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Reduction of water consumption in an integrated first- and second-generation ethanol plant

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ABSTRACT

The aim of this study was to estimate the increase in industrial water consumption and withdrawal in a conventional sugarcane ethanol mill due to the introduction of second-generation ethanol production by a bagasse hydrolysis process, and to identify opportunities of water reuse, in order to minimize water withdrawal. Simulations in ASPEN PLUS® software were performed for mass and energy balances. Three cases were evaluated: a conventional ethanol production plant (Case I), and two second-generation plants incorporating bagasse hydrolysis differing only in their glucose concentration processes, namely by evaporation (Case II), and by membrane separation (Case III).

Results show that external withdrawals of 738 L/t of cane for Case I, 955 L/t of cane for Case II and 853 L/t of cane for Case III are required to cover the water deficit of the plant. These values are lower than the mandated limit of 1000 L/t of cane for the sugar cane industry in the State of São Paulo. Moreover, for Cases II and III, which need large additional amounts of water for the hydrolysis stage, water usages of 10.77 and 9.38 L of water per litre of ethanol produced were achieved, approaching the figure of 9.34 L water per litre of ethanol produced by the conventional plants (Case I). This highlights the high potential for reduction practices based on the concept of energy and water integration.

Introduction

Production and consumption of biofuels grew rapidly in recent years. However, this has raised questions regarding their sustainable production throughout the supply chain. Among them, water use may become as important as the indirect land-use change issue or the food-versus-fuel battle (Dale, 2011; Zuurbier and van de Vooren, 2008).

Water is necessary in two steps during biofuel production: in crop production, and in the industrial stage. Since sugarcane in São Paulo State is mainly a rain-fed crop, the industrial stage of ethanol production accounts for most of the blue water consumption (Chavez-Rodriguez and Nebra, 2010). Previous studies have been done for water consumption minimization in the production of first-generation ethanol from sugarcane (Chavez-Rodriguez, 2010; Chávez-Rodríguez et al., 2011; Elia Neto, 2009; Jannuzzi et al., 2012).

Sugarcane bagasse, as well as other lignocellulosic materials, can also be used for ethanol production. However, from the perspective of energy and water use, the introduction of bagasse hydrolysis in the current ethanol production system is a real challenge, because bagasse, used as fuel in the current process, would become the feedstock in the new one (Palacios-Bereche, 2011; Palacios-Bereche et al., 2011, 2012a, 2012b). Thus, the aims of this study are to estimate the increase in industrial water consumption and withdrawal in ethanol production by the bagasse hydrolysis process, and to identify opportunities of reuse with the purpose of water withdrawal minimization.

Materials and methods

Ethanol production process simulation

In order to estimate the water demand and assess the reuse potential in an autonomous distillery (first-generation ethanol), as well as in an integrated plant for second-generation ethanol production, we used the simulation described in (Palacios-Bereche, 2011; Palacios-Bereche et al., 2011). The simulations were modelled in Aspen Plus®, based on data collected from the literature, as well as actual data for the case of the conventional process, and experimental data for the case of second-generation process. The basic characteristics of the modelled plant are: mill capacity, 2,000,000 t cane/year; crushing rate, 500 t cane/h; season operations hours, 4000 h/year; bagasse production, 277 kg/t cane; steam consumption, 500.9 kg/t cane; anhydrous ethanol production, 79 L/t cane.

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The plant simulated for Case I represents the typical operating parameters and process configuration of the current Brazilian industry, and comprises the following operations: cleaning, preparation and extraction, cogeneration, juice treatment, juice concentration, must preparation, fermentation, distillation, and dehydration for anhydrous ethanol production. For Cases II and III, part of the sugarcane bagasse is used as feedstock for second-generation ethanol production by means of an enzymatic hydrolysis process with a steam explosion pretreatment. A block flow diagram of the integrated first- and second-generation ethanol production from sugarcane is shown in Fig. 1.

In the integrated process, the glucose liquor needs to be previously concentrated to meet the conditions suitable for fermentation. Two systems were examined for liquor concentration: multiple effect evaporation (Case II), and membrane separation (Case III). Six assessment scenarios were generated by combining each of the two concentration systems with three levels of solids load for enzymatic hydrolysis. The scenarios were named EV5, EV8 and EV10 for Case II, and ME5, ME8 and ME10 for Case III. The main operational characteristics for Cases II and III are shown in Table 1.

Table 1
Operational parameters for the integrated first- and second-generation ethanol production plant.

Parameter	Value					
	EV5	EV8	EV10	ME5	ME8	ME10
Steam consumption (kg/t of cane)	793.2	754.7	742.3	689.8	690	690.2
Bagasse for enzymatic hydrolysis (kg/t of cane)	110.3	149.5	172.7	195.9	206.2	212.4
Trash processed (kg/t of cane)	78	78	78	78	78	78
Anhydrous ethanol production (L/t of cane)	86.7	88.1	88.7	92.6	91.5	90.9

Water consumption in the simulated plant

The water consumption estimate in the industrial process took into account all water demands. To represent them, the plant was simulated without any closed circuit for reuse, and adopting average water consumption rates found in the literature, and in actual mills. Table A1 of the Appendix A shows the water streams and their parameters for all three cases. A value of 13.68 m3/t of cane crushed was reached for Case I — less than the 15 m3/t of cane for the same purpose reported by Elia Neto (2009) and Hugot (1986). The difference is due to the adoption of a dry cleaning system, which consumes less water than the conventional water washing system, and barometric condensers instead of multi-jet condensers. Water requirements in the distillation and dehydration systems correspond to 31% of the total water used in the plant.

In second-generation ethanol production, new processes, such as pre-treated biomass washing (xylose washing), and enzymatic hydrolysis, significantly increase water consumption. The large volume of must resulting from the fermentation step increases water requirements for cooling must and vats; this represents on average 40% of the total consumption. Liquor concentration by evaporation in Case II significantly increases water consumption for the barometric condenser, leading to a higher total demand than in Case III (concentration by membrane).

Water savings by closing circuits

The large amounts of water spent in the production of first-generation ethanol have led Brazilian mills to adopt the practice of closing circuits, whether by treating effluents (regeneration), or by reusing them directly. Typical choices for closing circuits are: cooling tower water, spray pond cooling water, scrubber water from boiler, and boiler blowdown. In the present study, some losses were assumed in each of them (Elia Neto, 2009; Ensinas and Ensinas, 2008; Hugot, 1986; Pizaia et al., 1999). In Appendix A, two tables were included; the first one shows the water consumption for each process without any kind of reuse, the second one shows the water consumption considering that all the circuits before mentioned were closed.

With this practice, the effective water demand for Case I has dropped to 1070 L/t cane for the process as a whole. This is a reduction of about 80–90%, demonstrating the massive impact of closing circuits. Nevertheless, an integrated production of first- and second-generation ethanol would shoot up demand to 3000 or 4000 L/t cane — substantially higher than the base case.

Water streams for reuse in the simulated plant

The next step was the identification and quantification of candidate reuse water streams to supply the needs of the plant. For the

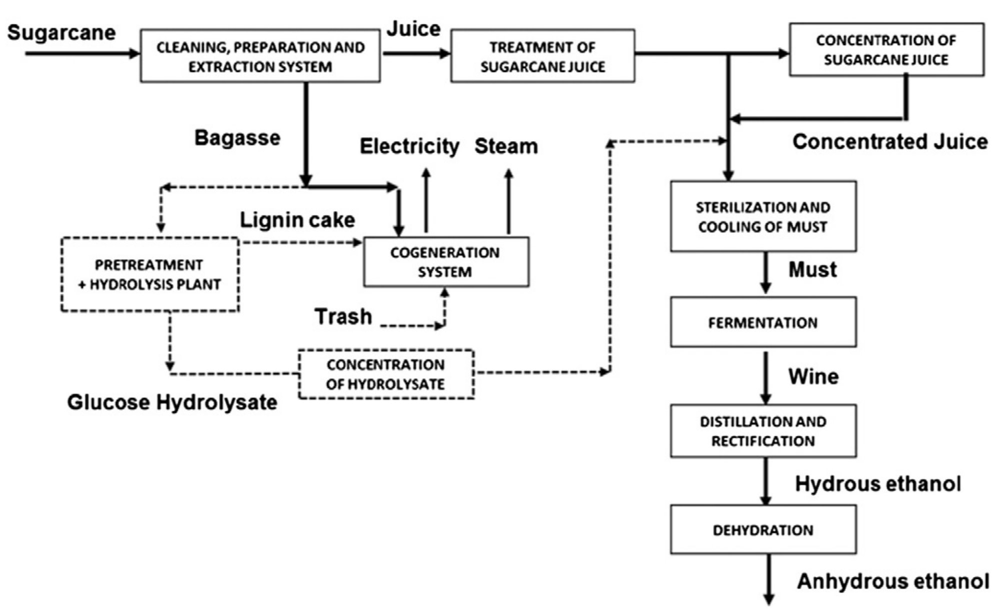

Fig. 1. Simplified block flow diagram of the integrated production of first- and second-generation ethanol from sugarcane.