REDUCTION OF WATER CONSUMPTION IN THE PRODUCTION OF SUGAR AND ETHANOL FROM SUGAR CANE

Mauro Francisco Chavez Rodriguez, juanfranciscr@yahoo.com
Lais Menezes Ko , laismko@hotmail.com
Mechanical Engineering Faculty, University of Campinas, P. O. Box 6122, 13083-970, Campinas, SP, Brazil

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

Silvia A. Nebra silvia.nebra@pesquisador.cnpq.br
Interdisciplinary Center of Energy Planning, University of Campinas, Cidade Universitária "Zeferino Vaz", P.O.Box 1170, 13084-971 Campinas, SP, Brazil

Abstract. *Nowadays, in the state of São Paulo, the sugarcane sector represents 23% of the industrial water demand. Considering a water average consumption of 1.83m^3/ton of sugarcane in the harvest season, this sector would demand 31.4 m^3/s, which represents 7% of the State industrial water requirements . Thus, research on the reduction of water consumption becomes essential in order to increase the sustainability index of a large scale ethanol supply. This work pretends to evaluate the potential of water consumption reduction in the industrial process of ethanol production. In order to evaluate water consumption, a sugar cane plant was modeled with a milling capacity of 12,000 ton of sugarcane/day, being 50% for sugar and 50% for hydrated ethanol production. Common practices of water consumption, re-use, and treatment were considered and opportunities of improvement were identified. Practices that reduce water consumption such as dry cleaning of sugarcane, closing of cooling system, handling of condensed vapors, use of more efficient condensers and vacuum equipments were adopted in order to evaluate the balance and final consumption of water. Finally it is proposed a thermal integration, to evaluate its impact in the water consumption.*

Keywords*: Water Re-use, Thermal Integration, Sugar Cane, Sustainability*

1. INTRODUCTION

Starting in the eighties, increasingly in the nineties, and getting stronger and more developed in this new century, water re-use started to become popular as a means of reducing the total amount of water intake. This, in turn, not only saves upstream treatment of raw water but also reduces wastewater treatment costs. In addition, the concept of distributing the treatment among the various polluted streams and even decentralizing it is gaining acceptance (Bagajewicz, 2000).

The current drive towards environmental sustainability and the rising costs of fresh water and effluent treatment have encouraged the process industry to find new ways to reduce freshwater consumption and wastewater generation (Manan and Foo, 2003).

Another driving force in the research of this topic is that the consumption of water in the world doesn't follow the population growth in the same proportion, being at least two times higher than that, encouraged also by the industrial consumption and irrigation requirements. Thus it results in an imperative need to preserve water resources.

The water consumption in the ethanol industrial process is one of the key points to reach higher sustainability index in the use of this biofuel in large scale. Considering average values of collected water, just few estimates are found in the literature. About the industrial demand it has been estimated that the sugarcane sector would be responsible by around 23% of the Sao Paulo State demand of water (Elia Neto,2009). The values are between 1.83 and 5.60 m³/t of sugar cane (Macedo, 2005), showing a great variation in the process water management practices. In spite of the high values of water collected, it represents a sector with great opportunities of water management improvements.

The tax imposed for the use of water and the wastewater produced without treatment in some Sao Paulo State rivers is a important mechanism to stimulate the rational use and avoid the waste of water (ANA, 2007). In that way, estimating a water consumption of 5.6 m³/t of sugar cane in a mill which crushes 2,000,000 tons of sugar cane per season and considering a cost of 0.01R$/m³ of water, the expenses that will commit the mill would be around of R$112,000.

2. LITERATURE REVIEW

Compared with the literature available concerning to thermal integration, the topic of water integration and re-use has been studied just by a few authors.

Jensen & Schumann (2001) relate the actions taken by the Maidstone Sugar Mill in order to decrease the negative environment impact caused by their effluents, throwing away the best effluents and recycling the worst in the process. They reached the objective of zero effluent production, however, it resulted in 0.13% of sugar losses.

A study done by COPERSUCAR (1985), based in a field research of the cooperated industries, identified and characterized in terms of BOD and temperature, the effluents generated in a sugar-ethanol mill.

Kesserlingh (2002) studied a mill located in Riberão Preto in Sao Paulo State with a rate of 5.56 m³ of water/t of sugar cane crushed. The author mapped the collecting points of water, their respective use in the industrial process and the throwing points of effluents. By taking measures of reuse of water proposed by the author, this sugar mill could reach a rate of 0.64 m³ of water/t of sugar cane, however the author didn't considered some losses of water in the cooling circuit and in the barometric condensers that would increase that rate. However, this work is one of the few studies that characterize the water quality of some circuits in the mill, discussing also the industrial management related to water and concepts like housekeeping.

Tenorio and Callado (2007) studied a sugar-ethanol mill located in the state of Alagoas, which crushes 1 700 000 t cane/year, and collects 400m³ of water/h. In this mill the main reuses are: the output water in the barometric condenser of the evaporators, the use in the condenser at the distillery section for the cane washing, the condensates of vapor to the imbibitions process, the water for the scrubber of the boiler.

Rein (2007) has a chapter in his book dedicated to water and condensate systems, where a water balance of a sugar mill is presented. The overall balance without considering the cane washing results in a surplus roughly 20 to 30% of the water entering in the cane. Besides that, the author discusses the topic of condensates recovery and sugar contamination in condensates, and different technologies to treat the effluents.

Andre Elia Neto apud Macedo (2005) by his side, identifies the uses of water in the sugar-ethanol mills and give averages flow values reported in the sector, standing out the washing of water with 5.33m³/t of sugar cane, the multi-jet/barometric condensers of the evaporators and pans with 2 and 4 m³/t of cane respectively, the water used for cooling in the condensers at the distillery with 4 m³/t of cane and cooling water for vats of fermentation 3m³/t cane. According to Elia Neto, the mills in Brazil have an average use of water of 21 m³/t of cane, and in distilleries of 15 m³/t of cane. The author proposes to the sector goals of collection of water of 1m³/t of cane, consumption of 1m³/t of cane and zero effluent.

Ravagnini et al. (2007) made a pinch analysis with the objective of thermal integration, and for the reduction, proposed some modifications, getting a new water circuit resulting in a reduction from 12m³/t to 1m³/t of cane. In the thermal integration they proposed the use of vinasse to heat the water coming from the treatment station and used for the boiler make-up water. In that way they avoid the use of exhaust steam to heat the water. It resulted in savings of 5,525 kg of exhaust steam/h. Besides that the authors proposed the use of water getting out of barometric condensers for imbibitions.

In the Workshop "Uses of water in the production of ethanol from sugar cane", Leite (2008) presents the evolution of the sugar cane sector in the practices related to water use: closing of the circuits of cane washing, cooling of vats, cooling of bearings and turbo-generators, barometric/multi-jet condensers, being barometric condensers preferred by the fact that the multi-jets present most of the water losses. Some of these measures were proposed also by Kesserlingh (2002), Tenorio and Callado (2007), Elia Neto and Ravagnini et al.(2007). In the same Workshop, Carmo (2008) focused new technologic developments undertaken by the company DEDINI S/A Indústria de Base, with significant reduction of sugar losses by water evaporation, also as using vinasse concentration, dry cleaning, and purging vapor of the last effects. These reductions allow that only the water that gets in with the cane (average of 700 liters by ton of cane) could be enough for a sugar-ethanol mill (water autonomy mill).

Moreover, another technological solution developed by DEDINI, is proposed producing sugar, ethanol, organic-mineral fertilizer and surplus water. In other words, from the 700 liters of water that get in with the sugar cane, 409 liters are used (consumption and water contained in the products) and the 291 remaining liters are "exported" (Carmo, 2008).

Maybe one of the most complete and useful works done in Brazil is the work done by Piazia et al (1999), where are shown calculation procedures for the use of water, classification of the streams (extern and intern), the availability of water and the requirements of the process. Besides that, some measures to reduce the consumption of water and increase the generation of condensates are presented, as: increase of the number of bleedings in the evaporation, installation of the pre-evaporator for the distillery circuit, installation of the heat exchanger mixture juice/condensate water and use of this last for imbibitions in the milling system, substitution of water by clarified juice in the dilution of polymers, molasses and massecuites and setting in series the cooling water from the vats and condensers.

According to Rossell (2008), progresses in the last years about water use rationalizing (reducing in the collecting from 5 to 1.8 m³/t cane) were relatively easy, that is, it doesn't demanded great investments. From now to forward, the efforts will be much higher for little reductions.

3. SUGAR CANE MILL MODELING

It was modeled a standard plant which represents the common characteristics of a sugar cane mill, producing simultaneously sugar and ethanol from juice of sugar cane. The simulation of the mill developed by Ensinas (2008) using the software Engineering Equation Solver ® (EES, 2007) based in data collected in real mills and literature sources.

It was considered that the first stages of the production of sugar and ethanol are commons, including the cane handling, cane washing, the cane preparation, and the extracting of the juice. The raw juice extracted follows to a specific treatment for the production of sugar and ethanol, being consumed in subsequent stages according to its destination. The production of sugar is completed with the juice evaporation, crystallization, centrifugal separation and drying. The production of hydrated ethanol, in the other way, counts with a stage of preparation of juice for ethanol, fermentation, besides the distillation and rectification.

For the distribution of sugars presented in cane it was considered that 50% of sucrose was used for the production of sugar and 50% for the production of ethanol, being this carried out with the residual molasses from the sugar production, besides some amount of syrup and treated juice. The general characteristics of the modeled plant, as the parameters used for the simulation, are described in the Table 1. These values are considered for all cases presented in this study.

Table 1 Operation Parameters of the sugar-ethanol mill modeled

Parameter	Value
Mill Capacity (t cane/year)	2,000,000
Crushing Rate (t cane/hr)	500
Season Operation Hours (hr/year)	4000
Fiber Content of cane (%)	14.0
Pol of cane (%)	14.0
Sugar production (kg/t cane)	65.0
Hydrated Ethanol production (l/t cane)	40.0

4. WATER USE IN THE SUGAR CANE MILL

The water use in the industrial process was analyzed considering all the needs of water. To represent the water requirements the mill was simulated without any closed circuit and considering average water rates consumption founded in literature and in real mills. Table 2 shows the water streams and its parameters.

Table 2. Water use in a sugar-ethanol mill.

Water Uses	m (kg/s)	T (ºC)	P(bar)	m (kg/t cane)	%
Washing Cane	416.7	25	1.01	3000	19.9%
Imbibition	41.7	50	6.00	300	2.0%
Bearings Cooling	6.9	25	1.01	50	0.3%
Oil of Lubrification Cooling	55.6	25	1.01	400	2.7%
Sulfitation Cooling	3.1	25	1.00	22	0.1%
Preparing of lime	3.2	107	6.00	23	0.2%
Filter Cake Washing	9.7	107	6.00	70	0.5%
Water for centrifugal washing	2.3	107	6.00	17	0.1%
Water for dilution of poor molasses	0.3	107	6.00	2	0.0%
Water for dilution of sugar	1.2	107	6.00	9	0.1%
Water added to pans	0.4	107	6.00	3	0.0%
Barometric Condenser of Evaporation	360.3	30	1.01	2594	17.2%
Water for vacuum in the filters	12.5	30	1.01	90	0.6%
Cooling of juice for fermentation	151.3	25	6.00	1089	7.2%
Water for vacuum in the pans	337.6	30	1.01	2431	16.1%
Dilution of yeast	17.0	25	6.00	122	0.8%
Cooling of fermentation vats	242.7	25	6.00	1747	11.6%
Condenser of Distillation	7.9	30	1.01	57	0.4%
Condenser of Rectification	105.7	30	1.01	761	5.0%
Cooling of Hydrated Ethanol	7.0	30	1.01	50	0.3%
Washing Scrubbers(boiler)	169.8	25	1.01	1222	8.1%
Boiler feed water	97.0	128	22.00	701	4.6%
General cleaning	6.9	-	1.01	50	0.3%
Drinkable uses	4.2	25	1.01	30	0.2%

Cooling of Turbogenerators	27.8	30	1.01	200	1.3%
Cooling of Crystallizers	4.2	30	1.01	30	0.2%
			TOTAL	15071	

The value of 15 m^3/ ton of cane crushed is smaller than the 21 m^3/ ton of cane for the same purpose of producing sugar and ethanol reported by Elia Neto (2008). It is due the fact that it were considered for washing a cane a table inclined at an angle 45º that uses less water, 3 m^3/t of cane REIN (2007) compared with Elia Neto´s value of 5.33 m^3/t. Another difference is that for the simulation is being considered the use of barometric condensers, instead of multi-jet condensers.

As can be seen in Table 2, vacuum for pans and barometric condenser of evaporation represents 33% of the water used in the mill. This consumption added with water for sugar cane washing (20%) and for cooling vats (12%), represents 65% of the total, so from this analysis it can be noticed that the main action for water savings would be the closing off these circuits. Just with this measure, without considering the losses in the closing circuits (evaporation, leaks, etc), it is possible to decrease from a consumption of 15.00 m^3/t of cane to 5.25 m^3/t of cane.

The water sources of the mill were identified and quantified. These streams of water have the potential after treated (if it is necessary according to the quality) and be may be reused to supply the needs of the mill. Table 3 shows these "water sources", their flows, temperature and pressures.

Table 3. Water Streams for Reuse

Water Sources	m (kg/s)	T (ºC)	P(bar)	m (kg/t cane)	%
Condensate of filtration	0.4	70	0.31	3	0.2%
Condensate of 1st effect Vapor (collected in the output of the 2nd effect)	7.9	115	1.69	57	3.8%
Condensate of Bleeding 1st effect Vapor to treatment of juice heating	20.2	115	1.69	145	9.8%
Condensate of Bleeding 1st effect Vapor to Pan A heating	11.8	115	1.69	85	5.7%
Condensate of Bleeding 1st effect Vapor to Pan B heating	2.2	115	1.69	16	1.1%
Condensate of 2nd effect Vapor	8.5	107	1.31	61	4.1%
Condensate of 3rd effect Vapor	9.1	98	0.93	65	4.4%
Condensate of 4th effect Vapor	9.7	83	0.54	70	4.7%
Condensate of 5th effect in Barometric Condenser	10.5	50	1.01	75	5.1%
Condensate of Vapor of Pan A	8.3	50	1.01	60	4.0%
Condensate of Vapor of Pan B	1.5	50	1.01	11	0.7%
Boiler Blowdown	4.9	25	1.01	35	2.3%
Washing cane water losses	20.8	25	1.01	150	10.1%
Washing scrubber water losses	8.5	25	1.01	61	4.1%
Vinasse*	61.5	76	6.00	570	38.3%
Cleaning water collected (50%)	3.5	25	1.01	25	1.7%
	TOTAL			1489	
	Without Vinasse and Washing Cane water losses			769	

Table 3 shows the total value of available water and indicates that the mill has a potential volume to reuse of around 1.49 m^3/ t cane crushed. The readers must not confuse this value with the water content in cane. The first considers external water that is added in the different stages in the process that could be reused. Without considering the water content in vinasse and the washing cane water losses, it would result in 0.769 m^3/ t of cane. Actually, unless the water vinasse content is separated by evaporation or methods as reverse osmosis, a direct reuse of its water would result very difficult due to its high load of suspended solids, Biochemical Oxygen Demand (BOD) and low pH. Washing cane water losses as vinasse is highly pollutant and a treatment must be done before its reuse in the mill. From Table 3 may be deduced that condensates are the main sources of water in the mill and the condensates of the evaporator section represent 43% of the total potential of reduction.

5. CLOSING WATER CIRCUITS

To illustrate the effective collecting water to attend the process it was considered a mill where there is treatment and/or recirculation in closed circuits. Table 4 shows the losses in these circuits.

Table 4. Water Losses of Closed Circuits. Based in Rein(2007)

Closed Circuits	Water Losses (%)
Treatment Washing Cane Water	5
Treatment Bearing Cooling Water	3
Treatment Oil Lubrification Cooling Water	3
Treatment Sulfitation Cooling Water	3
Spray Ponds Cooling Water	4
Cooling Towers Water	3
Treatment Washing Scrubbers Water	5
Recirculation Boiler Feed Water (blowdown)	5

For the simulation it was considered that the water from the spray ponds attends the system of vacuum in filters, evaporators and pans, condensers of the distillation and rectification columns, and the cooling of ethanol. This water was assumed to return to spray ponds at 50.0°C, being cooled down to 30.0°C and then used again. The cooling with towers is destined to the stages of juice for ethanol and vats cooling, sulfitation cooling, turbogenerator cooling, bearing and oil of lubrification cooling, being the water at the inlet at 30.0°C and outlet at 25.0°C (Ensinas, 2008).

The effective collecting of waters occurs for the make-up of the closed circuits and to attend the demands of yeast dilution, drinkable use and general cleaning. Other consumptions of water in the process are attended by vapor condensates, being these:

- Imbibitions Water
- Preparing of lime
- Washing of filter cake
- Dilution of molasses and washing in centrifugals.

Figure 1. Shows a process stream diagram to illustrate the plant simulated.

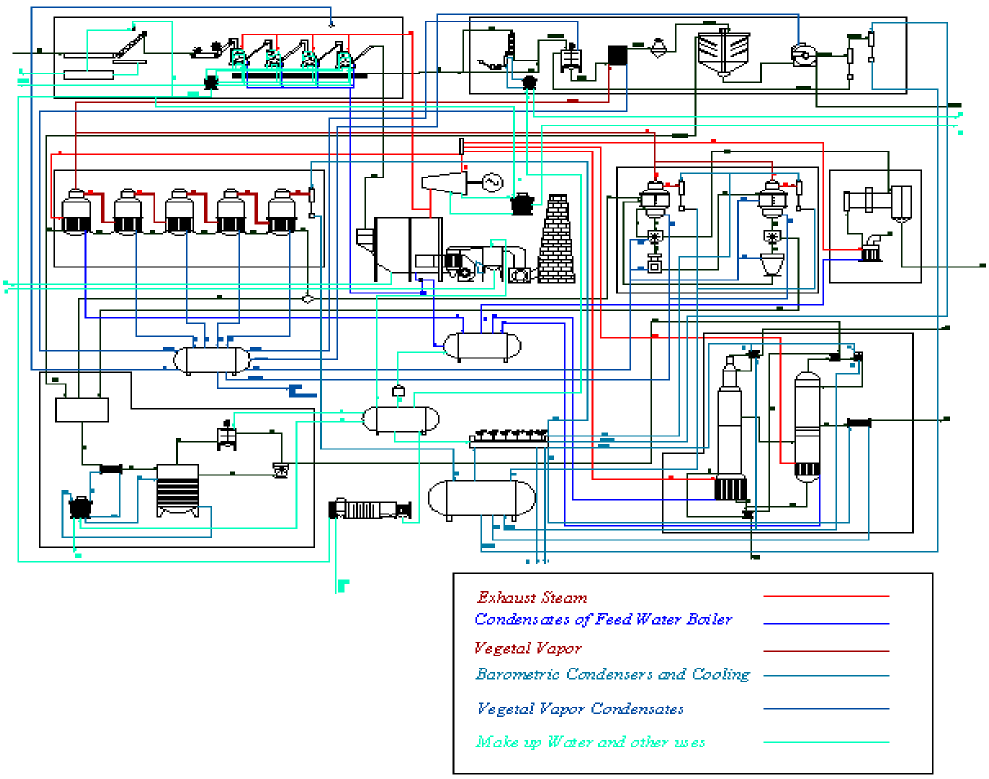

Figure 1. Process Diagram of the Sugar-Ethanol Mill modeled

Table 5 shows the effective collecting water by process. These values represent the demand of water in real time, so without considering the content water in cane reflected in water sources. In theory, the Water Treatment System has to supply these quantities from the water collected in rivers, lakes, etc. It may be deduced that reusing stream water sources in mill would result in a lower water plant capacity.

Table 5. Effective Collecting Water by Process

Effective collecting water by process	m (kg/s)	T (ºC)	P(bar)	m (kg/t cane)	%
Make-up Washing Cane	20.8	25.0	1.01	150	12.2%
Imbibition	41.7	50.0	6.00	300	24.5%
Make-up Bearing Cooling	0.2	25.0	1.01	2	0.1%
Make-up Oil Lubrification Cooling	1.7	25.0	1.01	12	1.0%
Make-up Sulfitation Cooling	0.1	25.0	1.00	1	0.1%
Lime preparing	3.2	107.4	6.00	23	1.9%
Washing filter cake	9.7	107.4	6.00	70	5.7%
Washing centrifugals	2.3	107.4	6.00	17	1.3%
Molasses Dilution	0.3	107.4	6.00	2	0.2%
Sugar B Dilution	1.2	107.4	6.00	9	0.7%
Added to Pan B	0.4	107.4	6.00	3	0.2%
Make-up Barometric Condensers Evaporation	14.8	30.0	1.00	107	8.7%
Make-up water for vacuum in the filter	0.5	30.0	1.00	4	0.3%
Make-up water for juice ethanol cooling	4.5	25.0	6.00	33	2.7%
Make-up Vacuum Pans Circuit	13.9	30.0	1.00	100	8.1%
Yeast dilution	17.0	25.0	6.00	122	10.0%
Make-up Fermentation Vats Cooling	7.3	25.0	6.00	52	4.3%
Make-up Distillation Condensers	0.3	30.0	1.00	2	0.2%
Make-up Rectification Condensers	4.2	30.0	1.00	30	2.5%
Hydrated Ethanol Cooling	0.3	30.0	1.00	2	0.2%
Make-up Washing Scrubber	8.5	25.0	1.00	61	5.0%
Make-up Feed Water Boiler	4.9	25.0	1.00	35	2.8%
General Cleaning	6.9	-	1.01	50	4.1%
Drinkable Water	4.2	25.0	1.01	30	2.4%
Make-up Turbogerators cooling	1.4	30.0	1.01	10	0.8%
Make-up Crystallizers Cooling	0.2	30.0	1.01	2	0.1%
			TOTAL	1228	

If we subtract the value of 0.769 m^3/t of cane of potential water for reuse without vinasse and washing cane water losses (Table 3) from the 1.228m^3 / t of cane, the net effective collecting water of 0.459 m^3/t cane is obtained. This value considers that the water from "water sources" had a previous conditioning to re-use it.

As we can see from Table 5, the main consumer of water in the modeled sugar-ethanol mill is the imbibitions, however, great part of this water would be recuperated in evaporation condensates. Losses by evaporation the Barometric Condensers and Vacuum Pans Circuits represent together 16%. It could be avoided if dry towers cooling are used, but in practice it would be very difficult taking into account that these are much more expensive, requiring larger areas than cooling towers in direct contact with air. Another important consumer of water is the use for the yeast dilution. This water finishes in the water content of vinasse. If dry cleaning system is used, instead of wet system, it would result in an effective collecting water demand of 1.078 m^3/t of cane. Subtracting the 0.769 m^3/t of cane of water for re-use, it would result in a rate of 0.309 m^3/t of cane to external collection, very close to the goal of zero collecting.

Excepted for dry cleaning, at this stage, "easy" measures have been tested to avoid water losses as the closing of the circuits and re-use of available streams water sources as condensates. Besides that, streams at high temperatures have energy content which may be recovered as heating source inside the process. This capacity would be used in a second stage of measures to decrease the losses of water using the thermal integration to reduce cooling water requirements.

6. THERMALLY INTEGRATED SUGAR CANE MILL

Ensinas (2008) developed a procedure of integration for a sugar-ethanol mill using the Pinch Point analysis, modeling a standard plant. This work is useful for the evaluation of the possibilities of thermal integration in the process in a systematic way. A three stages procedure is proposed:

- Stage 1. Thermal Integration of the main process streams available, excluding the columns of distillation, rectification and the evaporation system.
- Stage 2. Thermal Integration of the distillation and rectification columns to the remaining process.
- Stage 3. Thermal Integration of the evaporation system to the process.

Pinch method was used as a tool for developing of an initial project of a heat exchangers network integrated to the evaporation juice system. The final thermal integration it is showed in Figure 2 and Table 6.

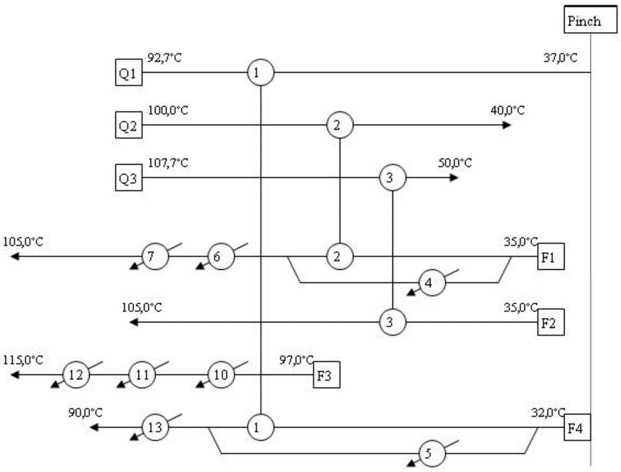

Figure 2. Heat Exchangers Network Proposed. Source: Ensinas (2008)

Table 6. Heat Exchangers Network Data

Heat Exchanger	Hot Stream				Cold Streams				Q (kW)
	Stream		T_{in} (ºC)	T_{out} (ºC)	Stream		T_{in} (ºC)	T_{out} (ºC)	
1	Q1	Juice for Fermentation	92.7	37.0	F4	Centrifugated Wine	32.0	89.6	10917
2	Q2	Vinasse	100.0	40.0	F1	Juice for sugar production	35.0	96.5	15412
3	Q3	Condensate of 1º to 4º effect Vapor	107.7	50.0	F2	Juice for ethanol production	35.0	105.0	13426
4	CR	Condenser Rectification Column	78.0	78.0	F1	Juice for sugar production	35.0	68.0	6102
5	CR	Condenser Rectification Column	78.0	78.0	F4	Centrifugated Wine	32.0	68.0	3147
6	VV3	3 º Effect Vapor Bleeding	105.9	104.5	F1	Juice for sugar production	85.4	99.0	5997
7	VV2	2 º Effect Vapor Bleeding	111.1	110.5	F1	Juice for sugar production	99.0	105.0	2646
10	VV2	2 º Effect Vapor Bleeding	111.1	110.5	F3	Clarified juice for sugar	97.0	100.0	1233
11	VV1	1 º Effect Vapor Bleeding	115.4	115.0	F3	Clarified juice for sugar	100.0	111.5	4735
12	VE	Exhaust Steam	127.4	127.4	F3	Clarified juice for sugar	111.5	115.0	1444
13	VV3	3 º Effect Vapor Bleeding	105.9	104.5	F4	Centrifugated Wine	82.5	90.0	2108
14	CR	Condenser Rectification Column	78.0	78.0	AR	Cooling Water	30.0	50.0	9536

The thermal integration project proposed allowed that be reached significant improvements in relation to the demand of hot and cold utilities in the mill. It was obtained an expressive reduction of process steam, decreasing the demand to 458 kg/t cane estimated for the standard plant down to 307 kg/t cane in the plant with thermal integration. This reduction made possible a decrease in the operation costs and an increase in the surplus of bagasse and/or surplus electricity in the cogeneration system.

The thermal integration also had impact on some water uses as shows Table 7. The reduction of steam demands impact in the boiler feed water and in the washing scrubber (less exhaust gases to clean). Barometric condensers of the evaporation and crystallizers system presented significant reductions, consuming 28% e 21% less water respectively when compared to the "standard" mill. It is explained in the case of evaporation by the fact that the 5th effect vapor to condensate in the "standard" mill was 10.5 kg/s compared to the 7.5 kg/s of vapor to condensate in the integrated mill.

In the case of crystallizers system the increase of Brix in syrup in the output of evaporation resulted in less water to evaporate in pans and consequently less water was used to condensate vapors.

Table 7 Reduction in the water uses due to the thermal integration

Water Uses	m (kg/s)	m (kg/t cane)	m (kg/s)	m (kg/t cane)	% Reduction
Barometric Condenser of Evaporation	360.3	2594	258.8	1863	28%
Water for vacuum in the pans	337.6	2431	270.6	1948	20%
Washing Scrubbers(boiler)	169.8	1222	131.6	948	22%
Boiler feed water	97.0	701	75.2	541	22%

The effective collecting water of the thermally integrated plant resulted in 1.007 m^3/t of cane. In that number it was considered also a change in the cane cleaning system and washing cane was replaced by dry cleaning. Many authors as Vignes (1980), Birkett and Stein (2004) and Eijsberg (2006) reported losses of sucrose in the operation of washing cane. According to Procknor (2002) the washing cane circuits are tending to finish or to stay reduced to a sporadic use in rainy days, as a consequence of mechanical harvesting intensification. Comparing the value of 1.007 m^3/t of cane of this plant to the 1.078 m^3/t of cane of effective collecting water of the plant with dry cleaning, it can be observed that the influence of the thermal integration in the final water consumption is small. The difference in the total value between the standard plant and the thermally integrated was caused by the reduction in the boiler blowdown and the washing scrubbers' water losses.

Subtracting the available water for reuse resulted in the thermally integrated plant (0.747 m^3/t of cane) from the effective collecting waters needs (1.007 m^3/t of cane), a net effective external water collecting of 0.260 m^3/t of cane is obtained. The difference of this value and the 0.309 m^3/t of cane of the standard plant with dry cleaning is caused by the reduction in water losses in the barometric condensers for evaporation and crystallization systems. To reach the scenario of zero water collection, around 46% of vinasse in volume could be evaporated; however, it would result in higher heating demand.

It must be remarked that the values of effective collecting water presented in this work are the resulted of a mass balance which considers that waters for reuse have suffered a previous treatment(if it was necessary) to be reused without mass losses in those treatments. This wouldn´t happen actually, for example it´s very difficult to recover the water lost in washing operations due to it is in moisture sludge form, another example is the recovering of boiler blowdown due to an additional cooling system to condensate would be necessary which could bring additional costs. However this work is useful to estimate limits in the recovering and reuse of water in sugar and ethanol plants.

7. CONCLUSIONS

In order to reach higher index of sustainability the sugar cane sector must put efforts for the decreasing the consumption of water.

The sugar-ethanol mill modeling allowed the identification of different water uses and potential of re-use in the process. Water used in barometric condensers for the evaporation system and crystallization, together with water for washing the sugar cane and for cooling fermentation vats represented around 65% of the water demand in the mill. Condensates are the main sources of water reuse in the mill, being the condensates from the evaporator section responsible for 43% of this potential.

This research showed that for the standard sugar-ethanol mill modeled values of effective water collecting of 0.46m^3/ of cane could be reached making action of closing circuits and reuse of available streams water sources as condensates. Using dry cleaning system this value could be reduced down to 0.31m^3/t of cane.

Finally, it is known that the thermal integration can reduce hot and cold utilities demand of the mills and is important for the surplus electricity generation in the cogeneration system. Moreover, decreasing the cooling water with the integration, make possible to reduce water systems scale. This measure can avoid investment expenses and at the same time, reduce water losses in 0.05m^3/t cane as shown in this paper.

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