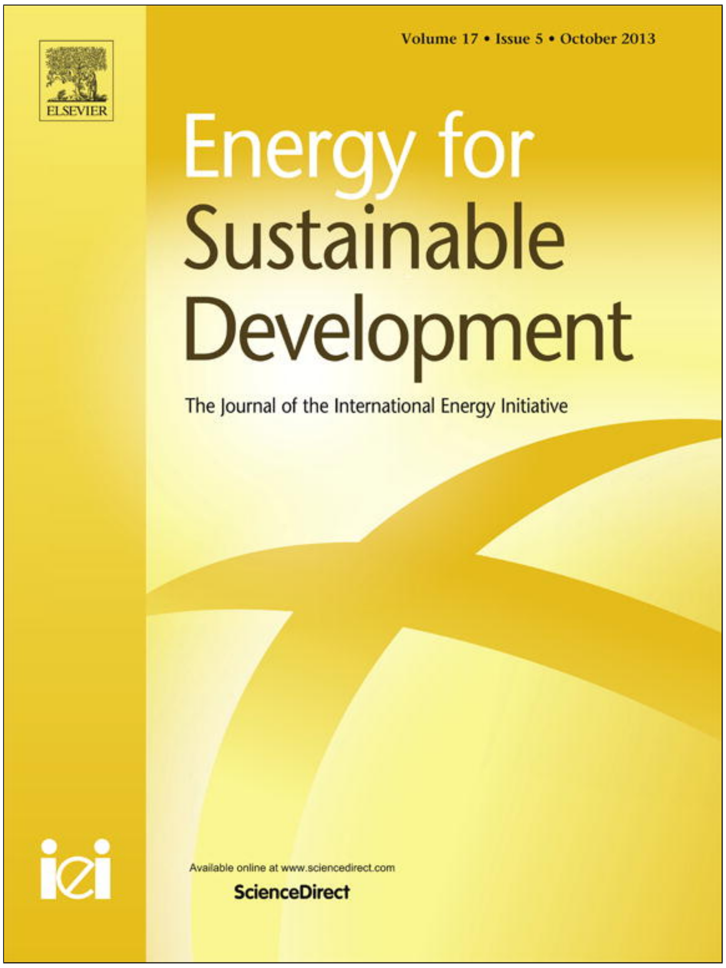
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Water reuse and recycling according to stream qualities in sugar–ethanol plants

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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about the high water consumption of biofuel production, which could even bring social conflict over the use of water withdrawn from rivers, lakes and the underground for consumption by sugarcane plants.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

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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.

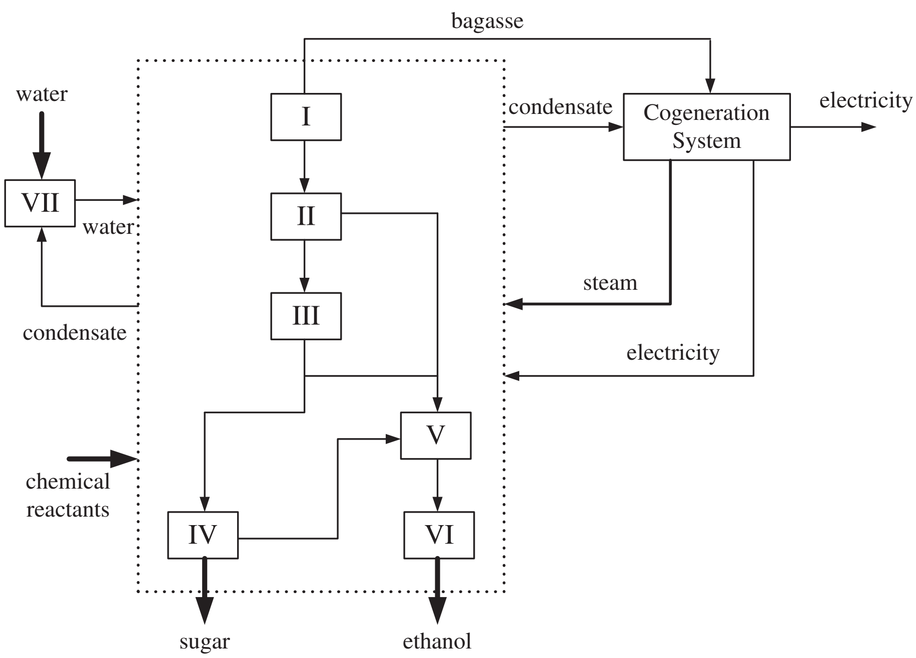

Fig. 1. Scheme of sugar and ethanol plant (Ensinas et al., 2007).

Regarding the distribution of sugars present in the cane, it was assumed that 50% of TRS was used for the production of sugar, and 50% for ethanol. The latter is made from the residual molasses of sugar production, as well as some amount of syrup and treated juice. The general characteristics of the modeled plant and the simulation parameters are described in Table 1.

Stream quantities

Water demands

The analysis of water use in the industrial process took into account all water demands. In order to reveal water requirements, the mill was simulated as having no reuse closed circuits. The assumed average water consumption rates were obtained from the literature and directly from real mills. A complete table, found in the Appendix (Table A.1), shows the water streams and their parameters under this setting.

It emerges that the vacuum system of crystallizers and the evaporation barometric condenser, taken together, represent 33% of the water used in the mill. Sugar cane washing accounts for another 20%, and cooling vats for 12%. Together, these represent 65% of the total, suggesting that the most pressing action for water savings would be closing these circuits. With this measure alone, it is possible to drop consumption from 15 m^3/t of cane to 5.25 m^3/t of cane (losses, such as evaporation and leaks, not taken into account).

Table 2, based on Rein (2007), lists the circuits to be closed and their respective estimated water losses.

Fig. 2 shows the effective water demanded by each process, taking into account only recirculation and losses (i.e., excluding any water reuse among pieces of equipment). It is based on Table A.2 of the Appendix, and arrives at a total effective water demand of 1.23 m^3/t of cane.

Reuse water streams

Candidate reuse water streams were identified and quantified. Potentially, they could supply, after treatment, all the needs of the mill. Fig. 3 shows the streams, and Table A.3 of the Appendix details their rates, temperatures and pressures.

Despite being the single largest stream, vinasse has not been considered for industrial reuse in this study, because of the widespread practice of using it for fertirrigation, which is also a form of water conservation.

Fig. 3 shows that, except for vinasse, condensates are the largest reuse stream. The mill has a reuse potential volume of about 1.49 m^3/t of crushed cane. Excluding the vinasse water content and cane washing water losses, 0.769 m^3/t of cane would be available. Actually, vinasse water could be separated by evaporation or other methods such as reverse osmosis; however, a direct reuse of this stream would be very difficult due to its high load of suspended solids, high Biochemical Oxygen Demand (BOD) and low pH. Similarly, cane washing water losses are highly pollutant, and a special treatment would be required before their reuse. Thus, condensates are the main sources of water reuse in the mill; they represent 43% of the total reuse water potential.

Table 1
Operation parameters of the modeled sugar–ethanol mill.

Parameter	Value
Mill capacity (t cane/y)	2,000,000
Crushing rate (t cane/h)	500
Season operation hours (h/y)	4,000
Cane fiber content (%)	14
Cane pol (%)	14
Sugar production (kg/t cane)	65
Hydrated ethanol production (L/t cane)	40

Table 2
Water losses of closed circuits.

Closed circuits	Water losses (%)
Cane washing water	5
Bearing cooling water	3
Lubrification oil cooling water	3
Sulfitation cooling water	3
Spray pond cooling water	4
Cooling tower water	3
Washing scrubber water	5
Recirculation boiler feed water (blowdown)	5

Subtracting 0.769 m^3/t of cane of potential reuse water (which does not include either vinasse or cane washing water losses) from the water demand of 1.23 m^3/t of cane, an effective water collection requirement of 0.46 m^3/t of cane is found. This assumes that the reuse water streams have had a previous conditioning.

Stream qualities

Water demands

For the boiler water feed, a more complete treatment is required. Generally, the treatment process seeks to keep the boiler water at a high pH, and completely free from dissolved oxygen (Elia Neto et al., 2009). Thus, a demineralization or deionization process is recommended, which will remove practically all the present ions. Required chemical parameters for the water are shown in Table 3. Two other technologies used for the purpose of demineralizing water are ultrafiltration and reverse osmosis. The former can be used as a pretreatment for the latter, working as a barrier for particles and microorganisms, and removing substances that cause obstruction and damage (Crittenden et al., 2005; INGE, 2002).

For yeast dilution, clean, cold water is recommended (Elia Neto et al., 2009) to avoid overloading the must cooling system. Use of condensates for yeast dilution without a prior treatment is not advisable.

Water for the dilution of molasses and massecuite (mixture of sugar crystals and mother liquor resulting from the crystallization process), and for washing sugar in the centrifuges, is used above 80 °C. Condensates are the usual sources (Elia Neto et al., 2009). For cake washing, Elia Neto et al. (2009) recommend good quality water, because it will become part of the juice, which is a raw material. The temperature range should be from 75 °C to 80 °C, to improve extraction; to keep the wax contained in the cake hot, preventing impermeability; and to avoid bacterial proliferation (Rein, 2007).

Likewise, in lime milk preparation, use of clean raw water is recommended, because it will also be integrated into the juice. Condensates can be used here.

As shown in Fig. 2, imbibition is the process with the highest effective water demand. Rein (2007) says that raising the imbibition water temperature from 75 to 80 °C can increase extraction by 0.2%. On the other hand, Honig (1953) sustains that raising water temperature to the range of 85 to 95 °C does not result in more wax extraction than keeping it at 28 °C. In view of these statements, as well as the advantages of process simplicity, condensates without cooling could be directly used in the imbibition process.

A chemical treatment is necessary for replenishing water in the cooling tower circuits in order to adjust pH and control bacterial slime growth, which over time can cause corrosion, flow obstruction, and heat transfer diminution. Rein (2007) states that it is essential to control the pH by adding lime and chemicals to reduce water corrosiveness. Table 3 shows the recommended quality standards for cooling water and steam generation. As shown, with the exception of BOD content, condensates can be directly reused in the cooling system. When the organic load is not reduced, corrosion can happen

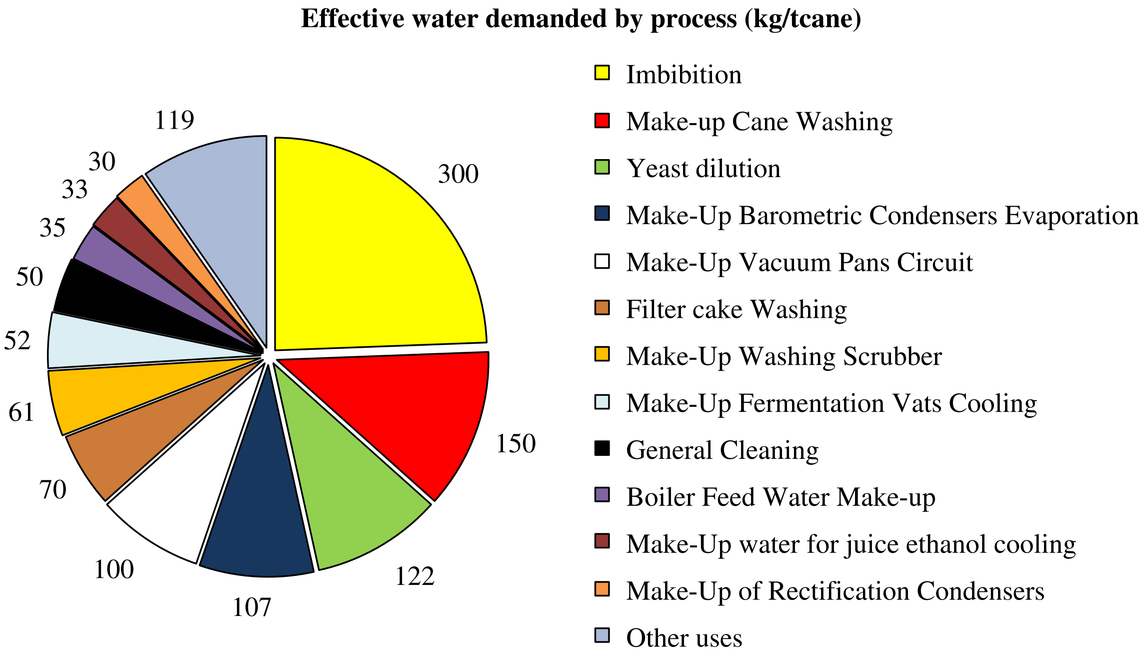

Fig. 2. Effective water demand by process (kg/t cane).

due to microbial action such as growth of algae, fungi and bacteria on surfaces (Betz Laboratories, Inc, 1991).

For the make-up of vacuum circuits (barometric condensers), water should not contain coarse suspended solids, in order to prevent obstruction of the spray pond sprinklers. According to Rein (2007), problems related to dragging sugar in the system are solved through degradation by biologically stable natural organisms, provided that there is enough water.

The practice of cane washing tends to disappear because of the increased adoption of mechanized harvesting. When the cane is chopped, washing is not recommended because of the considerable sugar losses that can take place. When a washing system does exist, it is closed; the water is subjected to decantation, and recirculated. It is also necessary to keep recirculating water with a basic pH in order to avoid its degradation and consequent corrosion of devices.

For some scrubber building materials, such as metal or epoxy, scrubber water must have the same quality as that of spray ponds, and corrosion inhibitors are needed. Water for boiler scrubbers is usually kept in a closed circuit, and requires decantation and flocculation of the suspended material, which can be done either in large chambers or in more compact devices such as decanters or soot floaters. Due to their low organic load and high solid content, purges can only be reused indirectly, and must first go through the Water Treatment Plant (WTP).

Finally, low-hardness water (<80 mg CaCO3/L) is required for floor and equipment cleaning. Condensate streams can be used for this purpose.

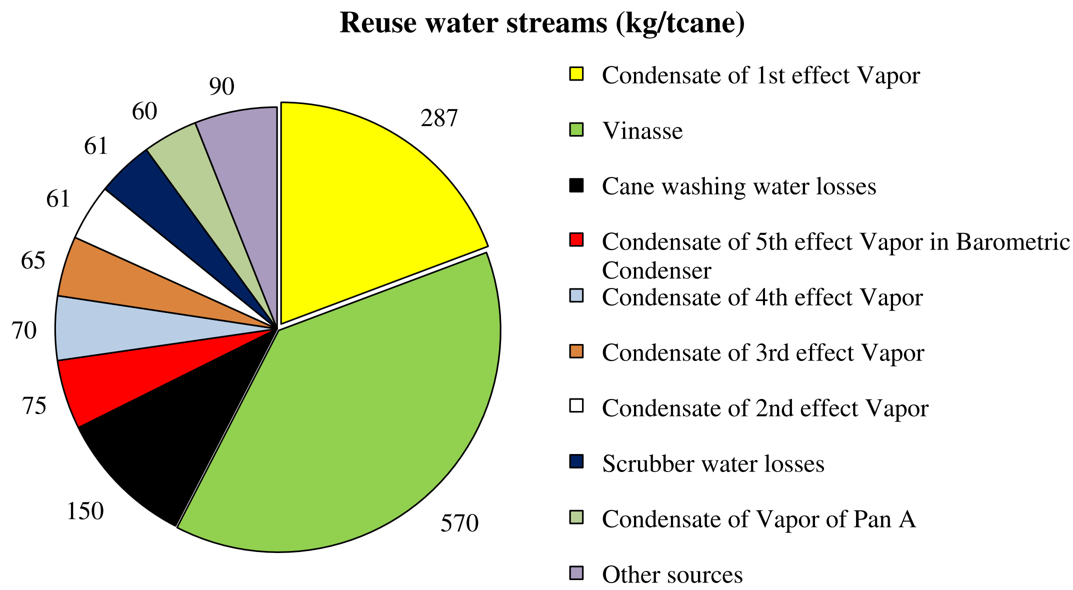

Fig. 3. Water streams for potential reuse (kg/t cane).

Table 3
Standards of quality recommended for cooling water and steam generation (FIESP, 2004).

Parameter	Cooling water	Steam generation		
		Low pressure boiler (<10 bar)	Medium pressure boiler (10 to 50 bar)	High pressure boiler (>10 bar)
Chloride	500	+	+	+
Total dissolved solids	500	700	500	200
Hardness	650	350	1.0	0.07
Alkalinity	350	350	100	40
pH	6.9 to 9.0	7.0 to 10.0	8.2 to 10.0	8.2 to 9.0
COD — chemical oxygen demand	75	5.0	5.0	1.0
Total suspended solids	100	10	5	0.5
Turbidity	50	–x–	–x–	–x–
BDO	25	–x–	–x–	–x–
Organic compounds	10	1.0	1.0	0.5
Ammoniacal nitrogen	1.0	0.1	0.1	0.1
Phosphate	4.0	–x–	–x–	–x–
Silica	50	30	10	0.7
Aluminum	0.1	5.0	0.1	0.01
Calcium	50	+	0.4	0.01
Magnesium	0.5	+	0.25	0.01
Bicarbonate	24	170	120	48
Sulfate	200	+	+	+
Cooper	–x–	0.5	0.05	0.05
Zinc	–x–	+	0.01	0.01
Substances extracted in carbon tetrachloride	–x–	1	1	0.5
Hydrogen sulfide	–x–	+	+	+
Dissolved oxygen	–x–	2.5	0.0007	0.0007

* Values are expressed in mg/L, except for pH and Turbidity that are expressed in units and TU respectively.
+ In case that other parameters are attended, accepted as received.
–x– No information.

Reuse water streams

The main characteristics of the effluents generated in the sugarcane industry have been reported by Elia Neto et al. (2009), and are shown in Table 4. In this table, DR means dry residues, and OG, oils and grease.

As seen in Table 4, stream characteristics can be quite diverse, ranging from effluents similar to raw water, such as condensates, to highly polluting acid effluents such as vinasse.

The wide range of data reported for some of the parameters can be traced back to several process differences among sugarcane mills: type of raw material (juice or molasses), type of harvesting (mechanized or manual), cane cleaning system (wet or dry), whether ethanol is produced, whether water circuits are closed, reuse practices, effluent handling system, location where samples were taken (e.g. barometric column outputs or recirculation tanks), etc.

Methodology and results

A heuristic method was used to apportion the available water streams among the different demands. Its first step is to collect information about flow rates of reuse streams and water demands, as well as their physico-chemical parameters (quality).

In the second step, water demands and reuse waters are ranked by quality level. An attempt is made to fulfill the highest-quality demand by the highest-quality reuse stream. If the reuse stream satisfies the quality requirements, it is directly reused; otherwise, water from the WTP must be brought in. In some cases, a special water treatment could be needed, such as ultrafiltration, reverse osmosis, etc., in order to satisfy the requirements. If the reuse stream rate exceeds the demand rate, the surplus will be used for the next demand on the ranking. If, on the contrary, it is not sufficient, the next ranked reuse stream is considered, in terms of quality and rate, to complete the volume needed. Fig. 4 presents a scheme of the method.

Once the first water demand is fulfilled, the same procedure is repeated for the next demand, and so on, until all water demands are covered, or all reuse streams are allocated.

The method foresees the possibility that some water streams may not be suitable for direct reuse for any demand, in which case a cleaning treatment is considered to improve its quality, such as the intake water

Table 4
Summary of wastewater characteristics of sugar mills and distilleries.

Wastewaters		Physical–chemical characteristics					
		pH	T (°C)	DR (mg/L)	COD (mg/L)	BOD_5 (mg/L)	OG (mg/L)
Cane washing		5–6	Amb	5–10	280–700	180–500	0
Equipment cooling (milling, turbines and turbogenerators)		7	<30	<0.5	0	0	–
Barometric and multi-jets condensers		6–7	45	<0.2	20–80	10–40	0
Cooling at distillery	Juice for must	7	<45	0	0	0	0
	Vats	7	<35	0	0	0	0
	Condenser	7	50–60	0	0	0	0
	Total	7	50	0	0	0	0
Gas boiler scrubber		8	80	50–100	200–300	100–150	0
Condensates	Exhaust steam	7	80	0	0	0	0
	Vapor	5–6	60–80	0	600–1500	300–800	0
Floors/equipment cleaning		5–6	Amb	<0.5	1000–3000	800–1500	>20
Domestic sewage		6–7	Amb	5–20	600	300	–
Vinasse and phlegmasse		4–4.5	80	3–5	25,000–40,000	15,000–20,000	8

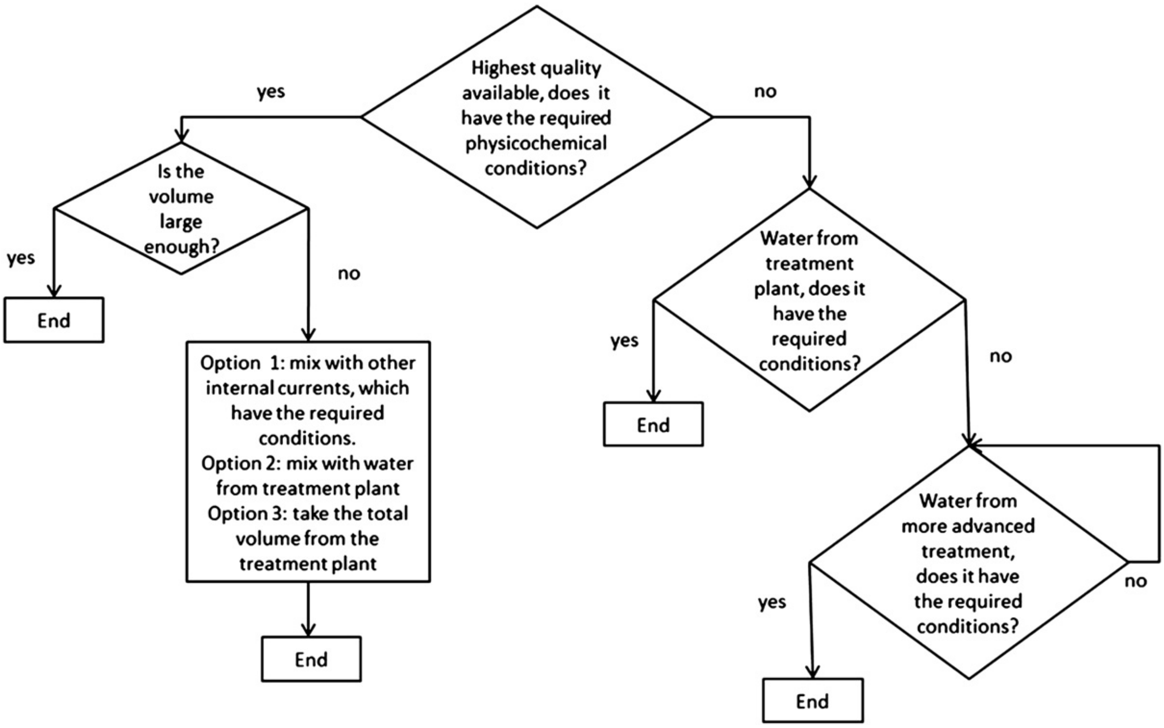

Fig. 4. Scheme of the heuristic method.

treatment and sludge dewatering. This will reduce the volume of externally collected water, but is contingent on the economic and technical viability of the required cleaning procedure. For instance, a stream containing heavy metals may not be viable for recycling.

The method has the disadvantage that, after exhausting all available reuse water streams, it will take recourse to water from the WTP to supply the missing volumes. Depending on the judgment of each designer, streams of lower quality (e.g. recycled scrubber water losses) could be mixed with those of higher quality (WTP). Due to the more or less discretionary use of that possibility, different reuse schemes will result when different individuals apply the method.

In order to exemplify the reuse according to this method, an analysis of a plant with the same characteristics of the modeled plant, i.e., with water demands and reuse water streams according to Figs. 2 and 3 respectively is presented. Appropriate treatment systems are proposed where necessary.

The water treatment system has a conventional water treatment plant providing water for industrial use, and an ultrafiltration system for higher uses. For boiler water, a reverse osmosis system is used, and the membrane rejects return as raw collected water.

Recycled water mixing has also been adopted for this configuration: streams that cannot be used directly, due to their high solids content, are mixed with raw collected water.

Cane washing losses are treated as waste sludge, and undergo thickening and dewatering processes. In this example, it is assumed that 60% of the water from the sewage cane washing losses are recovered and recycled in the ETA.

Fig. 5 shows the scheme of the system.

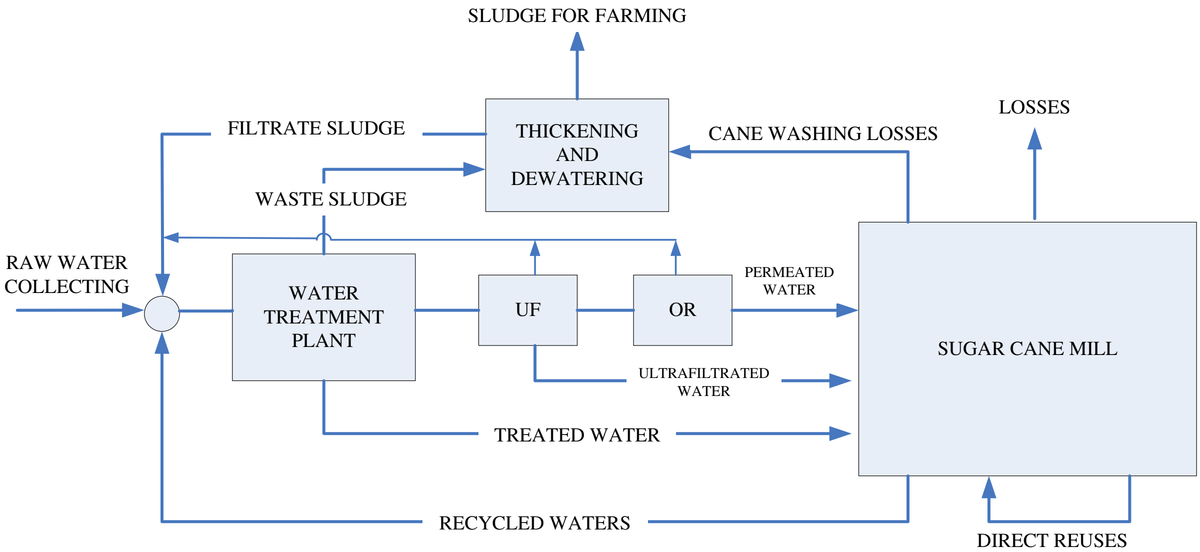

Fig. 5. Scheme of the mill's external water treatment system.

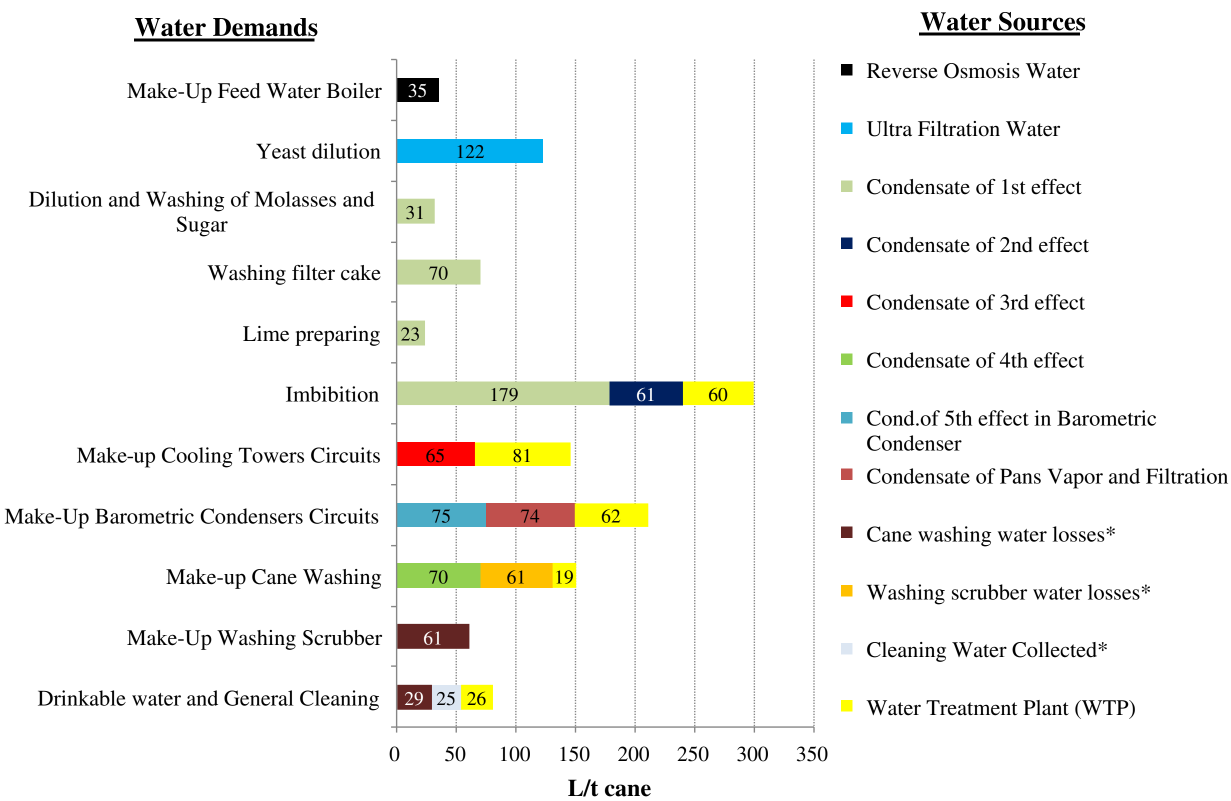

Fig. 6. Water management scheme according to demands and reuse streams, assuming mixture of streams. *Recycled streams.

Fig. 6 shows a sugar plant water management scheme obtained by applying the method and its criteria to the data about water demands, reuse streams, and quality of available water.

From a total demand of 1229 L/t cane, 648 L/t cane can be provided by direct use of condensates from three sources: juice evaporation, sugar crystallization, and filter cake filtration. The streams of cane

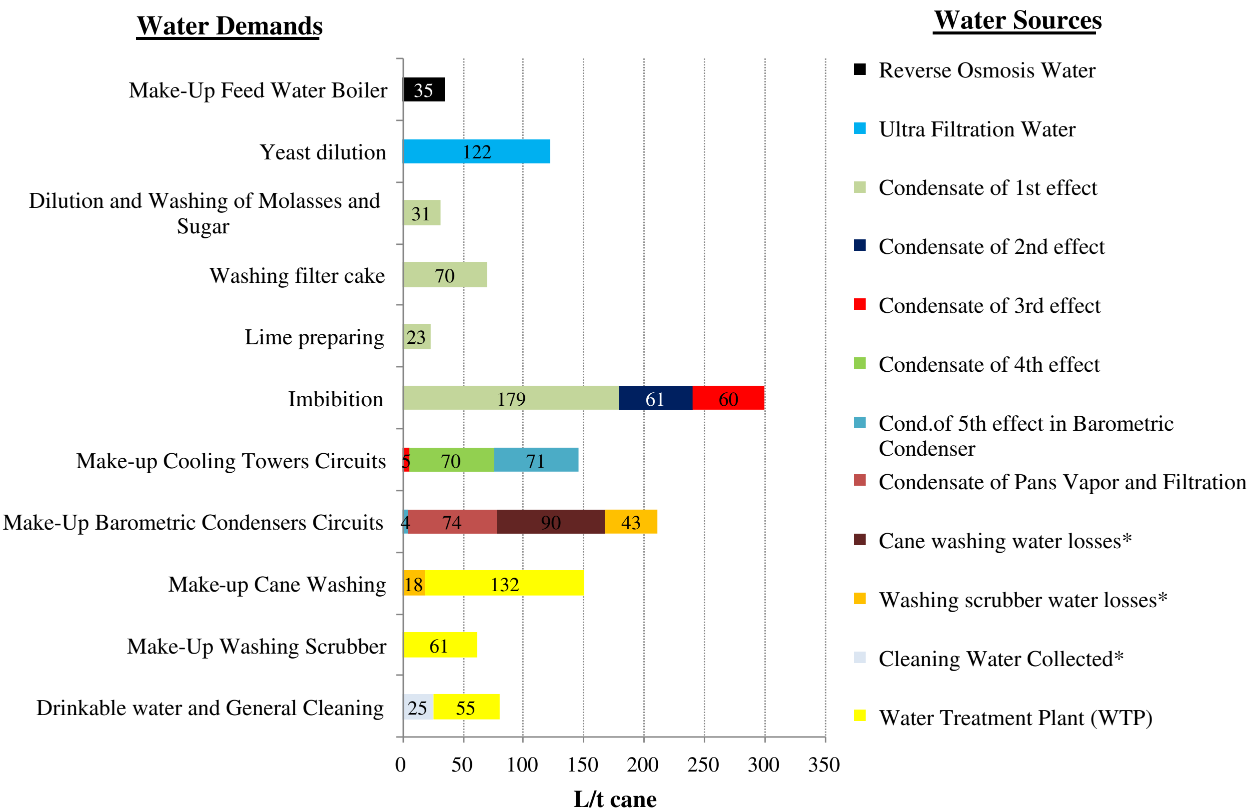

Fig. 7. Water management scheme according to demands and reuse streams by the cascade methodology. *Recycled streams.

washing water losses, washing scrubber water losses and collected cleaning water, totalling to 176 L/t cane, are sent to the Water Treatment Plant to be recycled. The three following demands, which add up to 405 L/t cane need to be covered with fresh water: boiler make-up (reverse osmosis water), yeast dilution make-up (ultra filtration water), and water indicated as coming from the treatment plant. If recycled streams are not taken into account, the external collection would reach 581 L/t cane, a value well within the limits established for the sugar cane industry in the State of Sao Paulo, of 1000 L/t cane in general, and 700 L/t cane in some regions (Agro-Environmental Zoning for Sugar Alcohol Sector for the Sao Paulo State, 2009).

To show the impact of designer decisions, another water management scheme is presented in Fig. 7. It is based on the ordered direct reuse of wastewater streams according to their qualities, from highest to lowest, without recourse to mixing streams. Comparing the two schemes, the volume required from the Water Treatment Plant is the same in both cases, and the selection will depend on logistic suitability.

Each stream management plan will depend on particular plant characteristics, on process type, and on operational preferences. Nevertheless, economic and operational factors will define the stream management possibilities and the extent of external collecting reduction achieved.

Conclusions

This work shows the physical and chemical characteristics of water streams with potential for reuse inside sugarcane mills, as required by different processes.

A heuristic methodology is proposed to match water demand and supply. Depending on how the methodology is applied, different results can be reached, not in terms of the water volume to be treated in the Water Treatment Plant, but in terms of stream logistics, due to different possible reuse distributions.

More advanced methodologies can be devised in the future, provided that systematic studies of recommended stream quality for each process are done.

For the case discussed in the present work, the quality requirement of the boiler makeup water is the highest; thus, it is not recommended to reuse water from other streams for this process. With the exception of this process and the fermentation dilution process, condensates can be used in different processes in the plant, because of their good quality. Nevertheless, the organic load must be monitored in the closed circuits in order to prevent bacterial growth.

It was also shown that, in addition to simple reuse, water recycling is a mechanism that can complement the water supply when the physicochemical parameters of the available streams do not satisfy the standards required for the different processes, and whenever mills are required to reduce their surface or underground water withdrawal.

Other possibilities of water reuse and recycling can be contemplated in addition to those discussed in this study. Biogas can be produced from vinasse. Two streams will be obtained from this process, an energetic one, the biogas itself, which can be used in the boilers, and a second one, consisting of water plus fertilizers. The latter can be filtered and also evaporated to separate the fertilizers; from that, a third stream of better quality water can be obtained for other uses.

Acknowledgments

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Appendix A

Table A.1
Water use in a sugar–ethanol mill.

Water uses	m (kg/s)	T (ºC)	P (bar)	m (kg/t cane)	%
Cane washing	416.7	25	1.01	3,000	19.9%
Imbibition	41.7	50	6.00	300	2.0%
Bearing cooling	6.9	25	1.01	50	0.3%
Lubrication oil cooling	55.6	25	1.01	400	2.7%
Sulfitation cooling	3.1	25	1.00	22	0.1%
Milk lime preparation	3.2	107	6.00	23	0.2%
Filter cake washing	9.7	107	6.00	70	0.5%
Centrifugal washing	2.3	107	6.00	17	0.1%
Dilution of poor molasses	0.3	107	6.00	2	0.0%
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	1.00	2594	17.2%
Barometric condensers of filters	12.5	30	1.00	90	0.6%
Juice cooling for fermentation	151.3	25	6.00	1089	7.2%
Water for vacuum in the pans	337.6	30	1.00	2431	16.1%
Dilution of milk yeast	17.0	25	6.00	122	0.8%
Cooling of fermentation vats	242.7	25	6.00	1747	11.6%
Distillation condenser	7.9	30	1.00	57	0.4%
Rectification condenser	105.7	30	1.00	761	5.0%
Hydrous ethanol cooling	7.0	30	1.00	50	0.3%
Scrubber washing (boiler)	169.8	25	1.00	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%
Turbogenerator cooling	27.8	30	1.01	200	1.3%
Crystallizer cooling	4.2	30	1.01	30	0.2%
Total				15,071	

Table A.2
Effective water demanded by process.

Effective water demanded by process	m (kg/s)	T (°C)	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	10.0%
Make-up oil lubrication cooling	1.7	25.0	1.01	12	1.0%
Make-up sulfitation cooling	0.1	25.0	1.00	1	0.1%
Lime preparation	3.2	107.4	6.00	23	1.9%
Filter cake washing	9.7	107.4	6.00	70	5.7%
Centrifuge washing	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 of barometric condenser of 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 for ethanol juice cooling	4.5	25.0	6.00	33	2.7%
Make-up vacuum pan circuit	13.9	30.0	1.00	100	8.1%
Yeast dilution	17	25.0	6.00	122	10.0%
Make-up fermentation vat 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%
Hydrous 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 turbogenerator cooling	1.4	30.0	1.01	10	0.8%
Make-up crystallizer cooling	0.2	30.0	1.01	2	10.0%
Total				1229	

Table A.3
Water streams for reuse.

Reuse water streams	m (kg/s)	T (°C)	P (bar)	m (kg/t cane)	%
Condensate of filtration (condensate of 1st effect vapor)	0.4	70	0.31	3	0.2%
Condensate of bleeding 1st effect (collected in the output of the 2nd effect)	7.9	115	1.69	57	3.8%
Vapor to treatment of juice heating (condensate of bleeding 1st effect)	20.2	115	1.69	145	9.8%
Vapor to pan A heating (condensate of bleeding 1st effect)	11.8	115	1.69	85	5.7%
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 vapor in barometric condenser	10.5	50	1.01	75	5.1%
Condensate of pan A	8.3	50	1.01	60	4.0%
Condensate 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%
Scrubber water losses	8.5	25	1.01	61	4.1%
Vinasse*	61.5	76	6	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	

* Included only for volume balance purposes, because the vinasse needs a severe treatment for its re-use as a water stream.

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