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MATERIAL FLOW ANALYSIS TOWARDS CLEANER PRODUCTION IN HOA BINH SUGARCANE COMPANY, VIETNAM

Nguyen Thi Ha[1], Ngo Quoc Phong[1], Le Thi Hoang Oanh[1], Nguyen Xuan Hai[1] and Drangert Jan-Olof[2]
[1]Faculty of Environmental Sciences, VNU- Hanoi University of Science
[2]Vatema AB, Stockholm, Sweden
E-Mail: nguyenthiha@hus.edu.vn

ABSTRACT

Wastes from the sugar industry have negative impact on water steams and aquatic life as well as profitability. This is especially worrying for sugar companies using backward technology and non-integrated processes. A Material Flow Analysis (MFA) can together with the waste hierarchy help to reduce wastage and improve recycling and material resource management. Rather than adding end of pipe pollution control technology, a change to cleaner production processes and recycling lead to more sustainable solutions that improve both the economic performance and the environment. To this end, the material flows at Hoa Binh Sugar Company (Hoasuco) in Vietnam is presented and analyzed. Results show that the loss of sugar added up to 17.1% of potential production. Solid flows from extraction, filtration and crystallization accounted for 10.6%; and the remaining 6.5% is lost in steam released from evaporation and crystallization. Clarification is the most inefficient process, with a sugar loss almost nine times greater than the benchmark value. On the other hand, Hoasuco lost 30% less of sugar left in molasses. Water usage in the Hoasuco was very high, ranging from 18 to 23m^3 per ton sugarcane of 15-20 L/kg of manufactured sugar compared to 0.5-0.9 m^3/ton sugarcane reported in a World bank study and 4 L/kg of manufactured sugar in another studies. Based on these findings, the present study proposed various measures for cleaner production and recycling of waste: avoid mixing wastewater of very different composition to facilitate the treatment and recycling of each flow, both effluent and sludge. The solid waste fraction could be minimized by improved monitoring of the operations of processes. The solid waste should be reused and recycled (biogas extraction included), while incineration and landfilling should be avoided. The demand for water, cane and energy could be significantly reduced by such by measures.

Keywords: cleaner production, flow analysis, material balance, sugar processing, Vietnam.

INTRODUCTION

Sugar factories add value to the raw material sugarcane and play an important role for the national economy, employment and social development in many countries[11].Sugar and alcohol production is an important agribusiness in many countries to meet the increased demand for sugar and renewable fuel [4,25]. Sugarcane processing can cause harmful environmental effects due to the generation of large amount of solid wastes and wastewater, and emission of toxic gases and odorous substances [2]. In addition, chemical pollutants used in the production process may percolate through subsoil layers and reach the ground water. Several studies have found such contaminated ground water [5,2]. Wastewater from sugarcane processing in some sugar factories in India contains very large quantities of organic compounds with load of 5,915mg/L of COD; 1154mg/L of BOD and 5,759mg/L of SS [22]. Also, BOD_5 values in wastewater from sugar processing is often high and in the range of 350 – 2,750 mg/L, while pH may be acidic or basic [9,10,14].Sugar processing wastewater is coloured due to the presence of organic acids and metal salts discharged from the ion exchange resin regeneration. Sugar mill waste water often contains a high amounts of organic carbon that affects soil negatively. By contrast, Renu *et al.*(2014) reported that organic carbon content in soil samples at the mills ranged from 1.42 to 2.39% which is considered to have good fertilizing property. Most chemicals used in sugar processing were found to be toxic and untreated effluent could adversely affect the receiving water bodies [1,18]. This polluted water is often used by human for drinking, domestic, agriculture and industrial purposes. Therefore, wastewater from sugar processing must be treated to ensure safe water quality standard for aquatic life and human health.

Environmental management in general and cleaner production in particular is a priority concern in the sugarcane industry. Cleaner production is an effective environmental management tool to identify the opportunities and solutions for improved environmental performance and economical benefit. In addition, it also improves the company's prestige and competitive edge.

The applied material flow analysis (MFA) is 'a systematic assessment of the flows and stocks of materials within a system defined is space and time [6]. MFA has been effectively used to identify and respond to emerging environmental problems in developing countries [17]. In particular, this approach has been shown to be a valuable mean in waste utilization, reproduction and treatment [8].

In this study, the material and waste flows of Hoa Binh Sugar Company (Hoasuco) were analyzed to find practical proposal for cleaner production and improved efficiency of waste and wastewater management.

RESEARCH METHODOLOGY

System definition

The system boundary is the sugar processing at Hoasuco, Hanoi, Vietnam. The flows in focus are

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materials including cane and sugar, water and wastewater and other solid flows.

Data collection

Information on sugarcane processing was gathered from Hoasuco in Hoa Binh. Flow data was assembled in a variety ways including literature review, field survey, and interviews with staff and experts.

Data processing and visualization

The material and waste flows were measured and calculated based on the production reality, benchmark calculation and MFA methodology [3,16,19,31]. Mass flow calculation based on the parameters given in Table-1.The software STAN [27] was used to visualize the results. Weighted arrows are used to indicate the amount of mass in each flow. Diagrams were created for each individual process, as well as for representations of larger parts of the system comprising of several processes.

RESULTS AND DISCUSSIONS

Total mass balance for the Hoasuco

According to design, the annual sugar production at Hoasuco is 9,500 tons of sugar during the 3-4 month cane harvesting season from 93,000 tons of cane. In practice, however, the production is much lower. For example, in 2014 the production reached 5,034 tons sugar (50,000 tons of cane). The total mass balance in Figure-1 was calculated based on an input of 1,250 tons cane per day.

The mass balance calculations shown in Figure-1 tells that cane constitutes 75.57% of total input material and water for extraction, washing and filtration processes accounts for 21.73%. The remaining inputs of 2.7% comprised $Ca(OH)_2$, SO_2, $P_2O_5$and coagulants. After processing, the total sugar product is145.26 tons/day or 11.62% of the cane input. That proportion is significantly lower than the rough estimate of the 30% reported by Paturau (1988). However, this result is in agreement to another study in which the proportion of sugar reached 10.0-10.3% [21].

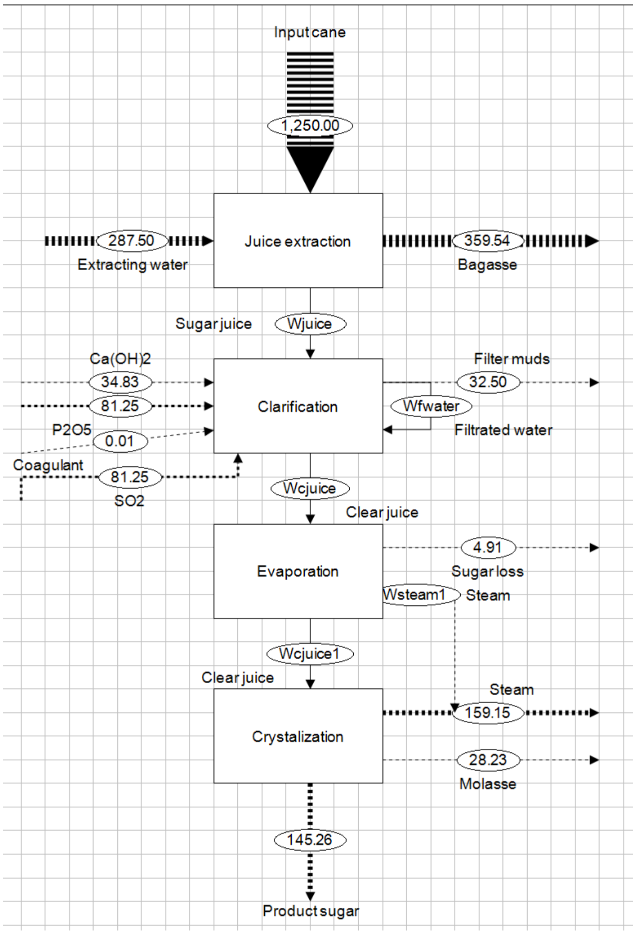

Figure-1. The total mass balance of Hoasuco in tons (for 1250 ton input cane/day).

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Table-1. Parameters used for material flow analysis.

Parameters	Description	Calculation
P_{DM}	Percentage of dry mass	$PDM = \frac{DM}{M} * 100\%$ Where: DM- Total dry mass = $DM_{non\text{-}sugar} + DM_{sugar}$; M- Total mass
P_{SM}	Percentage of sugar mass	$PSM = \frac{SM}{M} * 100\%$
Ap	Sugar purity	$Ap = \frac{PSM}{PDM} * 100\% = \frac{SM}{DM} * 100\%$
$DM_{bagasse}$	Total dry mass in bagasse	$DM_{bagasse} = \frac{SM_{bagasse}}{Ap_{juicemixture}} * 100\%$
$M_{bagasse}$	Total bagasse mass	$M_{bagasse} = \frac{DM_{bagasse} + M_{inputcane} * P_{fibreininputcane}}{100\% - WC_{bagasse}} * 100\%$ Where: WC = water content
$P_{DMbagasse}$	Percentage of dry mass in bagasse	$P_{DMbagasse} = \frac{SM_{bagasse}}{Ap_{juicemixture}} * 100\%$
$M_{Extracted\ water}$	Total mass of extracted water	$M_{Extracted\ water} = M_{input\ cane} * P_{Extracted\ water\ per\ mass\ unit\ of\ input\ cane}$
$M_{juice\ mixture}$	Total mass of juice mixture	$M_{juice\ mixture} = M_{Extracted\ water} + M_{juice\ in\ input\ cane} - M_{juice\ in\ bagasse}$
$M_{non\text{-}sugar\ in\ juice\ mixture}$	Total non-sugar mass in juice mixture	$M_{non\text{-}sugar\ in\ juice\ mixture} = Bx_{juice\ mixture} * M_{juice\ mixture} - SM_{juice\ mixture}$ Where: SM - Total sugar mass
$DM_{input\ cane}$	Total dry mass in input cane	$DM_{input\ cane} = DM_{non\text{-}sugar\ in\ input\ cane} + SM_{input\ cane}$
M_{lime}	Total mass of lime	$M_{lime} = \frac{M_{usedCaO}}{C_{CaO}} * 100\%$
$M_{juice\ mixture\ for\ filtration}$	Total mass of juice mixture for filtration	$M_{juice\ mixture\ for\ filtration} = M_{neutralized\ juice\ mixture} - M_{Supernatant\ juice\ mixture}$
$M_{Filter\ muds}$	Total mass of filter muds	$M_{Filter\ muds} = M_{Juice\ mixture\ for\ filtration} + M_{Water\ for\ sludge\ washing} - M_{Wet\ sludge}$
M_{Syrup}	Total mass of syrup	$M_{Syrup} = M_{Supernatant\ juice\ mixture} + M_{Filter\ muds}$
SM_{Loss}	Total sugar mass loss	$SM_{Loss} = SM_{Juice\ mixture} - SM_{Syrup} - SM_{Sludge}$
$P_{Sugar\ loss}$	Percentage of sugar mass loss	$P_{Sugarloss} = \frac{SM_{Loss}}{M_{Juicemixture}} * 100\%$
$H_{Clarification}$	Yield of clarification	$H_{Clarification} = \frac{Ap_{Syrup} - Ap_{Juicemixture}}{Ap_{Syrup} * (100 - Ap_{Juicemixture})} * 100\%$
M_{Steam}	Total mass of steam	$M_{Steam} = M_{Syrup} * (1 - \frac{Bx_{Syrup}}{Bx_{Mollasse}})$
$M_{olasses}$	Total mass of molasses	$M_{olasses} = M_{Syrup} - M_{Steam}$
$P_{Sugar\ in\ molasses}$	Percentage of sugar in molasses	$P_{Sugar\ in\ molasses} = \frac{SM_{Molasses}}{M_{Purifiedmolasses}} * 100\%$
$P_{DM\ in\ molasses}$	Percentage of dry mass in molasses	$P_{DM\ in\ molasses} = \frac{DM_{Molasses}}{M_{Purifiedmolasses}} * 100\%$
Am_{ylase}	Sugar purity in molasses	$Ap_{Molasses} = \frac{Pol_{Molasses}}{Bx_{Molasses}} * 100\%$
$H_{Sugar\ production}$	Yield of sugar production	$H_{Sugarproduction} = \frac{Ap_{Molasses} - Ap_{Molasses\ residue}}{Ap_{Whitesugar} - Ap_{Molasses\ residue}} * 100\%$
$M_{Sugar\ product}$	Total mass of sugar product	$M_{Sugar\ product} = DM_{Molasses} * H_{Sugar\ production}$
$M_{molasses\ residue}$	Total mass of molasses residue	$M_{molasses\ residue} = DM_{Molasses} * (100\% - H_{Sugar\ production})$

Sugar flow analysis

The sugar balance for Hoasuco is presented in Figure-2 and based on field survey data and calculations in Table-1.The balance shows that sugar losses in solid flows, including bagasse from the extraction process, residues from vacuum filtration, and molasses from the crystallization process were 7.73, 2.24 and 7.88 tons/day, respectively. These losses equalled some 10,6% of the sugar in the cane input. In addition, sugar was also lost with the steam from both evaporation and crystallization processes to the tune of 11tons/day or 6.48% of total sugar in the cane input. Thus, the total loss of sugar during processing was 17.1% which is higher than reported in some previous studies [30,31].

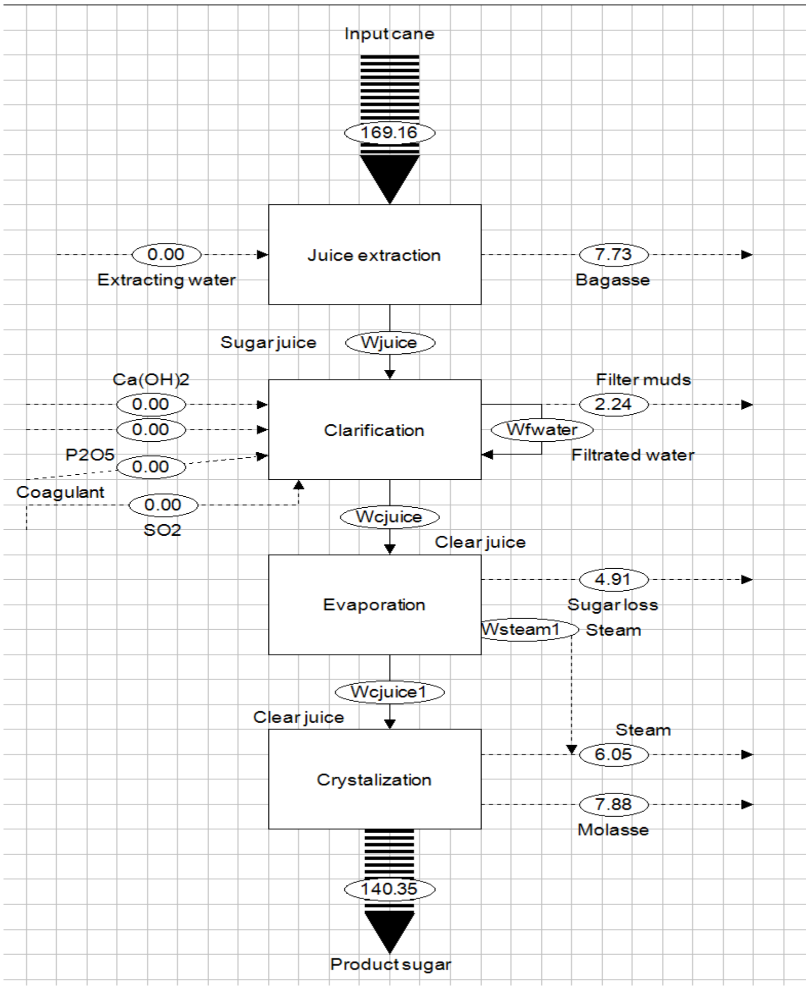

Figure-2. Sugar balance of Hoasuco in tons(for1250 ton input cane/day).

Reasons for sugar loss at the Hoasuco include:

- Sugar production technology is old and backward. There were leaks in equipment because maintenance was ineffectively controlled.
- Workers are not systematically trained and they mostly work according to experiences
- The automatic control system is not available which causes the disruption of operational processes as well as incorrect response of equipment. For instance, the vacuum pump was operated by a mechanic valve which regulates the pressure and input material for the vacuum filtration process. If this valve is not operated property, it results in high vacuum pressure leading to loss of sugar, or low pressure leading to low evaporation efficiency. Also, the addition of lime or purging of SO_2 were controlled manually, hence additional amount were incorrect which lead to the development of microorganisms which consumed sugar.

A comparison between yield of products of Hoasuco and benchmark values from using corresponding technology is presented in Table-2.

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Table-2. Comparison of Hoasuco products and benchmark values using corresponding technology

Flows	**Sugar** (in tons)		**Ratio** (%)	
	Hoasuco	**[25]**	**Hoasuco**	**[25]**
Input sugar in cane	169.16	156.25	100	100
Bagasse	7.73	7.81	4.6	5
Filter muds	2.24	1.56	1.32	1
Sugar loss in clarification process	6.05	1.25	3.6	0.8
Molasses	7.78	10.84	4.7	6.93
Sugar loss in evaporation process	4.91	0	2.9	0
Product sugar	140.35	134.79	82.97	86.27

Table-2 shows that, in Hoasuco sugar loss to bagasse was 0.4% less and to molasses 2.23% less than benchmark values. This is due to the improvement of extraction system from 4 to 5 shafts which increase the extraction efficiency. The investment in an additional centrifugator decreases sugar in molasses. However, sugar loss in filter muds was about 0.32% higher than benchmark value due to lack of washing system for input cane which increase miscellaneous compositions in sugar juice, filter muds and also sugar loss in filter muds. The sugar loss in the clarification and evaporation process was nine times higher than benchmark value with equals 5.7% of the total amount of sugar produced. This is the main reason for low recovery efficiency of sugar and high organic load in the wastewater.

Water flow analysis

The sugar processes require large volumes of fresh water and subsequently discharge the bulk effluent into the environment. The water flow analysis for Hoasuco is shown in Figure-3.

The total daily water use is about 2,814 m^3/day. This kind of water is stored in a fresh water tank. Water used for cooling and boiling purpose is stored and recycled in order to decrease water discharged into environment. Steam processing with two major activities as heating and condensing caused the loss of approx. 200 m^3/day. The hot condensed water is reused to extract sugar, dissolve sugar as well as dissolve molasses, which accounted for approx. 400m^3/day, hence this amount of water could replace input water every day. Input fresh water was also used for domestic, lab, washing and machine cooling purposes. Water usage in the Hoasuco was very high, ranging from 1.8 to 2.3m^3 per ton sugarcane or 15-20L/kg of manufactured sugar. In comparison, only 0.5-0.9m^3/ton sugarcane was reported in a study of the World Bank Group (2007)and 4.02 L/kg of manufactured sugar in another study [22].

The company discharges a total of 2,820 m^3/day of wastewater, of which 1,100m^3/day from condensed juice steam and the rest comes from lab, domestic, washing and cooling uses. All wastewater was collected and treated in biological ponds located inside the company compound. Wastewater from Hoasuco can be divided into two streams:

- **Stream 1:** wastewater from machine cooling which was contaminated with oils/grease from machines or sugar leakages from sugar pumps; condensed juice steam from heating, evaporation and crystallization processes which carried a certain amount of sugar loss;
- **Stream 2:** wastewater from washing processes and pipe leaking which contain a large amount of sugar loss. In addition, wastewater from domestic use was also included into this stream.

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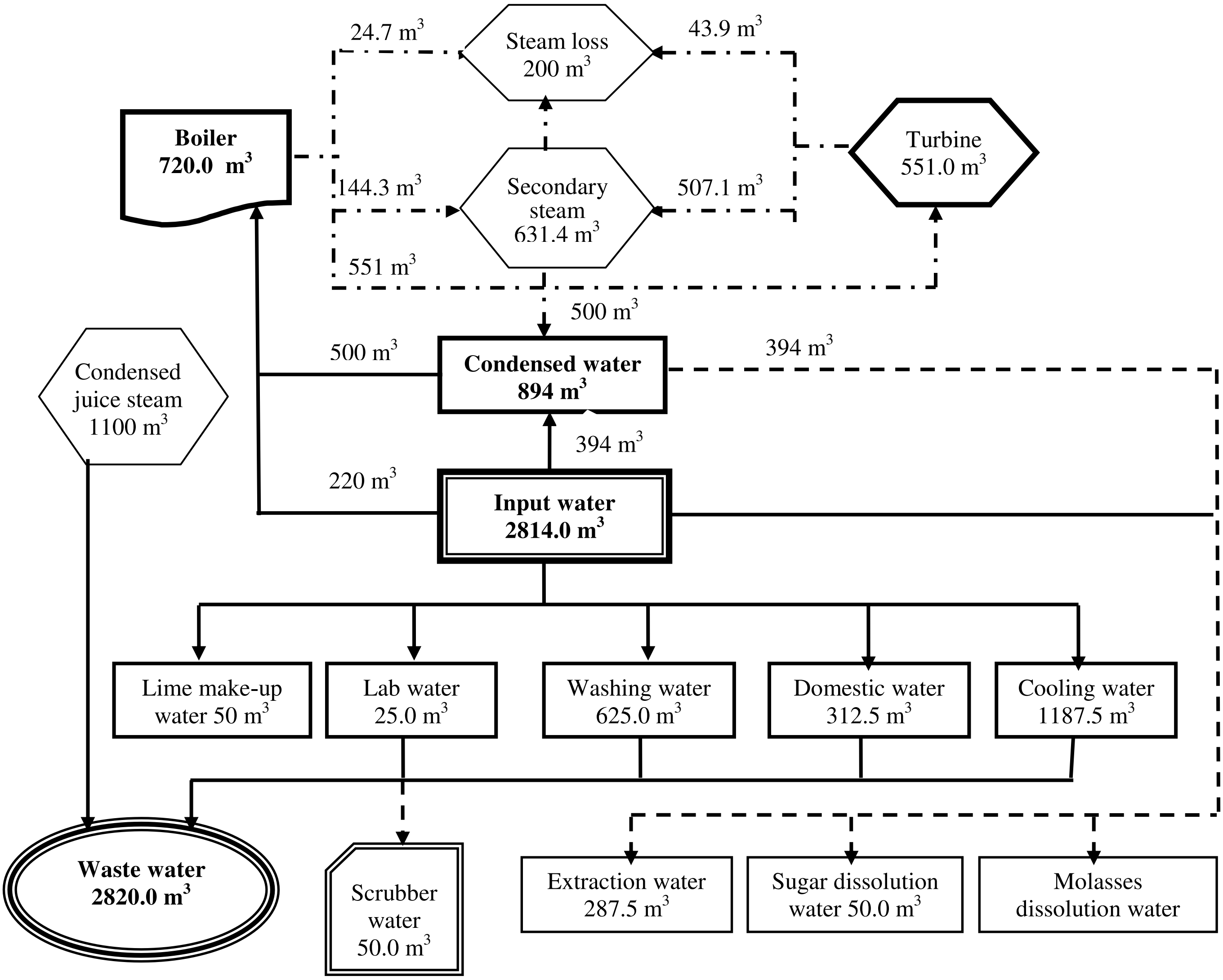

Figure-3. Water flow balance of Hoasuco in tons (for1250 ton input cane per day).

Solid flow analysis

The analysis of flows of solids in Figure-4 is based on an input of cane of 1250 tons per day. The earlier calculations showed a total input of solids of 374.21tons/day, while the total solid waste is 234.62tons/day, i.e. 62.7% of total input solids. The dominant part of solid waste is bagasse, accounting for 50.4% of total input solids and 80.3% of total solid waste. Molasses was the next dominant part of solid waste, being counted for 7.5and 12.0% of total input solids and total solid waste, respectively. However, the ratio of molasses per input cane found remarkable lower than that reported in the study of Rangnekar (1988), counted 2.6 and 4.2%, respectively. The solid loss during the clarification and evaporation processes was 3.8 and 6.1%of total input solids and total solid waste, respectively. The residue from the vacuum filtration process had the least amount, which was found at2.5 and 4.0% of total input solids and total solid waste, respectively. It is noticed that, the domestic solid waste generated from the kitchen, ash/slag from boilers, sludge generated from wastewater treatment system including the hazardous waste washes not yet taken into account.

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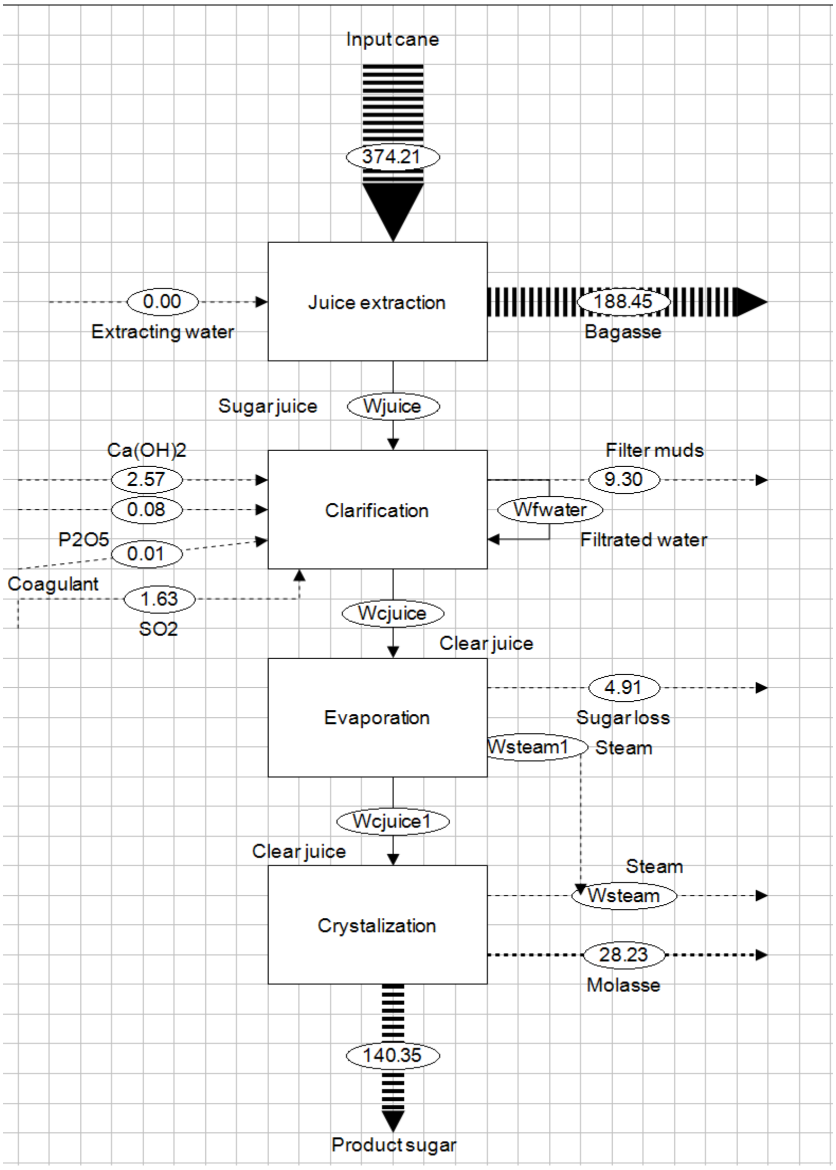

Figure-4. Solid flow analysis in Hoasuco (for 1250 tons of input cane per day).

Cleaner production opportunities

In Hoasuco, about 190 tons/day of bagasse was used as the input material for boilers. This solution was also popular in many sugar companies where bagasse was utilized and became a significant part of the bio based fuel [5,26]. It is expected that the sugar industry will become greener or cleaner as bagasse being utilized for electricity production and used within the sugar mills [15,24].However, for the sustainable development the bagasse ash and filter mud should be effectively used for compost and molasses for alcohol production. According to Higgins *et al.* (2009), this should be considered as a continuous improvement process.

An extended waste hierarchy is introduced to integrate solid and liquid nutrient-rich wastes in order to develop functional measures for improved nutrient and water management [32]:

Step 1. Reduce (a) waste generation, and **(b)** harmful contents in products and flows;

Step 2. Reuse the waste/wastewater more or less as it is;

Step 3. Recycle the waste/wastewater as input to new products (including biogas production);

Step 4. Incinerate to extract the energy content in the remaining waste;

Step 5. Safely **landfill** residues remaining after exhausting the previous steps.

Steps 4 and 5 are applied only for a tiny part of the original waste/wastewater.

Bagasse dominates in solid waste from sugar manufacturing. The hierarchy suggests to first reduce the volume and contaminants. This can be done by improving the operations in the company and lessen the use of toxic substances in the processes. The benchmark figures indicate that there is scope to do so. Step 2 talks about reuse of wastes. Today, the bagasse is used as fuel (Step 4) instead of becoming feed for animals or fertilizer, or recycled to produce board or other wood-like material (Step 3). Similar measures could be explored for filter muds, molasses, and other sludge. Incineration and landfilling should be abandoned. It is better to generate electricity for the machinery from solar panels instead of burning bagasse or molasses to reduce toxic air emissions. Water usage in Hoasuco is very high compared to industry benchmark [7,18]. The wastewater could be collected in three separate flows (by retrofitting pipes) depending on ease to treat it before recycling. The water that (1) has few alien substances (e.g. cooling water), (2) water with high organic content but few chemicals (e.g. wash water), and (3) water with both organic and chemical content (e.g. vacuum filtration water, sludge thickening water) [14]. These three flows are treated in different treatment units, and recycled in processes which require the appropriate water quality. For instance, cooling water need hardly any treatment before being used as cooling water again. Another example is water used for washing sugar canes. It is high in organic material which is easy to treat/remove before used again for washing. The discharges that do not clearly belong to the three categories may be lumped together in category (3). In so doing, the need for freshwater is reduced to a trickle of what is being used today. Moreover, the volume of contaminated wastewater is also reduced drastically. At the same time, the sludge is of more uniform composition and can be composted, recycled in cane production or destructed.

CONCLUSIONS

The material flow analysis of the Hoa Binh Sugar Company indicates a recovery rate of 83% of the total sugar contained in the cane, while 17%is lost. 10.5% is lost in the solid flows, and 6.5% in the fluid flows. Water usage is very high compared to findings in other studies, and in the range of ten times as high. Based on these findings, the present study proposes various measures for cleaner production and recycling of waste. For example, avoid mixing wastewater of very different composition to facilitate the treatment and recycling of each flow, both effluent and sludge. The solid waste fraction could be minimized by improved monitoring of the operations of processes. The solid waste should be reused and recycled (biogas extraction included), while incineration and landfilling should be avoided. The demand for water, cane and energy could be significantly reduced by such.

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