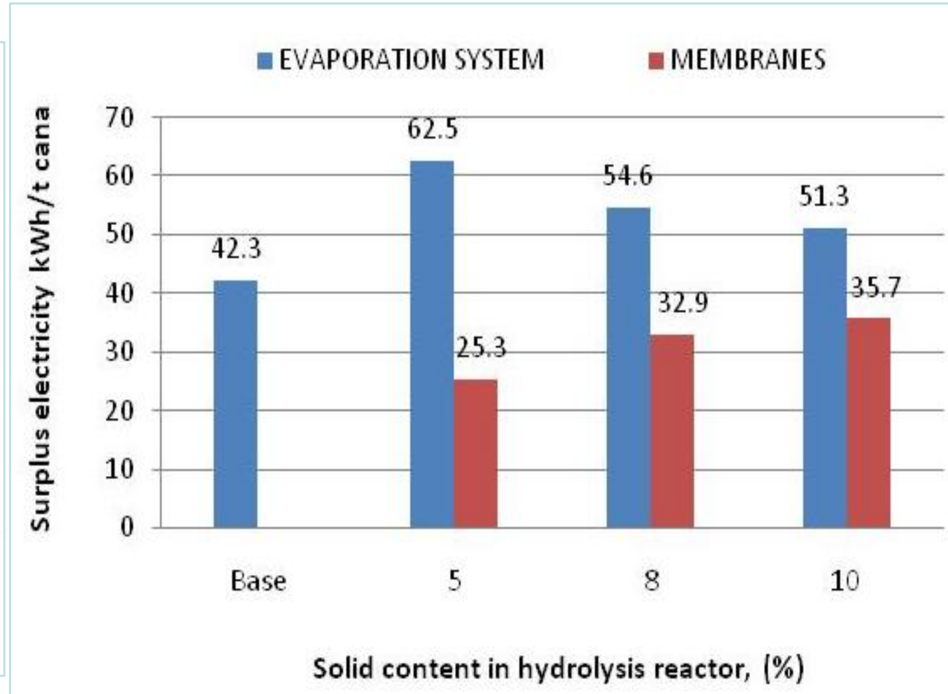


Balance of bagasse (kg/t cane) for cases that consider glucose liquor concentration by **membrane system**

RESULTS



A



B

A) Ethanol production increase (%) ; B) Surplus electricity (kWh/t cane)

THERMAL INTEGRATION USING PINCH POINT METHOD

- Two cases were evaluated to accomplish the thermal integration procedure:

  - Case V - EV: Conventional process + enzymatic hydrolysis process considering 10% of solid content in hydrolysis reactor and glucose liquor concentration by evaporation system.

  - Case VI - ME: Conventional process + enzymatic hydrolysis considering 5% of solid content in hydrolysis reactor and glucose liquor concentration by membrane system.

3. Thermal integration using Pinch Analysis

- The minimum approach difference of temperature (Δtmin) adopted in this study was 10°C for process and 4°C for evaporation system.
- To determine the thermal integration of currents and also the value of vapor bleedings in the evaporation stage, a procedure in four steps is made:
  - Step 1. 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.
  - Step 4. Re-calculation of the steam consumption of overall process until to achieve the convergence.

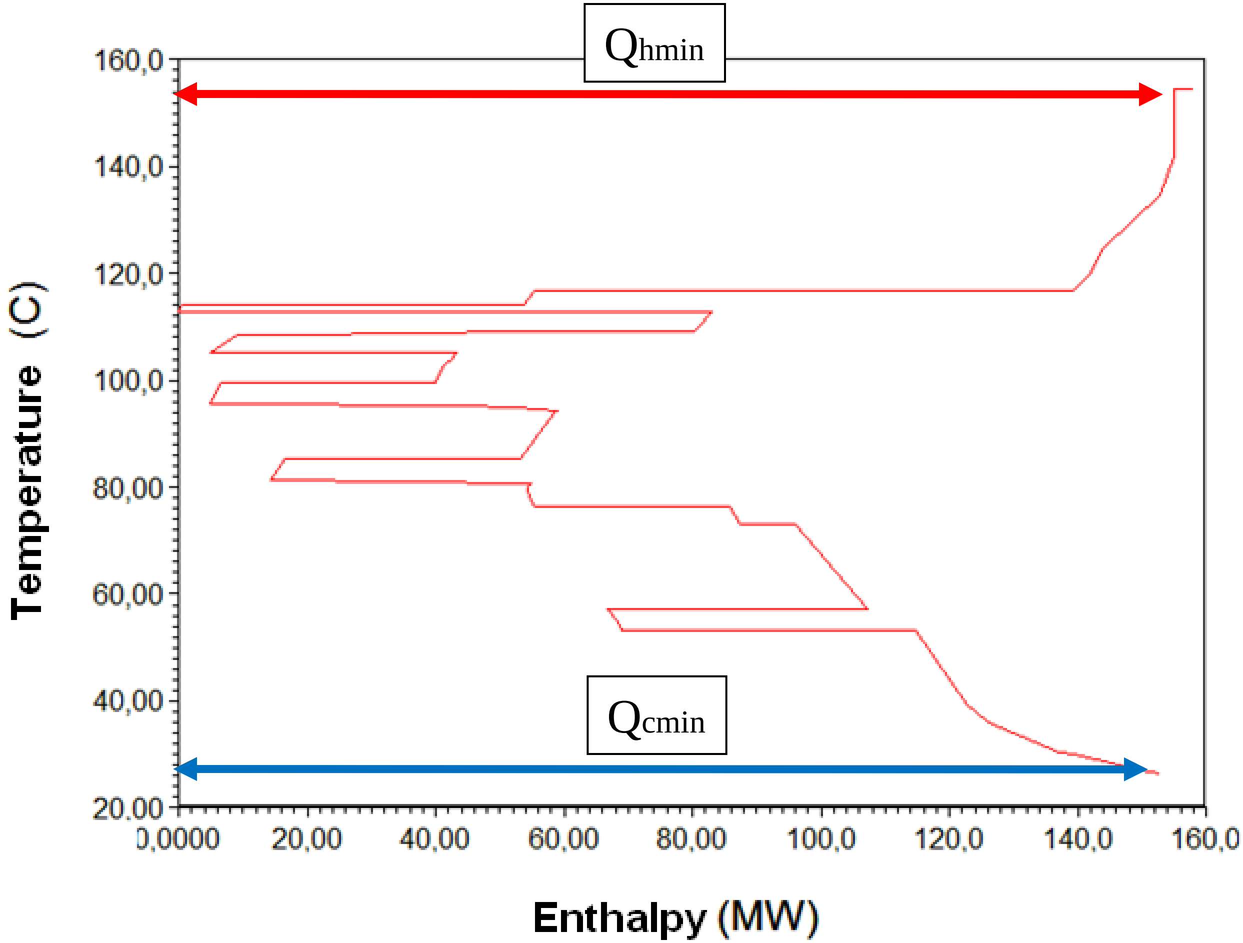
3. Thermal integration using Pinch Analysis

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

THERMAL INTEGRATION USING PINCH POINT METHOD



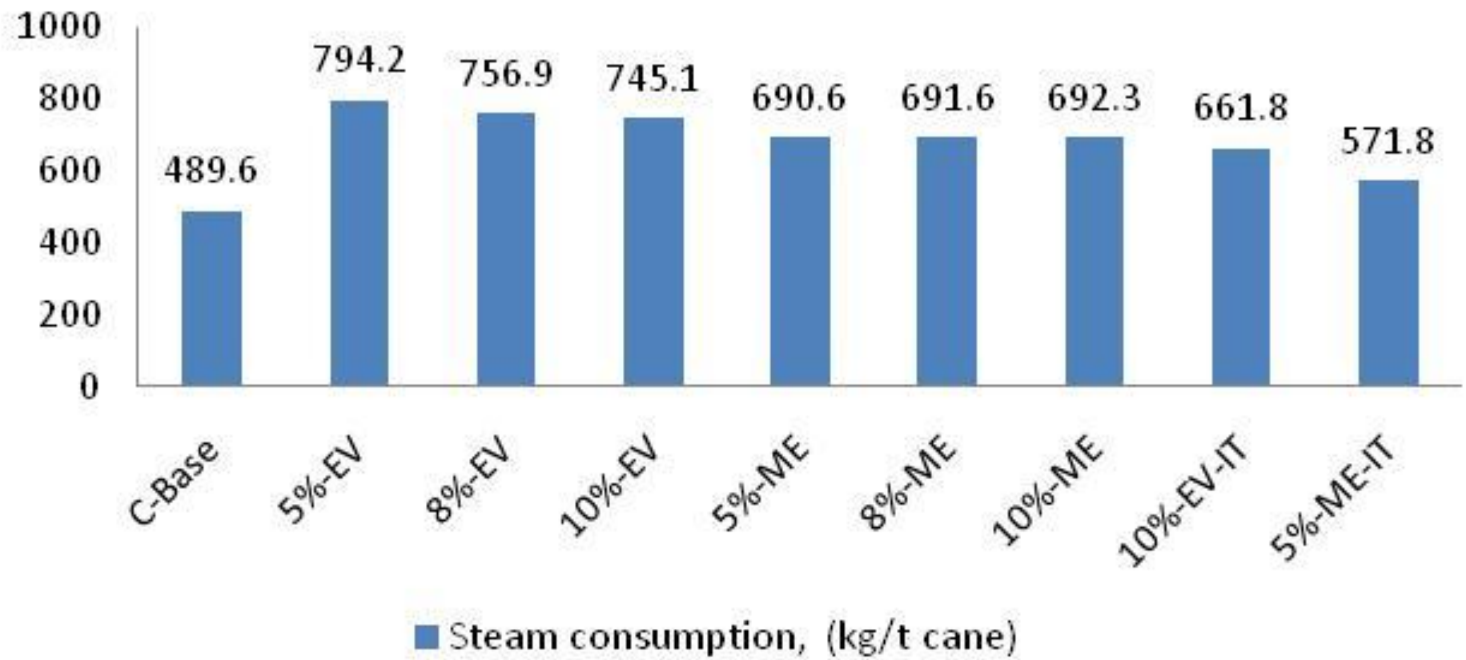
Grand Composite curve for Case V

THERMAL INTEGRATION USING PINCH POINT METHOD

Products and by-products for the integrated cases

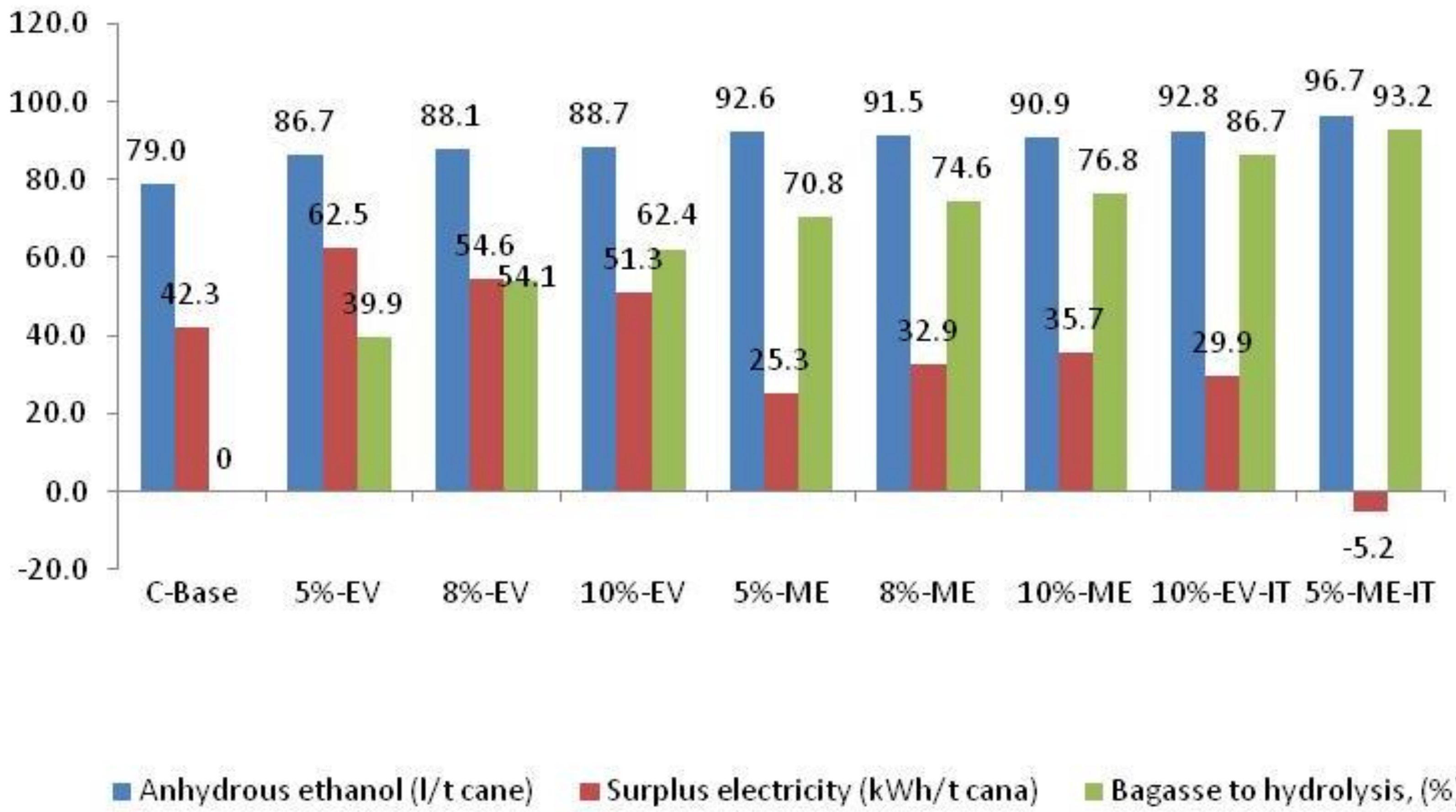
Parameter	Case I	Case V-EV	Case VI-ME
Solid content in hydrolysis reactor, (%)		10	5
Bagasse to enzymatic hydrolysis, (kg/t cane)	0	239.7	257.8
Bagasse to enzymatic hydrolysis, (%)		86.7	93.2
Products and by-products			
Anhydrous ethanol, (l/t cane)	79.0	92.8	96.7
Alcohol of second grade, (l/t cane)	2.3	2.8	3.0
Electricity surplus, (kWh/t cane)	42.3	30.5	-5.2
Vinasse (t/t cane)	0.88	1.06	1.12
Ethanol production increase, (%)		17.4	22.4
Ethanol production increase, (l/t cane)		13.7	17.7

THERMAL INTEGRATION USING PINCH POINT METHOD



Steam consumption for each case (kg/t cane)

THERMAL INTEGRATION USING PINCH POINT METHOD



Comparative graphic showing ethanol produced, surplus electricity and bagasse to hydrolysis process for all evaluated cases

CONCLUSIONS

- From the energetic point of view, this study permits to evaluate the ethanol production increase due to the inclusion of enzymatic hydrolysis process.
- The ethanol production increase was modest, due to low solid content in the hydrolysis and the concentration of glucose liquor through an evaporation system (9.7% of increase for 5% of solid content)
- The increase of solid content in the hydrolysis process allows a higher increase in ethanol production in cases where glucose liquor is concentrated through an evaporation system (12.3% of increase to 10% of solid content).
- The use of membranes for the concentration of glucose liquor permitted a significant increase in ethanol production (17.2% of increase to 5% of solid content)

CONCLUSIONS

- The thermal integration promotes a higher increase in ethanol production (22.4% of increase in ethanol production) as consequence of the reduction in steam consumption in integrated process. Also there is a reduction in the electricity surplus.

- About electricity consumption, the estimations showed a significant increase due to the insertion of the hydrolysis process. From these consumptions the power used for reactor agitation is important. However more research in this topic is necessary.

- This study also permitted to recognize technological bottlenecks, for example the recovery of trash, the appropriate amount of trash that should be taken and the trash combustion.

SUGESTIONS FOR FUTURE WORKS

- It is important to accomplish studies aiming the reduction of vinasse production .
- Studies of biogas generation from vinasse and from residues that contain xylose. (may be in the future, xylose liquor could be used to produce ethanol)
- Studies of enzymatic hydrolysis of trash
- Studies of thermal integration of enzymatic hydrolysis process in a production unit of sugar, ethanol and electricity.
- Balance of water for the integrated process
- Exergetic and thermoeconomic analysis for the integrated process.
- Analysis of economic viability of the integrated process

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Thanks for your attention!