Energy for Sustainable Development 17 (2013) 546–554

Contents lists available at ScienceDirect

Energy for Sustainable Development

Water reuse and recycling according to stream qualities in sugar–ethanol plants

Mauro F. Chavez-Rodriguez [a], Klever Joao Mosqueira-Salazar [a], Adriano V. Ensinas [b], Silvia A. Nebra [b,c,*]

[a] *School of Mechanical Engineering, University of Campinas, Campinas, SP, Brazil*
[b] *Centre of Engineering, Modelling and Social Sciences, Federal University of ABC, Santo André, SP, Brazil*
[c] *Interdisciplinary Centre for Energy Planning, University of Campinas, Campinas, SP, Brazil*

ARTICLE INFO

Article history:
Received 14 February 2013
Revised 2 August 2013
Accepted 3 August 2013
Available online 27 August 2013

Keywords:
Sugarcane
Ethanol
Sustainability
Water consumption
Heuristic method

ABSTRACT

Sugarcane is one of Brazil's most important industries, mainly because of ethanol, one of its products. Ethanol has a low production cost and low GHG emissions per unit of energy produced, as compared to other fossil fuels. However, several authors have expressed concern about the high water consumption expected in the coming years for biofuel production. This work presents a proposal to reduce water consumption in the industrial stage, taking into account demand and supply quality restrictions. A water supply mix is suggested, with direct reuse of 648 L/t of cane, and another 176 L/t of cane covered indirectly by recycled streams. This reduces the required external withdrawal to 405 L/t of cane — a value within the limit mandated for the sugarcane industry in the State of Sao Paulo.

Introduction

In recent years, biofuels have emerged as an energy option for low-carbon transport, and their demand by 2020 is expected to be more than twice the current levels. Among first-generation biofuels, ethanol from sugarcane is remarkable for its lower production cost and low GHG emissions per unit of energy produced (Chavez-Rodriguez and Nebra, 2010). This is why a high demand for Brazilian sugarcane-based ethanol is expected from countries seeking to satisfy their low-carbon biofuel requirements. However, several authors (Berndes, 2002; Chavez-Rodriguez and Nebra, 2010; Fingerman et al., 2010; Gerbens-Leenes et al., 2009; Hong et al., 2009; Jannuzzi et al., 2012; Rosegrant et al., 2002) have expressed concern about the high water consumption of biofuel production, which could even bring social conflict over the use of water withdrawn from rivers, lakes and the underground for consumption by sugarcane plants.

Systematic methods and techniques for water consumption minimization in the industry have usually taken two different approaches: (a) the pinch analysis technique (water pinch analysis) (Foo, 2009; Manan et al., 2004; Wang and Smith, 1994, 1995) and (b) methods based on mathematical optimization (Ahmetović and Grossmann, 2011; Jödicke et al., 2001; Mariano-Romero et al., 2007; Saeedi and Hosseinzadeh, 2006). However, the large number of parameters necessary to characterize the sugarcane industry wastewater streams makes both approaches unfeasible. The purpose of this work is to make an initial proposal to reduce water consumption in the industrial stage taking into account demand and supply quality restrictions. A heuristic method was used, in which higher quality demand is supplied by available higher quality streams, complemented as necessary by the water from the treatment plant.

This method was selected because it is the most suitable to handle the available information (or lack thereof) regarding the feed stream requirements for each process. Except for the water feed for boilers, the only information that could be gathered was in the form of recommendations or reports of practical use, lacking clear specifications of properties.

Qualitative data about the streams were taken from the literature. Quantitative data, including water demand and streams available for reuse, were obtained from a simulation of a standard plant producing sugar and ethanol. Furthermore, for water streams that could not be directly reused, treatments were considered, such as the intake water treatment plant and sludge dewatering systems.

Process description

In the Brazilian sugarcane industry, most factories produce sugar and ethanol in integrated plants. Part of the Total Reducing Sugars (TRSs) from the sugarcane juice is used for sugar production; molasses, a by-product of this process, is used with the remainder of the TRS for ethanol production. The selection of the TRS partition will depend on the market; in usual installations, it varies from 40%/60% to

---

* Corresponding author at: Interdisciplinary Centre for Energy Planning, University of Campinas, Campinas, SP, Brazil. Tel.: +55 11 49968215.
E-mail address: silvia.nebra@pq.cnpq.br (S.A. Nebra).

0973-0826/$ – see front matter © 2013 International Energy Initiative. Published by Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.esd.2013.08.003

60%/40%, and the default value is 50%/50%. Fig. 1 shows a plant sketch according to Ensinas et al. (2007), with the basic process steps described below.

I. *Sugarcane preparation and juice extraction*: Before entering the extraction system, a cleaning system removes excessive amounts of soil, rocks and trash coming with the sugarcane. After cleaning, sugarcane is prepared by means of rotary knives and shredders that cut it into small pieces, suitable for the subsequent extraction process. A juice extraction system separates bagasse and juice by compressing the cane. Bagasse is used as fuel for the cogeneration system, and the raw juice is sent to the processing system.

II. *Juice treatment*: Some non-sugar impurities are separated by adding chemical reactants such as sulfur and calcium oxide; heating is necessary for the purification reactions. Following that, the juice goes through a flash tank before entering the clarifier (settler). The precipitate is separated from the clarified juice and sent to filters. The filtrate is returned to the process and mixed with the main juice stream, and the filter cake is rejected. The clarified juice is sent to the evaporation system. Juice processing for ethanol and sugar production can be very similar, differing only in the sulfur addition step, which is used exclusively for sugar production.

III. *Juice evaporation*: Juice for sugar production is concentrated in a multiple-effect evaporator. Exhaust steam from the cogeneration system is used as a thermal energy source in the first effect; water evaporated from the juice is used as heating source for the subsequent effect. The multiple-effect evaporator works with decreasing pressure due to a vacuum imposed on the last effect, producing the necessary temperature difference between consecutive effects. Vapor bleed can be used to cover heat requirements of other parts of the process, such as juice processing heaters and the sugar boiling system. Part of the juice for ethanol production goes through the evaporation system to reach the necessary concentration for the fermentation process. The remainder of the juice destined for ethanol production bypasses concentration and goes directly to the fermentation process, to be mixed with concentrated juice and molasses for mash preparation.

IV. *Sugar boiling, crystallization, centrifugal separation and drying*: Syrup is boiled in vacuum pans for crystal formation, and taken to crystallizers to complete crystal enlargement. Following that, sugar crystals are separated from molasses by centrifugation. Sugar dryers operating on exhaust steam reduce the sugar moisture content.

V. *Fermentation*: Integrated sugar and ethanol plants use a mixture of molasses and juice for mash preparation. Good quality water is needed for this operation. After fermentation, the liquor, containing about 8% of ethanol (mass basis), is taken to the distillation system to remove the water.

VI. *Distillation*: Ethanol produced by fermentation is recovered by distillation. Fermented liquor is heated to a suitable temperature before entering the first distillation column. Hydrous ethanol is obtained by stripping and rectification stages. In order to remove the remaining water and produce anhydrous ethanol, a dehydration stage is required at the end of the process. A large amount of vinasse is generated – 10 to 12 L/L of ethanol – which must be handled as an effluent.

VII. *Condensate tank and water cooling system*: The condensate tank receives all condensates generated in the process, except the exhaust steam condensate, which returns directly to the cogeneration system. Separate tanks are used to store hot condensates such as those originating in the 1st, 2nd, 3rd and 4th evaporation effects. The water cooling system, consisting of spray ponds, allows condensate water to be re-circulated as cooling water for fermentation, distillation, sugarcane washing, and vacuum systems.

Demand and reuse water streams

A standard plant was modeled, reflecting the characteristics of a usual sugarcane mill producing sugar and ethanol from sugarcane juice. The simulation was developed by Ensinas (2008) using the EES (2007) (Engineering Equation Solver® software), and was based on data collected from real mills and from the literature.

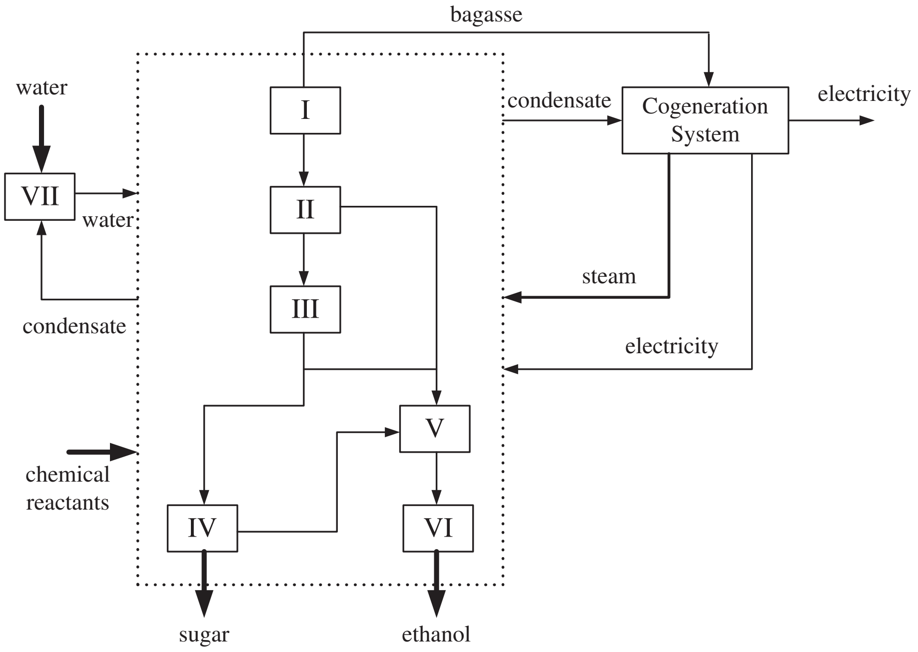

Fig. 1. Scheme of sugar and ethanol plant (Ensinas et al., 2007).