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Extraction Process in the Ethanol Production from Sugarcane – A Comparison of Milling and Diffusion

Reynaldo Palacios-Bereche[a], Adriano V. Ensinas[a,b], Marcelo Modesto[a], Silvia A. Nebra*[a,c]

[a] Centre of Engineering, Modelling and Social Sciences, Federal University of ABC (CECS/UFABC), Rua Santa Adélia 166, Bangu, Santo André, SP, Brazil, CEP 09210170,
[b] École Polytechnique Fédérale de Lausanne, Switzerland,
[c] Interdisciplinary Centre of Energy Planning, University of Campinas (NIPE/UNICAMP), Cidade Universitária "Zeferino Vaz", Rua: Cora Coralina, 330, P.O.Box: 6166, CEP: 13083-896, Campinas, SP, Brazil
silvia.nebra@pq.cnpq.br

The objective of the extraction process in the ethanol production from sugarcane is to separate the sucrose-containing juice from the remainder of the cane, mainly fibre. The two currents, products of this process, are the juice and the bagasse. The juice is used to produce ethanol and the bagasse is the fuel for the boilers. Two types of devices are employed to perform this operation: mills and diffusers. Each one of them consumes different types of energy: mills consume mechanical energy, diffusers consume basically thermal energy. As both devices utilize an important quantity of energy, their effect in the energy balance of the factory needs to be taken into account. Aiming to discuss and characterize these effects, simulations of the complete ethanol production process, including the cogeneration system, were carried out using the Aspen Plus software, considering both devices. Process integration was also performed targeting to reduce the energy consumption. These results are presented and compared. Considering the integrated ethanol production process, with extraction -condensing steam turbines in cogeneration system, working with mills, it can produce an electricity surplus of 83.4 kWh/t of sugarcane, however, for the same conditions, working with the diffusion extraction process a production of 91.3 kWh/t of cane can be obtained, including also a small increase of 2 % in the ethanol production.

1. Introduction

The industrial process of ethanol production begins with the preparation of the cane and the extraction of the juice, which will be used in the sequence as the principal raw material for the final product.

The pre-treatment system consists of feed tables for whole stick cane discharge, carrier rollers, leveller knives, set of knives and shredder. Heavy duty knives are necessary depending of the kind of extraction system.

Extraction systems usually adopted are composed by mills and/or diffusers. In Brazil, from 455 total mills in 2011, 23 uses diffusers; the use of diffusers is increasing in the last years (Oliverio et al., 2013). Mills are generally connected to direct drive turbines that consume steam (22 bar, 300 ºC) as driving force, but electric engines are increasingly being used due to their best energy performance. The diffuser is another option for juice extraction. The principle of the diffuser is the application of imbibition water in the cane for the extraction of the juice through a lixiviation process. The water and the juice re-circulated in the piece of equipment are heated with low pressure saturated steam (2.5 bar or lower).

As both types of equipment consume different energy inputs, their impact in the factory energy balance is completely different and deserve to be analysed. Comparison of the energy consumption between milling and diffusers has been done by some authors; see for instance Hoekstra (1995). The change of the traditional milling systems by diffusers should increase 3 to 6 % the sugar production at very reasonable cost (Van Hengel, 1990). The introduction of diffusers in place of mills changes the energy profile of factories (Birkett, 1999).

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This paper aims to assess both extraction systems: mills and diffusers using direct drive steam turbines or electrical engines, evaluating their influence on electricity generation. Two types of cogeneration systems were simulated that use back pressure and extraction – condensing steam turbines. The energetic integration through the Pinch method was performed for the diffusor extraction system.

2. Production System

Figure 1 presents the block diagram of the ethanol production process adopted in this study. The process simulation was carried out using software Aspen Plus ®. Cane dry cleaning, and two different extraction systems were assumed. In the juice treatment, the following operations were adopted: screening, heating, liming, decantation, and mud filtration. Since the must for ethanol production is prepared from sugarcane juice; treated juice should be concentrated until an appropriate sugar concentration for fermentation process (approximately 17 %). The concentration of treated juice takes place in a multiple-effect evaporation system (5 effects) (Dias et al., 2009). Vapour bleedings resulting from the concentration process are used for heating raw juice in the treatment step. Must sterilization is carried out by a HTST-type treatment (High Temperature Short Time), with heating to 130 °C followed by fast cooling down to the fermentation temperature of 32 °C (Dias et al., 2009). In this study, fermentation was based on the Melle-Boinot process (cell-recycle batch fermentation). Following that, the wine is sent to distillation and rectification columns where hydrated ethanol (93.7 % wt. of ethanol) and vinasse (0.02 % wt. of ethanol) are separated. For ethanol dehydration, a process of extractive distillation with monoethylene glycol was simulated. The main operational parameters of the modelled plant are: mill capacity, 2,000,000 t cane/y; crushing rate, 500 t cane/h; season operations h, 4,000 h/y; and bagasse production, 277 kg/t cane. The specific parameters for unit operations were adopted according to Palacios-Bereche et al. (2013).

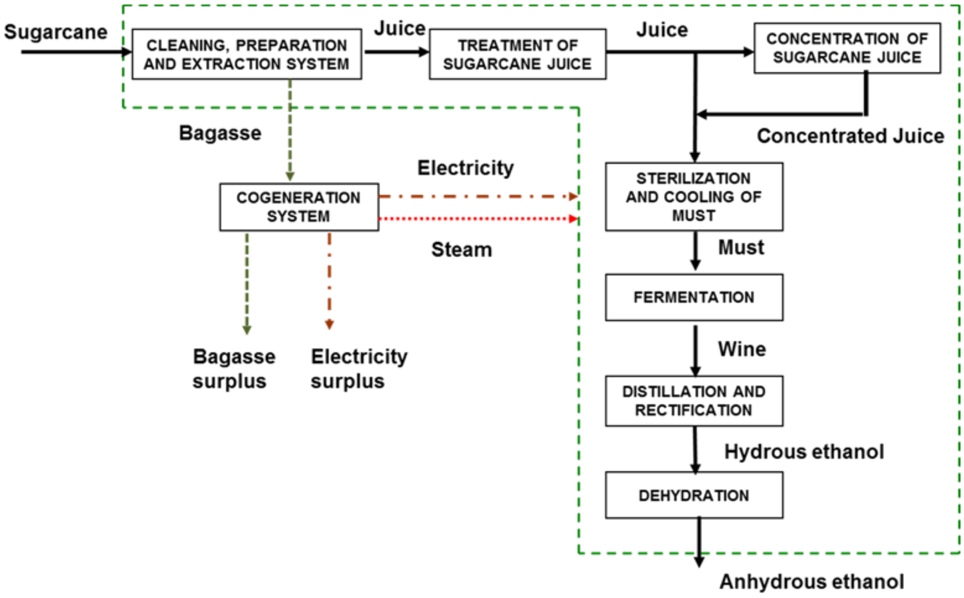


Figure 1: Scheme of the ethanol production process from sugarcane

2.1 Milling and diffusor

A scheme of both systems is presented in Figure 2. Both systems are preceded by a sugarcane mechanical preparation system (Rein, 2007).

Milling units perform extraction in successive and gradual compression stages. The combined arrangement of a series of mills form what is called “milling tandem”. Imbibition water is added in counter-current to the bagasse. The combination of imbibition with mechanical crushing allows attaining extraction rates similar to those of diffusers (Oliverio et al., 2013). Up to 70 to 80 % of the sugars contained in the juice are extracted in the first stage of the tandem.

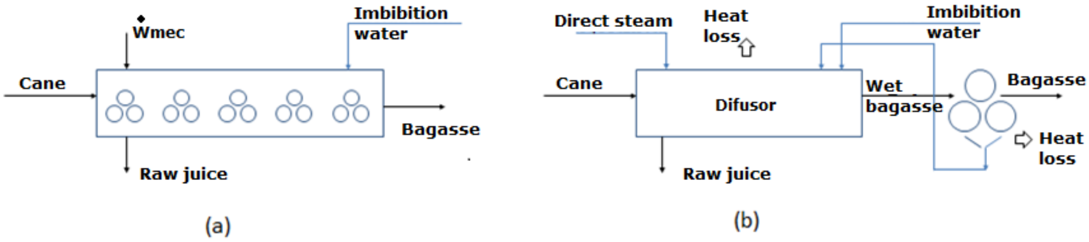


Figure 2: Scheme of the extraction systems: a) milling, b) diffuser

The operating principle of the diffuser is that the imbibition water percolates through a bed consisting of the cane fibrous material (the prepared sugarcane), employing gravity as driving force, the extraction of the juice is made through a lixiviation process (Rein, 2007). The diffuser can be combined with a first stage of milling. It can reach an sucrose extraction of 98.5 %, milling presents a lower extraction parameter (Oliverio et al., 2013). The diffuser is followed by a dewatering mill to reach a value of 50 % (w.b.) of moisture content in the bagasse, same value than the milling system (Modesto et al., 2009)
Table 1 reports the value of the parameters adopted in the simulation of the extraction systems.

3. Cogeneration System

The system is constituted by boilers, back pressure turbines and/or extraction condensation turbines, electric generators, deaerator, pumps. Bagasse is used as fuel. The main characteristics are reported in Table 2. Two products are obtained: steam at 2.5 and 6 bar and electric energy. The values selected for the temperatures and pressure of the steam are the highest found nowadays at the Brazilian industry.

Table 1: Parameters adopted in the extraction systems

Parameter	Milling	Diffuser
Imbibition water (kg/t of cane)[1,2]	300	358.4
Temperature of imbibition water (°C)[3,4]	50	85
Sugar extraction efficiency (%)[5,6]	96.2	98
Bagasse moisture content (%)[2]	50	52
Mechanical power demand (kWh/t of cane)[2]	16	9
Diffuser operational temperature (°C)[6]		80
Raw juice temperature (°C)[6]		60
Bagasse temperature (°C)[6]		63
Recirculation rate in the juice heat exchangers (%)[6]		300
Juice temperature in the output of the heat exchangers (°C)[6]		90

[1]Elia Neto et al. (2009) for milling; [2]Ensinas et al (2007) for diffuser; [3]Ensinas (2008); [4]Fernandez-Parra (2003); [5]Palacios-Bereche (2011) for milling; [6]Rein (2007)

Table 2: Main parameters adopted in the modelling and simulation of the cogeneration system

Parameter	Value
Generated steam pressure (bar)	100
Generated steam temperature (°C)	530
Turbines isentropic efficiency (high and medium pressure) (%)[1]	80
Turbine isentropic efficiency (low pressure) (%)[2]	70
Generator efficiency (%)	97.6
Turbines Mechanical efficiency (%)	98.2
Isentropic efficiency of the direct drive turbines (%)	55
Pump Isentropic efficiency (%)	70
Boiler thermal efficiency % (LHV base)	86
Electric power demand of the conventional process (kWh/t of cane)	12
Condenser pressure (bar)[3]	0.1

[1] Turbines of electric generation; Ensinas et al. (2007); [2] Sanchez Prieto (2003); [3] for the cycle with extraction – condensation turbines

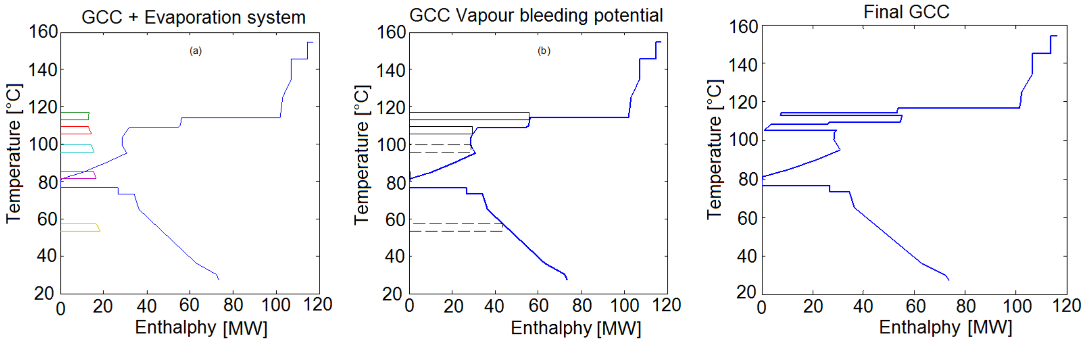
4. Thermal integration

The thermal integration was performed considering the most interesting energetic option, which is an extraction system constituted by a diffuser and electric drivers. Table 3 shows the streams taken into account in the thermal integration.

Figure 3 shows the grand composite curve - GCC for three situations. According the method adopted (Palacios Bereche et al., 2014), Figure 3 (a) is referred to the integration of the currents without assuming the possibility of using vapour bleedings from the evaporation system. Horizontal bars represents each one of the effects of the evaporation system, it can be seen that only the fourth stage intercepts the GCC; if the operating pressure of this effect is reduced, the entire evaporation system can be included in the process without an increment of the hot utilities. Figure 3 b shows the magnitude of the vapour bleeding that could be used in the process. Different options of thermal integration plus bleedings in the evaporation system can be implemented. Analysing the curves, and checking different options, a final decision was taken: to adopt an evaporation system of only two effects, with bleedings of 45.8 t/h in the first effect and 32.9 t/h in the second. For this option (Figure 3 c), a minimum consumption target of 116.3 MW is obtained.

Table 3: Streams included in the thermal integration

Hot streams	Ti (°C)	Tf (°C)	ΔH* (MW)	Cold streams	Ti (°C)	Tf (°C)	ΔH* (MW)
Sterilized juice	130	32	41.8	Juice - HX Diffuser	80	90	17.9
Phlegmasse	103.8	35	3.1	Juice – Direct vapour - Diffuser	76.3	80	8.5
Vinasse	109.3	35	37.9	Imbibition water	25.0	85	12.5
Anhydrous ethanol	78.3	35	8.8	Juice treatment	60.2	105	29.6
Vapour condensates	115	35	10.0	Juice pre-heating	98.1	115	2.9
Condenser - column D	84.9	35	20.5	Juice for sterilization	95.5	130	15.2
Condenser - column B	81.6	81.6	26.4	Final wine	31.2	90	35.0
Condenser extractive column	78.3	78.3	7.6	Reboiler column A	109.3	109.3	45.5
				Reboiler column B	103.8	103.8	22.5
				Reboiler extractive column	140.5	140.5	7.3
				Reboiler recuperative column	149.6	149.6	2.5



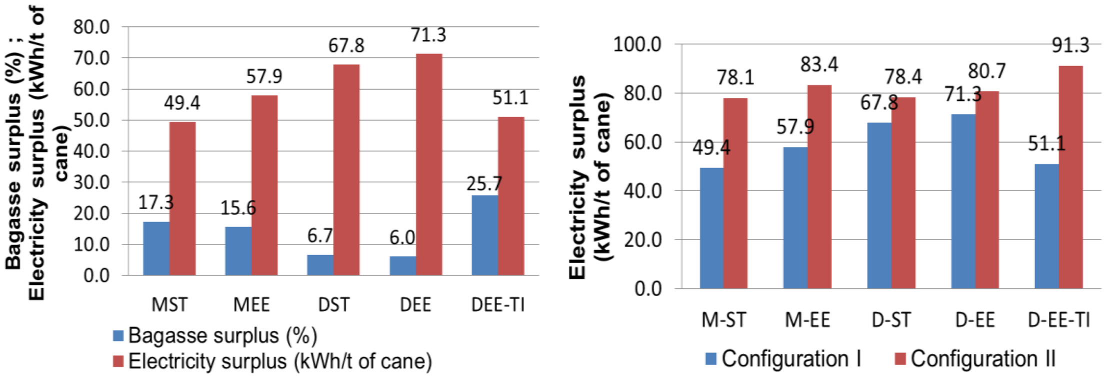
a) b) c)

Figure 3: a) GCC and evaporation system, b) GCC and potential use of vapour bleedings, c) Final GCC with the evaporation system of two effects

5. Results and discussion

Five situations are analysed: MST- milling with direct driven turbines, MEE – milling drive by electric engines, DST – diffuser with direct driven turbines, DEE – diffuser with electric engines, DEE-TI – diffuser with electric engines and thermal integration. Moreover, two configurations are included, relatives to the cogeneration system: the first one considers that only back pressure turbines are used, so it presents a bagasse surplus, the second one considers the use of extraction condensation turbines, with total consumption of the available fuel.

Figure 4 shows the results obtained. The best result is obtained with the DEE-TI system, configuration II, with an electricity surplus of 91.3 kWh/t of cane. Comparing the cases DST and DEE in configuration I, the bagasse surplus of these cases are the lowest.



(a) (b)

Figure 4: (a) Electricity and bagasse surpluses for the first configuration. (b) Electricity surplus for the first and second configuration

In the case of milling, a production of 81.9 L/t of cane is obtained, a little lower than the diffuser, where 83.6 L/t of cane are obtained. The standard steam consumption is of 467.5 kg/t of cane for milling use and 500.9 kg/t of cane in the case of diffuser, but when thermal integration is introduced, the steam consumption diminishes to a value of 385.9 kg/t of cane.

The thermal integration assumed that a vapour bleeding of the first effect is used in the reboiler of the second distillation column and vapour bleeding of the second effect is used in the juice treatment and in the diffusor heat exchangers and direct injection.

From these results, the thermal total consumption of the diffuser reaches 51.4 kWh/t of cane, similar to that reported by Modesto et al. (2009).

6. Conclusions

Modelling and simulation of different extraction systems were made. The use of diffusers shows a greater consumption of steam that conducts also to a greater production of electricity in the cogeneration system. But, with thermal integration, the consumption of steam is significantly reduced and also, the electricity produced if back pressure turbines are used, but if extraction condensation turbines are included, the electricity generation in this case is the highest.

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